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# Microinvasive Dentistry

Clinical Strategies and Tools



John J Graeber

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# Preface

Tooth decay remains the most prevalent disease on earth. As Health Professionals, our goal is primarily to help heal our patients in need. This requires that we DO NO HARM.

In my opinion, **we do harm** when we do not avail ourselves of the most up-to-date devices and methods, which aid in the earliest possible diagnosis and intervene with the least invasive treatment, preventive or otherwise.

**Microinvasive Dentistry** is a series of manuscripts, which address prevention, management, early diagnosis, and treatment of caries – the most prevalent disease of mankind.

This book begins with a review of preventive techniques and current best practices with fluoride. The earliest signs of tooth decay can be treated with penetrating resins, sealants, and fluoride preparations when utilized early in the disease process.

Earlier diagnosis presents us with an opportunity to provide a better service, but only when we have the tools necessary for objective measurement and/or monitoring of the decay process. Several chapters of this book explain, in practical detail, devices, which far exceed the accuracy of the oldest dental instruments – the **explorer** and the dental bitewing X-ray.

The latest microbiological findings about caries are published here for the first time – shattering traditional concepts, not only in the discovery of novel causative species but also questioning current concepts of the anti-caries value of restorative materials. The potential of regeneration of dental materials is discussed by world-class researchers and clinicians.

Where caries has extended into the dental tissue, new methods of caries excavation and cavity preparation are explained and demonstrated in great detail by leading edge clinicians, based on years of real-life experience. The advantages of air-abrasives and all-tissue laser devices have been shown over the decades to be far safer on human teeth than the high-speed drills, which have been in common usage for the past 70 or so years. The time has arrived when we should be retiring the GV Black concepts designed for metallic restorations.

So, I invite you to read and study this book on **Microinvasive Dentistry** and challenge you to become part of the **New Age in Dentistry**.

John J Graeber

March 2020



# Contents

Preface	v
Contributors	ix
Acknowledgments	xi
The future is now	xiii
<b>Section I Caries prevention</b>	
<b>Chapter 1</b>	
Prevention: Fluoride and enamel regeneration	3
<b>Chapter 2</b>	
Caries-penetrating resin therapy	11
<b>Chapter 3</b>	
Identifying patients at risk of caries	19
<b>Section II Diagnosis</b>	
<b>Chapter 4</b>	
Intraoral video cameras	29
<b>Chapter 5</b>	
Near-infrared transillumination	35
<b>Chapter 6</b>	
The Canary System	45
<b>Chapter 7</b>	
SoproLife dental caries detection system	55
<b>Chapter 8</b>	
Laser fluorescence caries diagnostic device: DIAGNOdent	61
<b>Chapter 9</b>	
The surgical microscope for diagnosis and treatment of caries	67
<b>Chapter 10</b>	
Conventional diagnostic pitfalls	77



**Section III Treatment options and techniques****Chapter 11****Microbiological aspects of caries treatment 83****Chapter 12****Air abrasion: Background and cavity preparation 99****Chapter 13****Air abrasion technique 107****Chapter 14****Erbium laser physics and tissue interaction 119****Chapter 15****Carbon dioxide lasers (9300 nm) 135****Chapter 16****Dentin regeneration 143****Chapter 17****Ozone therapy 153****Chapter 18****Conventional treatment failures 161****Section IV Future caries diagnosis and management****Chapter 19****Enamel regeneration 171****Chapter 20****Photobiomodulation 185****Index****197**

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Of course, my family and wife, Karen made the greatest sacrifice of all-giving up family time with me, somehow we made it through, but many thanks to her and our children and grandchildren.

No work of this breadth could be produced by just one individual. Fortunately, my professional career has taken me both far and wide – far in the aspect of being invited all over the world to share my knowledge and experience in the practice of Laser Dentistry, and wide in the aspect of being in the frequent company of so many talented dentists and health professionals especially in these past 30 years.

I am eternally grateful to the many contributors to this book. Their contributions to better dentistry are awesome.

I also must inform you that many of the contributors are my fellow members of the Academy of Laser Dentistry. As a founding member and Past President, I am so grateful for the insight and foresight of so many members who not only inspired this text but contributed to the formation of many of its ideals and aspirations.

**John J Graeber**



# The future is now

John J Graeber

## Introduction

In the past few decades, the delivery of routine restorative care in dentistry has undergone transformative changes. New materials, techniques, and minimalist philosophy have outpaced general acceptance.

The dental explorer, mirror and high-speed handpiece remain as the standards of care. If so much change for the better in materials has taken place, why have most practitioners held onto outmoded techniques of diagnosis and treatment? Why is speed of delivery so important to the average practitioner? If less invasive techniques have been shown to produce less destruction to tooth structure, why haven't they been implemented?

Perhaps there is truth to the adage: dentists have been *overly trained* and *poorly educated!* Is it so difficult to change the way every dentist has been trained? If we subscribe to the Ethical standard of "DO NO HARM" why do we find it so hard to understand that tried and true methods may no longer be the right thing to do?

Over the past 25–30 years, there have been technological and clinical developments in dentistry, which have not become fully integrated on the delivery of routine restorative care.

Part of the cause of this is the reluctance of Dental Schools and General Practice Residency Programs to introduce many of these new technologies to their students. Rightly asked, "Why Not?"

In defense of these programs, it might be argued that the teaching staff has not been exposed to these technologies either and how could students be possibly taught by those who not yet learned themselves. Another reason is that many of these technologies are costly, and institutions are already under fire with budgetary constraints. But unfortunately, the idea of a "slower" diagnostic process, or slower treatment modalities have no obvious compelling economic benefit to the practitioner.

If we still subscribe ethically to the "do no harm" principle, then the information and evidence is there to support the idea of utilizing the most accurate techniques in diagnosis as well as treatment modalities.

In nearly 50 years of practicing dentistry, I long ago moved away from many of the principals and techniques taught in my undergraduate program. Many of those techniques and principles I questioned even then, and later came to realize that certain techniques were merely taught so as to have the entire class able to pass both required proficiencies and board exam requirements. Continuing education experiences (nearly 4,000 hours and 2 Masterships) over my career began to reshape my techniques and knowledge base. The plethora of new materials and technologies introduced during my professional career also has heavily increased my questioning of how and why. To date, there has been too little written concerning these developments. Many long-standing principles of practice have been challenged under the "medical model" scenario or the move to evidence-based care.

Beyond the cost and ethical dilemmas, what about serving the patient better? All dentists lament the fact that only about half of the population seek care on an annual basis. Why? Every dentist also has heard the two most frequent barriers to care: The "Shot" and the "Drill". Would there be an increase of patients seeking care if both of the main objections to care were eliminated? (other than obvious economic barriers)

Most practicing dentists surveyed, indicate a lack of familiarization with the more accurate diagnostic and treatment options available to them. This seems so true despite the constant flow of device advertisements in the dental literature.

The purpose we hope to fulfill with the publishing of this textbook is to familiarize General Restorative Dentists with the updated information about these devices and how to

practically incorporate them into practice. If adopted, as some dentists have already, that the incorporation of the devices in this book will increase their ability to make earlier diagnoses, make more evidence-based decisions and better educate their patients in their disease management. A bonus would be to do less iatrogenic damage to the dentition, with methods that are far more acceptable to the average patient. The net benefit to the population is earlier treatment, more scientific management and far more patients seeking this type of care. This can have a major impact on the “busy-ness” issue for many offices and clinics. There is little controversy that the smaller the restoration, the longer the tooth will most likely survive for a lifetime.

---

## Prevention

Even though dentistry is mainly concerned with three chronic diseases: tooth decay, periodontal disease and occlusal disorders, any approach to diagnosis and treatment must be rooted in sound preventive principles. So this text will begin with an updating chapter on fluorides and preventive methods. Fluoride supplementation has become one of the foundations of prevention. While we can make teeth less susceptible to the decay process, bacterial control is essential. The approach must be tailored to each individual and adjusted throughout life’s oral changes and challenges. While children are taught to brush the “tops of teeth” when should practitioners introduce the technique of sulcular brushing? When is it advisable to move patient from flossing to interproximal brushing? Isn’t diet monitoring necessary throughout the various stages of life? How precisely do we track patient medication and their side effects in the oral cavity? When do we introduce occlusal monitoring into the examinations process? At every stage of life, different strategies must be employed to match changing oral conditions.

When should sealants be placed? What are the best practices for sealant preparation? Clear sealants versus opaque. Fluoride release materials versus plain unfilled resin? How do you accurately determine if a sealant is indicated or a restoration? What happens if caries is present and teeth are sealed over decay? Are they worth doing at all?

Is there a way to cause melting of the sides of a fissure and coalesce the walls as a “natural” sealant? Which device could be used for this technique? Within this text, you may find the answers.

---

## Contemporary caries management

The concept of a structured assessment of risk for caries should assist the diagnostician in weighing the treatment options. A simple carious lesion can be monitored, minimally treated non-invasively or restored aggressively depending on the risk factors for an individual patient. The goal is to perform the least necessary treatment after having thoroughly assessed each patient’s risk for serious treatment consequences. Each of the risk factors need to be weighed carefully by the diagnosing dentist and an individualized treatment plan created and is explained to the patient.

---

## Decalcification management

The process of decalcification is generally considered the precursor of the decay process and bacterial infection. If early intervention is to be incorporated into practice, a course of non-invasive re-mineralization needs to be included in the treatment options. This can be a combination of chemical intervention, penetrating resin-based, or sealant therapy. Each strategy needs to be matched to the needs of the individual patient if we are to be successful before invasive treatment becomes necessary.

---

## Death of the bitewing X-ray?

The bitewing X-rays, both anterior and posterior have been a reliable test for interproximal decay once teeth have attained contact. There are devices currently available that offer more diagnostic information without the use of ionizing radiation. A controversial subject with pros and cons.

Transillumination with white light has been utilized for many decades. This technique has

inherent limitations due to the weakness of white light to transmit through tissue deeply.

New devices currently available utilize near-infrared light that is invisible to the naked eye. However, one property of near-infrared is potentially deeper penetration into both hard and soft tissue than white light. One such device transmits this infrared light through gingival and osseous tissue and then through the roots of teeth and into the crown. A miniature infrared camera (similar to a night vision device) records this phenomenon in real-time and display an X-ray like image on a computer monitor. Besides being much more sensitive than an X-ray, the images can be saved to the patient's record. One reason that it is more accurate is that the beam travels up the root and into the crown of the tooth contrary to the penetration of an X-ray. This change in angulation of the "beam" in conjunction with visualizing a bitewing X-ray will have an almost 3D appearance. Other advantages of this type system is being able to better visualize the extent of decay in both the enamel and the dentin; the exact location of the lesion in a buccolingual dimension is also easily determined; seeing cracks in both the restorations and the enamel; imaging decay under a composite restoration or lingual or buccal to an existing metallic restoration. This is usually completely blocked in an X-ray image.

No inference should be drawn that bitewing X-rays do have value in finding other types of pathology such as alveolar bone levels and calcification density.

---

## New diagnostic devices

The restorative dentist has always relied on the dental explorer as his primary decay-detecting device. While it should remain as the device of choice for detecting marginal defects of restorations, it fails the test as a diagnostic tool for virgin decay. Studies have shown almost a 50% failure rate in decay detection of pits and fissures. The medical model demands objective testing to support accurate diagnoses. The old methods have failed us miserably.

There have been introduced a number of simple diagnostic devices which utilize various wavelengths of light. They have been

demonstrated to more accurately pinpoint the extent of carious progression into both decay and dentin. More sophisticated devices can analyze lesions for decalcification. Others measure the column of bacteria in a pit or groove base utilizing the principle of laser fluorescence.

The digital age of miniaturization and high definition has enhanced what we can see in real time. Intraoral video cameras have come a long way since their first introduction in the 1980s. Not only is this methodology important to the diagnosing dentist but it is also a very essential element in the education of patients. While these cameras are justifiable in the hygienist's hands, it is also essential that the diagnosing dentist record and present these images to the patient for their understanding and treatment acceptance.

Other cameras utilize specific wavelengths of light to highlight bacterial concentrations, plaque accumulation, etc. One such camera system (SoproLife) allows for differentiation of normal structure from carious both pre- and intraoperatively. Use of this system could make the messy dyes commonly used for decay visualization unnecessary.

---

## Magnification

Fortunately, magnification used in dentistry has advanced significantly in the past few decades. The standard of care now recognizes the diagnosis and treatment needs to be carried out under magnification. Virtually all training programs involve training with face mounted magnification. Suffice it to say that this has greatly assisted all dentists toward a higher quality of care. So what is the next step?

The operating microscope has gained favor with the endodontic and surgical specialties. How long will it take the average dentist to adapt to this higher standard of magnification?

---

## Microbiology of the carious lesion

While it has long been established that tooth decay is primarily a bacterial infection, it has only been a recent discovery and identification of the multiple microorganisms involved in the caries



infection. Once thought of as a single causative bacterium, *Streptococcus mutans*, there are many more causative and facilitative organisms. This disease has many causes, and there are no current therapies which can all eliminate microorganisms completely from a tooth. No restorative techniques currently can completely seal out their return!

A clearer understanding is needed for practitioners for this disease to become eradicated or at least better treated.

---

## Drill elimination!

The high-speed handpiece is entering its 8th decade of use! In this day and age, is there finally an alternative to the destructive nature of this device? Decades of research has shown now that every high speed handpiece causes fracturing of tooth structure when used intracoronally! This occurs due to the friction, heat and eccentricity of these devices at speeds 100,000 RPM and higher. If the high-speed handpiece were submitted to the FDA today, would approval be given? If approval were required, and not just grandfathered, would they be approved for use? What are the alternatives to use them?

More than 70 years ago, an air abrasive device was introduced to the profession. While reports at the time indicated general acceptance by both practitioners and patients, the technique did not facilitate retention of the restorative materials – amalgam and/or gold. Both of these materials require mechanical retention with undercuts.

The nature of air abrasives does not create mechanical undercuts sufficient to mechanically retain most materials. A re-introduction of the devices met with good acceptance in the 1990s for bonded restorations. The manufacturers failure to control the airborne particles has led to abandonment by most practicing restorative dentists. Newer techniques of particle management require another look by practitioners. The adherence of materials to an air abraded surface is significantly improved, and highly recommended.

---

## Cut teeth with light? Painlessly?

More than 20 years have passed since certain wavelengths of laser light have been used to prepare carious lesions for restoration. Early models of these devices were underpowered, and overpriced for the average practitioner. As a result, only about 10% of practices adopted them. Much has changed: cost has been reduced, speed of cutting has approached that of high-speed handpieces, and software has improved the performance of hard tissue lasers. They are virtually silent; they definitely can prepare most cavities without perceptible pain and leave a very bondable and clean surface for bonded direct placed restoratives. There are now more wavelengths available for use.

---

## Regeneration?

Once prepared and restored, can a tooth heal? It has been observed that new reparative dentin can be seen on post-treatment radiographs. There seems to be little correlation to the traditional restorative materials. The chapter on dentinal regeneration offers some suggestions as to how to attain this reparative dentinal result more predictably. New materials introduced into the market have the potential to cause complete and predictable remineralization on remaining dentinal structure.

Enamel, on the other hand is non-living structure. It is crystalline in structure, with protein sandwiched in between the crystal prisms. In attempting to re-create it, researchers have tried any number of techniques. Unfortunately, formative ameloblast cells are lost as teeth erupt into the oral environment. This has somewhat hampered research. Chemical, electrical means and lasers low-level have been used in the regeneration trials. More work is indicated in the quest to develop more natural restorations.

Could enamel be re-grown in situ? Is this the future of restorative dentistry? This has already been done in the laboratory, but can it be done intraorally? Please see the Chapter 19

to find out how stem cells stimulated by photobiomodulation may hold the key to completely replacing lost enamel.

Although beyond the scope of this text, there is ongoing work on the use of stem cells to re-populate the pulpal space with functioning tissue. This has the potential to markedly change endodontics.

---

## Preparation sterilization?

One of GV Black's principles 100 years ago was to "toilet the cavity" prior to placement of a restoration. Great idea, with what? Many materials have been offered as the best practice for cavity cleansing prior to restorative steps. Do they work? New evidence suggests that very few are effective as anti-infective agents. Some favor Ozone treatment (not yet FDA approved due to environmental concerns) others suggest glutaraldehyde preparations and many other chemicals have been suggested. Certainly removal of the cause of the problem remains a goal not yet fully realized.

---

## Therapeutic lasers: A place in restorative dentistry?

Besides surgical lasers, which can cut both hard and soft oral tissues, there are class of lasers which are non-surgical and impact cellular structures and functions without any effect on normal cells. They are approved for pain control and reduction of inflammation. These devices have been employed by Chiropractors and Physical Therapy Specialists for decades. They are currently employed in dental practices in pain reduction for TMD disorders, reduction of post-treatment inflammation and expediting orthodontic movement. Other potential uses include reduction of pre- and post-treatment inflammation, pulpal analgesia, and promotion of nerve regeneration.

This type of treatment is now known as Photobiomodulation.

---

## Buyer beware!

The suggestions in this textbook could be taken as overwhelming! It would be wise to consider making one change in your practice at a time. I strongly recommend picking one technology

that you feel could make the most difference in how you treat patients. Here are some practical guidelines on how to incorporate new technologies into practice.

- Insist on appropriate training with a device! Whether it calls for a few hours with a trained technician or salesperson, or a course of study leading to a certification or credential
- Determine the return on investment for a particular technology. This could range from 1 month to up to a year or longer!
- Only take on one new technology at a time! It isn't the easiest thing to learn on the job but one device at a time will promote understanding and aid in implementation
- Time is needed to incorporate any change in office routine. The time invested will be worth it in the end
- Train your staff! Even the receptionist must understand the value of any treatment device (i.e. the person who will ask treatment questions by patients)
- Always contact several colleagues who have incorporated a particular technology into their practice prior to your purchase

---

## Conclusion

The purpose of this book is to bring new information to general practitioners all over the world. It is also meant to serve as a WAKE UP CALL to all who cling to the outmoded principles and techniques of the past.

Today's technological explosion has had a major impact on the practice of medicine. To a far less extent, this explosion has been much less on the practice of dentistry. Some of the reasoning is the isolated nature of dental practice, and some is the economic burden on the individual practitioner. Dentistry does not command the fee levels that medicine and hospital care command. Reduced fee programs have a negative effect on new equipment purchases.

Where the tried and true methods have proven less than adequate or prevent patients from accessing care, they should be replaced.

No one practitioner could or should employ every technology or methodology mentioned in this textbook. If every practice implemented just one of the technological changes in diagnosis or treatment, the impact on patient care could be demonstrably better.



# Section I

## Caries prevention

Chapter 1    **Prevention: Fluoride and enamel regeneration**

Chapter 2    **Caries-penetrating resin therapy**

Chapter 3    **Identifying patients at risk of caries**



## Introduction

For more than 70 years, fluoride has been a main component of Preventive Dentistry. A co-equal partner with home care and diet control, the Dental Profession has been able to drastically reduce tooth decay rates among those patients with access to fluoride sources and regular professional care.

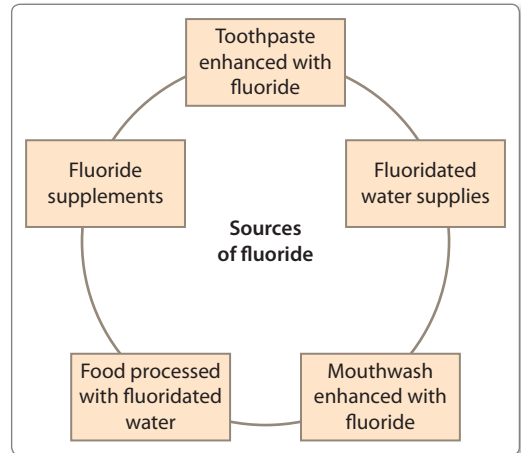
Fluoride is not without its controversies regarding its addition to water and various home care products. Only massive research efforts worldwide have maintained fluoride in proper concentrations, it is safe to use and can provide benefits to patients and their oral health.

## Background

The fluoride mineral is a naturally occurring trace element found primarily in ground and surface water. Researchers in the 1930s and 1940s noted lower tooth decay rates in areas where the fluoride levels approximated 1.0 parts per million (ppm). This discovery led to adjusting fluoride levels in public water supplies in the ensuing decades to this therapeutic level. The number of people served by these public water suppliers has approached 75% of the US population.

By the mid-1950s fluoride began to be added to oral health products such as toothpaste, mouth rinses and in professionally applied therapeutic agents such as gels, foams and varnishes. Over time researchers found that there was an additive, positive effect as each form of fluoride was further incorporated into the American oral health regimen (**Figure 1**).

Fluoride addition, however, is not without its controversies. Some may consider fluoridation to be a form of “forced medication”. They cite incidences of fluorosis, that its use is equivalent to putting “rat poison” into our food supply; and that

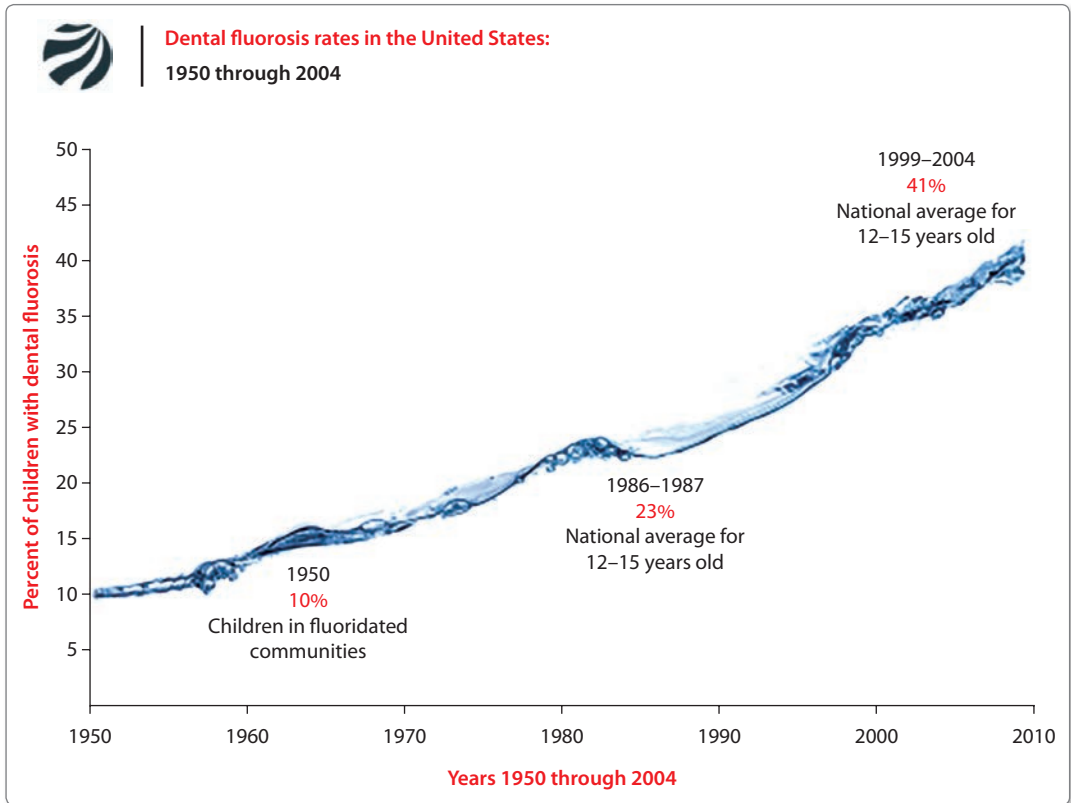


**Figure 1** The sources of fluoride.

it causes cancer and other forms of disease. Most of these claims appear to be a result as a general misunderstanding or deliberate manipulation of data to support their views and perhaps generate a general mistrust.

Dental decay is, by far, the most common and costly oral health problem in all age groups worldwide. It is most certainly one of the main causes of tooth loss for all ages and especially those who are part of a poor economic demographic. Decay continues to be a major issue for middle-aged and older adults, particularly root decay, as gingival tissue recedes naturally and pathologically over a lifetime. This gingival recession, can be complicated by decreased salivary flow (xerostomia), is often exacerbated by the use of certain medications, the combinations of medications or medical conditions.

Studies have clearly shown that the availability of topical fluoride during the initial formation of decay (demineralization) cannot only stop the decay process in the enamel in the presence of



**Figure 2** Dental fluorosis rates in the United States 1950-2010.  
(Courtesy: Public Health Reports, July August 2015 Vol 130)

calcium and phosphates remineralize the tooth, but also make the enamel surface more resistant to future acid attacks.<sup>1</sup> Toothpastes with fluoride have been responsible for a significant drop in caries since 1960.<sup>2</sup> In an effort to encourage people use toothpaste with fluoride, ADA has developed Stamps of Approval for each package of fluoridated dentifrice (**Figure 2**).

To date, scientific research continues to uphold the efficacy and safety of fluoride and as such it remains a cornerstone of public health oral preventive measures.

## Indications

As part of a thorough examination, the patient's fluoride exposure history should be part of the initial and ongoing caries assessment (see Chapter 3). Signs that a patient may be lacking necessary fluoride are high smooth surface

caries rate, hypocalcifications, as well as signs of fluorosis.<sup>3</sup> The patients' health history should include the following questions:

- Live or grew up in a fluoridated community (**Figure 3**)?
- Take vitamins with fluoride (children)?
- Take fluoride supplements?
- Drink non-fluoridated bottled water?
- Use fluoridated toothpaste?
- Use fluoridated mouth rinses (see **Table 1**)?
- Any other fluoride supplementation?

## Methods

Common protocol suggests that all preventive measures should be instituted prior to the placement of 'final' restoratives in a caries prone patient. This can help the patient take ownership of their disease entity and enable them to potentially reduce the recurrence of decay. Some dental



**Figure 3** Major Cities in US with Adjustment of Fluoride concentration.

\*Fluoride pending

**Table 1 Available fluoride mouth rinses**

Product	Company
ACT Anticavity Fluoride Rinse (Cinnamon, Mint)	Chattem, Inc.
ACT Kids Anticavity Fluoride Rinse (Bubble Gum & SpongeBob Ocean Berry)	Chattem, Inc.
ACT Mint Anticavity Fluoride Rinse (2x/day)	Chattem, Inc.
ClōSYS Fluoride Rinse	Rowpar Pharmaceuticals, Inc.
Colgate Phos-Flur Ortho Defense (Bubble Gum, Cool Mint, Gushing Grape)	Colgate Oral Pharmaceuticals, Inc.
Core Values Anticavity Fluoride Rinse (mint)	Harmon Stores, Inc.
Core Values Kids Anticavity Fluoride Rinse	Harmon Stores, Inc.
Crest Anticavity Fluoride Rinse	Procter & Gamble Co.
Crest Pro-Health Complete Rinse	Procter & Gamble Co.
CVS Kids Anticavity Fluoride Rinse Bubble Gum	CVS Pharmacy, Inc.
CVS Mint Anticavity Fluoride Rinse	CVS Pharmacy, Inc.
Dollar General Kids Anticavity Fluoride Rinse	Dollar General
Equaline Kids' Anticavity Fluoride Rinse	Supervalu, Inc.
Equate Kids Anticavity Fluoride Rinse	WalMart Stores, Inc.
Equate Mint Anticavity Fluoride Rinse	WalMart Stores, Inc.
Firefly Anticavity Mouthrinse (Bubblegum, Strawberry, Melon)	Dr. Fresh, LLC
H.E. Buddy Bubble Gum Anticavity Fluoride Rinse	H.E. Butt Grocery Company

*Continues overleaf*



Table 1 Continued

Product	Company
H-E-B Mint Anticavity Fluoride Mouth Rinse	H.E. Butt Grocery Company
Inspector Hector Tooth Protector Anticavity Fluoride Rinse	Vi-Jon, Inc.
Kid's Crest Anti-Cavity Fluoride Rinse	Procter & Gamble Co.
LISTERINE SMART RINSE (Mint Shield, Berry Shield, Fab Bubble Gum, Bubble Blast)	Johnson & Johnson Consumer, Inc.
Meijer Anticavity Fluoride Rinse Fresh Mint Flavor	Meijer, Inc.
Meijer Kids Anticavity Fluoride Rinse Bubble Gum	Meijer, Inc.
Publix Kids Anticavity Fluoride Rinse	Publix Super Markets, Inc.
Rite Aid Mint Anticavity Fluoride Rinse	Rite Aid Headquarters Corp.
ShopRite Anticavity Fluoride Rinse For Kids – Bubble Gum Blast	Wakefern Food Corp.
ShopRite Mint Anticavity Fluoride Rinse	Wakefern Food Corp.
Sunmark Mint Anticavity Fluoride Rinse	McKesson Drug Co.
Swan Anticavity Fluoride Rinse (Mint)	Vi-Jon, Inc.
The Natural Dentist Cavity Zapper Fluoride Rinse, Berry Blast	Revive Personal Products
The Natural Dentist Healthy Teeth Anticavity Fluoride Rinse, Fresh Mint Flavor	Revive Personal Products
Tom's of Maine Alcohol-free/Natural Children's Anticavity Fluoride Rinse (Juicy Mint)	Tom's of Maine
TopCare Anticavity Fluoride Mouth Rinse	Topco Associates LLC
TopCare Kids Anticavity Fluoride Rinse	Topco Associates LLC
UP & UP Anticavity Fluoride Mouthrinse (Mint)	Target Corporation
UP & UP Kids' Anticavity Fluoride Rinse	Target Corporation
Walgreens Children's Anticavity Fluoride Mouth Rinse	Walgreen Co.
Western Family Anticavity Fluoride Rinse Kids Bubble Gum	Western Family Foods, Inc.
WinCo Foods Anticavity Fluoride Rinse	WinCo Foods

(Courtesy: ADA Website Accessed 7/22/18)

professionals and/or patients may not wish to fully employ these types of preventive measure, for various reasons. However, if this destructive cycle is not interrupted, the catastrophic damage will lead to tooth loss, which ultimately leads to reduced efficiencies in eating and proper intake of nutrition.

Since bacterial control is essential to the reduction in decay, these interventions should be given priority. This can include one on one personalized oral hygiene instructions done by a well-trained auxiliary team member. This can be one of the most important components to the successful oral health improvement for the patient. Diet is the next most important factor in reducing caries and then finally, fluoridation and remineralization. The first suggestion would be to directly attack the primary problem first: such as caries severity and location.

- Basic tooth brushing techniques proficiency and frequency

- Interproximal management of biofilm
- Anatomical defect management:
  - Sealants (see Chapter 13)
  - Penetrating resins (see Chapter 2)

## Diet

Ingestion of sugars and other fermentable carbohydrates will often lead to demineralization and ultimately caries. Patients exhibiting significant caries require an examination and alteration of carbohydrate intake.

This nutritional intervention is essential to caries control.

## Fluoride regimens

Naturally occurring fluoride is found in many groundwater sources but must be added by the water supplier in local areas.

**Table 2 Fluoride content by source**

Source	Range, mg/L
Municipal water (fluoridated)	0.7–1.2
Municipal water (naturally fluoridated)	0.7–4.0+
Municipal water (nonfluoridated)	<0.7
Well water	0–7+
Bottled water from municipal sources	0–1.2
Spring water	0–1.4 (usually <0.3)
Bottled infant or "Nursery" water	0.5–0.8
Bottled water with added fluoride	0.8–1.0
Distilled or purified water	<0.15

Unless the patient drinks tap water, the patient should be informed the need for additional sources of fluoride and why they should be employed.

There is a growing trend worldwide to drink commercially available bottled water. As of this writing, there is a growing concern as to ecological disaster of using plastic bottles (Table 2).

Current optimal concentration of drinking water fluoride is currently set at 0.7 ppm. This has been reduced from 1.0 ppm because of the proportion of foods and drinks processed with fluoridated water and its halo effect. In areas where fluoride water is not available, fluoride can be prescribed either as a vitamin supplement or in chewable form. Typically, this is ordered as 0.5 mg daily per dose. Children should be receiving ascending amounts of fluoride per the current recommendations for children under 16.<sup>8</sup> When choosing topical fluoride preparations, both the fluoride concentration and the contact time with tooth structure should be considered so that optimum benefits can be provided at the lowest therapeutic dose.

## Remineralization

An acid oral environment will promote the loss of natural mineral content from all tooth surfaces. Among the causes of low pH can be diet, fluid intake choices, and gastric regurgitation or acid reflux (Box 1).

Any combination of the above or each individual factor can overwhelm the buffering capacity of saliva. The lower the average pH, and the greater the amount of time that the teeth are in this acidic solution, the more the

### Box 1 Remineralization products (major brands)

- MI Paste with Recaldent (GC Dental Products)
- MI Paste Plus with Recaldent (GC Dental Products)
- MI Paste One (GC Dental Products)
- Enamelon Treatment Gel (Premier Dental Products)
- ProNamel Toothpaste Sensodyne (GSK)
- Enamel Health Toothpaste (Colgate)
- CTx3 Rinse (Carifree)
- CTx4 Gel 1100 (Carifree)
- Remin Pro (Voco Dental)

minerals will leech out of the dental structure. It is important to note that exposed root structures will demineralize twice as fast as enamel, and so the reduction/elimination of these acidic conditions becomes even more critical. As such, reduction in intake of highly acidic foods and drinks is very important for all patients. There are adequate treatment regimens for internal acid reflux conditions, but oral acidic reduction will require intervention by the patient and the dental professional as will be described below.

Caries begins as bacteria attach to tooth structure in plaque that accumulates around and between teeth. Within this milieu, acids are secreted which then removes minerals from the tooth structure. Once the minerals have been lost as evidenced by hypocalcification (white spot lesions), remineralization treatment should be implemented as the initial treatment of choice. The most common remineralization agent is casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) commercially known as Recaldent. Application of this compound to affected areas can assist in providing the needed minerals (calcium and phosphate) needed in the 'rebuilding' the natural structure. Additionally, these areas can simultaneously incorporate the fluoride ion for further acid protection. Increasing the contact time through the use of custom application trays may be of benefit.<sup>4</sup>

## Over the counter preparations

- Toothpaste
- (Caution: some newer formulations of toothpastes have very high abrasivity indexes, please see Chapter 3 addendum)
- Mouth rinses
- Lozenges

## Prescribed supplements for geographic areas without acceptable optimum fluoride content

- In vitamins (where available)
- Sodium fluoride tablets 2.2 mg (1.0 mg fluoride)
- Toothpaste w/5,000 ppm sodium fluoride
- ACP with Ultramulsion preventive treatment gels (w/970 ppm fluoride)

## Professionally applied fluoride and anticaries preparations

- Foams
- Gels
- Varnishes
- Glutaraldehyde/resin
- 1% chlorhexidine and 1% thymol varnish
- Silver diamine fluoride (Figure 4).<sup>5</sup>
  - As Advantage Arrest by Elevate Oral Care, 38% silver diamine fluoride is approved by the Food and Drug Administration (FDA) for the reduction of dentinal hypersensitivity, but it has also been shown to reduce bacteria and matrix metalloproteinases (MMPs), which are responsible for the degradation of dentin, and it is believed to arrest carious<sup>6</sup>

## Fluoride varnish indications

Patients exhibiting the following conditions are likely candidates for fluoride varnish application at preventive appointments.



**Figure 4** Carious dentition treated with sodium diamine fluoride.

- Sensitive teeth
- Periodontal disease
- Frequent tooth decay
- Exposed tooth roots and gum recession that leave them highly vulnerable to decay
- Practice less than optimal home care
- Dry mouth symptoms
- Drink soda or pop frequently, or other highly acidic drinks:
  - Most prepared packaged drinks are highly acidic
- Multiple restorations
- Developmental defects, deep pits and fissures
- Orthodontic appliances which can trap plaque in or around them

## Benefits

Community fluoridation of drinking water has been credited with the reduction of 30% in the prevalence of decay since 1960.<sup>3</sup>

Fluoride present in saliva and dental biofilm works through topical remineralization of tooth surfaces. An additive effect of fluoride dentifrices and mouth rinses has been reported.

## Drawbacks

Ingestion of higher than recommended amounts of fluoride can result in fluorosis. Mild fluorosis appears as whitish lines or areas, pitting of teeth, and mild staining. More severe are dark stains and opacity due to the malalignment of enamel rods.<sup>7</sup>

Most cases can be traced to groundwater concentration of fluoride greater than 4 ppm. Additionally, children with fluorosis have been associated with the ingestion of unusual amounts of fluoridated toothpastes especially since the introduction of child-friendly flavors.

## Conclusion

With all the available research and information about fluoride, it is important that we educate our patients into understanding why we are suggesting fluoride as an important part of their dental care. It is helpful to take the time to answer patient's questions, provide them with flyers and brochures to help patients understand why fluoride is such an important part of the dental preventive world and their overall dental health and well-being.

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## Introduction

Treatment of caries has evolved dramatically over the past decade. Advances in epidemiology of caries, dental materials, and technology as well as use of individual caries risk assessment have resulted in a much more conservative approach to surgical treatment of incipient lesions.

While surgical intervention has become more microinvasive in order to retain maximum tooth structure, research has shown dental restorations will need to be replaced many times in a patient's life span. Therefore, preventing an incipient lesion from becoming cavitated is crucial to avoid surgical intervention and subsequent restoration.

Recently, a product marketed under the brand name of Icon (DMG America Company, Englewood, NJ), has become available for non-surgical treatment of non-cavitated caries on interproximal and smooth surfaces of permanent teeth. The basic technique involves etching the incipient lesion with a strong acid, rinsing and desiccation, then filling the caries with a low-viscosity resin. The resin is allowed to penetrate deeply into the enamel lesion (near the DEJ) and is then hardened with a curing light. Resin infiltration forms a diffusion barrier in the tooth and thereby seals the lesion from further acid attack.

Clinical studies using resin infiltration on interproximal lesions on permanent teeth have shown very promising results. This paper reports on the clinical use of resin infiltration in order to achieve maximum clinical benefits for patients.

## Diagnosis and treatment thresholds for interproximal caries

Cavitation of enamel is thought of as a critical event in the caries process, as a formed

microcavity may harbor a cariogenic biofilm and protect it from mechanical disruption.<sup>1</sup> For this reason, cavitation of enamel is a common threshold for determining if caries lesions should be treated by surgical intervention. As diagnosis of interproximal caries is most commonly made through radiographic examination, and the clinician must determine the radiographic presentation that corresponds to interproximal enamel cavitation. Clinical studies have investigated the relationship between the radiographic display of the caries lesion and the presence of cavitation.<sup>2</sup> Several studies determined that 52–78% of lesions that displayed radiographic evidence of caries lesions in the outer third of dentin were cavitated as assessed during cavity preparation.<sup>2</sup> Other studies determined that 28–100% of lesions that displayed radiographic evidence of caries lesions in the outer third of dentin were cavitated as assessed by direct observation following tooth separation.<sup>2</sup>

With such variation in the reported correlation between radiographic display and enamel cavitation, the clinician is faced with ambiguity related to a threshold for surgical treatment. The International Caries Classification and Management System (ICCMS) was developed to help the clinician classify and treat caries lesions.<sup>3</sup> This system considers not only the radiographic display, but also the activity of the lesion and clinical staging. For example, an inactive lesion which is not likely to progress would not require surgical treatment. Clinical staging refers to the visual changes that can be seen in enamel throughout the caries process, including white demineralization bands, dark shadowing and frank cavitation. According to the ICCMS treatment matrix, active interproximal lesions without visual signs of caries activity do not require surgical treatment until radiographic display at the middle third of dentin. On the other

hand, for an active lesion in the inner third of dentin with early visible surface changes to the enamel, the recommendation allows the clinician to decide whether to perform surgical treatment.

As it is ultimately the clinician who must decide if a caries lesion will receive surgical treatment, it is useful to survey practicing dentists to determine their radiographic threshold for treatment. A 2009 study from the US Dental Practice-Based Research Network surveyed 500 dentists in the United States and Scandinavia.<sup>4</sup> The study reported that in high caries risk patients, 66% of dentists chose to surgically treat lesions radiographically observed in enamel only and 24% chose to wait until the lesions progressed to the inner third of the dentin. In low caries risk patients, 39% of dentists would treat the enamel only lesion surgically and 54% would wait until it progressed to the inner third of dentin. This survey demonstrates that many dentists perform invasive treatment to lesions that are radiographically evident in the enamel or inner third of the dentin despite evidence and professional recommendations that surgical treatment may not be necessary. The clinical niche for resin infiltration is to provide a treatment option to stop the progression of early caries lesions and prevent surgical treatment of savable tooth structure.

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## Development of resin infiltration for interproximal lesions

The histopathology of enamel caries can be summarized as acid dissolution and enlargement of intercrystalline spaces creating enamel porosity and channels for acid to progress to the dentin.<sup>2</sup> The initial caries lesion, the white spot lesion, forms when the subsurface of the caries lesion becomes more porous than its outermost 10–30 micron surface. The surface of the enamel is more resistant to dissolution due to the presence of less acid soluble fluorapatite.<sup>5</sup> The principle of resin infiltration is to occlude the porosity formed during the caries process and prevent pathways for acid to further dissolve the tooth structure.<sup>6</sup> The two basic steps to achieve this goal are to remove the less-porous surface layer of enamel

and allow resin to infiltrate the internal enamel porosities through capillary movement.

As the surface of a carious lesion may act as a barrier to resin infiltration, several preliminary studies evaluated different acid solutions for removal of the surface layer. A solution of 15% hydrochloric acid applied for 90–120 seconds was shown to almost completely remove the 45-micron thick surface layer of the lesion.<sup>7</sup> Solutions of 5% hydrochloric acid and 37% phosphoric acid were only able to remove about half the depth of the surface layer of the lesion.<sup>7</sup> Lesions etched with 15% hydrochloric acid could be infiltrated with a dental adhesive to a depth of 58 microns whereas the use of 37% phosphoric acid only allowed 18 microns of infiltration.<sup>6</sup>

After removing the surface layer of the caries lesion, the next step is to infiltrate resin into the porosities created during dissolution of intercrystalline enamel. The ability of several dental adhesives and 66 experimental resin infiltrants to penetrate porous enamel was estimated using their physical properties. Infiltrants containing triethylene glycol dimethacrylate (TEGDMA) showed the highest potential for penetration.<sup>8</sup> An experimental infiltrant containing about 90% TEGDMA and 10% ethanol was shown to penetrate deeper into caries lesions than a commercially available dental adhesive,<sup>9</sup> and later an infiltrant containing only TEGDMA was shown to penetrate deeper than other formulations of infiltrants.<sup>10</sup>

The commercially available resin infiltration product, Icon, was released in 2010. This product contains a 15% hydrochloric acid etchant, an ethanol solution for desiccating the enamel and a TEGDMA-based resin infiltrant. When applied for 3 minutes, the Icon infiltrant was shown to penetrate deep into non-cavitated interproximal caries lesions.<sup>11</sup> Initial laboratory testing showed that infiltrating enamel lesions with Icon resin infiltration was able to inhibit the progression of demineralization in an acidic solution.<sup>12</sup> There are some limitations. Salivary contamination of the infiltration process decreased its ability to prevent demineralization and infiltration is not able to fill the cavities present in cavitated interproximal lesions.<sup>13</sup>

## Evidence for the effectiveness of interproximal resin infiltration

In a split-mouth study of fifty 5–8-year-old children, 62% of untreated interproximal lesions progressed within a year, whereas, only 23% of those infiltrated showed radiographic progression.<sup>14</sup> In another split-mouth trial of 39 adult patients, 32% of infiltrated, 41% of sealed, and 70% of untreated interproximal lesions showed progression after 3 years.<sup>15</sup> In a third split-mouth trial of 29 young adult patients, 42% of untreated interproximal lesions progressed within 3 years, whereas, only 4% of those infiltrated progressed.<sup>16</sup> In a split-mouth trial performed in a practice-based network, lesion progression was noted in 10 out of 186 infiltrated lesions and 58 out of 186 untreated lesions.<sup>17</sup> Based on the results of these clinical studies, a Cochrane review for microinvasive treatments for managing dental decay concluded that microinvasive treatments for interproximal caries (such as resin infiltration) significantly reduces the likelihood of caries progression more than non-invasive treatments.<sup>18</sup>

## Procedure for interproximal resin infiltration

The caries risk of the patient must be determined based on the presence of caries lesions and the patient's diet. Diet counseling should be

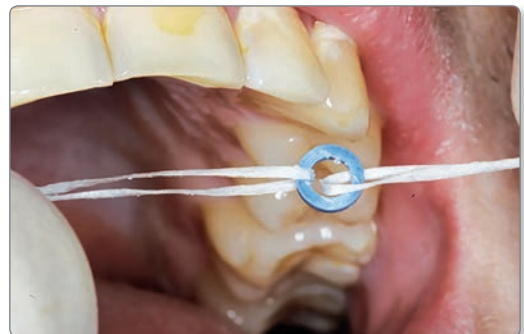
performed and patient was encouraged to substitute sweetened beverages with water. The surfaces to be treated using resin infiltration should be identified in the treatment plan and informed consent should be obtained. A bitewing radiograph will indicate the extent of penetration of the interproximal lesion (**Figure 1**).

Prior to treatment, orthodontic rubber separators should be placed (**Figure 2**) between the teeth to be treated in order to facilitate placement of the interproximal foils. The clinician must balance the inconvenience of scheduling time to place the separators and the uncomfortableness of wearing the separators with the ease of performing treatment that can be achieved with long-term use of separators. A larger separator is preferred for maximum results. In most cases, the resin infiltration procedure will not be performed during the visit where the determination for the need for the procedure is made. Therefore, it is generally possible and preferred to allow a minimum of a 72-hour period for interproximal separation for the teeth prior to performing the Icon procedure.

An easy method to place the separators is to loop two pieces of floss through the separator (**Figures 3a and b**) and then pull the separator taut. One side of the floss can then be passed through the contact. The separator is then pulled through the gingival embrasure so it is positioned apical the contact. The separator is then pulled coronally to wedge it between the contact. In order to remove the separator without inducing discomfort, it should be cut with scissors to open it up and then pulled underneath the contact with hemostats.



**Figure 1** Pre-treatment BW radiograph.



**Figure 2** Placement of separator.





**Figures 3a and b** Technique for placement of orthodontic separator prior to use of resin infiltration.



**Figure 4** Placement of rubber dam showing inversion of rubber dam.

After removing the orthodontic separator, a rubber dam is placed (**Figure 4**) to prevent saliva from contaminating the surface to be treated. It is also essential to avoid the hydrochloric acid from irritating the soft tissue, and the resin infiltrant producing an unpleasant taste to the patient. It is important to use a latex rubber dam with this treatment, as resin infiltrant can dissolve non-latex rubber dams. If the patient is allergic to latex, the



**Figure 5** Use of clamp acceptable on tooth to be treated if mesial surface is treated.

rubber dam material to be used should be tested with some of the infiltrant to verify it will not be affected by the resin. Based on the amount of excess infiltrant that contacts the rubber dam, a non-latex dam can form a perforation prior to completing the first 3 minutes of infiltration if not verified that this effect will not occur. As demonstrated in this case, the tooth receiving treatment can be clamped as long as the wings of the clamp do not infringe on the space needed to place the interproximal foil (**Figure 5**).

When the orthodontic separator is placed in advance, the wedge is only needed to stabilize the matrix during the procedure and not to separate the teeth. Using a wedge might cause bleeding which could interfere with the need for a completely dry environment. The wedge should be directed through the contact initially ensuring that the tip of the wedge is seen on the other side of the tooth and that it was not inadvertently directed apically into the soft tissue. Generally, local anesthesia is not needed. Once the wedge is in place, it should not be removed until treatment is completed as removing the wedge will frequently cause bleeding that will contaminate the procedure. Note that the wedge should only be used to stabilize the matrix system and not to separate the teeth. Separation is easily achieved via use of orthodontic separators.

The next step was to etch the tooth with Icon-Etch hydrochloric acid (**Figure 6**). The film in the interproximal foils is perforated on the side with the green border and unperforated on the side with the white border. Therefore, the foil is positioned with the green-bordered side facing toward the surface being treated. When sufficient



**Figure 6** Placement of Icon delivery system to introduce 15% hydrochloric acid solution.



**Figure 8** Positioning of air-water syringe and suction.



**Figure 7** Positioning of foil to introduce hydrochloric acid solution.



**Figure 9** Placement of alcohol solution.

separation is achieved, the foil can be easily placed by pushing the foil apically while slightly sliding the foil back-and-forth in the buccal-lingual direction (**Figure 7**).

If it is challenging to slide the foil through the contact (as demonstrated in the case above), the foil can be separated from the dispensing syringe so it is easier to manipulate. The foil is grasped with two fingers on one side and hemostats on the other in order to pull the film taut and prevent it from folding. It is then helpful to start at an occlusal point angle (mesiolingual-occlusal point angle) and gently saw the foil into the contact point. Generally, this last step is not needed when adequate separation exists via pre-placement of an orthodontic separator.

After etching for 2 minutes, the foil is removed and the tooth should be thoroughly rinsed with water for 30 seconds and dried completely. The air-water tip is placed in direct contact with the tooth to ensure it is completely dried (**Figure 8**).

The Icon-Dry alcohol solution should be applied to the interproximal area of the tooth. Several drops of the solution should be applied to the treated proximal surface so that desiccation of the surface can be achieved (**Figure 9**). After 30 seconds, the tooth should be completely dried with the air syringe after verifying that the spray will be completely dry.

A new foil is then placed between the teeth and the Icon-Infiltrant resin is introduced (**Figure 10**). Prior to dispensing the infiltrant, the overhead light must be adjusted with an orange filter to prevent premature polymerization of the resin. Over a 3-minute period, infiltrant is dispensed through the foil via rotation of the handle. Excess material should be removed with a low volume evacuator in order to prevent the patient from tasting the resin.

After removing the foil, a gentle stream of air and floss are used to remove excess resin (**Figure 11**).



**Figure 10** Placement of Icon infiltrant.



**Figure 13** Placement of second Icon infiltrant matrix to allow 1 additional minute of infiltration.



**Figure 11** Use of dental floss to remove excess Icon resin infiltrant after 3 minutes of placement.



**Figure 14** Special kit with devices to place Icon resin infiltration interproximally.



**Figure 12** Curing of Icon resin infiltrant circumferentially for 40 seconds total.

The infiltrant is polymerized with a light curing unit (minimum 1,000 mW/cm<sup>2</sup>). The light tip is placed in contact with the tooth and moved from the lingual to the occlusal to the buccal surfaces of the teeth for a total of 40 seconds (**Figure 12**).

The Icon-Infiltrant is then returned to the interproximal surface of the tooth with a new foil for the second application (**Figure 13**). The infiltrant is again applied for 1 minute and then the same clean-up and light polymerization procedures described previously are repeated. The wedge and the rubber dam should be removed, and the patient's mouth should be thoroughly rinsed. All of the elements of the product needed are available in a "kit" of Icon used for this interproximal lesion treatment purpose (**Figure 14**).

At the end of the visit, the patient is informed which teeth were treated with Icon resin infiltration and the treatment performed noted in the patient's chart. The patient must be informed that this treatment is not visible on radiographs, and therefore must be monitored through signs of radiographic progression.

## Resin infiltration for demineralized smooth surface lesions after orthodontic treatment

In the same way that resin infiltration is effective to arrest the progression of pre-cavitated interproximal caries lesions, it is also effective at halting progression of white lesions created as a result of inadequate oral hygiene during orthodontic treatment. Unfortunately, and too often, lesions appear around orthodontic brackets, which become highly visible and of great esthetic concern after orthodontic treatment. In the anterior region in particular, these white spot lesions can be highly unsightly. This is particularly problematic whereas a primary objective of orthodontic therapy is to improve esthetics. Because these lesions are specifically caries lesions, they can be treated using resin infiltration. The sequence of steps is the same except that the interproximal matrix is not needed. A separate “kit” of Icon is available specifically for this purpose (**Figure 15**).

An example of the immediate effect of resin infiltration treatment using the Icon system can be seen in **Figures 16** and **17** (pre- and post-treatment).

## Conclusion

Clinicians are well aware of the need to always provide the most conservative treatment possible when deciding how to manage dental caries lesions. The use of resin infiltration (Icon) is one of the most conservative lesion management techniques in terms of halting progression of caries lesions. With careful post-treatment monitoring, excellent results and minimal overall loss of tooth structure is achieved with this technique.



**Figure 15** Special “kit” for use of Icon resin infiltrant for anterior facial white spot treatments.



**Figure 16** Pre-treatment after rubber dam place showing white spots after orthodontic treatment.



**Figure 17** Immediately after treatment with Icon resin infiltration.

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## Introduction

Each patient who enters a dental office is a unique human being, with a unique set of lifestyle choices, health issues, and genetic factors. As dentists, we must be able to quickly judge the risk of caries and recommend appropriate treatment protocols. Our ability to successfully diagnose and manage caries-related risk factors is what will allow dental professionals to restore health to diseased mouths, to maintain health in caries-free mouths, and to build a foundation for excellent, long lasting, restorative and cosmetic treatments in your practice.

While quick fixes and instant solutions may be popular with patients, they're ultimately destructive. Several studies have found that between 60% and 70% of all restorations are replacements of failed restorations.<sup>1</sup> In order to help patients achieve and maintain dental health, it's important to target the underlying disease, not simply the damage it causes shift to proactive, non-surgical caries management restores health and prevents decay. It spares patients pain and anguish while setting the stage for more effective and attractive restorations.

## How to assess risk of caries during an office visit?

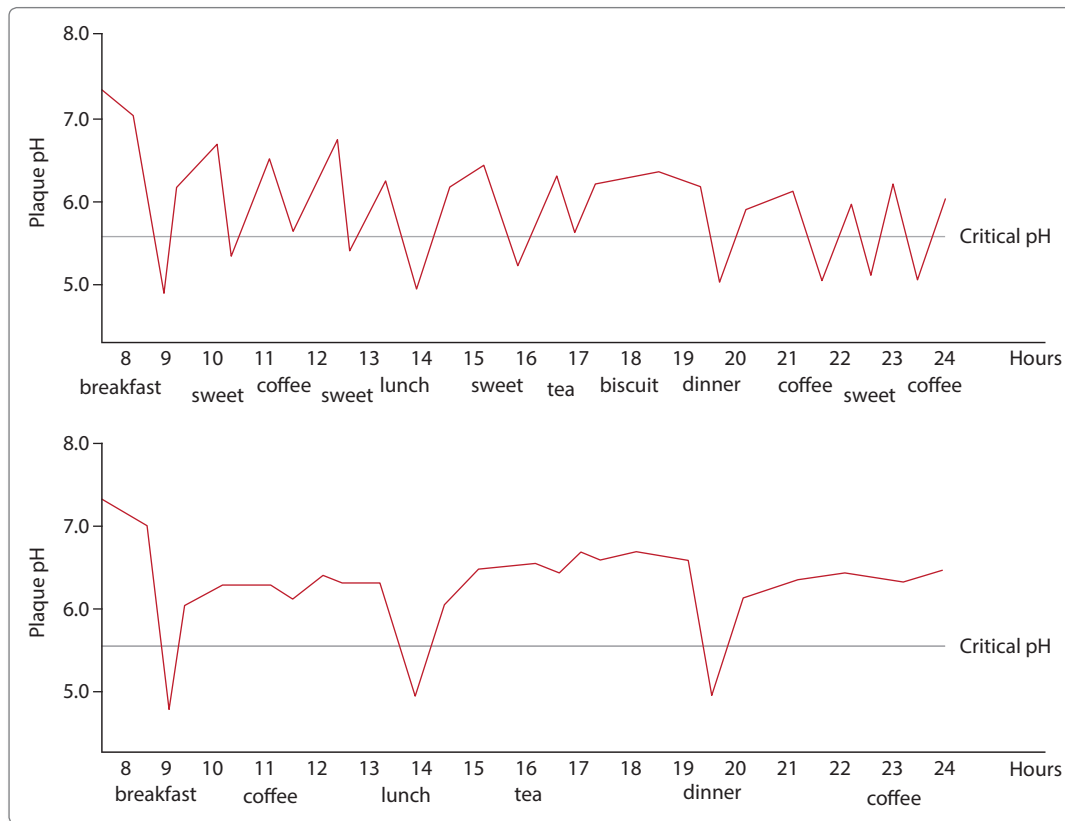
In order to prevent decay through proper caries management, each patient must be screened to determine their caries risk. Caries Management by Risk Assessment (Caries risk management) protocols sort patients based on their individual risk profiles and suggest treatment plans tailored to individual life assessments. As in the cases of the three patients highlighted at the beginning of the chapter, thorough assessment provides the information needed to address modifiable risks and take proactive steps to counteract non-modifiable risks.<sup>2</sup>

Practices newly implementing Caries risk management procedures must also conduct a thorough risk assessment on all existing patients. New patients should always receive an evaluation at their first appointment. After the initial assessments, reevaluate high-risk patients every 3 months and low-risk patients once a year.

A good caries risk assessment begins with a questionnaire (see **Figure 1**). Many of the modifiable risk-factors related to caries are unlikely to be observed during the clinical exam, so it is essential to collect accurate information on a patient's daily life. Before answering questions, each patient should receive an explanation as to why the team needs the information to develop an effective treatment plan. Otherwise, patients may conceal issues such as medications or carbonated drink consumption in order to avoid embarrassment.

While questionnaire focus and wording may vary with practice, it should address the following issues:

- *Patient issues with food lodged in crevices between teeth:* Food lodged between teeth can affect the pH of the mouth and provide nutrition to dangerous bacteria. This risk factor can be moderated with an enhanced at-home oral hygiene regime, with cosmetic treatments to change the shape of the tooth, or with orthodontia to move teeth and close gaps.<sup>3</sup> Contours of existing restorations may be changed or modified to minimize food impaction
- *Patient history of root canals and especially failed root canals:* Failed root canals are often a sign that the patient has been colonized with cariogenic bacteria. Without adequate treatment of the underlying infection, the patient will be at risk for further decay and failed restorations<sup>4</sup>
- *A patient history of failed crowns and fillings:* As with a failed root canal, these failures can



**Figure 1** Selections from a sample CRA form.

(Source: Public Health Reports, July August 2015 Viol 130)

point to an underlying, recurrent infection by cariogenic bacteria. Steps can be taken to correct the oral environment and improve the composition of oral bacterial cultures<sup>5</sup>

- *Patient reports of tooth sensitivity or pain:*

Sensitivity can result from decay, overly aggressive brushing that leaves teeth vulnerable to demineralization, or existing demineralization. Since damaged teeth are more susceptible to bacteria, sensitivity suggests a need for mitigation and prevention strategies.<sup>6</sup> Patients who consume packaged drinks with a low pH also increase sensitivity especially on exposed root surfaces

- *Patient's primary water source:* A growing number of adults and children do not drink fluoridated water. This could put them at risk for demineralization and tooth damage, especially in women who are or may become pregnant, and in young children whose permanent teeth have not yet erupted<sup>7</sup>

- *Medications and other risk factors for xerostomia:* Without adequate saliva, the mouth cannot restore normal pH levels after meals and cannot wash away harmful bacteria. The buffering capacity of saliva is an important self-protective mechanism of the oral cavity. Xerostomia (see **Figure 2**) is a risk factor that must be addressed in order to restore or maintain dental health<sup>8</sup>
- *The patient's history with eating disorders:* Anorexia can damage teeth by depriving them of vital nutrients and causing dry mouth. Meanwhile, the purging phase of bulimia bathes teeth in acid. If a patient has an eating disorder contributing to decay, the psychological problem must be treated before a long-term resolution to dental issues is possible<sup>9</sup>
- *Reports of bruxism from the patient or family members:* While severe tooth-grinding can be diagnosed during the clinical exam (see **Figure 3**), it can be helpful to ask about



**Figure 2** The effects of xerostomia on teeth and gums.



**Figure 4** Damage to teeth from poor brushing habits.



**Figure 3** Physical damage from tooth grinding.

related complaints from the patient and family members. Often a spouse is the first to notice night-time grinding behaviors, and this information adds important data to the overall risk profile

- *The patient's history of gastroesophageal reflux disease (GERD) and related disorder:* A well-written questionnaire won't just ask about a diagnostic history of GERD. It will also list the symptoms of GERD, like: heartburn, sour taste in mouth, difficulty swallowing, hoarseness, sore throat, and acid reflux. Many patients may suffer from GERD but may not have consulted a physician or received a diagnosis. However, undiagnosed and untreated GERD has been decisively linked to tooth erosion and decay<sup>10</sup>
- *The patient's food and beverage consumption habits:* Soft drinks lower the oral pH, provide nutrition to cariogenic bacteria, and contribute to demineralization and decay. Black coffee also lowers pH, and many popular coffee and tea-based beverages contain large

amounts of sugar. These beverages are especially damaging when the patient sips them throughout the day, keeping the oral pH constantly in the acidic zone. Meanwhile, beverages like milk and water have actually been shown to neutralize pH and exert a protective effect on the teeth.<sup>11</sup> It is important for patients to recognize that their beverage consumption plays a very important role in their overall risk profile. "Refer to the Ph list of packaged drinks"

In the same way, food choices prevent a modifiable risk. Constant sugary snack also keep the oral pH in the unsafe range, while regular, healthy meals followed by pH moderating beverages or rinses can reduce decay and even encourage remineralization.

Finally, while not strictly considered a food reop item, chewing and bubble gum can either increase the risk of caries, in the case of sugared gum, or decrease it, in the case of sugar-free gum with xylitol. It is important to ask not only whether a patient chews gum, but for information on which brands of gum the patient chews.

- *The patient's home oral care regimen:* Many people have acidic foods or beverages with breakfast. Brushing immediately after such a meal can remove enamel and leave teeth vulnerable to bacterial attack.<sup>12</sup> In addition, some patients brush too long, too vigorously, or with abrasive pastes and brushes. These habits can also contribute to gum damage, demineralization, and decay (see **Figure 4**). It is important for the dentist to get a full picture of the at-home oral care regime, since there are so many modifiable variables in the home environment that can contribute to caries risk



- *Current prescription and non-prescription drugs:* Many drugs can promote demineralization or can lead to xerostomia or pH imbalances in the mouth. It is important to get a complete list, including any illegal drugs, so that an appropriate treatment plan can be developed. The team member conducting the interview should emphasize that the information is only for the purposes of assessing oral health risks and will not be shared without patient permission
- *The patient's overall health,* including a full listing of chronic and systemic conditions that may increase the risk of decay or require alterations to standard treatment protocols. Many chronic diseases impede the body's ability to fight off disease. A patient's total health profile is an important factor in gauging their risk for cariogenic bacteria, tooth damage, and decay

The importance of the patient screening questionnaire in the CAMBRA process cannot be over-emphasized. The goal of treatment is not simply to correct current carious lesions, but to prevent future damage to the teeth. In order to achieve this goal, it is essential for providers to receive a very detailed description of each patient's habits, illnesses, and lifestyle choices.

## Screening for caries risk during an initial physical examination

During each existing patient's annual exam and during each new patient appointment, the dentist should conduct a focused screening to assess the risk of cariogenic bacteria and future decay. To accurately assess risk, it's important to have a clear understanding of the most recent research on the etiology of decay.

Decay is a symptom of an imbalance in the oral bacterial cultures, which in turn results from an unhealthy oral environment. No mouth is sterile. However, the composition of the oral biofilm varies from person-to-person. While certain bacterial cultures are highly correlated with decay, scientists now understand that the physical condition of the teeth and jaw, the rate of demineralization, the quantity of saliva, the age and economic status of the patient, and lifestyle habits also play a role in the decay process.

The more risk factors for decay that a patient has, the more likely they are to experience decay. Current evidence suggests that the Caries Management by Risk Assessment (CAMBRA) protocol helps reduce and prevent caries formation in high-risk patients while avoiding the over-treatment of low-risk patients.<sup>2</sup> After the initial 'patient questionnaire' stage of the CAMBRA process, it is the examining dentist's duty to carefully observe and record clinical data that will help determine the patient's risk profile and course of treatment (**Table 1**).

Special attention must be paid to:

- Any signs of notching at the gum line (see **Figure 5**)
- Chipped or cracked teeth
- Abrasion and erosion of enamel
- Irregularities on X-ray or other images

After the physical examination of the teeth, the dentist has several options for obtaining further information about the state of the patient's oral ecosystem.

- *ATP screening:* A 1-minute chairside screen (see **Figure 6**) uses bioluminescence to identify the biofilm's bacterial load and to gauge how active those bacteria are. This provides a concrete, actionable data point to help gauge a patient's risk of decay<sup>13</sup>

Table 1 Sources of CAMBRA forms

List of "Most Harmful Drinks" mg/cm <sup>2</sup> Enamel destroyed in 14 days continuous exposure	
KMX Energy drink	29
Snapple Classic lemonade	28
Red Bull	22
Gatorade Lemon-lime	20
Powerade	17
Amp energy Drink	14
Nantucket Nectars	12
Propel Fitness Water	12
Fanta orange	12
Nestea sweetened lemon	9
Arizona Iced tea	8
Coca-Cola	3
Black Tea	1

(Source: von Fraunhofer JA, et al. AGD Dental Notes, Spring '05, p.1)

- *pH check for educational purposes:* While checking the oral pH isn't useful for diagnostic purposes, some practitioners find it useful for patient education. It is especially helpful to encourage patient use of pH remediation protocols
- *Optional bacterial culture:* Recent research has shown that bacterial culture screens do not correlate well with actual risk of decay. However, some practitioners have continued to conduct the screening for the purposes of patient education and motivation. Since it can take up to 48 hours to receive the results of the culture, it can be difficult to communicate the results to patients and to use the results to effectively educate and motivate, especially in a busy practice

Use the International Caries Detection and Assessment System (ICDAS) coding system



**Figure 5** Notching at the gum line.

for the most accurate risk assessment. Researchers have found that the ICDAS coding system for decay is the most effective way of assessing risk and tracking the progression of disease and infection within the oral cavity (Table 2). It can be augmented with quantitative light-induced fluorescence system (QLF) technology to give both practitioner and patients hard data on the state of decay and the health of their teeth.<sup>14</sup>

While X-rays and sharp explorer tips remain popular diagnostic instruments, they introduce a high degree of variance into the diagnostic process. This can result in the same patient getting different risk assessments from different dentists, and then forgoing needed care. Chapter 5–9 will highlight many of the diagnostic devices available for more objective and caries definitive caries diagnosis.



**Figure 6** Chairside screening device used to measure bacterial load.

**Table 2** ICDAS coding system

ICDAS code	0	1	2	3	4	5	6
Definitions	Sound tooth surface, no caries change after air frying (5 sec) or hypoplasia wear, erosion, and other non-caries phenomena	First visual change in enamel seen only after air drying or colored, change "thin" and limited to confines of pit and fissure areas	Distinct visual change in enamel seen when wet, white, or colored. Wider than the fissure/fossa	Localized enamel breakdown with no visible dentin or underlying shadow, discontinuity of surface enamel, widening of fissure	Underlying dark shadow from dentin with or without localized enamel breakdown	Distinct cavity with visible dentin, frank cavitation involving less than half of a tooth surface	Extensive distinct cavity with dentin, cavity is deep and wide involving more than half of the tooth

Continues overleaf

Table 2 Continued...

ICDAS Code	0	1	2	3	4	5	6
Histologic depth		Lesion depth in P/F was 90% in the outer enamel with only 10% into dentin	Lesion depth in P/F was 50% inner enamel and 50% in the outer 1/3 dentin	Lesion depth in P/F with 77% in dentin	Lesion depth in P/F with 88% into dentin	Lesion depth in P/F with 100% in dentin	Lesion depth in P/F 100% reaching 1/3 dentin
Sealant/ Restoration Recommendation for low risk	Sealant optional, DIAGNOdent may be helpful	Sealant optional, DIAGNOdent may be helpful	Sealant optional, or caries biopsy if DIAGNOdent is 20–30	Sealant or minimally invasive restoration needed	Minimally invasive restoration	Minimally invasive restoration	Minimally invasive restoration
Sealant Restoration recommendation for MODERATE RISK	Sealant optional, DIAGNOdent may be helpful	Sealant recommended, DIAGNOdent may be helpful	Sealant optional, or caries biopsy if DIAGNOdent is 20–30	Sealant or minimally invasive restoration needed	Minimally invasive restoration	Minimally invasive restoration	Minimally invasive restoration
Sealant Restoration recommendation for HIGH RISK*	Sealant recommended DIAGNOdent may be helpful	Sealant recommended DIAGNOdent may be helpful	Sealant optional, or caries biopsy if DIAGNOdent is 20–30	Sealant or minimally invasive restoration needed	Minimally invasive restoration	Minimally invasive restoration	Minimally invasive restoration
Sealant restoration recommendation for EXTREME RISK**	Sealant recommended DIAGNOdent may be helpful	Sealant recommended DIAGNOdent may be helpful	Sealant optional, or caries biopsy if DIAGNOdent is 20–30	Sealant or minimally invasive restoration needed	Minimally invasive restoration	Minimally invasive restoration	Minimally invasive restoration

\*Patients with one (or more) cavitated lesion(s) are high-risk patients.

\*\*Patients with one (or more) cavitated lesion(s) and xerostomia are extreme-risk patients.

\*\*\*\*All Sealants and restorations to be done with a minimally invasive philosophy in mind. Sealants are defined as confined to enamel. Restoration is defined as in dentin. A two-surface restoration is defined as a preparation that has one part of the preparation in dentin and the preparation extends to a second surface (Note: the second surface does not have to be in dentin). A sealant can be either resin-based or glass ionomer. Resin-based sealants should have the most conservatively prepared fissures for proper bonding. See chapter 9 & 11 for suggested sealant preparation systems. Glass ionomer should be considered where the enamel is immature or where fissure preparation is not desired, or where rubber dam inclusion is not possible. Patients should be given a choice in material selection.

Table 3 Toothpastes RDA value

Straight Baking Soda	7
Close up with Baking Soda	120
Arm & Hammer powder	8
Colgate Whitening	124
DentLE CARE	35
Crest Extra Whitening	130
Oxyfresh	45
Ultra Brite	133
Tom's of maine sensitive	49
Crest Multicare Whitening	144
Arms & Hammer Peroxicare	49
Colgate Baking soda whitening	145

Table 3 Continued...

Rembrandt Original	53
Pepsodent	150
Closys	53
Colgate tarter control	165
Tom's of Maine children	57
Crest Multicare Whitening	144
Arms & Hammer Peroxicare	49
Colgate Baking soda whitening	145
Rembrandt Original	53
Pepsodent	150
Closys	53
Colgate tarter control	165

Table 3 Continued...

Tom's of Maine children	57
Colgate 2 in 1 tarter control/white	200
Colgate regular	68
Colgate total	70
Sensodyne	79
FDA Recommended Limit	200
Aim	80
ADA Recommended Limit	250
Colgate sensitive max strength	83
Aquafresh sensitive	91
Tom's of Maine regular	93

Table 3 Continued...

Crest reg.	95
MENTADENT	103
Sensodyne Extra Whitening	104
Colgate Platinum	106
Crest sensitivity	107
Colgate herbal	110
Aquafresh whitening	113
Arm & Hammer tarter control	117
Arm & Hammer Advance White	gel 117

(Source: Public Domain)

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# Section II

## Diagnosis

- Chapter 4    **Intraoral video cameras**
- Chapter 5    **Near-infrared transillumination**
- Chapter 6    **The canary system**
- Chapter 7    **SoproLife dental caries detection system**
- Chapter 8    **Laser fluorescence caries diagnostic device:  
DIAGNOdent**
- Chapter 9    **The surgical microscope for diagnosis and treatment  
of caries**
- Chapter 10   **Conventional diagnostic pitfalls**



*John J Graeber*

## Introduction

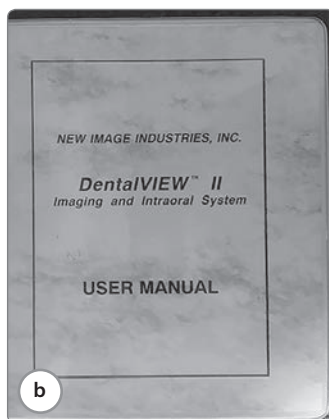
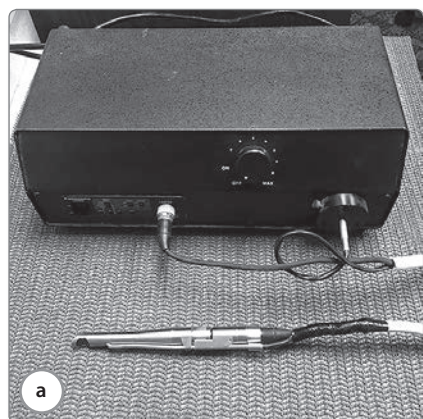
Intraoral video cameras (IOVC) were developed for dental practice in the late 1980s and their use was the first instance of the application of video camera imaging in caries diagnosis. Early models, such as those produced by Accucam and Fuji, were extremely expensive (costing approximately \$15,000), difficult to use, and were usually sold as part of rudimentary systems (by today's standards). The introduction of this technology served to heighten interest in cosmetic dentistry treatment at the time when highly invasive treatments (veneers, full coverage crowns and bridges) were very popular within the profession. IOVC preceded both tooth whitening and other more sophisticated devices (such as CariVu, DIAGNOdent) for use in the early diagnosis of caries.

One of the immediate benefits of these first generation video cameras was the ability to show patients live footage of the condition of their teeth, improving their awareness and enhancing the likelihood that they would follow advice relating to oral hygiene provided by their dentist. The increased magnification and better illumination also allowed dentists to more effectively monitor the changing nature of the

decay process due mainly to the positive effects of fluoridation. Since fluoride had begun to be added to the US water supplies, it became less common for decay to present as deep and well-defined cavitations, but instead appeared more subtly as discoloration, dark pits and fissures, and hypocalcifications on the surface of teeth. The introduction of IOVC has allowed dentists to detect these subtle signs and implement preventative treatments. Conventional diagnostic tools of the time (radiographs and mirror/explorer) were far less accurate and much less effective at identifying evidence of decay.<sup>1</sup>

## Development of the IOVC

Early IOV cameras were bulky due to the attached control box, which contained the light source. From the 'box', the light beam was carried to the intraoral camera via fiber optic cable. These cameras were usually included in cosmetic dentistry systems and were highly priced. The IOVC ensemble system often included a digital printer to produce color photographs, which either were given to the patient or saved in the patient record. One negative flaw present in these early cameras was the wear and tear causing premature failure of the fiber optic cable (see **Figures 1a and b**).



**Figures 1a and b** Early Accucam unit and instructions for use of software for cosmetic dentistry case presentations.



The development of the USB camera has allowed miniaturization of the camera device. Powered by the USB port of a computer, (usually from a laptop or tablet) the light emanates from the head of the camera wand. The LED light is brighter and whiter than previous fiber optic light sources providing a more accurate image. These devices are much lighter than older cameras.

Today's IOV cameras have improved the images immeasurably:

- LED illumination is far brighter than original fiber optic incandescent or halogen illumination
- LED's have improved color rendering due to the optimum color temperature of the LED
- Digital cameras have much higher resolution
- Digital cameras are usually automatically focused
- Some models are cordless reducing wear and tear on the cables

One disadvantage of the USB types is the smaller lens and relatively lower resolution when compared to smart phone mounted cameras or SLR Dental photographic equipment.<sup>2</sup>

## Method

The IOVC employment should be the first step in the examination process. Using the camera to quickly scan the dentition in this way allows the dental examiner to obtain an overview of every tooth, and any suspicious or questionable areas can be frozen and saved as a still image and can be reviewed later for closer scrutiny. Most patients can be IOVC scanned in less than a minute. Best practices are as follows:

- Cover the camera with a transparent “shield” to avoid cross-contamination between patients. Most cameras will have a shield specific to each model
- Clean teeth to remove plaque or debris, and place cotton rolls and/or dry angles to help with access and salivary control
- Further salivary control can be achieved by air-drying each quadrant prior to examination, using a dental air syringe. Drying immediately prior to examining each quadrant will help reduce light reflection and increase accuracy
- If a patient has salivates excessively, you may need to remove the camera after completing your examination of each quadrant to allow the patient to swallow

- Always start examination in the same quadrant and complete one arch at a time
- As an aid in focusing, rest the camera on tooth surfaces either in the same quadrant or on the opposing teeth
- Use lip and tongue retractors to help manipulate soft tissue. This will reduce the likelihood of poor image quality due to restricted access
- Freeze any image where decay or any anomaly is suspected. Remember to further check for caries or marginal defects in existing restorations (see **Figures 2 to 7**)



**Figure 2** Typical frozen frame from a quality IOVC to be shown to a patient while presenting treatment.



**Figure 3** IOVC image clearly showing fracture between 2 separate amalgam restorations through transverse ridge on maxillary molar.



**Figure 4a and b** IOVC images of hypocalcification.



**Figure 5** IOVC image of recurrent decay adjacent to bonded retainer arm.



**Figure 7** IOVC image of suspected decay under existing restoration.



**Figure 6** IOVC image of a fractured porcelain veneer.

- Complete exam with conventional steps as appropriate
- Clean the camera after each use to prevent possible cross contamination

Many intraoral cameras are kept in the hygiene room. While this affords the motivated hygienist an opportunity to show patients biofilm accumulations, home care deficiencies and compare healthy and inflamed gingival tissue, the diagnosis of caries is not the hygienist's responsibility.

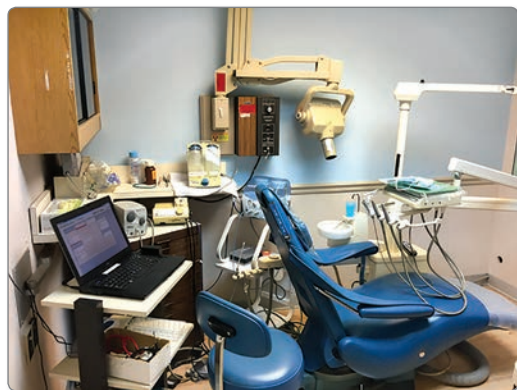
Consideration of the location of the IOVC is also important because every procedure done in the office setting requires it to become an efficient

part of the “flowchart”. Examining a patient in the hygiene room has significant disadvantages:

- Often there is too little space for diagnostic equipment
- The exam time wastes too much of the hygienist’s chair time
- Current infection control and sanitization tasks create enough chair “down time” thus negatively impacting on room use efficiency

This will require every exam patient moved to it for the Doctor’s examination. An adjacent operator if available can be used as the “Exam/ Consultation Room”. Minimum equipment is required for a dedicated exam room (see **Figures 8 to 10**):

- Chair and light
- Air syringe



**Figure 8** Typical hygienist operator.



**Figure 9** Using the IOVC with patient.

- Intraoral video camera/monitor/computer
- Mirror/explorer/periodontal probe
- X-ray viewer/computer for digital radiographs

## Use of IOVC in case presentation

Identifying dental pathology is just one part of the diagnostic process; presenting the need for treatment and acceptance is the far more difficult task. Lesions, which require a treatment recommendation, can now be shown immediately to a patient. Few patients had ever been shown what a small carious lesion actually looked like. Patients showed utter amazement when viewing the pathology “up close”.

Suffice it to say, the intraoral video camera has ushered in a new era of patient education. Patients are able to more easily understand and visualize a color image than they ever could do with X-rays. Patients now understand what and where their dental problems are and tend to show a far greater acceptance of treatment options.

When ready to present findings to the patient, an image of each recommendation can be queued-up so the presentation can be efficiently made to the patient.

The intraoral camera images save chair time in explaining pathology to patients – remember the old adage: one picture = 1,000 words!



**Figure 10** Exam room.



Figure 11a and b Fractured teeth.

## Advantages

- Enlarged view of teeth and oral pathology
- Creates a permanent record of preoperative condition
- Show coronal fractures for support of necessary indirect restorations (see **Figures 11a and b**)
- Made part of the patient's permanent record
- Are easily sent via email to insurance provider for pre-estimates or claim payment

## Disadvantages

- Cost of IO camera units
- Cost of integrating software and maintenance
- Time to integrate into examination routine
- Cost of training Staff/Doctor

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## Units in the dental marketplace

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  - SoproLife, Acteon
  - Schick, Sirona-Dentsply
  - Discovery 360, RF America
  - Mouthwatch, Mouthwatch, LLC
  - CS 1500, Carestream Dental
  - EZcam wireless, Ashtel Dental
  - Firecam HD, 3 disc Americas
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John J Graeber

## Introduction

The use of near-infrared (NIR) transillumination for caries detection allows for a broad range of diagnostic ability without exposing the patient to ionizing radiation of conventional bitewing X-rays. While radiographs are necessary for comprehensive examinations, X-rays have shown a low sensitivity to detect early carious lesions, especially on occlusal surfaces. Angelino et al. reported, "Transillumination of teeth with the near-infrared range offers a non-ionizing and safe approach to detect dental caries."<sup>1</sup> Early caries detection can lead to less invasive corrective procedures, as well as smaller restorations and greater longevity of the tooth over the patient's lifetime.

Gomez added the importance of using a method of caries detection that allows for information to be digitally saved in the patient's record. Caries risk assessment is one of the cornerstones in patient caries management and should be carried out and documented in patient's chart either for treatment planning or as a didactic aid for patient motivation.<sup>2</sup>

The challenge for dentists is the limitations of various forms of imaging in pursuit of caries detection. For example, interproximal caries is difficult to detect in radiographs unless it is larger than 2-3 mm deep in to the dentin, or one-third of the buccolingual distance.<sup>3</sup> Therefore, caries detection is a helpful adjunct to radiographic imaging methods and digital photographs. Angelino et al. further explained, "Because traditional radiographs capture a two-dimensional projection of all superimposed material between the film and source, there is attenuation or loss of finer detail. The orientation and severity of the feature directly affects its radiographic visibility; as such, some incipient caries, early demineralization, and the vast majority of cracks do not appear on the X-rays. Caries adjacent to and within direct line-of-sight of opaque amalgam fillings, such as instances of secondary caries, may also not be visible."<sup>4</sup>

## History of transillumination techniques

Caries detectors using light have evolved over the past half century. The forerunner of these technologies since the early 1970s is the fiber optic transilluminator (FOTI), consisting of a white light emitted from a cold light source passed through a fiber to an intraoral fiber optic light. Images of teeth obtained through visible-light, FOTI can be acquired with a digital charge couple device (CCD) camera, and sent to a computer for analysis with dedicated algorithms. The algorithms helped with the location and diagnosis of carious lesions in real time, and provide quantitative characterization for monitoring of the lesions.<sup>5</sup>

With the FOTI device, the light was placed on the buccal or lingual side of the tooth and seen from the occlusal view, and demineralized areas appeared darker when compared with surrounding tissue. The drawback to the FOTI technology was the lack of a visual record, so the next step, Digital Imaging Fiber Optic Transillumination (DIFOTI) (**Figure 1**) was developed to address this problem.<sup>6</sup>

The DIFOTI used FOTI technology as a basis and added the feature of a digital CCD camera. Using white light fiber optics as an illumination source, the images are captured by a camera and analyzed via computer. DIFOTI uses scattering of light to distinguish carious tissue from healthy enamel, with the carious part appearing dark and the healthy tissue appearing light. DIFOTI had the potential to detect early lesions as well as monitoring the lesion's progress, and could also detect fractures, decalcification, wear integrity of amalgam, composites, and sealants. The experienced clinician could also learn to better identify the difference between deep fissures, stains, and dentin lesions.<sup>7</sup> Unfortunately, this device, required up to several minutes to examine a single tooth and practitioners soon found this device impractical in private clinical settings.



**Figure 1** Digital imaging fiber optic transillumination (DIFOTI).

While these were groundbreaking technologies, early transilluminators lacked the ease of use of the most recent technologies. One dentist reported the frustrating challenge of trying to take a digital photograph while holding a mirror and the transilluminator at the same time.<sup>8</sup>

## Recent technological developments

Research and development teams continued to add benefits to the caries detection technologies. In 2013 and 2014, new devices were released – DIAGNOcam (KaVo in Europe) (**Figure 2**) and CariVu (DEXIS in North America) (**Figure 3**) are based on DIFOTI technology and support the diagnosis of occlusal, interproximal, and secondary caries as well as cracks (**Figures 4–7**). These technologies utilize two sources of infrared (invisible) light shining laterally through the tooth, making carious lesions visible as dark spots. They are easy to use, as the practitioner can simply place the tip over a tooth and capture the images or videos. The VDDS interface allows for communication with different software, and the TWAIN interface allows for easy integration with X-ray software.<sup>9</sup> The specific light of 780 nm wavelength emitted by the laser diode in DIAGNOcam and the light maximized at 788 nm for CariVu are able to penetrate through gingiva, alveolar process, and dental roots and from there up into the crown.<sup>10</sup> Angelino et al. explained that ‘The DEXIS CariVu has two light sources that enter the buccal and lingual side of a target tooth simultaneously for transillumination, and its camera is oriented directly toward the occlusal surface’. In addition, NIR transillumination uses longer wavelengths (**Figure 8**), allowing for



**Figure 2** DEXcam 4 high definition (KaVo).

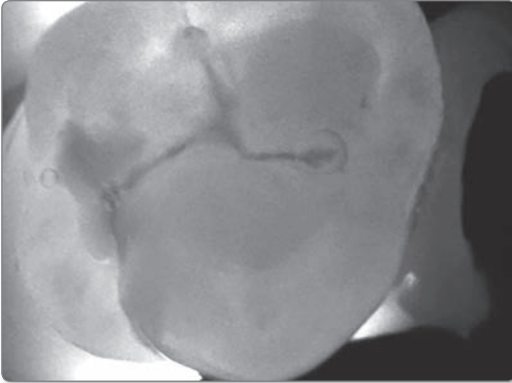


**Figure 3** CariVu (KaVo).

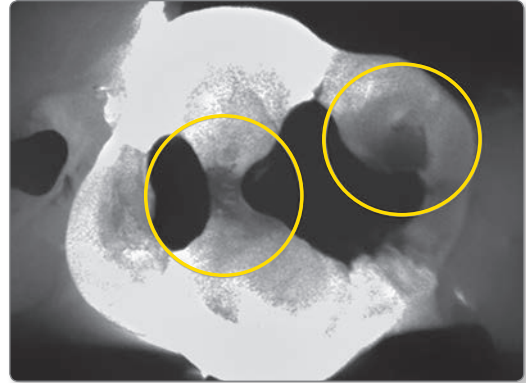
deeper penetration into the tooth.<sup>11</sup> The light enters the tooth root from two directions, and travels up into the crown, the camera views the image from the occlusal direction, the examiner can visualize the exact position of the lesion in the buccolingual dimension. This is especially helpful for rotated and malposed teeth where normal bitewings are useless.

## Method

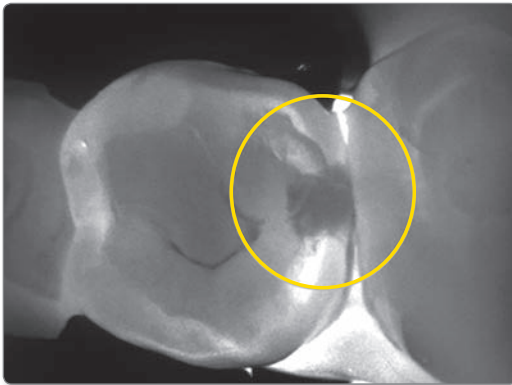
The flexible ‘arms’ on the end of the units’ tips straddle the alveolus, and NIR photons are emitted through these arms (**Figure 9**). At this



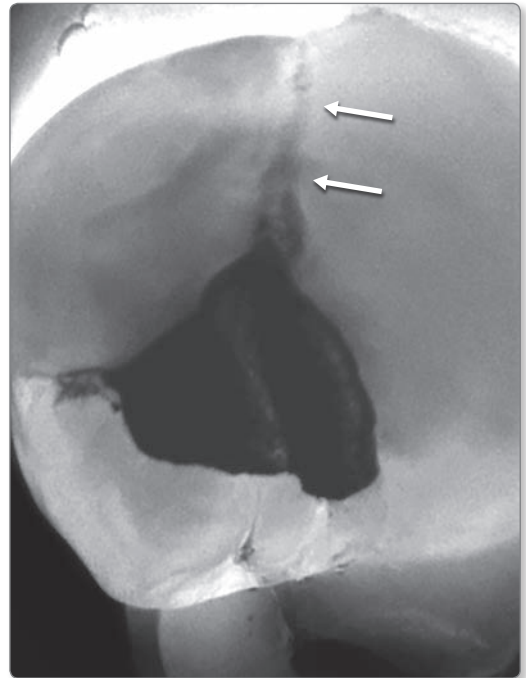
**Figure 4** Quantitative light-induced fluorescence (QLF) image showing potential caries in fissure pattern of mesial and possible undermining caries in distal surface of maxillary molar.



**Figure 6** CariVu image of maxillary molar with existing metallic restorations. Recurrent decay is indicated in circled areas, transverse ridge and mesio-buccal cusp. This indicates restoration failure, this is blocked from view in typical bitewing X-ray.



**Figure 5** Frank decay extending through the dentin–enamel junction (DEJ) suggesting a microinvasive procedure.

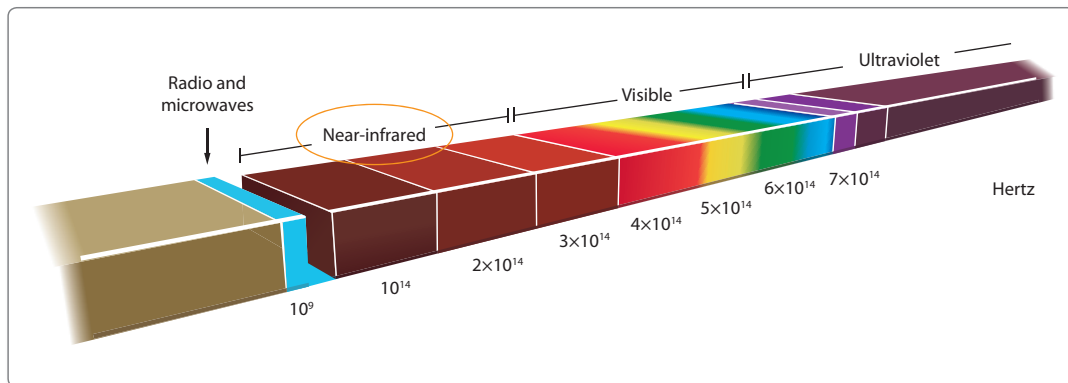


**Figure 7** Existing metallic restoration which shows decay in adjoining grooves in occlusal surface. Often, this is undetectable with an explorer or intraoral video camera.

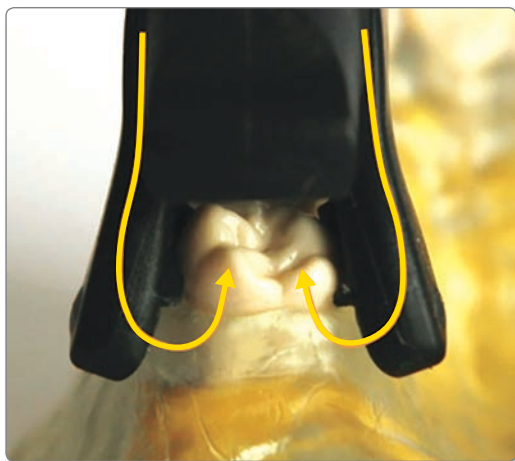
long NIR wavelength, the enamel becomes transparent to the photons while the porous lesions trap and absorb the photons (**Figure 10**), making the lesions appear as dark areas (**Figure 11**). The clinician can capture an image in one second with a squeeze of the wand, or capture short video clips using a ‘rocking’ technique that creates a 5-second video of the tooth seen at various directions instead of just a static image that is perpendicular to the tooth’s occlusal surface.<sup>12</sup> This technology brings an increased level of precision to caries detection

– DIAGNOcam and CariVu images have an interproximal dentin caries detection rate of 99%.<sup>13</sup>

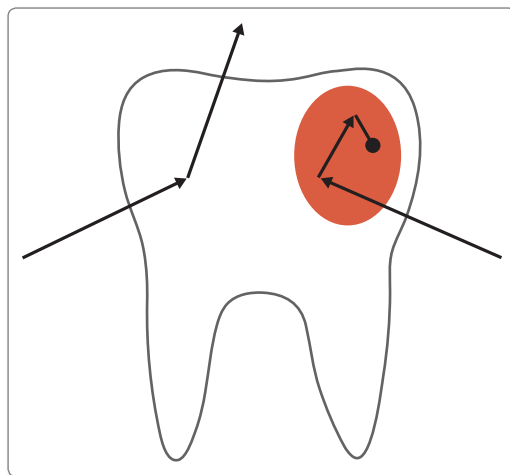




**Figure 8** Bar graph depicting the electromagnetic spectrum, wavelengths and bands of non-ionic wavelengths. CariVu is in the near-infrared band.



**Figure 9** Near-infrared light is carried through the instrument (black flexible rubber arms) exiting the arm and passing through the dental structures.



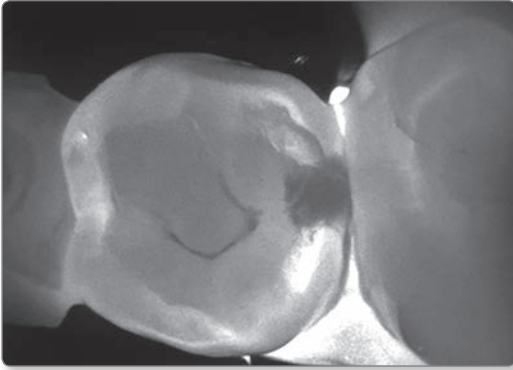
**Figure 10** Diagram showing how light passes through normal dental structures (left) and becomes trapped within non-intact structure.

Near-infrared transillumination allows dentists to see caries that may be undetectable with other forms of imaging. Dentist and lecturer, Parag Kachalia, DDS of San Ramon, California, states, "With the CariVu technology, the clinician can discover caries in areas that are difficult to detect". Before this device, caries detection devices could help to find occlusal caries and the presence of accumulated dental plaque, but no device on the market accurately assessed the proximal surface of the tooth.<sup>14</sup>

## Advantages

One of the most lauded benefits of transillumination technology is that it does not emit any ionizing radiation and can be used as often as needed. This is beneficial for patients with a range of medical and personal reasons for avoiding radiation-emitting imaging methods. These include:

- Patients who have recently received X-rays
- Patients with a history of radiation treatments or other medical therapies that preclude radiation
- Children for whom radiographs are not recommended
- Pregnant patients



**Figure 11** Existing composite restoration in distal of bicuspid (according to clinical record). Less light is transmitted through man-made materials than natural structure.

- Patients who are radiation averse for financial and/or philosophical reasons

Historically, bitewing X-rays were typically taken each year as a matter of course, even in children. In 2012, the ADA released radiographic protocols that recommended a more individualized approach regarding radiography. Besides a focus on the individual, the panel also recommended “thorough clinical examination, consideration of the patient history, review of any prior radiographs, caries risk assessment and consideration of both the dental and the general health needs of the patient should precede radiographic examination.”<sup>15</sup>

International lecturer Lou Graham, DDS, of Chicago, Illinois, agrees with this position, and posed the question, ‘Why do (dentists) take bitewings on 16-year-old and younger? To look for interproximal decay; we’re not looking for periodontal disease’. His protocol now is to capture CariVu images instead of X-rays on anyone under 20 unless they are high caries. He further states that one of the greatest advantages of this technology and the images it produces is seeing Class II lesions before it is seen on an X-ray.<sup>16</sup>

The NIR transillumination’s capacity for discovering caries as early as possible can fulfill the goal of creating restorations that are as small

as possible. The expected lifespan of a filling can be proportional to its size; the smaller the filling, the longer it potentially will last.<sup>17</sup> Detecting caries at its earliest stages and exact position facilitates the duration of the restoration and allows for minimal tooth removal.

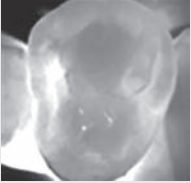
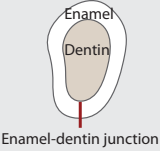
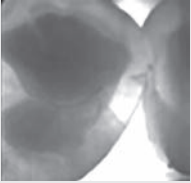

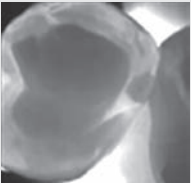

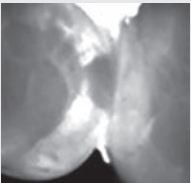

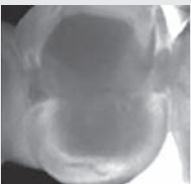

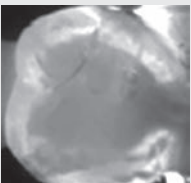

And, if an area is suspicious but does not show up on an X-ray, having a CariVu image in addition to X-rays can increase the trust in the doctor’s diagnosis. If the dentist is presented with an area that is questionable on an X-ray, especially one where difficult to detect interproximal decay may be present, the CariVu can offer a different type of view to determine the extent of the caries. If dentin penetrating caries is present, it is important to begin restorative treatment.

With the advent of NIR transillumination caries detection and its many benefits, dental professionals now have more diagnostic options and are not limited to only visual exams and X-rays. NIR transillumination devices can be used to assess the various forms of caries that both can be detected on X-ray and that may not be visible on X-ray. In the case of interproximal decay that is not visible or is minimally visible on X-ray, this chart (**Table 1**) can help to identify the shape and size of in all of its various forms.<sup>18</sup>

- No involvement, sound tooth structure
- At the first detectable signs of an enamel caries lesion
- An established caries lesion
- An established caries lesion that has reached the DEJ at a single point
- Dentin caries due to an established enamel caries lesion with extended involvement of the DEJ
- Established dentin caries

One advantage of NIR transilluminated images is that the clinician can discern if the lesion is more toward the buccal or lingual/palatal side to help plan the approach to restorative treatment. Once the dentist has established the exact location of the caries on the tooth, it can be eliminated in a more focused and minimally invasive process; that is, removing the least amount of tooth structure possible. With NIR transillumination, the dentist knows exactly where to go by looking at the obtained rather than making an educated guess of where the bur, Laser, or Air Abrasive device, should penetrate the marginal ridge to gain access to the proximal caries.

Table 1 Classification of CariVu findings<sup>20</sup>

	CariVu	Description	Clinical situation (possible dentin-extension in dotted lines)	Treatment options
0		Sound surface		<ul style="list-style-type: none"> <li>• Monitoring</li> <li>• Preventive intervention</li> </ul>
1		First detectable signs of an enamel caries lesion		<ul style="list-style-type: none"> <li>• Caries monitoring</li> <li>• Preventive intervention</li> </ul>
2		Established enamel caries lesion		<ul style="list-style-type: none"> <li>• Caries monitoring</li> <li>• Preventive intervention</li> </ul>
3		Established enamel caries lesion which reached the enamel dentin junction at a single point		<ul style="list-style-type: none"> <li>• Caries monitoring</li> <li>• Preventive intervention</li> </ul>
4		Dentin caries due to an established enamel caries lesion with an extended involvement of the enamel-dentin junction		<ul style="list-style-type: none"> <li>• (Minimal) Invasive operative treatment</li> </ul>
5		Established dentin caries		<ul style="list-style-type: none"> <li>• Invasive operative treatment</li> </ul>

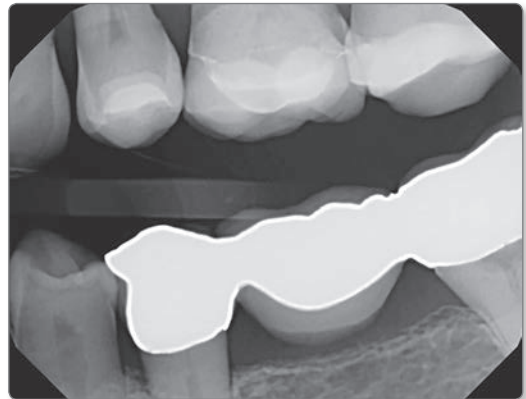
### ***An actual case***

Micro/minimally invasive dentistry does not always refer to initial caries. In many cases, the tooth may have existing restoration. Detecting and treating caries before it can further destroy tooth structure is also beneficial. Such is this in the published case by William McKibben, DDS, of Long Beach, California. A 62-year-old female patient had a small fracture on tooth No. 13 and an existing composite restoration on the occlusal aspect. Upon reviewing the clinical photograph (Figure 12), it was apparent that the occlusal composite was failing, and a tiny crack was barely showing on the distal portion of the tooth. The X-ray (Figure 13) did not show any problem in the tooth. However, on the CariVu image (Figure 14), the fracture was discolored enough to be reason for concern. After opening the tooth, it was discovered that caries was indeed present; in fact, (Figure 15) an increasing amount of caries was discovered as the clinician followed the fracture down deeper into the tooth and into the dentin. At this time, another CariVu image was captured that verified more caries (Figure 16). The restoration was then completed (Figures 17 and 18). Both the patient and clinician were surprised that the caries was not significant enough to show on the X-ray. The NIR transillumination device enabled the caries to be discovered and subsequently treated before it became worse. If X-ray was the only mechanism used and the only means of information available, the tooth may have gone untreated.<sup>19</sup>

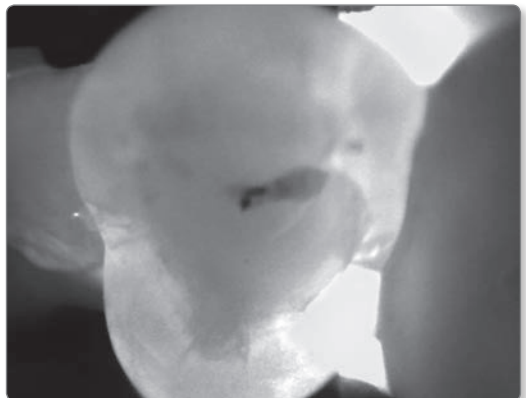
In these examples of NIR transilluminated images, all contain interproximal caries. However, they each demonstrate that each lesion is located in a different area along the marginal ridge, one with the lesion closer to the buccal aspect (Figure 19) and one with two lesions, both closer to the palatal aspect of the tooth (Figure 20). Without visual cues, and if using only a radiograph (Figure 21), the standard procedure would be to start at the center of marginal ridge and move out in a buccal-lingual fashion until the carious lesion was located, thereby removing more valuable tooth structure than needed.



**Figure 12** Apparent “stain” on occlusal surface of composite-restored Bicuspid. It is not possible to judge the depth of the stain by direct visualization.



**Figure 13** Bitewing radiograph of same tooth. No evidence of pathology.



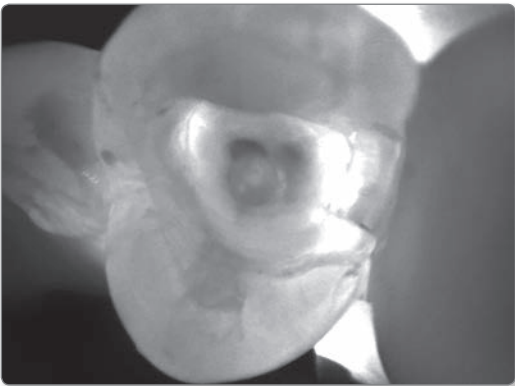
**Figure 14** CariVu image of same tooth: Clear evidence of a void within the existing restoration, and a potential fracture of distal marginal ridge, indicating treatment appropriate.



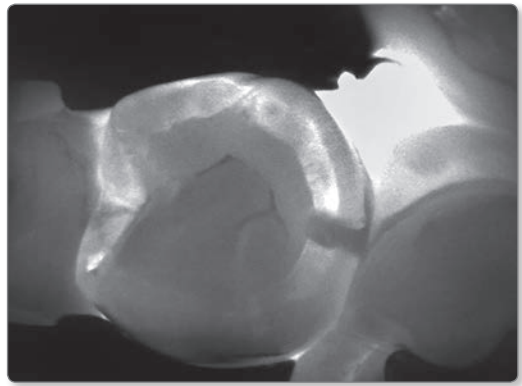
**Figure 15** Excavation confirming central fossa stained dentin and fracture in distal surface.



**Figure 18** Final composite restoration.



**Figure 16** CariVu image at the time of the photograph indicating affected dentin and remaining fracture line in distal after caries excavation.



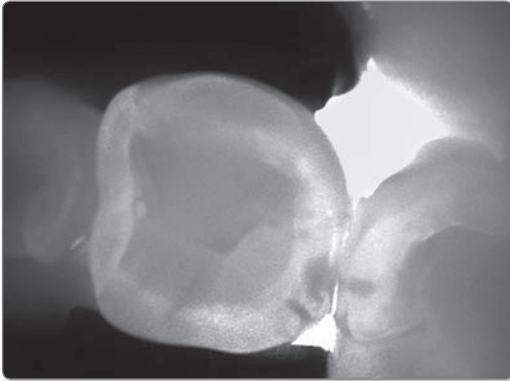
**Figure 19** Distal lesion on bicuspid: The buccolingual position is shown precisely.



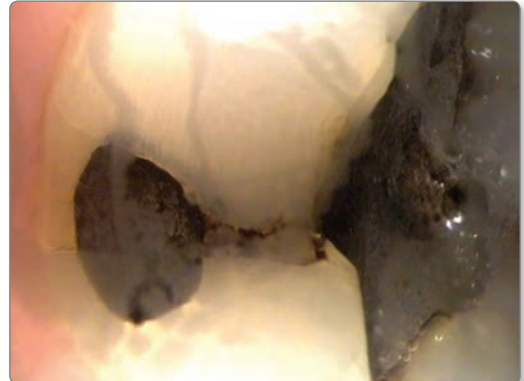
**Figure 17** Photo showing stained caries surrounding distal enamel fracture.

In the realm of caries detection technologies, NIR transilluminated images in particular provide visuals that particularly facilitate dentist-patient communication. The digital nature of

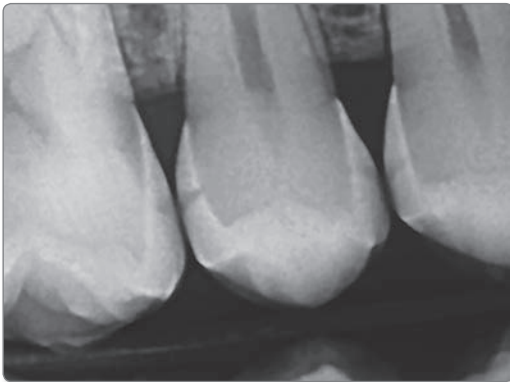
the DIAGNOcam and CariVu allow the image to be displayed on a computer screen either as a video feed or a frozen image so that both the patient and clinician can view the area of interest and identify and document the caries. Along with the dentist, the patient can see the light areas of the healthy tooth and any dark, questionable, carious areas. With a definite plan of restorative treatment, the patient can see why the practitioner would either want to wait to take X-rays until the next visit or whether he/she needs to begin preventive or restorative treatment immediately. In addition, documentation is also an important aspect to building and maintaining a historical monitoring system for caries that is being monitored. NIR transilluminated images can be captured, saved, and stored for documentation, and past and present images can be compared side by side (Figure 22).



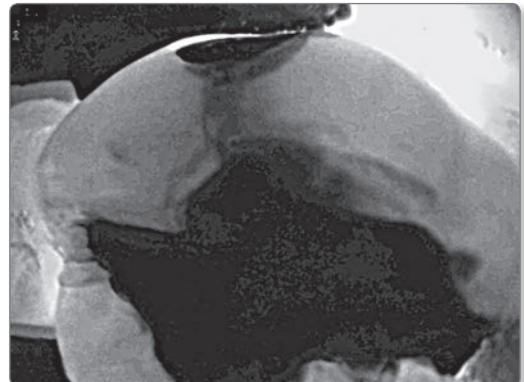
**Figure 20** Buccolingual position in a more likely place above the contact point with adjacent tooth.



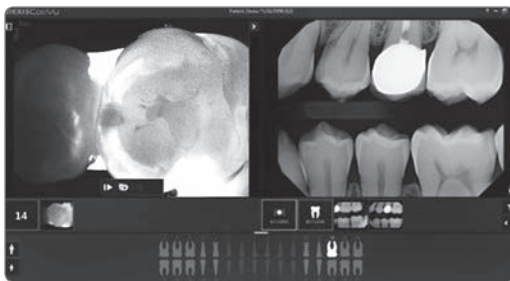
**Figure 23** Intraoral color photo potential decay between buccal and occlusal existing restorations.



**Figure 21** Bitewing X-ray of same tooth cannot distinguish the buccolingual position of the caries.



**Figure 24** CariVu image of same tooth showing recurrent caries between both existing restorations.



**Figure 22** Tooth 19 (36) exhibiting early dentinal caries on mesial surface with no indication of caries on same area in bitewing X-ray view.

“The structure adjacent to existing restorations can also be evaluated for recurrent caries (Figures 23 and 24)”.

While NIR transillumination is extremely beneficial in the early detection of caries, it is not a replacement for digital radiography. Rather, together with radiography and intraoral photographs, NIR transillumination devices can give the clinicians a more complete picture of a patient’s tooth structure, and allow them to make prudent decisions on whether to treat the lesion at an early stage or monitor the progress far more accurately.

## Summary of advantages – near-infrared transillumination

- No ionizing radiation
- Efficient to use as part of routine caries examination
- Images saved to patient digital record
- Very portable (USB connector)
- Integrates with most practice management software
- Far more sensitive than conventional bitewing X-rays
- Can detect lesions buccal or lingual to existing restorations<sup>20</sup>

## Disadvantages

- Cost 6–24 K depending on current digital X-ray software

- Links primarily to DEXIS Software
- Imaging of anterior teeth poor with current handpiece
- Cannot detect root or subgingival caries
- Is of no value in bone imaging

## Conclusion

The concept of employing NIR invisible light is a major step forward in early diagnosis, monitoring, and reducing the use of ionizing radiation in dentistry.

It should become the standard of care within a short time.

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Stephen Abrams

## Introduction

The Canary System, developed by Quantum Dental Technologies (**Figure 1**) uses a low-power laser diode (<45 mW at the tooth surface) at 660 nm and modulated at 2 Hz<sup>1</sup> to examine the tooth. Its unique energy conversion technology [photothermal radiometry and luminescence (PTR-LUM)] allows it to image and examine the crystal structure of the tooth. The PTR-LUM is able to measure and monitor two different phenomena: (1) modulated thermal infrared radiation (PTR), and (2) alternating current LUM.<sup>2</sup> When pulses of laser light are shone on the tooth, the laser light is converted to heat (photothermal radiometry or PTR) and light (luminescence or LUM), which are emitted from the tooth surface in response to these modulated pulses.

Caries, cracks and erosion modify the thermal properties (PTR) and LUM of healthy teeth. As a lesion grows, there is a corresponding change in the PTR-LUM response signal. In effect, the heat confined or trapped in a region with crystalline disintegration (dental caries) increases the PTR and decreases the LUM response signal. As remineralization progresses and enamel prisms start to reform their structure, the thermal and

luminescence properties begin to revert toward those of healthy tooth structure.<sup>3-7</sup> The Canary System detects very small changes in heat (<1-2°C), much less than that generated by a dental curing light. These pulses of laser light enable the clinician to examine lesions up to 5 mm below the surface.<sup>8-11</sup>

Research has demonstrated that Canary's energy conversion technology (PTR-LUM) can detect, diagnose, record and monitor:

- Lesions and defects 5 mm below the enamel surface<sup>11-15</sup>
- Occlusal pit and fissure caries<sup>8,13-15</sup>
- Smooth surface caries<sup>3,16,17</sup>
- Acid erosion lesions<sup>7,18-21</sup>
- Root caries<sup>22,23</sup>
- Interproximal caries lesions<sup>24-29</sup>
- Caries beneath fissure sealants<sup>30-33</sup>
- Caries around margins of restorations and crowns<sup>34-40</sup>
- Caries beneath the intact margins of composite resins<sup>37</sup>
- Caries beneath the intact margins of amalgam restorations<sup>38,39</sup>
- Caries beneath the intact margins of resin modified glass ionomer & compomer restorations<sup>39,40</sup>
- Demineralization and remineralization of early lesions<sup>6,7,23,41-45</sup>
- Caries beneath clear resin infiltrants<sup>46,47</sup>
- Caries around orthodontic brackets.<sup>48,49</sup>
- Lesions and teeth treated with SDF (silver diamine fluoride)
- High inter and intra-examiner repeatability<sup>33,40</sup>
- Detect and diagnose caries more accurately than radiographs<sup>24-26</sup>
- Detect and diagnose caries more accurately than fluorescence devices such as DIAGNODent or SPECTRA<sup>13,17,30, 33, 37,39,40</sup>



**Figure 1** The Canary System.

## Clinical trials

The Canary System has been investigated in three clinical trials. The first Health Canada-approved investigational study was completed in December, 2009. The trial involved 50 patients using the first



prototype in a number of clinical situations and found no safety issues.<sup>50,51</sup> The second Health Canada clinical trial was a follow-on study designed primarily to help QDT define the Canary Scale and determine how to best integrate the system into a dental practice. The study involved 98 patients among four trial sites with 38 patients involved in multiple visits for monitoring the effects of remineralization therapy.<sup>52-55</sup> The third clinical study was performed in 2014 at the University of Texas to investigate interproximal caries detection. The investigators found Canary was able to detect 92% of the lesions while radiographs only found 62%.<sup>26</sup>

One could consider other caries detection systems but the critical question is what exactly are they detecting? Currently, on market there are three different approaches to caries detection – fluorescence (DIAGNOdent, SPECTRA and SOPRO), transillumination (CARIVU, FOTI and DIFOTI) and PTR-LUM ('The Canary System').

## Fluorescence

Fluorescence is simply the emission of light from an object that has absorbed light at a specific wavelength.






These devices measure glow from the tooth surface when an LED or laser light is shone on the tooth. The literature indicates that the glow or fluorescence is from stain, bacterial porphyrins, tartar or food debris on the tooth surface.<sup>56</sup>

## Transillumination

Transillumination involves shining either visible light or near infra-red light through a tooth and measuring the scatter or disruption of the light. Sound enamel is composed of densely packed hydroxyapatite crystals which allow light to pass through them. When demineralization occurs, the light or photons are disrupted and the area will appear as a shadow. Shadows may indicate caries is present because demineralized areas of enamel or dentine scatter light more than sound areas. Therefore, caries appear as darker areas using FOTI,<sup>51</sup> DIFOTI and CARIVU. These detection methods still rely upon visual examination of grey shadows on images to determine the presence of caries and measurement of changes in lesion volume may be challenging. **Figures 2 and 3** provide a short summary of the clinical and technical characteristics of these systems.

## Method

The Canary System has a voice which provides the Canary Number after each 4 second scan. This helps both the operator and the patient to understand what is being measured (**Figure 4**). The Canary System also has an intra-oral camera so images of the surface being examined can be shown to the patient. Using the detail scan mode the Canary Numbers are recorded on the image and a report can be generated for the patient showing the Canary Numbers and treatment

Caries detection systems Clinical comparison					
PRODUCT	Canary System	DIAGNOdent	Spectra	SoproLife	CariVu
MANUFACTURER					
Detects caries and cracks on all tooth surfaces	✓	✗	✗	✗	Interproximal Only
Detects caries under sealants – clear and opaque	✓	✗	✗	✗	✗
Detects sub-surface caries	✓	✗	✗	✗	✗
Detects and measures tooth structure beneath White/Brown spots	✓	✗	✗	✗	✗
Detects caries around margins of restorations (amalgam, composite, crowns and glass ionomer)	✓	Not accurate measures porphyrins	Restorative materials glow preventing view of margin	Restorative materials glow preventing view of margin	Only large interproximal lesion at gingival margin
Detects caries around orthodontic brackets	✓	✗	✗	✗	✗
Quantifies changes in lesion size and volume	✓	Not accurate measures porphyrins	Not accurate measures porphyrins small scale	Image only no measurements	Subjective observation of black/white image
Monitors and creates reports on the effectiveness of remineralization agents	✓	✗	✗	✗	✗

\*Comparison information is based on published studies

**Figure 2** Caries detection system: Clinical features.

Caries detection systems Technical comparison					
PRODUCT	Canary System	DIAGNOdent	Spectra	SoproLife	CariVu
MANUFACTURER					
Measures changes in the crystal structure of tooth	✓	✗	✗	✗	✗
Method Of Detection	PTR-LUM Photothermal Radiometry and Luminescence	Measures porphyrins from bacteria, an indirect way to detect caries	Measures porphyrins from bacteria, an indirect way to detect caries	Measures porphyrins from bacteria, an indirect way to detect caries	Passes near infrared light through tooth (transillumination)
Use with ADA Code D0500 and CDA Code 04220 for caries detection – meets the code definition	✓	✗	✗	✗	Doesn't quantify lesion changes
Device output is quantifiable using a numerical scale	✓	Scale 0-100 does not measure changes in lesion volume	Scale 0-5 creates large degree of variability	✗	✗
Software is provided	✓	✗	✓	✓	✓
Patient and dentist reports provided – engages patients	✓	✗	✗	✗	✗
Cloud storage with access to data, reports and analytics	✓	✗	✗	✗	✗

Figure 3 Caries detection systems: Technical features.

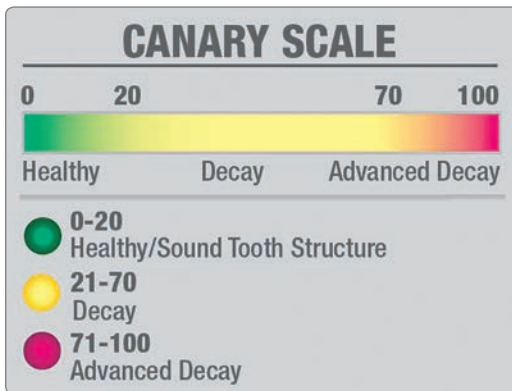


Figure 4 The Canary Scale.

recommendations. This creates the “medical model” for caries management. The patient can obtain a report (Figure 5) of the extent of the lesions on the teeth and recommendations on how best to treat them.

The earliest visual clinical sign of dental caries is the ‘white spot lesion.’ When this is first seen, the carious process has been going on potentially for months. Figure 6 shows a cross-section of a white spot lesion. Even though the surface appears intact the lesion is at least 530 microns in depth. In this case, scanning with the Canary System detected this lesion. These early lesions can be treated, before cavitation and they are amenable to remineralization.<sup>57,58</sup>

The key is to find the lesion and use technology to monitor the changes in the lesion as it undergoes remineralization.

### Integrating the Canary System into clinical practice

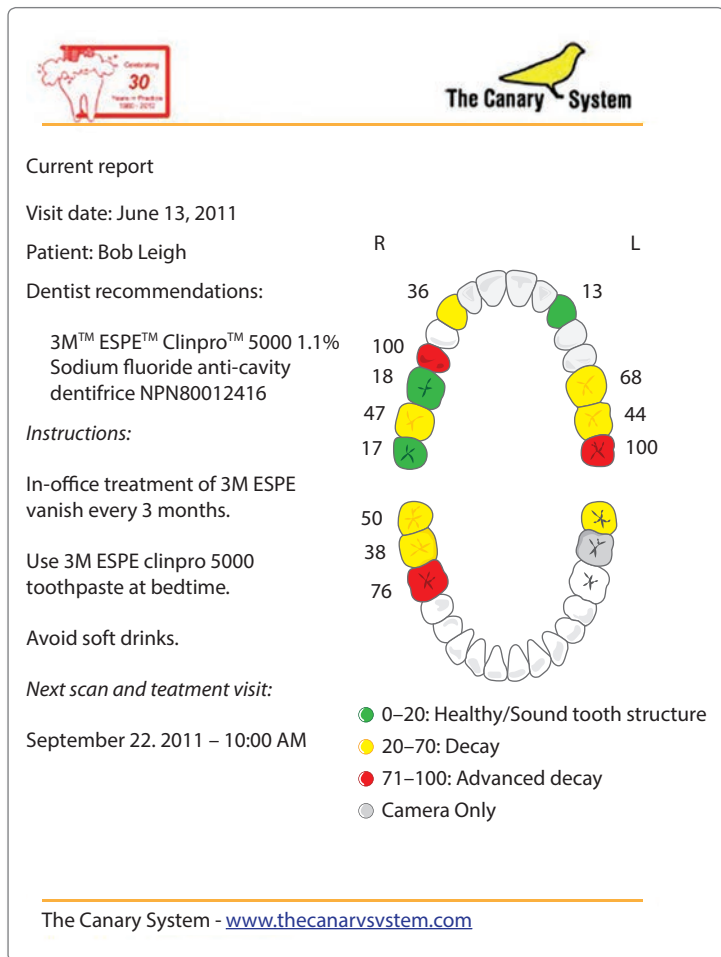
The Canary System can be integrated into three paths in a dental practice.

1. As part of the dental hygiene recall exam
2. Evaluating the progress of a remineralization/prevention program
3. As part of the new patient exam

The chart below provides a summary of how The Canary System can be integrated into a dental practice (Table 1).

What should be scanned during a hygiene/preventive visit?

- Status of pits and fissures on posterior teeth – helping to decide if sealants or restorations are required
- Status of the margins of restorations including composites, glass ionomers, amalgams, porcelain and metal crowns
- Stained marginal ridges to detect cracks
- White and brown spots on enamel or root surfaces
- Scan around orthodontic brackets to check for the development of white spots or caries beneath the bracket
- Interproximal areas to detect caries not seen on bitewing radiographs



**Figure 5** Canary patient report; it is available on the Canary Cloud or can be printed for the patient.

One should simply pick a quadrant (3–5 teeth) of most concern and assess all posterior teeth at the end of the appointment or scan teeth that are of concern.

## Who can use the Canary System?

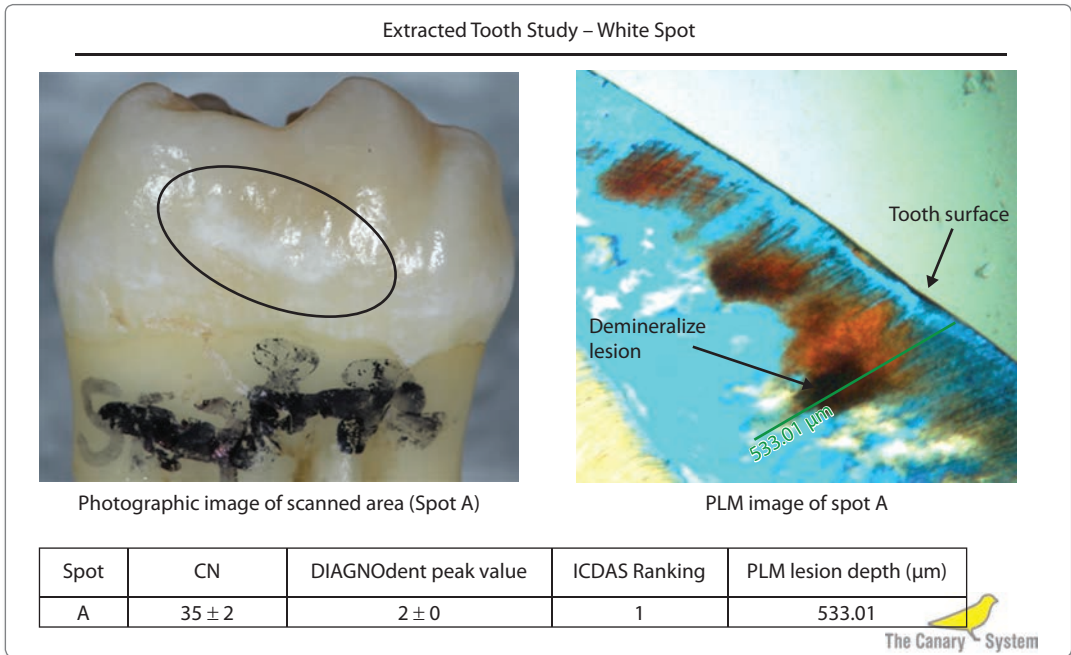
Any member of the dental team can use the Canary System, including dental assistants, dental hygienists and dental therapists. Once the scans are done, the dentist can then review the information and develop a treatment plan. Our canary recommended treatment guide provides guidance on how to treat various clinical situations.

## Clinical cases

Remineralization of brown spot lesions: A female patient, in her mid-twenties, had brown spot

lesions along the gingival crest of the second molars and the mandibular first molars. A remineralization program was started 4 years ago in an attempt to stabilize the lesions and prevent cavitation. At that time, the lesion surfaces were brown in color but had some surface roughness. Results from monitoring the mandibular left second molar over the last 42 months are displayed in **Figure 7**. The remineralization therapy consisted of a combination of 3M ESPE Vanish White Fluoride Varnish applied every 3–4 months in the office and the home use of 3M ESPE's Clinpro 5,000 toothpaste used nightly.

Initially, the patient started on the program and was able to decrease the Canary readout Number from “75” to “55” within the first 9 months of the program. There was no visible change but the patient was able to track their



**Figure 6** Extracted tooth study: Anatomy of a white spot lesion.

**Table 1** Integration of the Canary System into clinical practice workflow

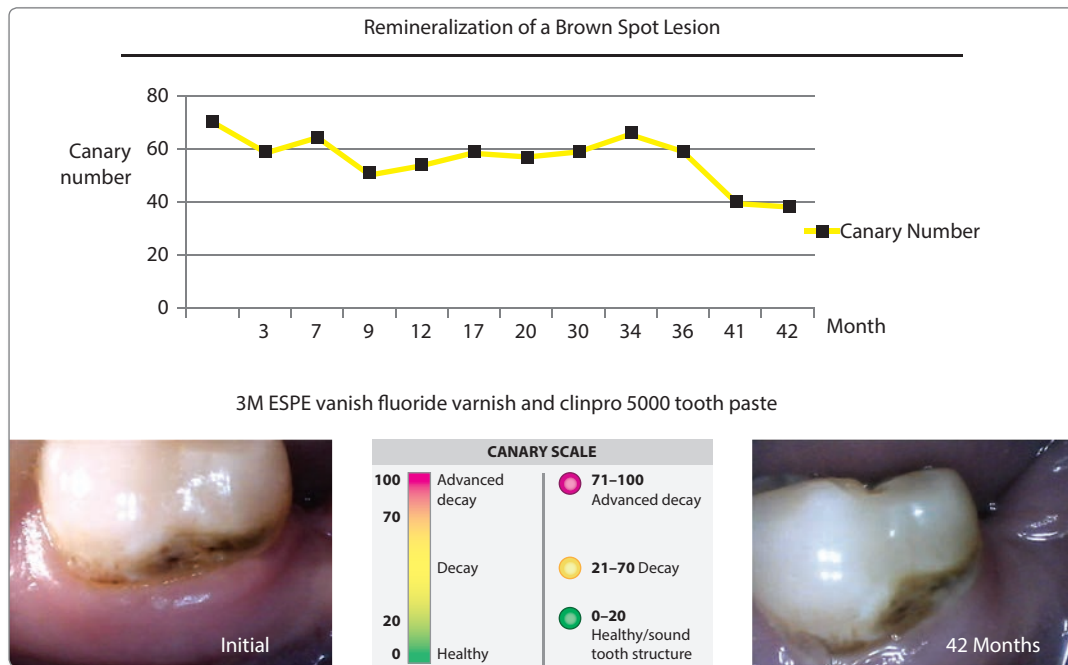
Examination type	Recall, re-care examination	Remineralization program	Full mouth examination
Details	Each scan takes 5 seconds. Scan 3–5 teeth and talk to the patient in under 4 minutes Scan at the end of the hygiene appointment while waiting for the dentist	Monitoring remineralization program using the Canary Book 15 minutes appointment to scan areas and apply remineralization product	A few offices book 45 minutes to 1 hour to scan the entire dentition. Some only focus on the posterior teeth and discolored areas on anterior teeth
Suggested billing code	Included in recall examination or use ADA code in the US (D0600) or Canadian Code (04220)	Remineralization/fluoride varnish or CAMBRA codes	US – ADA D0600* Canada – Specific Exam Code* or Caries Diagnostic code 04220
Staff	Hygiene team	Hygiene team or dental assistant	Hygiene team or dental assistant
Patient message	A new system for accurately evaluating the health of the tooth	Monitoring how our home and office tooth decay reversal program is working	There are a number of areas of concern that we can't assess with dental X-rays

\*Refer to the specific billing codes used in the US and Canada.

progress by accessing their reports on the Canary Cloud.

From month 12 to month 36 the lesion did not decrease in size and this was due to poor compliance with the remineralization program. No surface cavitation developed nor was there any pain on temperature change or exposure to sweet carbohydrates.

From month 36 onward, the patient decided to try to improve her Canary Numbers and did follow the simple home care regime. The Canary Numbers dropped to “25” and remained stable going forward. The tooth surface became smoother and no cavitation developed. Visually, there are no signs of remineralization or color change since initially this is mostly a sub-surface

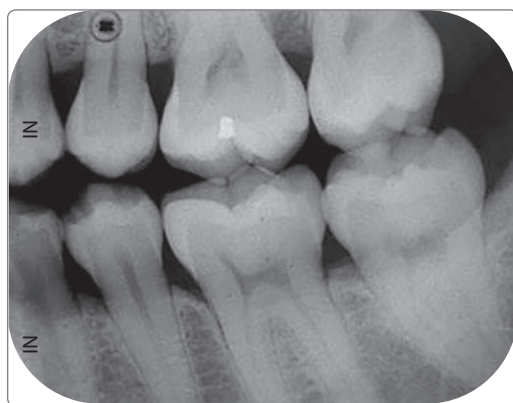


**Figure 7** Monitoring the remineralization of a brown spot on mandibular second molar. (Courtesy: Quantum dental and Dr Stephen Abrams)

phenomena. The ICDAS II ranking has remained at “4” throughout this process since it could not detect any sub-surface remineralization. Using the Canary System, we were able to monitor remineralization of the lesion. The patient was able to follow the remineralization process by accessing her reports on the Canary Cloud and listening to the voice on the Canary System as each scan was taken. This allowed the patient to take ownership of the management of her oral health.

### Clinical example of early caries detection using visual exam and radiographs

In this clinical situation, a 40-year-old female patient with minimal caries risk and only two pre-existing restorations was complaining of pain in the maxillary left first molar. The pain was low grade, not stimulated by chewing or cold. A routine bitewing radiograph (**Figure 8**) and visual examination revealed no sign of pathology, and both marginal ridges appeared intact with no signs of any radiolucency. Scanning the mesial contact area with the Canary System, however, indicated that a lesion was present beneath the occlusal aspect of the marginal ridge but toward



**Figure 8** Bitewing radiograph showing no interproximal lesions on the left side.

the buccal surface (**Figure 9**). Preparation of the tooth for a conventional composite restoration (**Figure 10**) confirmed caries on the mesial contact area as indicated by the Canary System. This clinical example illustrates situations where radiographs and visual examination may not be able to detect lesions due to their placement beneath a hard intact shell of radiopaque enamel – but treatment was required.



**Figure 9** Canary scan of the mesial marginal ridge of the maxillary molar. The Canary has detected an interproximal lesion.



**Figure 10** Opening the marginal ridge confirmed the presence of a lesion into the dentin not visible on radiographs.

## Advantages

- Ability to detect lesions far earlier than with visual or radiographic methods
- Ability to measure objectively changes in lesion demineralization
- Cloud and audible options aid the patient's motivation in remineralization efforts
- Virtual Training and online videos are available for training new staff

## Disadvantages

- Cost for equipment which is competitive with other technologies
- Time required for training/familiarization by the entire clinical team
- Time required for extensive testing of all suspected areas of demineralization

## Conclusion

Caries a common oral disease treated in clinical practice. Treatment of the disease does not involve placement of restorations but the detection and monitoring of changes if one is placing restorations or remineralizing lesions. The Canary System detects monitors and measures the changes in the crystal structure of the tooth which means it can be used as diagnostic device for the detection and monitoring of caries in clinical practice.

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Lawrence Kotlow

## Introduction

The standard of care for diagnosing and identifying dental caries has been the dental radiograph. The search for an alternative method for determining dental caries has been the goal set forth by many different techniques (see Chapters 5, 6, 8, and 9). One of the most challenging areas the dentist has to evaluate is on the occlusal surface of molars and bicuspids. The difficulty is to determine if dark occlusal areas are just stains or areas hiding caries just below the dentinal-enamel junction where radiographs may not detect the decay. In addition, the SoproLife device is beneficial when dental decay is difficult to identify as being completely removed during any restorative procedures, when it may appear that all the decay has been removed, but in actuality some decay is still remains.

In young children, pregnant women and in developmentally challenged patients, occlusal stains, may be present and these patients may not be cooperative enough to get acceptable radiographs and just a visual examination with or without an explorer to feel for decay which may prove inadequate, the SoproLife can be a valuable asset.

Acteon (La Ciotat, France) developed a device that uses the principle of autofluorescence including both white light for an excellent close magnification imaging of the tooth surface and a blue light-induced fluorescence to diagnose both healthy and decayed areas of the tooth. The SoproLife can reduce the need for dental radiographs in patients in general and for the patient who refuses radiographs, and it is an option to help in the diagnosis of healthy versus carious areas of teeth.

The SoproLife gives the dentist the ability to evaluate early areas of demineralization for

restoration or for attempting remineralization without the need for invasive caries removal by conventional dental drills or other means. This device also allows for early intervention by minimally invasive dental lasers (Carbon dioxide laser @9300 nm and erbium lasers).

The SoproLife is based on the optical property of the autofluorescence of enamel. Dentin and caries dental tissue when illuminated using a 450-nm wavelength. The unit uses a variable magnification intraoral camera. (Using three illumination modes – daylight, diagnosis mode, and treatment mode) and a caries detection system that appears able to detect differentiate the density, structure, and/or chemical composition of these tissues.<sup>2-4</sup>

## SoproLife

The SoproLife unit appears similar to many intraoral camera devices and attaches to the dental computer through a standard computer USB attachment (Figures 1 to 3). The software allows for easy integration with any digital computer imaging software.



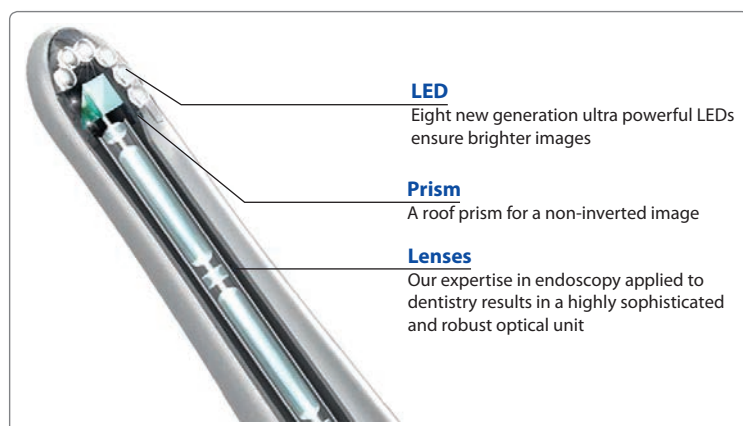
Figure 1 The SoproLife devise.



**Figure 2** SoproLife cable. Connection to the handpiece at one end and the USB connector at the other end of the cable.

The white or daylight mode allows for close up views of the areas to be saved within the digital X-ray software and can be used to compare the healthy or minimally decalcified areas at subsequent visits (**Figure 4**). It is an excellent tool when discussing oral care for orthodontic patients and keeping diagnostic photographs to evaluate oral care throughout the orthodontic period of treatment. The blue fluorescence mode is used to diagnose healthy decay free areas and also shows areas of enamel and dentinal breakdown of carious areas and remaining decay when restoring lesions.

The blue fluorescence mode will direct a beam of blue light at 450 nm into the area being examined and will reflect back a series of different colors depending on the health of the tissue (**Figure 5**). This ability of the dentist



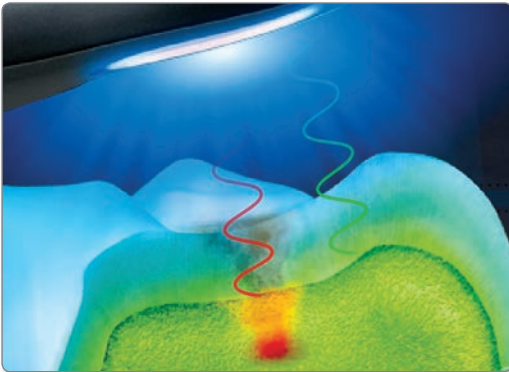
**Figure 3** The working head of the SoproLife handpiece.



**Figure 4** The operating portion of the SoproLife consists of four white LEDs, which allow for excellent imaging of the tooth and various magnifications from a full-face view to a close up of the tooth surface.



**Figure 5** The blue fluorescence mode is also included in the head of the camera where four blue LEDs emitting at a wavelength of 450 nm are located.



**Figure 6** Red reflection displays dental decay, green reflection shows area of healthy tooth.



**Figure 8** Placement of plastic sheath over camera.



**Figure 7** Patient safety requires the head of the camera be protected. A plastic sheath is laced over the camera head followed by a rubber cover which is placed over the tooth.



**Figure 9** Placement of the rubber cover which is placed over the questionable occlusal area.

to illuminate any area of the tooth will allow the dentist to determine the state of the area by observing the reflective beam. If the area of concern reacts with the dentin in a manner that results in the beam to reflect red, then there is decay is present, if it reflects green or black depending on the enamel thickness, then the area is non-carious. This ability to differentiate between healthy enamel, demineralized enamel and dental decay in combination with or without conventional dental radiographs augments the dentist's ability to both diagnosis oral disease in the earliest of stages and guide the patient's oral care program.

The SoproLife can also be used to determine if caries has been completely removed when

restoring decayed teeth and preserving healthy noninfected tooth structure (**Figure 6**). The SoproLife can be used as a reproducible and reliable assessment tool categorizing noncariious lesions and visual changes in enamel.<sup>1</sup>

### Incorporating it into your preventive program

The SoproLife head requires the use of a plastic sheath to cover the entire head (**Figures 7 to 9**). Then a plastic black opaque serializable cover slides over the camera lights, when placed over an individual tooth crown. It is then saved in a digital radiography program, such as the Schick CDR (**Figure 10**).

## Diagnosis

There are few disadvantages of incorporating the SoproLife device into your office. There is a modest cost and to use it efficiently, you may want a unit for each hygiene chair and the dentist's primary chair. The learning curve should not be a problem for most offices. You will need a computer at each operatory. Using the unit does often increase the time needed for the hygienist to complete the visit (Figures 11 to 16).



**Figure 10** Dr Kotlow placing the camera on a questionable area and then saving image directly into patient's digital radiograph program.



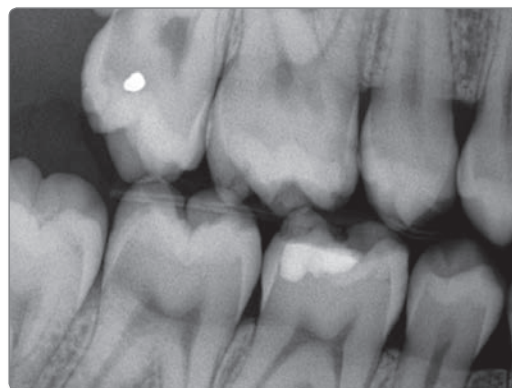
**Figure 11** Close up photo using the white light to evaluate the dark areas on the occlusal areas.

## Conclusion

The SoproLife camera is an extremely versatile imaging device combining a variable magnification intraoral camera and laser fluorescence in one head may both enhance the dentist's ability to follow dental disease closely and fulfill the idea of minimally invasive dental care as well as provide a means to educate patients. SoproLife assessment tools allowed for excellent caries score differentiation.<sup>5</sup>



**Figure 12** Using the blue fluorescence portion of the head the dark areas not display red, indicating decay is present.



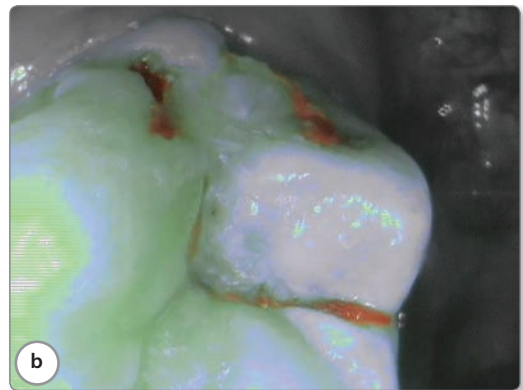
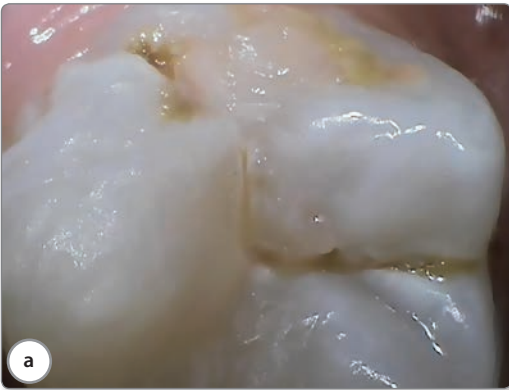
**Figure 13** X-ray showing no interproximal decay occlusal for interproximal.



**Figure 14** Soprolife white light and magnification and questionable area.



**Figure 15** Soprolife showing tooth with decay interproximally and in other areas.



**Figure 16** (a) Same tooth showing decay in white light; (b) Tooth showing decay on occlusal surface with fluorescence.

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John J Graeber

## Introduction

One of the most challenging pathologies to diagnose is the discolored pit or fissure. An accurate diagnosis of the depth of the lesion is impossible to make accurately with an explorer. This chapter will explain the use of the first available device which will assist the diagnostician in making a more accurate assessment of an individual questionable pit or fissure.

The KaVo-Kerr DIAGNOdent was the first objective diagnostic device utilizing laser energy and was introduced into the profession in 1998.

The current devices consist of a pen-like hand-held instrument as well as the original counter top model. It emits a visible low-level laser beam (655 nm), which detects changes in the fluorescence of a tooth. When the beam strikes decayed structure the reflected beam changes to a different wavelength of light. This change in wavelength is analyzed by the software in the device and is converted to a numeric value between 0 and 99 (Table 1). The higher the displayed number, the greater the caries extent for the particular spot on the surface of the tooth being tested (Figures 1 to 3).<sup>1</sup>

Observations during this author's over 20 years' experience with instrument while opening lesions using dry air abrasive particles are consistent with clinical histologic findings. The following scale quantifies dentinal decay:

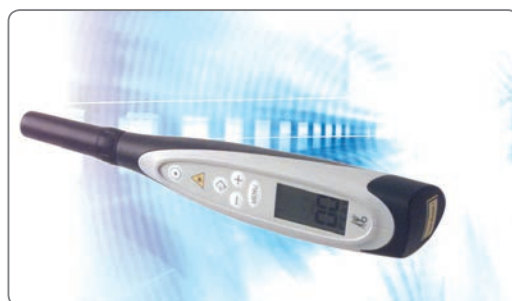
- D-1 considered caries extending just into dentin
- D-2 moderate dentinal involvement



**Figure 1** Photo of original model of KaVo-Kerr DIAGNOdent Pen.  
(Courtesy: KaVo-Kerr Corporation)

**Table 1** Extent of caries according DIAGNOdent value

DIAGNOdent value	Clinical observation
0-5	No pit/fissure depth
5-10	Potential site of a sealant
10-15	Early enamel caries (sealant indicated)
15-20	Advanced enamel caries
>20	Dentinal (D1) decay
>35	Dentinal (D2) decay
= 99	Dentinal (D3) decay



**Figure 2** Pen Model DIAGNOdent  
(Courtesy: KaVo-Kerr Corporation)





**Figure 3** Newest counter top model DIAGNOdent.

- D-3 dentinal decal likely extending into pulpal tissue fissurotomy with air polishing devices is highly recommended over rotary instruments

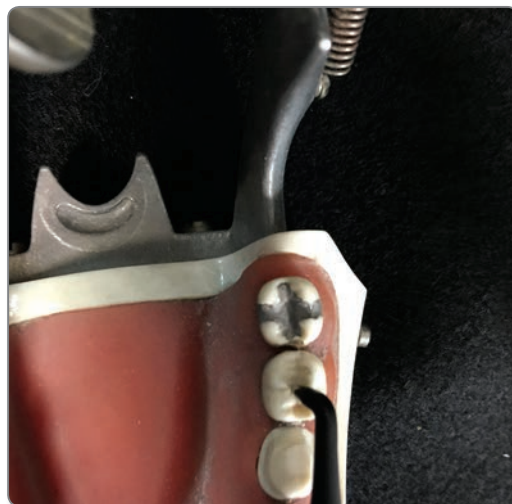
Even the smallest rotary instrument has the capability of causing microfractures within the tooth structure.

In research by Lussi, et al. both the specificity as well as the sensitivity for dentinal caries were established to be in the 74–86% ranges.<sup>2</sup>

## Method

The tooth being examined must first receive prophylaxis, including superficial removal of visual stains in the pit and fissure system. Fissure stain removal is best accomplished by air polishing with a mild abrasive powder (see Chapter 12, 13 on Air abrasion). The tooth is dried of excess moisture and saliva but not desiccated. The device is then calibrated on a clean, healthy surface of the tooth to be examined according to the manufacturer's directions. The probe is then run slowly over the entire pit and fissure system where caries is most likely to occur. This includes occlusal, buccal and lingual surfaces. The probe should be pointed both left and right at a diagonal to the pits and fissures (**Figure 4**).

The numerical readout has two readout windows:



**Figure 4** Use of the DIAGNOdent probe being directed toward the patient's right while examining the central groove of lower left second molar.

- The moment is the actual reading in the last point of measurement
- The peak is the highest reading found since reset up to that time in the examination

Both should be reset to zero before moving onto the next tooth to be examined.

## Use of the DIAGNOdent in the examination

Stained pits and fissures are the primary areas tested with this device. Every area of the pit and fissure system of each tooth should be evaluated, including the lingual grooves of maxillary anteriors.

Lesions adjacent to restorations are not good candidates for testing. The suspected lesions should have been air polished and dried with an air syringe prior to testing. This will prevent false positives.

## Use of the DIAGNOdent in diagnosis

A thorough examination will enable the examiner to make a judgment regarding approximate demineralized depth directly beneath the probe and plan appropriate management or surgical intervention of the lesion. Clinically, this often suggests in multiple restorative options on a single surface.

Modern techniques of placing composite restoratives do not require the joining of any adjacent restorations. Some pits and fissures on the same surface may only require a sealant, but in dentinally involved areas, a separate traditional composite restoration. These restored or sealed areas often will be separate locations in order to preserve the maximum unaffected enamel and dentin. It is only with an accurate and precise objective device can this conservative approach be viable.

The DIAGNOdent device is also valuable in monitoring the progress of enamel-only lesions over successive evaluations.<sup>3</sup> Readings registering under 10 generally will be limited to enamel only decalcifications. Readings which change significantly over time (>5-10) indicate an actively decaying lesion.

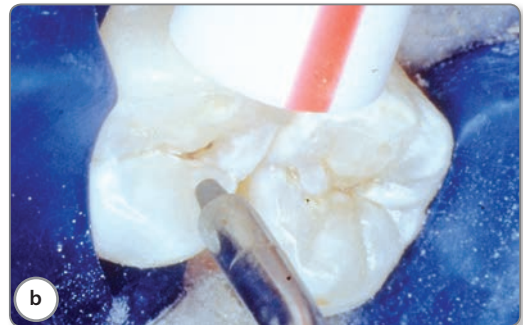
Preventive management of initial caries can then be evaluated for effectiveness and/or modulation. External methods such as fluoride varnish can be evaluated over time for effectiveness (Figure 5).

As the DIAGNOdent value of a particular anatomical spot approaches 20, the lesion is increasingly likely to have penetrated the dentin-enamel junction (DEJ) and needs a decision on surgical intervention. Dietary factors and age of patient and the lesion should be a part of the decision to proceed with surgical intervention. The aggressiveness of the intervention is a sum of the above factors. But at least with the DIAGNOdent device, there is an objective measurement of the lesion when it is employed (Figure 6).<sup>4</sup>



**Figure 5** Photo showing both 'moment' and 'peak' ports of unit.

Using this device, sealant therapy can now be more accurately initiated. Adult posterior teeth especially 2nd and 3rd molars can be better protected for fissure decay when they exhibit deep fissures prior to starting the decay process. Unfortunately many 3rd party plans do not recognize this valuable service, however, when presented to a patient as an alternative to a more expensive need for restoration later in life; it becomes a viable and valuable preventive technique.



**Figure 6** (a) Photo of suspicious lesion on maxillary bicuspid with no probeable pit. (b) Air abrasive excavation in progress. (c) Final restoration utilizing a flowable composite.

## Use of DIAGNOdent in case presentation

Patients will be impressed by an instrument's objectivity.

In addition, the numerical readout being an objective comparison of previous measurements, the unit also emits a sound for readings over 20. This sound usually prompts a question from the patient: 'Does that mean I have a cavity?' This makes a patient more amenable to a treatment proposal once they realize the diagnosis is not made solely on the dentist's opinion.

## Advantages

- Provides specific numeric reading of the relative depth of carious involvement or hypocalcification
- Is far more sensitive than traditional means of pit and fissure decay: explorer or X-ray
- Does no damage whatsoever to the structure
- Involves no ionizing radiation
- Simple, quick and immediate results
- Trackable changes over time of the decay process
- Has similar but better results to electrical conductance devices
- Return on investment is probably the highest of any highlighted device in this textbook
- Protective eyewear is not required
- Has a moderate cost (\$2000 US) compared to other devices
- Promotes a more reliable and objective diagnostic information in the practice of microdentistry

## Disadvantages

- Stain, moisture, plaque can affect reliability of results
- Requires calibration step for each patient
- Does not link to patient records electronically
- Has no printout of results
- Fiber optic tips do wear out over several years of regular use
- Very unreliable for interproximal or smooth surface decay diagnosis
- No connectivity to management/digital X-ray systems
- Stains caused by black tea will cause false positives (**Figure 7**)



**Figure 7** Example of black tea stained occlusal surface.



**Figure 8** Failed amalgam margin.

- Excess moisture will cause similar errors
- Operating the probe too close to restorative or sealant margins will cause the readings to be erroneous
- Failure to calibrate on a clean surface makes the readings unreliable (**Figure 8**)

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## Conclusion

Clinical experience of this author with DIAGNOdent spans more than 20 years. It has found it to be accurate approximately 95% of the time. It has been my practice to open all the suspected fissures and pits with a 'dry' air abrasive device stopping as soon as the 'stain' disappears. This is quite different than utilizing a high-speed rotary handpiece which obliterates the fissure too quickly to be able to observe this

demarcation. This observation has solidified many users' reliance on the DIAGNOdent device as a reliable source of valid measurement in providing MicroDental diagnoses and treatment.

It is in my opinion the very best of the class of light-based diagnostic equipment for the evaluation of pits and fissure decay.

"You need this device!"

*Gordon Christensen*  
DDS PhD

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# The surgical microscope for diagnosis and treatment of caries

*Arthur R, Volker DDS, Michael Lippe*

## Introduction

The first practical surgical microscopes (generically, stereo microscopes) were realized and became available between 1951 and 1953, through a collaborative effort between the Carl Zeiss company in Germany (Hans Littman) and various otologists (ENT), gynecologists and neurosurgeons. Since then, the surgical microscope has proven invaluable (often, standard-of-care) for countless procedures requiring precision and optimal vision.

## Ergonomic advantages

Ergonomics and the long-term physical health benefits provided through the use of a microscope in dentistry cannot be over emphasized. Among the many occupational hazards the dentist face, musculoskeletal disorders rank among the highest. Chronic neck and shoulder pain, leading to numbness in the hands, along with many other related symptoms can become debilitating and require spinal surgery at an early age.<sup>1-3</sup> These common problems are frequently related to sub-optimal posture required in order to visualize the treatment area, often for extended periods of time.<sup>4</sup>

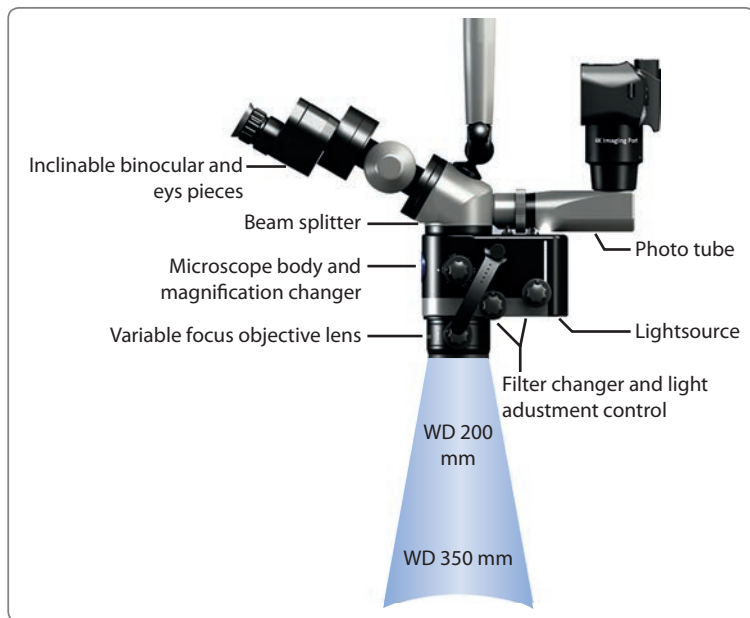
## Labeled parts of microscope

The surgical microscope offers considerable relief from strain of holding difficult postures. The user is able to maintain a relatively healthy, normal and upright posture during most treatments, as the microscope can be positioned at the appropriate viewing angle while the dentist remains comfortably upright. This is achieved through the use of variable-angle prism optics and objective lenses which allow the microscope to be pointed at many (and even quite extreme) angles of view and working distances.

Loupes or face mounted magnification cannot achieve this feat and in fact, cause further strain because the practitioner must still observe the treatment area at an uncomfortable angle, as it becomes even more critical to 'hold still' due to the added magnification. In addition, the microscope

employs infinity-based parallel optics, allowing comfortable and eyestrain free viewing, without converging the eyes. Loupes often increase eyestrain because they are by necessity, converging optics.<sup>5-7</sup> Think of looking out at the horizon versus looking at an object only a few inches away from your eyes. In the latter, one must also converge at a specific distance (e.g. 350 mm), causing further eyestrain.

Through proper use of the operating microscope, and given a modest amount of training, the dentist will learn to appropriately position the patient and the microscope such that he/she will be able to maintain a favorable and even comfortable posture. Certain specialized chairs and armrests can further increase comfort, and provide added stability while working at higher magnifications (**Figure 1**).



**Figure 1** Components of operating microscope.

## Clinical advantages

You can't treat what you can't see. New microscope users are often amazed by what they were not seeing prior to using a microscope. The added clarity and illumination simply cannot be appreciated until one spends some time treating under one.

- Caries infection in close proximity to healthy dentin is readily seen and treated with precision. Preservation of healthy areas is increased
- Much improved accuracy for margin preparation in restorative procedures
- Fractures and most other details are more important easily detected
- The dentist's personal comfort is increased allowing more relaxation, less fatigue throughout the day
- Using smaller instruments along with better vision can mean more precision treatment and less trauma to adjacent tissue

Workflow soon becomes more efficient as surgical skills improve. Many actions become faster as one works with vastly superior vision.

An action which would normally have taken multiple steps to insure the job was done, may be reduced to many fewer.

## Documentation advantages

When properly configured, the microscope offers huge advantages over intraoral or extraoral cameras. Most recently, users are employing high-resolution DSLR or increasingly, mirrorless full frame cameras. Those cameras (as well as dedicated compact video cameras) are adapted to the microscope via a beam splitter and photo tube/video tube accessories. Beam splitters portion off a specific amount of light away from the user and toward the camera tube. The camera tube along with the correct mount (specific to camera brand) must be of the appropriate focal length, matching the size of the image sensor within the camera. The most crop-sensor cameras require a 200-mm tube. Full frame sensors require a 300 mm. Selecting the matching tube insures magnification to the camera is most similar to that seen through the microscope. A wireless remote control for



**Figure 2** Typical scope with attached camera.

activating the still image function is highly recommended to reduce vibrations induced by otherwise manually/touching the camera's shutter release (**Figure 2**).

The manufacturer or dealer is responsible for installation of these devices. Proper operation requires these instruments to be in perfect balance and properly assembled.

Additionally, the light intensity is optimal and co-axial with the viewing optics which will minimize shadows. The light from the scope should mimic sunlight at about 5,500K for a pure white illumination. Phenomenon often observed are (as magnification increases) the depth of field and light to the observer decrease.

There are several ways in which this issue can be addressed. For presentation purposes, a photo can be taken at a lower magnification, then it can be cropped via post processing software (such as Photoshop or Lightroom). Additionally, a darker photo can be 'lightened' by altering the exposure in the same software. Alternatively, external flashes can provide additional light during exposure and are mounted to the microscope body, although

this can be complicated and limit working distance between the scope and the patient.

A monitor may be connected to the camera. This allows the assistant to view the procedure and will also allow the clinician to help 'frame' or center the video or images for documentation purposes. Patients can (in vivid detail) be easily educated regarding the condition of their teeth, aiding in consent for further treatment if needed.

Microscope eyepieces can be equipped with a reticle which provides a crosshair (much like in a rifle scope) to allow for easier centering of a photo. It is important that the scope be par-focal (calibrated) with the camera and user to insure the camera is in focus at all times. Par-focal is achieved by having the user's diopter settings on the eyepieces correct for the user's corrective eyeglass prescription. Some cameras will offer continuous and uninterrupted video streaming while a high resolution still shot is taken. Video still captures are another option, but are of lower resolution.

If desired, any recorded photos can be shown to the patient while they are in the chair for discussion of treatment or prognosis. Additionally, any recorded photos or videos can easily be kept in the patient's EMR (electronic medical record).

## Advantages to access and magnification

Perhaps the greatest benefit of the operating microscope is the access and magnification it affords. Scopes will typically have 3 to 6 steps of magnification, ranging from 2–24 $\times$ .

**Figures 3** and **4** demonstrate the advantage of extreme levels of magnification. The patient had root canal therapy on tooth #3 several months prior and was complaining of pain upon mastication. **Figure 3** shows the field of view of at 2.2 $\times$ , which is a commonly used loupe magnification. **Figure 4** is taken from the same angle and patient position, though at a 12.4 $\times$  magnification. Note that a fracture line can be easily and readily observed on the distal aspect of the tooth.





**Figure 3** Field of view of at 2.2x.



**Figure 4** Taken from the same angle and patient position as Figure 3, though at 12.4x. A fracture line is readily apparent on the distal.

## Components of a microscope

- Eyepieces: Typically 10× or 12.5×
- Objective lens: 250 mm or 300 mm for a fixed system, 200–350 mm for a variable focus lens
- Binocular tube: Most often an inclinable of 0° to 180°. This joint needs to be capable of swiveling
- Magnification changer: Allows the level of magnification to be altered. Typically, changed via a knob with 5 to 6 steps, but can be a lever or foot pedal in a zoom based system
- Handles for positioning ease
- Curing shield: An orange filter may be included to prevent premature polymerization of resin composite

### What features to look for in a microscope? (listed in order of importance)

- Optics are vastly different between the various manufacturers. The quality of the optics and illumination are critical. Not all manufacturers have equal optics. At the end of the day, optics are somewhat subjective, it is important you look through several to see which pleases your eyes the best
- Mechanical movement and overall build quality. Very important is the handling and moving of the microscope effortlessly and without hassle. The movement should be smooth and quite light to the touch
- A knowledgeable and available representative of the company to support you and your new microscope. This cannot be over emphasized

### Magnification

Most commonly, microscopes come equipped with a 5th or 6th step magnification changer.

These are standard within the industry and you can safely assume, each magnification step is the same for each manufacturer. Generally, 5 steps are perfectly acceptable. With the advent of the variable focus objective lens, having a 6th step is less important as they provide a much wider range of magnification options on any system.

### Mounting options

Most microscopes are offered in three mounting configurations, ceiling, wall and mobile floor mounts. Ceiling mount and wall mount are the most common and practical choices. With either, precious floor space is not taken by the rather large base associated with a mobile floor stand. Some new users opt for a mobile floor stand in order to use one unit in multiple rooms before committing to a scope in each room. Generally, ceiling mount is preferred, but the decision should be primarily based on the size of the operatory and the optimum placement for the particular operatory.

## In the market for an operating microscope there are a number of factors that must be considered

### Level of magnification

There are varying levels of magnification available to the clinician. Most scopes have 4 to 6 'steps' or levels of magnification (also talk about the light). The steps are usually three to six 'steps' of magnification. The lowest level is typically akin to 2.1 loupes. Magnifications can range up to 19× with the use of a 10× eyepiece magnifier, 250 mm objective lens and a 160-mm binocular. **Figure 5** demonstrates a crown preparation of maxillary first molar at 12.4×.

Each 'step' is typically accessed by rotating a knob or via a foot pedal. Most steps are sequential in increasing levels of magnification with each rotation, but that is not always the case at higher magnification. Some systems

such as those found in Kapps microscopes have instead a 1:7 motorized zoom.



**Figure 5** Crown preparation with small knitted cord at 12.4×.

### Method of placement

In an attempt to maximize space or structural support, there are several ways in which scopes can be positioned within an operatory. If there is adequate structural support, they can be mounted to a ceiling or to a wall beam. If support is inadequate, many scopes are available as a floor model, where they can be wheeled into position. Note that due to balance requirements, floor model tend to be quite heavy, and have a large footprint.

### Accessories

There are a number of accessories that are available to enhance the operator's experience with the microscope that are commonly available from most, if not all companies. A variable focus objective lens can be added to increase the depth of field. This will increase the depth of field which will keep an object in focus. This is particularly useful at higher magnifications, where even small movements that blur the operating field.

For those who plan to document with either photos or videos, a beam-splitter is an essential accessory. This will allow light to come from the scope to a mounted camera. This will permit

documentation to be easily taken in real-time from the same perspective as the operator.

### Unique ancillary features

There are several features that may be available from a manufacturer that many not be available from others. Some manufacturers offer a reticle on the lens. Typically, a rounded shape, the reticle acts as a target to allow the operator to position the scope to center to the desired area. This is useful for ensuring that a picture or video is properly framed (note that the reticle will not appear on the picture or video).

Quantitative light-induced fluorescence (QLF) is a recognized minimally invasive method for caries detection. A tooth will fluoresce when exposed to blue light. Healthy tooth structure appears green and caries, and demineralized tooth structure will appear red. There are some manufacturers who have a QLF functionality available.

Additionally, some manufactures will have power outlets on the arm which can directly power external devices, such as an SLR camera, so battery changes are unnecessary.

## Caries detection and treatment

Although the ability to inspect an area for dental caries is greatly improved with the operating microscope, ancillary methods can be employed to great benefit. Indicator dye can prove useful. Composed primarily of propylene glycol and food, drug, and cosmetics (FD&C), indicator dyes can help to visualize decay. However, caution must be taken as indicator dyes stain the organic matrix of under-mineralized dentin, even in the absence of caries.<sup>8</sup> As such it can stain demineralized dentin indiscriminately, particularly at the dentin–enamel junction (DEJ), and closer to the pulpal areas.<sup>9</sup> This can lead to false positives and over-reduction of tooth structure, so visual and tactile examination is also needed.

**Figure 6** demonstrates this phenomenon. The patient had fractured an existing restoration. Caries removal was initiated with rotary slow speed round burs. As an aid, caries indicator dye (Snoop, Pulpdent, Boston MA) was used. Note the staining present at the DEJ despite lack of carious tooth structure in this area, as well as visualization of a mesiodistal fracture line. Photo taken at 12.4×.

There are some factors to consider when using the microscope for fine caries removal.



**Figure 6** Caries indicator noted at dentin–enamel junction, though no caries are present in the area. A mesiodistal fracture can be observed as well.

One would be to consider the use of long shank round burs in  $\frac{1}{4}$  and  $\frac{1}{2}$  round sizes. The smaller depth of field found at higher magnifications may restrict visual access of larger and shorter burs. This also applies to hand instruments such as spoons. Finally, air abrasion is a wonderful minimally – invasive tool, though care must be taken to protect the objective lens from potential damage from the water and particle spray.

## Clinical vignette – deep cervical lesion

Patient presented with sensitivity at tooth #6 (**Figure 7**). Caries were noted at the cervical region. Following anesthesia, primary caries excavation was completed with the use of a slow speed carbide bur (**Figure 8**). A caries detecting solution (Snoop – Pulpdent, Boston, MA) was used, along with 12× magnification (**Figure 9**). **Figure 10** demonstrates the completed caries excavation as well as placement of a knitted retraction cord (Ultrapak – Ultradent, Provo, UT). A resin-modified glass ionomer (RMGI) (Activa – Pulpdent, Boston, MA) was used as a liner, ensuring that no RMGI contacted any peripheral enamel surface and remained



**Figure 7** Preoperative situation. Caries noted on cervical.

on the dentin. Then a 5th generation bonding agent was employed, and the tooth was restored with a combination of flowable and Paste composite (Renamel Microfilled - Cosmedent, Chicago, IL).



**Figure 8** Caries indicator applied to tooth.

**Figure 11** demonstrates a photo of the completed restoration using air to demonstrate a smooth, uniform margin.

**Figure 12** demonstrates the 3-month recall of the case.



**Figure 9** Removal of caries with carbide round bur.



**Figure 10** Cleaned cavity with #00 knitted cord placed to retract gingiva.



**Figure 11** Immediate postoperative of restoration with air spray used to help evaluate smoothness of margin.



**Figure 12** Three-month postoperative view of restoration.

## Customer support and training

As with any capital investment, it is critical to receive timely assistance from a manufacturer should an issue arise. This is not always easy as there tend to be few representatives from each company, especially if the microscope is manufactured in another country.

There is certainly a learning curve in using the scope. Training is of the utmost importance. It is important to understand the extent of the training provided by the manufacturer. That stated, the new microscope user is encouraged to attend peer-based training which is more clinical in nature.

## Fracture detection

The increase in magnification from the operating microscope allowed detection of fracture and craze lines in tooth structure that were previously not visible to the naked eye. This can prove valuable to minimally - invasive dentistry as we may be able to detect and treat these issues before they become deleterious.

Historically, methylene blue has been used as a dye to aid in detecting and visualizing fractures and are an excellent adjunct.

According to Clark, there are two types of two main types of dental fractures: oblique and vertical.<sup>10</sup> Oblique fractures are often found on teeth that exhibit sensitivity to mastication, often for only short periods of time, or on teeth that are

not sensitive. The cracks tend to run under cuspal areas and are best served by restorations that provide cuspal coverage. These fracture lines can lead to cuspal fractures, but do not often lead to pulpal issues.

Vertical fractures, by contrast, tend to be more severe as they are precursors to vertical radicular fractures.<sup>11,12</sup> They tend to run in a mesial-distal direction and can sometimes be visualized into a pulpal access during endodontic therapy (**Figure 13**). They are often associated with both thermal and masticatory sensitivity, and often require comprehensive treatment including root canal and cuspal coverage, if the tooth is salvageable. **Figure 14** demonstrates a non-restorable tooth with a vertical fracture. Note the fracture, enhanced by the use of methylene blue, running through the mesiodistal of the tooth.

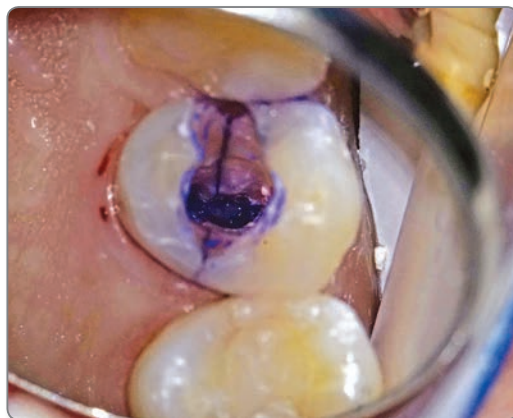
## Addendum: List of microscope manufacturers

CJ-Optik USA - Vision MicroDental, LLC  
4513 N. Florida Ave.  
Suite 208  
Tampa, FL 33603

Global Surgical Corporation  
3610 Tree Court Industrial Blvd.  
Saint Louis, MO 63122  
Carl Zeiss Meditec, Inc.



**Figure 13** Endodontic access at 7.7X. Mesiodistal fracture line is readily observed.



**Figure 14** Nonrestorable tooth with vertical fracture. Methylene blue used to enhance visibility of field.

5160 Hacienda Dr. Dublin,  
California 94568  
Seiler Precision Microscopes  
3433 Tree Court Industrial Blvd  
St. Louis, MO 63122  
Leica Microsystems Inc.

1700 Leider Lane  
Buffalo Grove, IL 60089

Carl Zeiss Meditec AG Göschwitzer Straße 51-  
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*John J Graeber*

## Introduction

Every dentist is trained to use the same basic visual and tactical instruments to search for caries, yet there are often disagreements between examiners on the presence of caries and treatment recommendations.

This chapter discusses the reasons for such discrepancies, and recommends the use of many of the recently developed diagnostic tools now available to the profession.

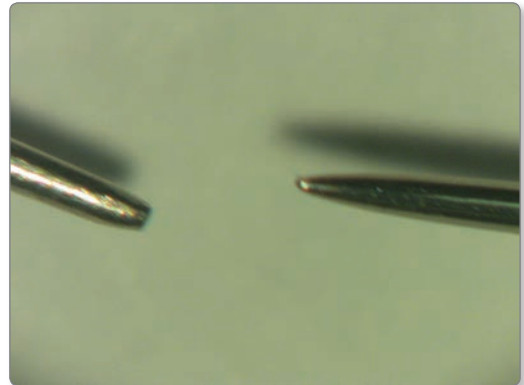
## Dental explorer

This instrument is used to probe for soft areas in hard dental structures, which can be an indication of caries. It is also appropriate for examining margins of existing restorations for caries and margin integrity.

However, the explorer may be inaccurate by as much as 50% when using it to detect caries,<sup>1</sup> which in itself may be the primary cause of diagnostic discrepancies among examiners. Its use in evaluating pits and fissures is also questionable – studies show that aggressive probing in fissures can cause enamel rod fracturing, which leads to the formation of primary caries over time.<sup>2</sup> Furthermore, an explorer may be too wide to accurately explore thinner pits and fissures.

Explorers also wear down over time, and should be used only for examinations to limit wear. **Figure 1** is an example of a sharp instrument on the right compared to a used, dull explorer on the left. A practical test of sharpness is to lightly run the explorer with no more force than its own weight over a fingernail; it should leave a visible scratch mark. New explorer instruments should always be kept on hand to facilitate replacement when necessary.

From an efficacy standpoint, explorers need to be used selectively, and attempting to judge



**Figure 1** Micro-photo of worn or broken explorer tip (left) compared to a never-used explorer instrument.

the depth of carious lesions with an explorer is contraindicated. More sophisticated devices for pit and fissure caries detection are superior to the conventional explorer.

## Dyes

Caries detection dyes have been recommended for more than 30 years. Whether red or green, they can be used in the initial examination for biofilm accumulation. Additionally, they are utilized during cavity preparation to identify demineralized structure which requires removal prior to restoration placement.<sup>2</sup>

## Dental mirrors

The surface of the mirror needs to be free of scratches, water spots and bonding materials. Are the examination mirrors changed when the surfaces are not pristine? Does the dental hygienist use the examination mirror while applying abrasive prophylaxis pastes? Imperfections can cause the examiner to miss the smallest of lesions. Dental mirrors also are produced with built-in magnification to enlarge the indirect surface image of a tooth.



Fogging of the mirror surface can affect the image it reflects. Mouth breathing is the obvious cause. Warming a cold mirror can alleviate some of the fogging. There are commercial anti-fogging solutions available for use. The simple act of drawing the surface of the mirror over moist cheek mucosa is a quick remedy for a fogging mirror by placing a thin film of saliva over its surface (Figure 2).

## Chairside lighting

Many of the traditional operatory light sources are made of halogen. The temperature of this type of light is not acceptable for matching shades because the hue is inherently in the yellow range. Brighter white light has become available to the profession. The latest in operatory lights are multiple light emitting diodes (LED). The brightness and whiteness of this type of light is far superior to a halogen or incandescent source for intra-oral illumination.

In addition, a second source of lighting the patient's mouth such as a head or loupe mounted source will assist in reducing shadows cast by the primary light source. Many of the recently developed models by many manufacturers are LED based.

Lighting built into the operating microscopes has significantly more lumens per square millimeter. The necessitating principal is that the more magnification the more lumens are required for the human eye to observe the object with adequate illumination (Figures 3 to 5).



**Figure 2** LED array on modern operating light (5 lites on 1 fixture).

Reducing general lighting in the operatory can help illuminate the oral cavity in relative terms during caries examinations. The more directed light entering the oral cavity appears brighter if the general room lighting is reduced or eliminated.

## Radiographs

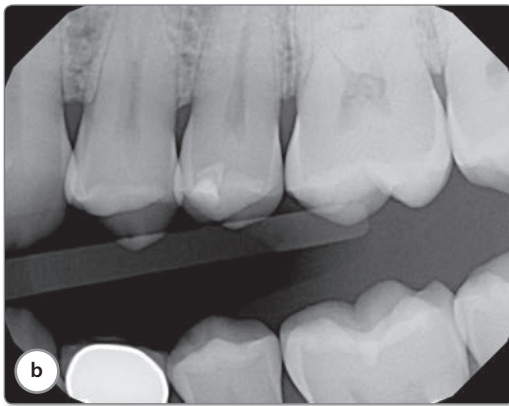
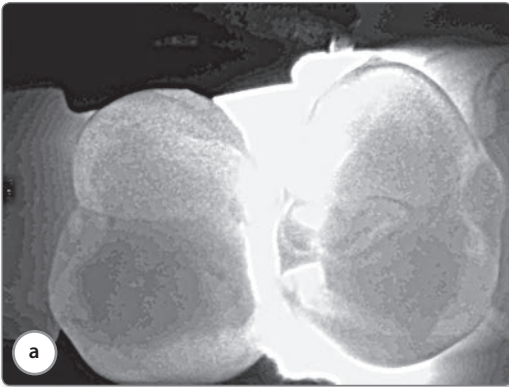
X-rays are an essential part of any oral examination, and the need for a bitewing X-ray to examine interproximal areas for decay is well established.<sup>3</sup>



**Figure 3** Single LED mounted on loupe frame creating a different angle of light delivered to the oral cavity.



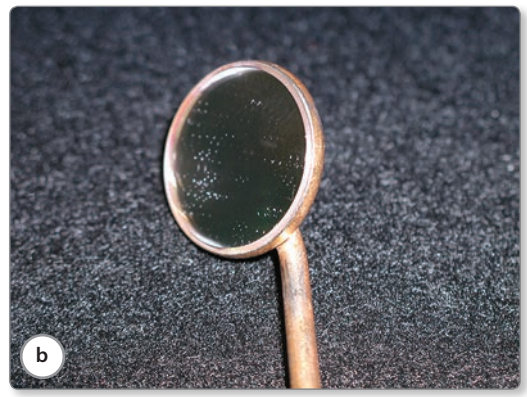
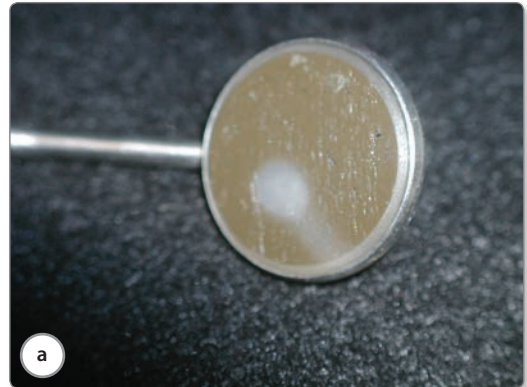
**Figure 4** Conventional halogen operating light.



**Figures 5a and b** CariVu image compared to Conventional X-ray bitewing (between photo is Figure a, dental X-ray is Figure b).

However, they are not always appropriate in the routine examination. For instance, patients who are or may be pregnant are advised by their obstetrician to refuse routine X-rays. Controversy exists as to whether the lead apron, used extensively, is of sufficient protection to the neck, chest, and abdomen after the radiation is scattered after exposure to the oral cavity. Lastly, there are economic objections by patients in the routine taking of X-rays especially where there are no symptoms evident to the patient.

On the technical side, regulations, filters and other “improvements” designed to limit exposure to ionic radiation have reduced the contrast of X-ray images, both digital and film. The larger grain size employed by current dental X-ray film has reduced the sharpness of the images significantly.



**Figures 6a and b** Debris on mirror.

In contrast, infrared and other light-based devices (e.g. CariVu) in place of bitewing images may replace the routine use of X-ray radiation in the diagnosis of interproximal coronal caries (see **Figure 6**). At this time, however, no other devices are available to match the efficacy of X-rays in the examination of bone and root pathology.<sup>4</sup>

## Other practical considerations

Should an examination occur before prophylaxis or immediately afterwards?

There are obvious benefits to either approach. Calculus and plaque/biofilm can obscure small potential lesions. The presence of the biofilm

can also pinpoint a potential causative factor for localized lesions. Fluoride varnish placed after prophylaxis can obscure all but the largest of lesions.

Teeth should be examined while they are dried of excessive saliva as the presence of its excess can mask small lesions, hypocalcifications and open restoration margins.

Gingival overgrowth often masks the presence of cervical decay.

Other chapters in this text have dealt with impediments to discovery of carious lesions while employing advanced diagnostic devices (see Chapter 5 to 9).

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## Subjectivity of tests

Unlike medicine, in dentistry objective tests are a rarity. Other than electrical pulp testing devices (many of which produce an arbitrary numeric value of pulpal electrical conductance), all other tests rely on subjective measurements or observations.

Since the explorer has been shown to be of limited benefit in detecting small pit and fissure lesions, its use should be restricted to large lesions and restoration margins. There are devices which measure the relative depth of a fissure

or pit, and the relative bacterial load within the fissure. Correspondingly, there is a need for technologies which are both efficient as well as efficacious, since examination requires the imaging of up to 32 teeth during the limited time for examination.

If an examining dentist utilizes more objective testing, examination results will be more accurate and reproducible. The key in moving dental diagnoses toward the subjective medical model is the employment of more objective devices and less reliance on traditional subjective instrumentation.

---

## Conclusion

Traditional dental instruments used in the examination have disadvantages which should be weighed carefully by the examiner. There should be less reliance on current methods of caries diagnosis, due to their subjectivity. Newer and more precise diagnostic instruments show greater reliability and are more consistent.

The chronic and episodic nature of dental caries must be monitored regularly, measured accurately, and managed carefully if we are to attain the goal of a life-long dentition for the patients in our care.<sup>4</sup>

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# Section III

## Treatment options and techniques

- Chapter 11 Microbiological aspects of caries treatment
- Chapter 12 Air abrasion: Background and cavity preparation
- Chapter 13 Air abrasion technique
- Chapter 14 Erbium laser physics and tissue interaction
- Chapter 15 Carbon dioxide lasers (9300 nm)
- Chapter 16 Dentin regeneration
- Chapter 17 Ozone therapy
- Chapter 18 Conventional treatment failures



Rella Christensen

## Introduction

Microbe invisibility makes it easy to deny their presence. The microbes in dental caries have generally been disregarded clinically. The emphasis clinically has been on removal of damaged tooth structure and insertion of various materials to restore the tooth's form and function. Little attention has been given to the possibility that the microbes that caused the original lesion might remain present, viable, and able to reinitiate destruction of the tooth after placement of the restorative material. More recently clinical emphasis has moved toward slowing lesion progress and cutting minimally, or not at all. However, attention to the lesion microbes has remained secondary to saving time, cost, and trauma during treatment.<sup>1-3</sup>

Current thought defines dental caries as "a biofilm disease"<sup>2</sup> caused by microbe shifts due to changes in the oral environment from inappropriate diet, poor oral hygiene, and/or medications that alter saliva flow and composition.<sup>4</sup> Authorities say these factors causing microbe shifts can be managed behaviorally, thus preventing development of dental caries.<sup>2</sup> However, experienced clinicians say patient behaviour changes occur sporadically, or not at all, and dental caries seem to be inevitable over a human's lifetime.

This debate has formed the primary research question that has directed our work since 2004. That question is: Is dental caries an inevitable disease in humans? Our work was initiated to investigate dental caries *in situ* from a microbiologists' point of view. A unique patient treatment area was designed and situated within a specialized laboratory dedicated solely to

oral microbiology. Clinical techniques have been developed that permit sterile harvest of the damaged tooth structure comprising dental caries lesions. Careful analysis of this material from many lesions has formed the basis of this chapter, which is a compilation of a series of studies performed over a 14-year period. The work is ongoing with plans to continue indefinitely. It is aimed at answering the five questions below that were posted in 2004 in our reception area as the mission statement of our laboratory:

1. When should we cut into a tooth?
2. How far should we cut?
3. How should a tooth preparation be treated?
4. How should a tooth preparation be restored?
5. If we don't cut the tooth to excise a caries lesion, what should we do instead?

From our point of view, dental caries is a microbial disease that requires action to control progression, pain, and stigmatizing loss of esthetics. The action can come from the patient, clinician, or both, but the infection cannot be ignored because microbes do not generally die or just go away on their own. Our goal has been to learn *in vivo*:

- Which microbes inhabit dental caries lesions
- Locations of specific microbes within these lesions
- Numerical concentrations of the microbes
- Methods necessary to stop lesion progression
- Potential of dental materials to seal, and how covering with materials affects the microbes

Through this work we hope to correct misconceptions that have developed in the absence of microbiological validation, and help clinicians treat patients more effectively, economically, and with minimal trauma.

## Methods used for aseptic harvest of microbes within caries lesions *in vivo*

A dedicated sterile area and aseptic techniques were developed to harvest microbes from within caries lesions *in vivo*, map their locations, and quantify them per milligram of substance removed. All harvested material was cultured before DNA sequencing to prove microbe viability, which is always debated with DNA identifications.<sup>5</sup> However, it is recognized that all microbes present *in vivo* may not grow using artificial medium and culturing.

All procedures had Internal Review Board approval and subject consent. Local anaesthetic and rubber dam were completed before entering the sterile area for: Rubber dam disinfection; sterile resin dam application; loading sterile surgical motors aseptically before each cut with a new sterile bur; removal of ~3.0 mg per cut; collection on sterile pre-weighed brushes inserted immediately into sterile pre-reduced pre-weighed Bacto Brain Heart Infusion broth (Becton Dickinson, Sparks, MD); immediate transport to anaerobic conditions (10% CO<sub>2</sub>, 10% H<sub>2</sub>, 80% N); weighing before separation for anaerobic and aerobic processing; serial

dilution and streaking onto aerobic or pre-reduced anaerobic Blood Agar #R01036 (Remel, Lenexa, KS); incubation at 37°C; growth photographed.

DNA sequencing of 500 bp 16S rDNA was performed internally and at a commercial laboratory (Charles River, Newark, DE). DNA was isolated (alkaline lysis), PCR amplified, and sequenced on ABI 3130XL Capillary Sequencer (Life Technologies, Carlsbad, CA). Data were assembled and analyzed by semi-automated reference method and compared to a proprietary, validated, reference database for identification. Similar steps were performed internally using Hitachi 3500 Genetic Analyzer with MicroSEQ ID Software, version 3.0 (Life Technologies, Carlsbad, CA). **Figure 1** shows how resulting data were mapped by bur Cut number. **Figure 2** shows the clinical lesion appearance together with quantification of the microbes per milligram of material removed. This was calculated from weight of the material removed in each Cut and organism growth on the Petri plates from each Cut.

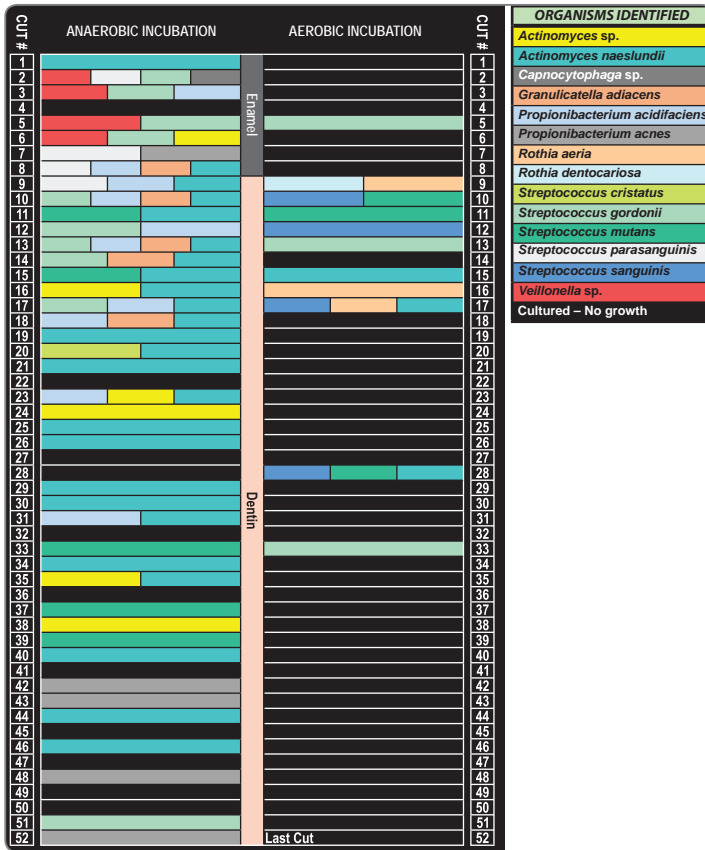
## Six clinically important points learned

### 1. *The demarcation between microbe infected and noninfected tooth structure currently cannot be detected*

When microbes infect tissue pathologically an important question is: Where does the infection end? This point can define treatment prognosis. We found hardness and appearance gave a rough estimation of the infected perimeter on surface enamel. However, in subsurface enamel and dentin, we could not determine microbe penetration accurately visually, tactically, or radiographically. Microbiologically, we found the microbes spread well beyond the borders detected by these methods. **Figure 3** shows the inability of radiographs to display accurately the extent of dentin infection.

**Figure 4** shows the microbe map of an upper first molar in a 65-year-old male which indicates that beyond Cut 10 no microbes were cultured, and this probably indicates the demarcation between infected and noninfected dentin. However, no growth could also be the result of difficulty obtaining growth when culturing *in vivo* organisms in artificial conditions and on artificial medium. So even microbiologically it is difficult to say with certainty where infected tissue ends.

Clinically, lesion surface characteristics such as hardness and color are still used to judge location of dental caries and whether the lesion is 'active' or 'arrested.' Clinicians look for tooth surfaces that are soft, hard, leathery, chalky white, honey tan, dark brown, shiny, dull, etc. **Figure 5** illustrates the error potential using these surface characteristics to determine microbe activity within a tooth. The clinical image shows a small



**Figure 1** Color coded map of the microbes cultured within material removed by each cut with a new sterile single-use bur. Shown are the microbes identified in aliquots cultured anaerobically and aerobically. They key at the right lists genus and specie names associated with the color coding. Black cells show where no growth was obtained, either because the environment and handling failed to result in growth.

‘pit lesion’ in a 64-year-old male. This area had not changed appearance clinically over many years, and was assumed ‘inactive.’ However, in the patient’s 64th year, he described occasional ‘stabs’ of pain. Special replica techniques and scanning electron microscopy of the lesion internal *in vivo* showed numerous microbes present deep within the lesion which had remained viable and active over the years, and finally penetrated into the pulp chamber. This case illustrates the central issues in microinvasive dentistry versus the behaviour of dental caries microbes. Humor aside, the question becomes what dies first, the patient or the tooth?

## Clinical application

Without hardness, appearance, or radiographs as accurate guides, the clinical question is: How to inactivate the invisible microbes causing tissue destruction within a tooth? The only

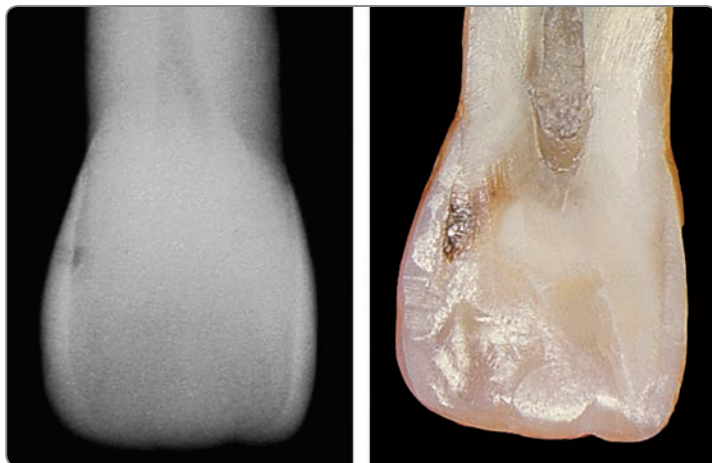
option currently is application of a therapeutic disinfectant. This is a non-specific approach aimed at killing the microbes that currently cannot be detected clinically and remain viable and active even after dental restorations are placed. Extending borders of a cavity preparation does not solve this problem because the rotary bur acts as an inoculating instrument, further spreading microbes present into adjacent dentin.

Tooth disinfection is not a new idea. Almost 100 years ago Black proposed and used disinfection of tooth preparations.<sup>6</sup> However, this critical step is not generally performed routinely by clinicians today. The permanent dark gray staining of the silver nitrate used by Black discouraged use as cosmetics became the emphasis, and no other tooth disinfectants were introduced. In our work we have observed that dental caries microbes do not spontaneously die or go away. Instead they pursue a slow,

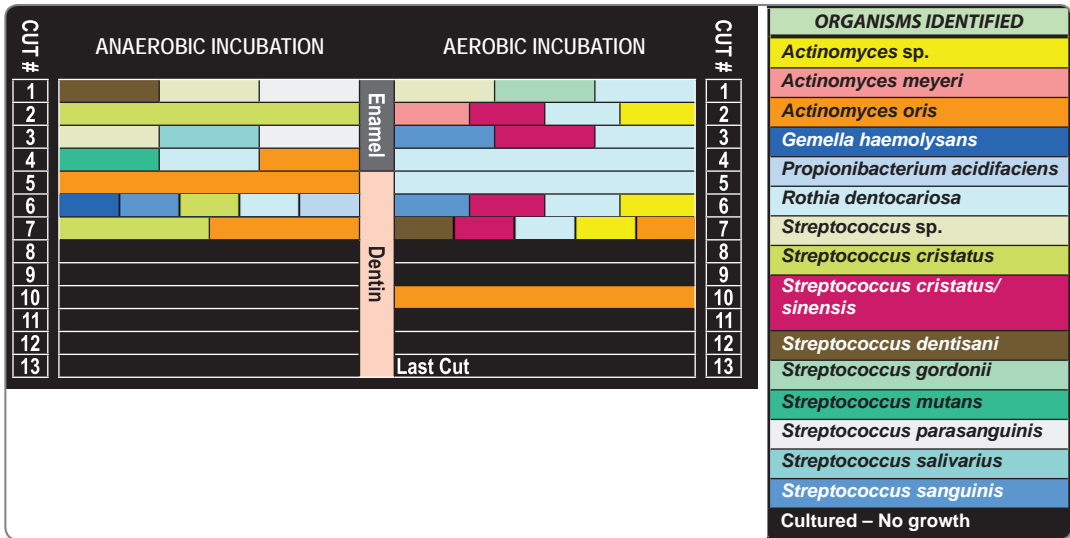




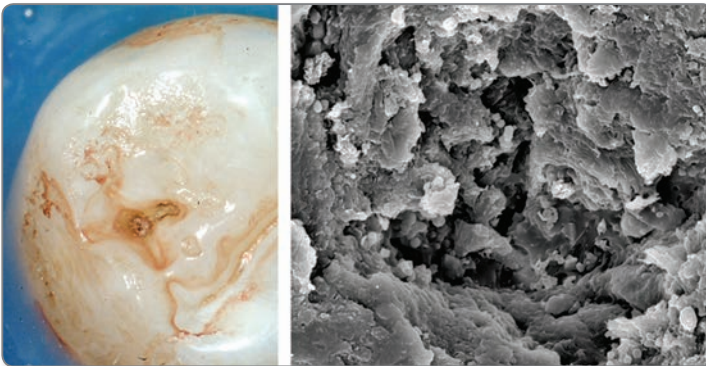
**Figure 2** Quantification of the microbes per milligram of material removed shown beside the clinical image of the lesion at the Cut number listed. Figure 2g shows the size of a milligram of tooth material relative to a millimeter scale to visually relate the microbe numbers to the mass.



**Figure 3** Comparison of a digital radiograph and subsequent dissection of the tooth with a caries lesion. Although the radiograph shows infection into dentin, it falls far short of displaying the depth and extent of tissue destruction, and gives no indication of microbe penetration.



**Figure 4** According to this microbe map of tooth C in Figure 10, after bur Cut 10, no microbes were cultured. We could say this shows where the microbe infection ends in this lesion. However, when culturing microbe infected *in vivo* tissue, lack of growth does not necessarily mean no microbes were present. It can be methods and medium used failed to grow the organisms present.



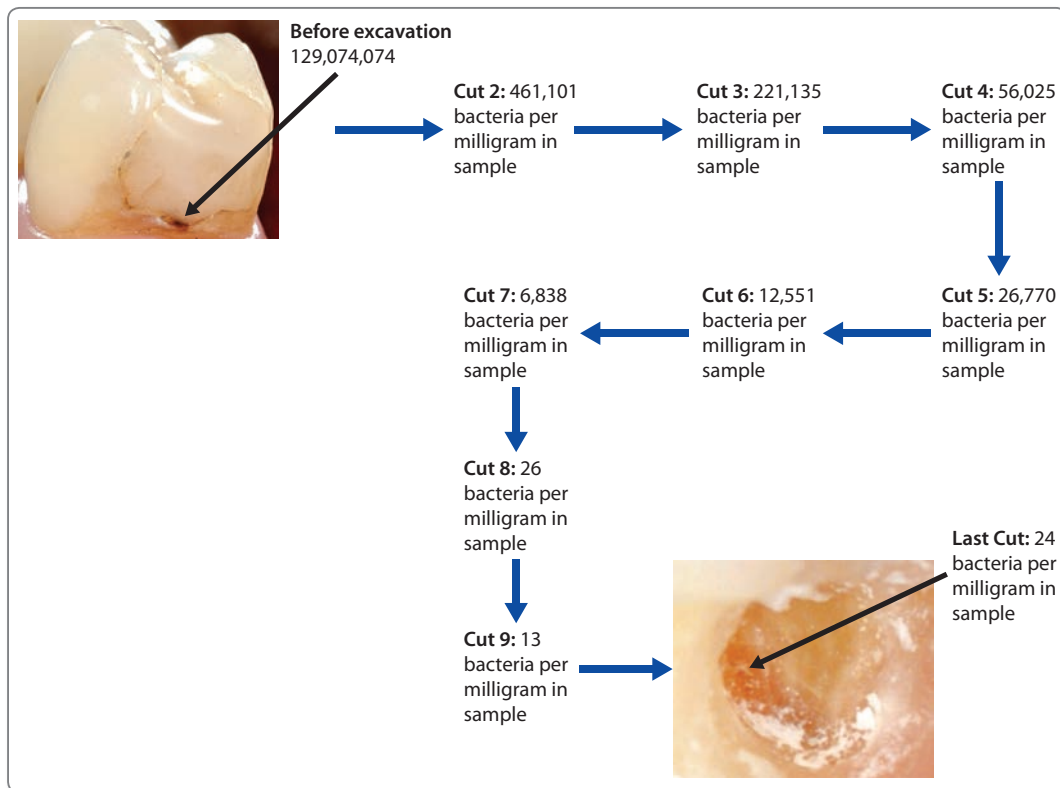
**Figure 5** The clinical image of a small discolored area in an occlusal pit of an upper premolar and a scanning electron microscope image of the defect's internal portions showing viable microbes throughout. This example illustrates the problem clinicians face when attempting to judge internal lesion activity by external surface appearance. This lesion had penetrated into the pulp chamber.

often pain-free, pathway toward the pulp chamber. Therefore, we propose application of a therapeutic disinfectant to kill the remaining viable microbes after conservative removal of the most damaged, most infected dentin.

## 2. Microbiologically there is no infected and affected layer in a caries lesion

By definition infected tissue contains microbes. Our work over 14 years shows microbes present throughout caries lesions, regardless of the individual lesion circumstances. We have seen dentin that was either characterized by one or more clinical indication of dental caries such

as discoloration, porosity, loss of hardness and contained high numbers of microbes OR dentin that had none of these clinical characteristics and contained no microbes we could culture. We have seen no 'affected' or microbe-free dentin at the deepest part of any lesion where the dentin appeared to be carious by any one of the several clinical parameters used to define presence of dental caries. However, generally the type and number of microbes within lesions decrease significantly from the lesion surface to its deepest point, with greatest numbers and types of organisms at the surface. **Figure 6**



**Figure 6** Clinical image of what appears to be a small lesion on the gingival margin of a resin restoration, which was actually a very deep lesion under the restoration. Note how the numbers of microbes present per milligram decreased dramatically after Cut 7 in the dentin immediately over the pulp. Although microbe numbers are substantially lower here, this is where microbe kill by a therapeutic disinfectant is most crucial.

shows the number of microbes per milligram of tooth material removed within a lesion before and during excavation, and at the last cut about 0.5 mm from the pulp. Note the significant drop in the number of microbes present per milligram of tissue removed after Cut 7. Cuts 8–10 represent careful small excisions made directly over the pulp chamber in a lesion that penetrated into the pulp chamber. We consider the decrease in numbers of microbes as the lesion deepens as the natural pattern in the development of an advancing microbial infection. Theoretically, organisms capable of driving lesion progression would be found at the interface between the infected and noninfected dentin. The fact that we have never been able to culture microbes in obviously noncarious dentin implies that healthy dentin is sterile. However, more work needs to be done before we have absolutely proven this point.

The infected-affected terminology was used by Massler and applied to pulp pathology in the late 1970s. He later also used the same terminology when discussing dental caries.<sup>7</sup> Twenty years later, Fusayama used these terms and related them to how deep a caries lesion should be excavated.<sup>8</sup> Both men were innovators and thought leaders, but neither had the microbiology resources available to perform a sterile harvest from lesions *in vivo* and then culture organisms from within the harvested material and identify them by genus and specie designations. In the absence of this capability, neither man could validate his observations. However, due to their prestige in the profession, their observations were accepted as fact. **Figure 7** shows the histologic appearance of a sectioned tooth exhibiting ‘infected’ outer and ‘affected’ inner areas on two proximal lesions. From our work, we now know



**Figure 7** Image of a sectioned tooth showing the histologic appearance of what has been called the “infected” outer and “affected” inner areas. Our work in Figure 6 shows clearly that millions of microbes infect the entire lesion.

that the microbes inhabit a dental caries lesion throughout, and a short distance beyond, the discolored disturbed dentin.

## Clinical application

At the deepest points within the preparation the clinician needs to slow down, change to new *sterile* burs, apply disinfectant, and allow the contact time required to kill the microbes within the tissues. It is at the deepest point of the microbe infection where we see use of the therapeutic disinfectant as being most crucial. We disagree that this is an ‘affected’ layer and needs no treatment and will recover on its own when the outer infected dentin is removed. However, in a very deep lesion, we agree that the dentin next to the pulp chamber should be left in place, and our work indicates disinfection of this critical tissue is both logical and highly indicated.

### 3. All finished tooth preparations are highly contaminated

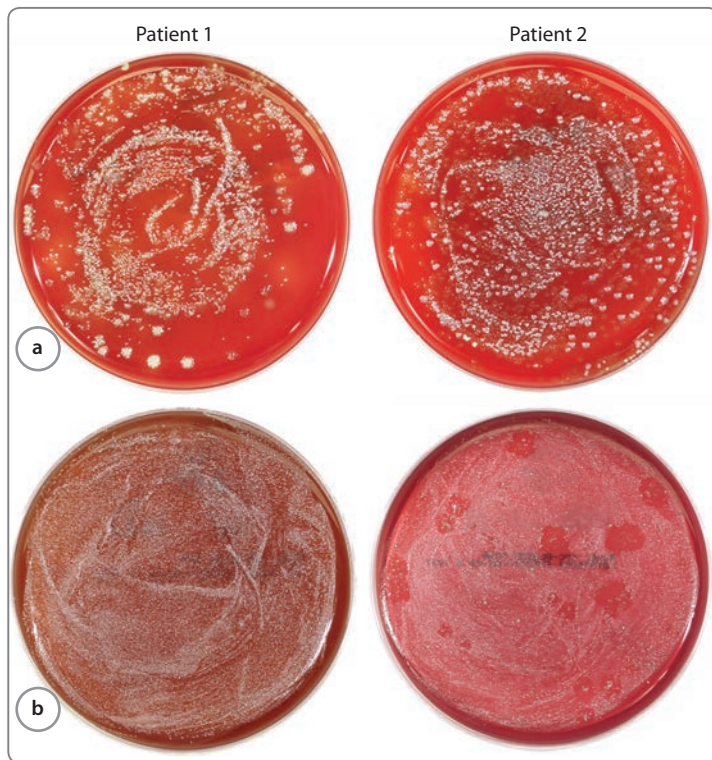
Two things cause all tooth preparations to be highly contaminated. First, clinicians inadvertently contaminate uninfected tooth structure by using the same one or two rotary

burs to cut the most infected dentin and the peripheral uninfected dentin. Second, clinicians elect to leave questionable tooth material, hoping if microbes are present, they will be killed by restorative procedures.

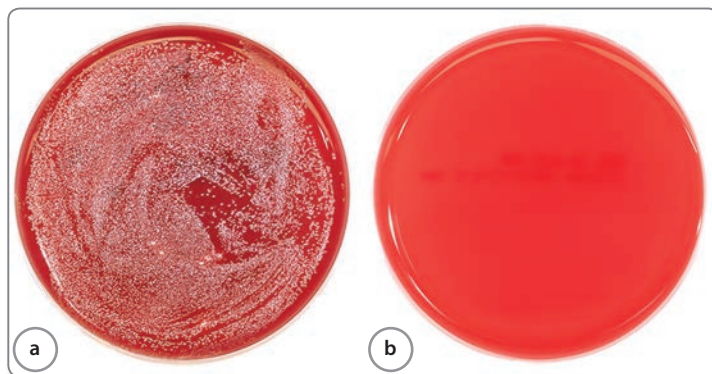
**Figure 8** shows the appearance of diverse and numerous microbe colonies from two different preparations on Petri plates handled aerobically (a) and anaerobically (b). Data we collected from 78 patients in private dental practices in 10 U.S. states indicate: (1) all finished tooth preparations were highly contaminated; (2) final treatment with or without acid etch and washing and drying did not eliminate the microbes; (3) microbe types varied by patient.

These findings prompted us to search for a formulation and technique that would accomplish tooth preparation disinfection. Our testing showed best microbe kill with a 5% glutaraldehyde – 35% hydroxyethyl methacrylate (HEMA) formulation. This formulation has been available commercially and used extensively worldwide for over 25 years, first as a primer in a dentin adhesive system (Gluma Adhesive, Bottle #3, Bayer AG, Leverkusen, Germany), and later for tooth desensitization (Gluma Desensitizer, Heraeus, Hanau, Germany). Today the formulation is available for tooth desensitization under several brand names. This formulation not only disinfects, but also, desensitizes, and modestly increases bond strength and longevity. **Figure 9** shows results from culturing an *in vivo* tooth preparation before and after two 1-minute paint-on applications of Gluma Desensitizer. The Sidebar summarizes steps in this tooth preparation disinfection procedure. Different methods of delivery and contact times were investigated and those listed in the Sidebar were found to be essential to achieve disinfectant penetration of the smear layer and underlying dentinal tubules.

*In vitro* testing by Clinicians Report Foundation (Provo, UT, U.S.A) indicates good compatibility of Gluma Desensitizer used as outlined in the Sidebar with glass ionomer, resin modified glass ionomer, and resin-based materials. It is imperative to apply the disinfectant precisely onto tooth structure only, since this chemistry can cause chemical burn of soft tissue. Use of 2× or higher magnification is helpful. No hard tissue postoperative negative sequelae



**Figure 8** Microbe growth on Petri plates processed aerobically (Row a) and anaerobically (Row b) from tooth preparations completed on two different patients. Note the extremely dense growth on the anaerobically processed plates. Most microbes within caries lesions grew well both aerobically or anaerobically, but growth was always most dense with anaerobic processing.



**Figure 9** Petri plates processed anaerobically before (a) and after (b) Gluma Desensitizer treatment.

have been noted or reported to us in 13 years of routine clinical use of this technique by clinicians worldwide.

### Clinical application

Our *in vivo* work with dental caries over the past 14 years indicates the microbes within lesions are astonishingly tenacious and not easily inactivated. We have searched for, and found, a disinfectant

formulation that we propose using to disinfect all tooth preparations, whether or not tooth excision is used.

4. **Many bacteria were identified within the caries lesions, and they differed by person, and by lesion within the same person**

**Figure 10** lists 78 bacteria that were proven viable and identified within caries lesions *in vivo* in 10 example teeth (two females and five males ages

Tooth	A	B	C	D	E	F	G	H	I	J
<i>Actinomyces</i> sp.	•	•	•	•	•	•	•	•	•	•
<i>Actinomyces meyeri</i>					•				•	
<i>Actinomyces naeslundii</i>	•	•		•						•
<i>Actinomyces odontolyticus</i>							•			
<i>Actinomyces oris</i>		•	•	•	•	•	•	•	•	•
<i>Actinomyces viscosus</i>		•							•	•
<i>Actinotignum</i> sp.			•							
<i>Atopobium</i> sp.							•			•
<i>Bacillus amyloliquefaciens</i>					•					
<i>Bacillus circulans</i>								•		•
<i>Bacillus humi</i>										•
<i>Bacillus pumilus</i>				•						
<i>Bacillus vallismotis</i>				•						
<i>Bacteroides</i> sp.									•	
<i>Campylobacter</i> sp.										•
<i>Campylobacter gracilis</i>					•				•	
<i>Capnocytophaga</i> sp.	•								•	
<i>Capnocytophaga gingivalis</i>									•	
<i>Capnocytophaga ochracea</i>									•	
<i>Capnocytophaga sputigena</i>									•	
<i>Clostridium</i> sp.									•	
<i>Corynebacterium durum</i>		•								
<i>Corynebacterium tuberculostearicum</i>					•					
<i>Eikenella corrodens</i>							•			
<i>Erysipelothrix</i> sp.									•	
<i>Fusobacterium nucleatum nucleatum</i>						•			•	
<i>Gemella haemolysans</i>			•							
<i>Gemella morbillorum</i>					•			•		
<i>Gemella sanguinis</i>							•			
<i>Granulicatella adiacens</i>	•				•					
<i>Kocuria rosea</i>				•						
<i>Lactobacillus fermentum</i>					•		•			
<i>Lactobacillus salivarius salivarius</i>						•				
<i>Lechevallieria</i> sp.									•	
<i>Microbacterium</i> sp.					•					
<i>Micrococcus flavus</i>								•		
<i>Micromonas micros</i>								•	•	
<i>Neisseria macacae</i>									•	
<i>Neisseria subflava</i>									•	

Tooth	A	B	C	D	E	F	G	H	I	J
<i>Paenibacillus</i> sp.									•	•
<i>Peptostreptococcus</i> sp.										•
<i>Prevotella</i> sp.										•
<i>Propionibacterium</i> sp.										•
<i>Propionibacterium acidifaciens</i>	•	•	•							
<i>Propionibacterium acnes</i>	•	•	•	•	•					•
<i>Rothia aeria</i>					•					
<i>Rothia dentocariosa</i>	•	•	•	•	•			•	•	•
<i>Rothia mucilaginosa</i>					•		•	•		
<i>Selenomonas</i> sp.										•
<i>Staphylococcus</i> sp.									•	
<i>Staphylococcus capitis capitis</i>							•			•
<i>Staphylococcus epidermidis</i>		•	•	•	•	•	•	•	•	•
<i>Streptococcus</i> sp.			•	•	•	•	•	•	•	•
<i>Streptococcus anginosus</i>						•	•			•
<i>Streptococcus constellatus constellatus</i>										•
<i>Streptococcus cristatus</i>	•	•	•	•	•				•	•
<i>Streptococcus cristatus/sinensis</i>					•					
<i>Streptococcus dentisani</i>					•	•				
<i>Streptococcus gordonii</i>	•	•	•	•	•	•				
<i>Streptococcus infantitis</i>		•								
<i>Streptococcus intermedius</i>						•				
<i>Streptococcus mitis</i>						•	•	•	•	•
<i>Streptococcus mitis/oralis</i>									•	
<i>Streptococcus mutans</i>	•	•	•	•	•	•	•			
<i>Streptococcus oralis</i>							•		•	
<i>Streptococcus parasanguinis</i>	•	•	•	•	•	•	•	•	•	
<i>Streptococcus pneumoniae</i>						•				
<i>Streptococcus salivarius</i>					•	•	•			
<i>Streptococcus sanguis</i>	•	•	•	•	•	•	•	•	•	
<i>Streptococcus sanguis</i>				•	•	•			•	•
<i>Streptococcus sobrinus</i>				•				•		
<i>Streptococcus tigurinus</i>									•	•
<i>Streptomyces coelicolor</i>										•
<i>Veillonella</i> sp.	•			•					•	
<i>Veillonella atypica</i>						•				
<i>Veillonella dispar</i>					•	•	•			
<i>Veillonella parvula</i>		•		•	•	•				
<i>Veillonella rodentium</i>					•	•	•	•	•	•

**Figure 10** Microbes cultured and identified within caries lesions of 10 teeth in seven adult humans 23–65 years of age as of the end of 2017. The black dots indicate microbe presence in the teeth coded by letters A through J at the top of the table.

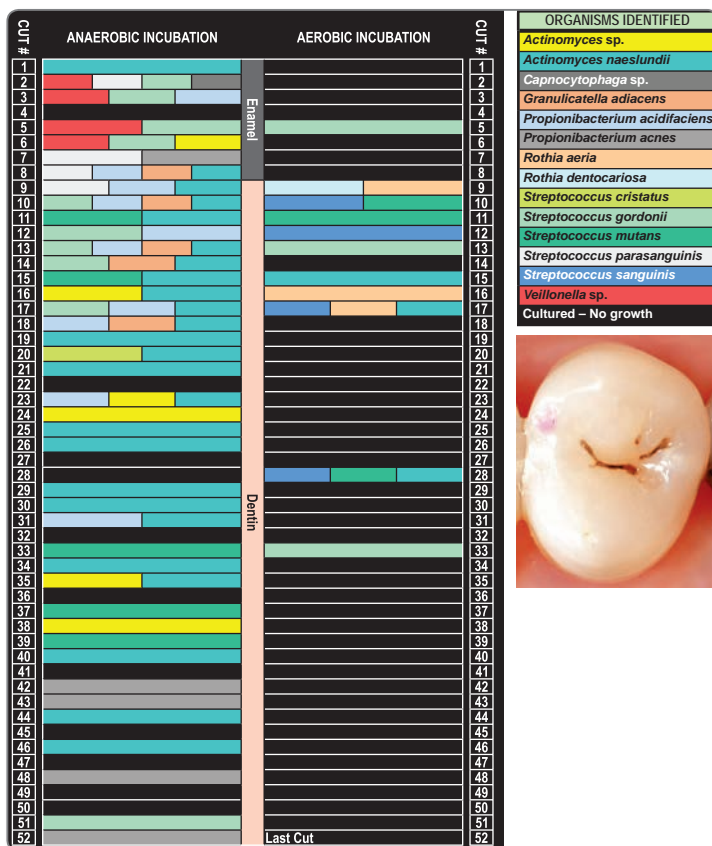
23–65 years at the end of 2017). Glancing across the rows and down the columns of **Figure 10** shows the microbe diversity.

**Figures 11** and **12** show fissure caries in upper premolars that are listed in **Figure 10** as columns A and B listed in the header labeled Tooth. Despite similarities in lesion appearance, tooth location, and number of organisms identified, comparison of the microbe maps shows many differences in microbes present, demonstrating that microbes differ by person.

**Figure 13** shows teeth C and D in **Figure 10** in a clinical image and the respective microbe

maps. These adjacent molars in the same person show multiple differences in their microbe maps, demonstrating that microbes differ by lesion within the same person.

We find it impossible, at this point, to implicate any one, or group of microbes as universally responsible for dental caries. However, it is noteworthy that unnamed *Actinomyces* species were found within 100% of the teeth studied (see **Figure 10**). Other microbes seen frequently were *Rothia dentocariosa*, *Actinomyces oris*, *Staphylococcus epidermidis*, *Streptococcus sanguinis*, and *Streptococcus* sp. Significantly,



**Figure 11** Comparison of Figures 11 and 12 show that two similar appearing lesions in two different people have different organism profiles.

*Streptococcus mutans*, long thought to be the causative factor in dental caries, was not found in 4 of the 10 lesions. Other research teams using different methods have reported similar findings.<sup>4,5,9</sup> Marsh proposed the 'ecological plaque hypothesis' where he concluded that patients' personal choices in diet, oral hygiene, and medications establish the oral environment which, in turn, selects for the oral microbes that ultimately determine oral health or disease.

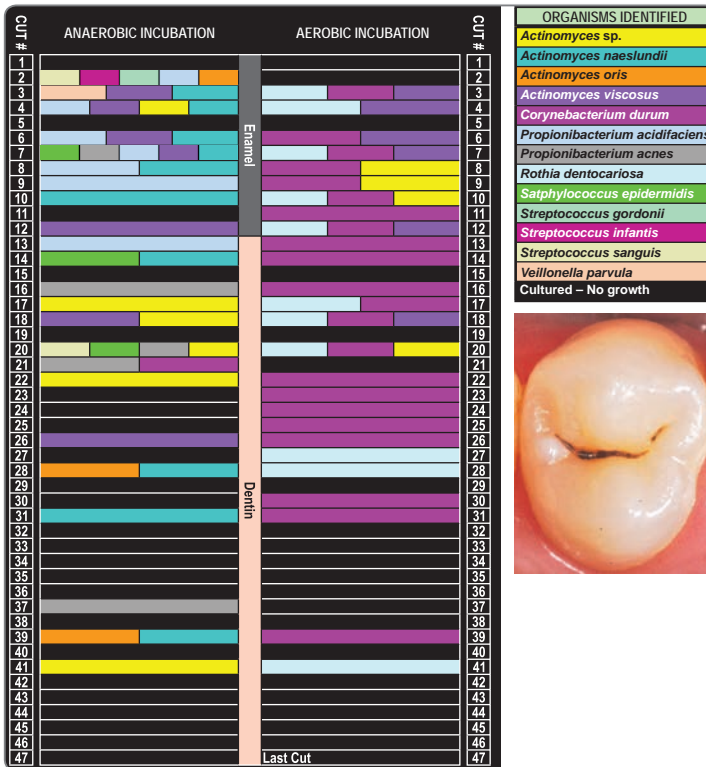
## Clinical application

We are interested in stabilizing oral pH within a range where enamel and dentin do not undergo pathologic demineralization, regardless of foods ingested. **Figure 14** shows a test material with buffer capacity and fluoride release placed as veneers on buccal and lingual surfaces of all molars for the purpose of gaining control of oral pH. We think the solution to the self-inflicted disease of dental caries is something that remains

in the oral cavity, and does not require a daily decision or action on the part of the patient. Since such a product is not yet available, we suggest teaching patients to:

- Forgo foods with added sugars on six of the seven days each week, then allowing themselves to eat anything they desire each 7th day
- Brush nightly just before retiring to bed with 5,000 ppm fluoride dentifrice, expectorate but do not rinse, and discontinue food intake after that
- Get pharmacist or physician help reviewing medications to identify and substitute for saliva inhibiting medications
- Obtain professional prophylaxis at a frequency that controls that individual's oral biofilm

Clinically, we have altered caries progression by changing the oral environment with a regimen called frequent polishing which is defined as

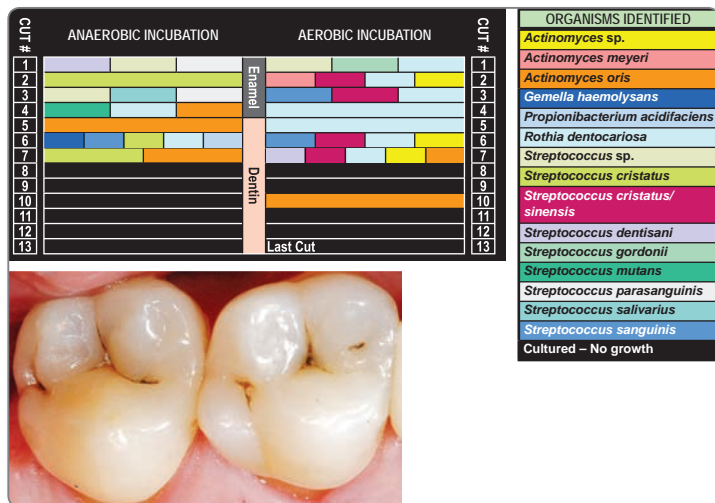


**Figure 12** Fissure caries microbes in this figure should be compared with those in Figure 11 to see that two similar appearing lesions in two different people have different organism profiles.

## Steps tested and found most effective for tooth preparation disinfection using 5% glutaraldehyde – 35% HEMA formulations:

1. Water wash and damp dry the completed preparation. If total etch is to be used, complete the etch, wash, and damp dry steps before proceeding to step 2
2. Dispense 1–2 drops of disinfectant into a dappen dish. Dip a small size microbrush (Denbur, Westmont, IL, U.S.A.) into the disinfectant and paint all portions of the preparation and onto the surfaces just outside the margins. Use 2× or higher magnification for precise placement on hard tissue only, since contact with soft tissue can cause chemical burn
3. Allow 1-minute contact time. (Reapply to keep surfaces wet throughout the 1 minute). (Do not rub or scrub during the contact time)
4. Suction to establish a damp surface. Place a second 1-minute application. Do not water wash or dry between applications. (Two 1-minute applications are necessary to penetrate the dentin smear layer and gain access into the underlying dentinal tubules which can harbour microbes)
5. After the second application, suction to obtain a damp surface. Follow directly with steps for cement or restorative or sealant. (Do not water wash or dry at any time after step 1)





**Figure 13** Clinical images of caries lesions in two adjacent molars and their microbiome profiles are very different, showing that lesions within the same person have different microbes.



a professional tooth polishing once a week for 12 weeks.<sup>10</sup> We encourage clinicians to try this approach when lesion progression does not respond to other approaches.

**5. Silver diamine fluoride provides good tooth desensitization, but poor antimicrobial activity on microbes within caries lesions**

Chemical treatment to stop dental caries progression, omitting all tooth excision, has been dentists’ dream for years, particularly for pediatric

dentists. In April, 2015, 38% silver diamine fluoride (SDF) was introduced in the U.S. to fulfil this dream (Advantage Arrest, Elevate Oral Care, West Palm Beach, FL). Clinicians have observed that SDF application generally alleviates dental caries pain in children<sup>11</sup> and hardens the lesion surface. These two characteristics have lead clinicians to believe that SDF arrests progression of dental caries.



**Figure 14** A commercially available dental material with buffer capacity and fluoride release being tested to determine if it can stabilize oral pH, regardless of the patient's food choices. This is a future possibility for controlling caries.

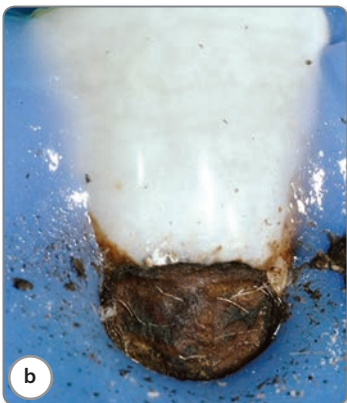
However, an important question not addressed is: How does SDF application affect the microbes within caries lesions? **Figures 15a-e** show the clinical appearance of an SDF treated lesion before excavation (A), and at four points in the sterile harvest procedure. Numbers of bacteria per milligram of material removed are listed with cut numbers. Note that numerically millions of microbes have remained viable throughout the lesion. **Figure 15** shows the 25 viable microbes identified and their locations within this lesion. This lesion was excavated 28 days after receiving 3-weekly SDF treatments and left uncovered by the dentist. Note that termination of the infected dentin was not reached due to proximity to the pulp. The clinical image at this last cut (**Figure 15e**) shows bright white highly demineralized dentin,



Before sterile harvest. Not cultured.



**Cut 3:** 7,534 bacteria per mg in sample

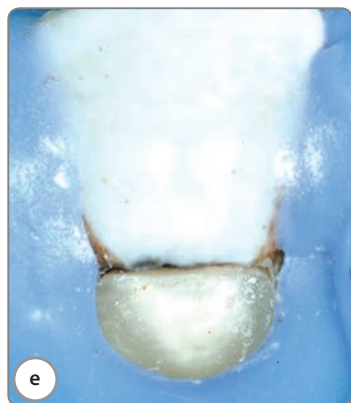


**Cut 1:** within silver stained layer 80,142 bacteria per mg in sample



**Cut 5:** 2,854 bacteria per mg in sample

**Figure 15** Clinical image of a tooth within a 36-year-old male treated with three applications of 38% silver diamine fluoride within eight days, and then excavated 12 days later to assess the status of the microbes within the lesion. Note the high numbers of microbes per mg of material removed and the microbes identified in each cut. *Continues overleaf...*



Cut 9 – Last cut  
3,248 bacteria  
per mg in  
sample

Figure 15 Continued...

and culturing and DNA identification show that this dentin is impregnated with eight viable species which SDF treatment did not eliminate. Application of 5% glutaraldehyde – 35% HEMA produced final elimination of all microbes.

## Clinical application

Millions of viable microbes recovered within and beneath SDF stained areas cast significant doubt that SDF stops dental caries progression. Four additional SDF treated cases from other dentists showed the same results in our testing as the example case in **Figure 15**. This failure of SDF to kill the microbes within caries lesions reminds us that clinicians cannot judge activity within caries lesions based on surface characteristics.

Silver diamine fluoride has characteristics that are helpful clinically for purposes other than microbe kill. First, it relieves dental pain in children.<sup>11</sup> Second, accurate permanent staining of all demineralized tooth surfaces marks locations of infection and can remind patients that changes in diet, oral hygiene, and medications affecting saliva flow are necessary. Third, desire to remove the stain can stimulate needed treatment. However, because SDF treatment leaves millions of microbes within lesions, clinicians are advised to monitor closely for lesion progression, and not assume arrest.

### 6. *Organisms remain viable and slowly destructive under sealants and restorative materials*

Choose any dental material serving *in vivo*, and scanning electron microscopy (SEM) performed on polyvinyl silicone replicas of the tooth-material

interface will show open gaps intermittently along margins. Polymer-based products display larger margin openings, with light-polymerized materials worse than auto-cured. Recently 'improved' conventional glass ionomers showed best margins and highest fluoride release (EQUIA Forte, GC America, Alsip, IL and Ketac Universal, 3M, St. Paul, MN). However, it is a fact that margins on dental materials notoriously lack true seal all the way around. Furthermore, segments along the margin that appear connected at one point in time can separate later. This is true of different formulations as well as types of materials including restoratives, sealants, cements, endodontic sealers, etc.

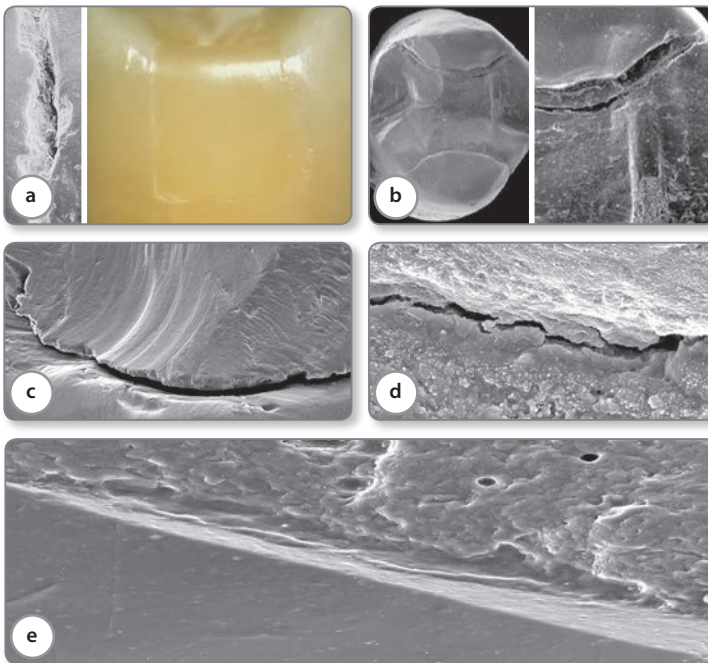
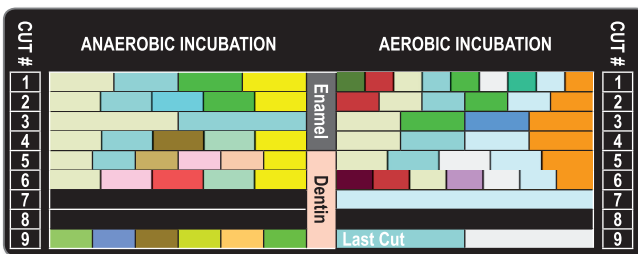
**Figures 16a–d** shows margin openings occur *in vivo* in a variety of dental materials but **Figure 16e** shows this is not a problem with the recently improved conventional glass ionomer materials mentioned above. Yet the caries literature repeatedly refers to 'material seal' that is supposed to cause eventual death of the microbes remaining under commonly used materials after clinical procedures. In reality, there is a free flow of microbes, chemicals, and nutrients around dental restorations and sealants. Oral microbes vary in size depending on organism type and morphology, growth stage, and method used to measure size, but all are far smaller than the tooth-material gaps shown in **Figures 16a–d**.

Even if margins did 'seal', caries microbes deep within lesions are not dependent on nutrients or oxygen from the oral cavity. They adapt to conditions at hand. The tooth itself can be their substrate, and lack of oxygen is not a problem for them as evidenced by the heavy growth on our anaerobically cultured Petri plates in **Figure 8b**. However, nutrients, pH, and other factors in the oral cavity environment are very important to the microbes on the tooth surfaces that initiate dental caries. Marsh theorizes that the surface microbes that initiate dental caries can be 'any species with relevant traits'<sup>4</sup>

## Clinical application

Clinicians cannot overcome lack of margin seal. This is a materials problem that belongs to the scientists associated with dental industry. However, clinicians can watch for improved materials and learn to use conventional glass ionomer materials which can be used as a 'therapeutic bandage' to seal over the

ORGANISMS IDENTIFIED	
<i>Actinomyces</i> sp.	<i>Streptococcus gordonii</i>
<i>Actinomyces odontolyticus</i>	<i>Streptococcus mitis</i>
<i>Actinomyces oris</i>	<i>Streptococcus mitis/oralis</i>
<i>Atopobium</i> sp.	<i>Streptococcus mutans</i>
<i>Eikenella corrodens</i>	<i>Streptococcus parasanguinis</i>
<i>Gemella morbillorum</i>	<i>Streptococcus salivarius</i>
<i>Gemella sanguinis</i>	<i>Streptococcus sanguinis</i>
<i>Lactobacillus fermentum</i>	<i>Streptococcus sobrinus</i>
<i>Micromonas micros</i>	<i>Streptococcus tigurinus</i>
<i>Rothia dentocariosa</i>	<i>Veillonella</i> sp.
<i>Rothia mucilaginosa</i>	<i>Veillonella parvula</i>
<i>Staphylococcus epidermidis</i>	<i>Veillonella rodentium</i>
<i>Streptococcus</i> sp.	Cultured – No growth



**Figure 16** Images of representative clinical cases demonstrating the microscopic lack of “seal” of current dental materials. (a) shows the “white line” gap produced by polymerization shrinkage on the margins of a conservative “slot prep” resin restoration, and a view of the white line by SEM (b) shows resin cement loss of seal on both the restoration and enamel sides of an inlay, and a SEM image of the entire MOD restoration, (c) shows resin sealant failure on beveled occlusal enamel, (d) is a closeup of a “bioactive” RMGI margin gap, and (e) shows the margin seal obtained with the improved glass ionomer Equia Forte.

5% glutaraldehyde – 35% HEMA disinfected tooth preparations to stop lesion progress. The improved glass ionomer restoratives show excellent margin seal at 2 years of service, but still fracture easily under occlusal loads. Therefore,

overlying with a stronger resin-based material (“sandwich technique”) is still a good idea, even though the resin material will have margin leakage. The hope is that the leakage will be blocked from deep access by the glass ionomer

dentin replacement material. Clinicians can also be influential in teaching patients how to maintain a healthy oral environment that develops high proportions of non-carious related microbes within the oral cavity.

## Summary and conclusion

Our message is that all dental caries lesions are 'active'. By this we mean we have found millions of viable microbes in all lesions we have investigated. We believe that these viable microbes need to be dealt with, and not just covered over with restorative material or left untreated to continue their slow progression toward the pulp. The data presented do not support intentionally leaving microbe infected enamel and dentin in caries lesions without first employing measures to kill the viable microbes before covering with restorative material. Our data indicate that the microbes left behind continue a slow, pain free, clinically and diagnostically invisible destruction toward the pulp chamber that does not stop by itself.

The data do support use of a therapeutic disinfectant to kill the microbes before any subsequent steps such as placement of restoratives, sealants, or a 'therapeutic bandage' like glass ionomer. Five percent glutaraldehyde – 35% hydroxyethyl methacrylate formulations have shown excellent microbe kill within tooth preparations as well as providing tooth desensitization and moderate increases in bond strengths and bond longevity. Many other formulations have been proposed and need to

be tested *in vivo*. The ultimate goal is to identify a therapeutic disinfectant that can be applied directly onto caries lesions to kill the microbes throughout the lesion and stop lesion progression, without any need to cut the tooth. At this writing, no such disinfectant exists. Although 38% silver diamine fluoride has been promoted for this purpose, our data show that the necessary antimicrobial activity is lacking in this formulation.

Our data indicate there is no one microbe always implicated in all caries lesions in all people. Our work confirms the work reported by Marsh<sup>4</sup> that what the person does drives the disease, and not the presence of a specific microorganism. What people do establishes the oral environment which, in turn, establishes conditions that do or do not lead to dental caries.

Restorative dentistry treatments have been limited by the fact that no material was available that truly and permanently sealed at the tooth-material interface. Currently, we are following the improved glass ionomers to see if they are the exception, but we now have only 2-year data on their margin seal, and more time in service is needed. There is simply no dental material that is equal to intact enamel and dentin. Microinvasive dentistry is an important step forward because its goal is to preserve intact tooth structure. However, in both prevention and treatment of dental caries, clinicians need to upgrade their methods of communication to convincingly convey to patients that dental caries in developed countries is primarily a man-made disease that is almost entirely preventable by control of diet, oral hygiene, and saliva inhibiting factors.

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*John Sulewski*

## Definition

Air abrasion may be broadly defined as a method of delivering an abrasive material under varying pressures for removing deposits and stains from teeth, debriding dental implants, modifying the surface of dental materials, or cutting tooth structure. Air abrasion may also be called air abrasive, airbrasive, micro air abrasion, kinetic cavity preparation, or accelerated particle ablation. Air abrasion uses range from prophylactic and polishing applications (lower pressure) through removal of enamel and dentin (higher pressure). This chapter concentrates primarily on the higher-velocity applications for preparing cavity preparations and for modifying surfaces to enhance bonding.

## Introduction

Picture yourself coming to your general dental practice one morning, reviewing the day's schedule of patients, most of whom are in need of caries treatment and tooth restorations.

You take stock of your current available resources to deliver state-of-the-art dental care:

- Your electric motor-driven dental handpiece delivers a maximum rotational speed of 5,000 revolutions per minute<sup>1</sup>
- You have a selection of either steel burs or diamond instruments at your disposal with which to prepare teeth<sup>2</sup>
- Your dental restorative materials are mostly limited to a choice of amalgam or gold<sup>3,4</sup>

As your patient settles into your dental chair, anticipating the procedure you are about to perform, you note the growing trepidation and deep-seated dread of having the teeth operated upon, the apprehension over the vibration, pressure, heat, and bone-conducted noise you are about to impart.<sup>3</sup>

You lament silently to yourself, 'Dentistry, of all the medical arts, has the unenviable distinction of offering the most widely feared service.'<sup>2</sup>

Amid these circumstances, you cannot help but think that there must be a better way. However, you have no high-speed handpieces, no carbide burs, no composite restorative materials, and no adhesive dentistry.

Such were the realities and conditions that Corpus Christi, Texas, dentist Robert Black, DDS, encountered in the 1940s as he worked toward realization of that 'better way' – development of 'a new medium for cutting enamel and dentin painlessly, rapidly, and silently.'<sup>2</sup>

## History and scientific principles

Black envisioned a device that relied on the translational (linear) kinetic energy of mass in motion rather than the rotational kinetic energy (friction) of cutting burs to achieve its objective. His notion was based on the principle of kinetic energy developed by French mathematician and mechanical engineer Gaspard-Gustave de Coriolis (1792–1843) in his text published in 1829, *Du calcul de l'effet des machines* ['The calculation of the effect of machines']. Expressed mathematically in the equation  $E_k = \frac{1}{2} mv^2$ , for a single particle of mass 'm' moving at velocity 'v', linear kinetic energy equals one-half mass times velocity squared. In this form, kinetic energy is a function of both mass and velocity, and energy increases dramatically as velocity increases.

Black used that principle to develop a technique for nonmechanical preparation of cavities and prophylaxis, using a stream of compressed air into which abrasive particles had been introduced and directed toward tooth structure. He coined the term 'airbrasive,' a

combination of the words air and abrasive, to denote the innovative technique.<sup>2</sup>

His experimentation with different prototypes eventually led to the 1951 introduction of the first commercially available air abrasion dental device, the Airdent, by the SS. White Dental Manufacturing Co., Philadelphia, Penn., USA. Within five years, Black reported that more than 2,000 dentists had used the device in the United States, and a limited number of devices were placed in Europe.<sup>5</sup>

The Airdent used carbon dioxide gas at a pressure of 80 psi (551 kPa) as the propellant into which particles of aluminum oxide with an average size of 30 microns were introduced. Aluminum oxide was chosen because it is nontoxic, chemically stable, inexpensive, neutral in color, and flows freely with no great affinity for water. The mixture of gas and abrasive particles traveled through a thin flexible tube to a contra-angle dental handpiece that terminated in a tungsten carbide nozzle with an aperture of 0.018 inch (457 microns). The particles escaped from the orifice at a linear velocity of approximately 1,900 feet (579 meters) per second. The Airdent also incorporated a 3-inch (7.6-cm) bore flexible tube connected to a vacuum unit, while the other end terminated in a suction hood that contained an operating light. During use, the hood was held closely to the patient's mouth to collect spent abrasive particles and tooth debris.<sup>5-7</sup>

The Airdent was able to rapidly prepare class I, II, III, and V cavity preparations, albeit rotary instrumentation was still necessary for precision shaping of the final preparation appropriate for the restorative materials of the era. The device tended to cut shapes in tooth structure that were rounded or beveled, uneven, without consistent definitive walls and well-defined cavosurface margins, and without flat floors. (The classic GV Black preparation forms preferred for amalgam and gold restorations still required supplemental use of the mechanical handpiece). Airbrasive was found to be especially well-suited for treatment of early stages of carious lesions. It was least effective in treating teeth with large open carious lesions or in teeth with previous restorations that required removal.<sup>3,8</sup>

Despite widespread recognition of its utility in operative dentistry, the Airdent did

have a number of limitations. The unit itself was relatively large, too bulky for use in small operatories, and it was awkward to move from one room to another. Some time and effort were necessary to make the transition from conventional instruments to air abrasion; unlike rotary instrumentation, the Airdent handpiece provided no tactile feedback to the operator as it was held out-of-contact with the target tissue. Its rapid cutting of solid tooth structure necessitated frequent inspection to check progress of the preparation and avoid over-excitation. The abrasive particles tended to abrade and etch the reflective surface of glass mouth mirrors. The Airdent rapidly cut enamel and dentin but did not affect soft, leathery, carious dentin. The suction hood was found to be inadequate in reclaiming the spent abrasive particles, and the accumulation of dust on nearby surfaces was found to be an annoyance.

Nevertheless, surveys of clinicians and patients at the time revealed positive impressions of the technology as a valuable and practical adjunct for tooth preparation. The use of the Airdent significantly reduced the heat, pressure, noise and vibration associated with conventional instrumentation, and required less anesthesia, just as Black had originally envisioned. Both patients and dentists were more relaxed while using the device. And the vast majority of patients preferred the airbrasive treatment over use of the bur.<sup>9,10</sup>

In some respects, the Airdent was a device ahead of its time. The tooth-structure-conserving shapes of its cavity preparations were well-suited to bonded composite restorations, but the development of adhesive dentistry materials was still some years distant. Additionally, by the mid-1950s, advances in other technologies overshadowed the impact of the Airdent. The introduction of the Page-Chayes belt-driven handpiece in 1955 significantly increased the speed of rotary instrumentation to 100,000 rpm, and in 1957 the Borden air-turbine angle handpiece achieved speeds of 250,000 rpm and more. Many dentists found such instruments faster and capable of doing all preparations with the mechanical retention characteristics required for amalgam restorations.

## Reappearance of air abrasion devices

The advent of bonded resin materials and pit and fissure sealants contributed to the philosophy of conservative and preventive dentistry and the preservation of healthy tooth structure. Moreover, composite resin, glass ionomer, and resin-bonded ceramic restorations required rounded or beveled cavosurface margins – just the sort of forms that air abrasion provides – to increase enamel surface area for retention. These developments prompted a second look at air abrasion as an effective and nontraumatic methodology for minimally invasive, conservative cavity preparation.

The US Food and Drug Administration granted marketing clearance on November 25, 1992 to Texas Airsonics for the Model 2000 Dental Air Abrasive System, marketed by American Dental Laser as the kinetic cavity preparation (KCT) 2000. Clinical indications for use included cavity preparation, removal of decayed and sound tooth structure, removal of restoration materials, preparation for pit and fissure sealant, and modification of enamel and dentin for increased bond strength. Within a few years a number of other air abrasion devices entered the dental marketplace and were widely adopted as an adjunctive tool in the operative dentistry armamentarium.

Compared to the Airdent, these newer air-abrasive cavity preparation systems had similar kinetic energy properties: The harder the target substance, the faster the cutting speed; the softer the substance, the slower the speed. Air abrasion devices rapidly cut harder materials such as enamel, dentin, and porcelain, but are much slower at cutting softer, less brittle materials such as gold or amalgam. Some of the kinetic energy is lost to the resilience of these softer materials.<sup>3</sup> Particles readily rebound after hitting rubber dams.

No matter how new these devices might have been, but they still shared the same principles of operation with the Airdent from 40 years ago i.e., the use of kinetic energy (mass in motion) to rapidly remove tooth enamel and dentin, and comfortably prepare conservative cavity preparations, cut porcelain, remove decay or preexisting composite restorative materials, and modify the tooth surface. These new devices

generally used medical-grade aluminum oxide particles (powder) as their abrasive agent and compressed air as their propellant. Many models provided a range of user-selectable air pressures and a choice of particle size (usually 27.5 or 50 microns) specifically designed for either cavity preparation or tooth surface modification.

## Particle delivery

All the devices had a mechanism by which the abrasive particles were introduced into the airstream. The particle feed systems differed, depending on the product design.

Generally, the least expensive models used a simple agitation particle feed system that worked much like an upside-down salt shaker. An agitator shook a reservoir of particles which allowed them to exit holes and flow into the airstream. In this particular design, the amount of powder delivered depends on the size of the holes, the amount of agitation, the volume of air in the delivery system, and the nozzle size.

More sophisticated is a modified venturi particle feed system in which powder in a reservoir was drawn through a small tube or venturi by a flow of air. In this design, the amount of particles delivered depends on the velocity of air and nozzle size.

The most sophisticated devices used a metered particle delivery system. In this design, powder from a reservoir enters the bottom of a chamber which is vibrated by an electrical motor. The motion of the vibration causes a set amount of particles to move evenly and precisely up a spiral-shaped channel where they are delivered into the airstream. In such a system, the air velocity, rather than affecting the volume of powder delivered, actually controls the kinetic energy of the particle stream, depending on the velocity setting selected by the operator. According to the equation for kinetic energy,  $E_k = \frac{1}{2}mv^2$ , the energy is affected much more by the velocity than by the mass, and increases significantly as velocity increases. Of the three types of particle delivery systems, the metered version provided the least amount of powder overspray, one of the ongoing objections to air abrasion technology.

Within the past several years, a number of air abrasive devices have incorporated a curtain or conical stream of water that operates



simultaneously with the airstream. This feature significantly reduces powder scatter and facilitates collection of spent particles by the evacuation system.<sup>11</sup>

## Types of particles

Most devices utilized for air abrasion cavity preparation have used aluminum oxide as the abrasive agent. It contains no silica, and is classified by the U.S. government as a “nuisance dust.” If inhaled, particle sizes larger than 10 microns cannot enter the alveoli and therefore this powder has low potential for causing respiratory problems. Proper use of evacuation and rubber dam that extends over the nostrils minimizes inhalation of particles by the patient.<sup>4</sup>

More recently, a bioactive glass powder (calcium sodium phosphosilicate) is also being used as an oral cavity abrasive polishing agent intended for the removal of weakened or decayed small enamel lesions and for the cleaning of enamel surfaces. It is contraindicated for use on patients with a known allergy to silica. This biologically compatible powder is significantly softer [420 knoop hardness number (KHN)] than aluminum oxide (2100 KHN). Bioactive glass is currently used in the oral cavity as a bone-graft material.<sup>12</sup>

An additional application of interest is the apparent ability of bioactive glass to close exposed dentine tubules. A 2010 study reported results of a double-blind, split mouth investigation involving 25 patients that assessed the effectiveness of prophylaxis treatment using bioactive glass in an airpolishing device in reducing dentinal sensitivity to cold air and cold contact (ethyl chloride). They found the treatment was clinically effective in reducing sensitivity for the duration of the 10-day study period, and indicated physical occlusion of dentinal tubules as the mechanism for its effect.<sup>13</sup>

The use of bioactive glass for remineralization is being studied. An *in vitro* investigation showed the feasibility of using it to increase the mineral content of artificial white spot lesions in human enamel samples following a 10-second air-abrasion preconditioning exposure to bioactive glass at relatively low air pressure of 20 psi. This was followed by application of bioactive glass slurry twice daily, 5 minutes per application, for 21 days.<sup>14</sup>

## Fundamental scientific research

Histologic investigations showed the air abrasive approach with aluminum oxide to be as kind or kinder to the pulp than high-speed rotary instrumentation with copious water spray; even with a near pulpal exposure with air abrasion, less cellular disruption of pulpal tissue occurred compared to the high-speed turbine.<sup>15</sup>

Scanning microscopic examinations revealed rounded cavosurface margins and internal line angles on class V buccal preparations made with air abrasion, without the microchipping and cracking of enamel that was evident after preparation with high-speed burs and that may contribute to premature failure of an otherwise sound restoration. Air-abraded tooth surfaces were microscopically rough and dentinal tubules were occluded.<sup>16</sup>

While air abrasion modifies the surface of enamel and dentin to increase surface area, it does not eliminate the need for acid conditioning before placement of sealants or composite resin restorations. Studies indicate the greatest bond strengths and least microleakage occur with a combination of air abrasion and acid conditioning of tooth structure.<sup>17-19</sup>

## Operational aspects

A number of variables affect air abrasion effectiveness (expanded and adapted Donovan 2013):

- Air pressure
- Particle type and hardness
- Particle size
- Powder flow rate
- Water flow rate (if so equipped)
- Nozzle orifice diameter
- Tip geometry
- Tip angle relative to target tissue or material
- Tip-to-target working distance (0.5–5 mm)
- Target substance hardness (enamel, dentin, composite, porcelain, etc.)
- Motion of handpiece
- Duration of exposure
- Amount of particle rebound in deeper areas
- Amount of overspray
- Evacuation effectiveness

## Safety considerations and precautions

The intraoral use of abrasive particles under pressure necessitates consideration of safe operational practices (expanded and adapted from “Clinical Procedures Performed with the KCP 2000 and KCP 1000 whisperjet Kinetic Cavity Preparation Systems,” American Dental Technologies, April 13, 1998):

- Ensure protective eyewear is worn by the patient, practitioner, and attending staff
- Use a high-speed evacuation system to remove spent kinetic particles and tooth debris. Keep the evacuation handpiece close to the site without impairing visibility, and adjust the handpiece angle to match the angle of particle rebound
- Use appropriate barriers to avoid injury to adjacent tissues:
  - Rubber dam to help avoid irritation or injury to gingiva and other soft tissue
  - Gauze squares to protect soft tissue not otherwise covered by a rubber dam
  - Rubber dam, stainless steel matrix band, or cellulose strip when directing the abrasive stream toward proximal areas to protect adjacent teeth
- Regularly inspect the delivery system (hose, handpiece, nozzle) for integrity and signs of wear and replace any worn component
- Direct the nozzle orifice away from an open pulp chamber or pulpal exposures, and avoid direct contact or extended contact with the gingiva
- Avoid activation of the particle airstream when the nozzle is directed away from target tissues
- Exercise care when working around soft tissue to minimize the risk of laceration, air dissection, and emboli<sup>4</sup>
- Cease operation if any signs of soft tissue inflation or subcutaneous emphysema are detected<sup>20</sup>
- Use direct vision wherever possible, as the kinetic stream etches mirror surfaces. Use disposable mirrors or abrasion resistant dental mirrors
- Check progress frequently (every 5–10 seconds) to examine the treatment area visually and with an explorer. Use caries detector dye to help differentiate between infected dentin (heavily bacteria-laden) and affected dentin (far fewer bacteria) to help in the selective

removal of the stained necrotic superficial layer and the preservation of the deeper, uninfected, remineralizable, and vital layer<sup>21</sup>

- Remove soft decay and dentin conventionally with a spoon excavator and slow-speed handpiece
- Execute cavity preparation outline form in enamel first as much as possible before penetrating into the dentin layer, as exposed dentin will be removed at a faster rate than enamel

## Contraindications

Certain circumstances contraindicate use of air abrasion:

- Medical conditions of severe asthma, dust allergy, or chronic obstructive pulmonary disease (COPD)
- Amalgam removal because of the risks of mercury vapor release, unwanted tunneling of interfacial tooth structure, pulpal exposures, and adverse pulpal effects
- Endodontic procedures
- Exposure to bone
- Exposure to gingiva and other soft tissues
- Subgingival caries removal
- Patients with recent extractions or other oral surgery, open wounds, advanced periodontal disease, and recent placement of orthodontic appliances<sup>22</sup>

## Clinical applications

Practitioners using air abrasive cavity preparation devices have found them to be effective for a variety of clinical applications, as shown in **Box**.

## Advantages

Compared to conventional operative dentistry methodologies, air abrasion furnishes a number of benefits. These include the conservation of healthy tooth structure with no microfracturing or chipping; reduced noise and vibration; reduced need for anesthesia; no odor of carious material being removed; nontraumatic treatment experience for the patient.

Now imagine again entering your dental practice, preparing for the day's patients. You marvel at the array of minimally invasive instruments (including air abrasion) and advanced materials at your fingertips, confident that you can

## Clinical applications

Clinical applications of air-abrasive cavity preparation devices:

- Penetrating and excavating enamel and dentin
- Preparing small class I, class II, class III, class IV, class V, and class VI cavity preparations for composite restorations
- Excavating preexisting composites, glass ionomers, porcelain inlays and onlays, fractured facings, and residual amalgam stains (amalgam restorations require removal via rotary instrumentation)
- Repairing failed composites and glass ionomers, fractured porcelain and facings, and margins of porcelain-laminated veneers
- Preparing the surface of abfractions and abrasions
- Cleaning and removing cements and adhesives from castings, bridges, and crowns extraorally, prior to re-cementation
- Achieving greater retention by roughening inner surfaces of crowns and during application of pit and fissure sealants
- Diagnosing and treating decay difficult to detect by other means, as a conservative method for early interception of decay
- Opening the porcelain surface of a porcelain-fused-to-metal restoration when endodontic access is desired (rotary instruments are used to remove the metal and remaining dentin)
- Opening acrylic or porcelain jackets (rotary instruments are used to remove the tissue beneath the jacket)
- Preparing adhesive surfaces of orthodontic bands and brackets to increase retention

provide a more comfortable treatment experience for your patients with an enhanced quality of care in a more relaxed environment. You wonder how you ever practiced without these advantages.

## Air-abrasive cavity preparation devices

**Table 1** identifies air-abrasive cavity preparation currently available.

**Table 1 Air-abrasive cavity preparation devices**

Device	Manufacturer	Contact Information
AquaCare AquaCare Twin	Velopex International	velopexusa.com (888) 835-6739 (USA)
PrepStart H <sub>2</sub> O PrepStart	Zest Dental Solutions (Danville Materials)	danvillematerials.com (800) 827-7940 (USA)

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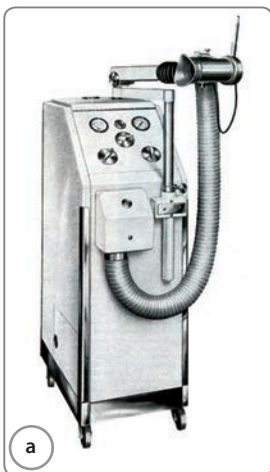
*John J Graeber*

## Brief history

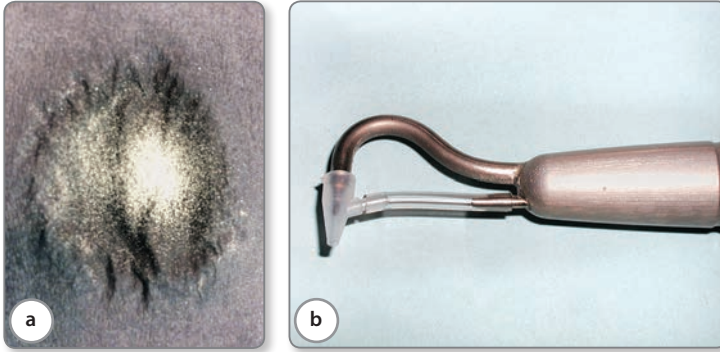
Every dentist has heard the pleas of patients for quieter and less painful treatments. For decades, a few dentists have sought kinder treatments for caries. This quest has been thwarted by the lack of available instrumentation. The first operational air abrasive device was developed by Dr Robert Black and was introduced in the late 1940s (the era of operative dentistry performed with low speed rotary instruments and infrequent local anesthesia). Reports from journals at the time were very favorable as to its operation and gentle effect on sensitive tooth structure. The SS White Company manufactured this unit as 'Airdent'. Many practitioners used the equipment to prepare carious teeth for restoration. Unfortunately, the predominant restorative material of that era was silver amalgam. Retentive requirements for amalgam were then and still are retentive areas which necessarily undercut the remaining structure. When solely implementing air abrasive techniques it was a difficult procedure to prepare retentive grooves of sufficient bulk to adequately retain these

restorations. Another common issue (which dentists struggled with) was the accumulation of the used or expended dry aluminum oxide abrasive powder both intra- and extra-orally. This occurred despite the external high speed vacuum built into the original unit. Hence, a patient-popular technique found less and less acceptance within the profession and ceased common usage by the early 1950s (Figures 1a and b).

As dentin/enamel-bonded restorations came into common usage by the early 90s, there was renewed interest in utilizing non-rotary instrumentation for cavity preparation. Flowable resins also made their debut during this period. The first renaissance device, Whisperjet 2000, was manufactured by American Dental Laser Company and introduced in 1993. Early users were pleased with its performance and restorative results. As time progressed as many as 17 manufacturers had devices on the market. Many of these devices lacked the sophistication and air pressure to be of significant improvement over the 1940 original. As many as 20,000 total units had been sold in the decade of the '90s'. Unfortunately, besides the shortcomings listed



**Figures 1a and b** The attempt to control the expended abrasive particles for the 'Dry Powder systems' required the use of 'elephant ears' extraoral vacuum units chairside. (Courtesy: John J. Graeber DMD)



**Figures 2a and b** The simple addition of an attachment to the air/particle nozzle connected to a passive water source operates by a venturi principle. The water surrounds the air/particle stream as shown on a black paper napkin. (Courtesy: T. Urella Velopex USA)

above, the common problem of expended ‘dust’ placed these devices back in the closet.<sup>1</sup>

As the years passed, many attempts to manage the ‘dust’ issue for the dental operator. One such remedy was to place the orifice of a large volume dry vacuum near the oral cavity to catch and filter the expended dust which exited the mouth after its use. Unfortunately, the noise caused by this type equipment is equally noxious (**Figures 2a and b**).

Fast forward to today. Other manufacturers recognized the shortcomings of the excess ‘dry’ dust and attempted to develop a ‘water shroud’ to surround the main air-particle stream and in order to contain the excess dust as a slurry of powder and water. The amount of exhausted dust was significantly reduced and the water made normal intra-operative suction devices far more efficient in managing the expended dust, now reduced to a ‘slurry’ as it mixed with the shroud water and saliva. Two additional immediate advantages became apparent to developers and user-dentists: The addition of water made the stream more comfortable for the patient, and the actual abrasion was more efficient by widening the beam and the resultant width of cut in both the enamel and dentin.

## Why air abrasion?

### Do no harm!

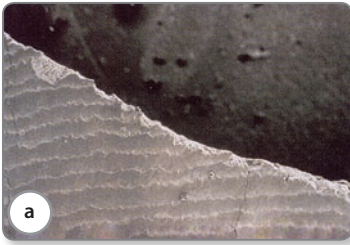
Rotary instruments, regardless of abrasive, diamond or carbide blade, and despite of handpiece quality, cause microfractures in enamel and pulpal inflammation. The main

causes have been identified as eccentricity, friction and heat. All of which are unavoidable due to the speed of the instrument and crystalline structure of the enamel. This can ultimately lead to postoperative hypersensitivity, leakage, catastrophic fracturing and pulpal necrosis.<sup>2</sup>

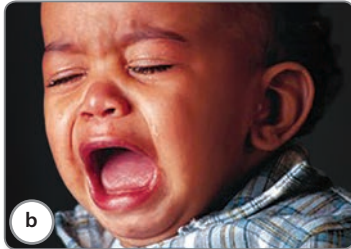
It has been the author’s experience over the past 25 years that a virgin tooth only prepared with air abrasives (or hard tissue lasers) have not suffered a single fracture when restored with dentin/enamel bonded composite. This concept needs to be accompanied by seismic change in a restorative dentist’s concept of cavity preparation. In essence, every carious tooth needing surgical intervention requires a conceptualization of an individual tooth treatment prescription rather than a ritualistic adherence to GV Black’s six step cavity preparation system (**Figures 3a and b**).

## Psychological harm

The vast majority of patients detest the sound a high speed turbine makes. The sound is deafening to patient and operator alike and has been associated with pulpal pain (when the local anesthetic is not utilized or adequate) and hearing loss to the operator and chairside staff. The vibrations caused by eccentricity of the rotary instruments are unnerving to most patients. When utilized in intracoronary preparations, the eccentricity and friction has been linked with enamel fracture.<sup>3</sup> Electric handpieces running at slower speeds and more torque may have less eccentricity of the bur but still vibrate and annoy patients with even louder sounds (**Figures 4a and b**).



**Figures 3a and b** These photomicrographs clearly show the damage to human tooth structure caused by the use of high speed rotary instruments. By contrast, air abraded enamel shows no such chipping, microfracturing and potential micro-leakage at margins. (Courtesy: American Dental Technologies)



**Figures 4a and b** Dental high speed instruments all cause pain due to friction, heat and vibrations. Patients reaction to many of the procedures dentists perform. (Courtesy: public domain)



**Figures 5a and b** When conventional rotary preparations approach pulpal tissue, there is significant aspiration of odontoblastic tissue as well as significant cellular damage in the columnar layer. Air abraded preparations show none of this histological disruption even when closer to the pulp as depicted. (Courtesy: American Dental Technologies)

### ***Air abrasion does no harm to enamel and dentin***

Its use produces no noise, no vibrations, and little or no sensitivity. If a carious tooth has exhibited hyperemic symptoms or responds negatively to air stimulation, preoperatively a local anesthesia is indicated for maximum patient comfort.

Otherwise, patients should experience little more than a gentle cool sensation when air abrading vital dentin. There is no aspiration of odontoblasts causing postoperative sensitivity. When dentin is abraded with abrasive particles, the collagen fibers may be seen under high magnification as compacted horizontally partially covering exposed odontoblastic tubules.

When properly operated, the metal nozzle should not touch the dental structure. Air, water and microparticles of aluminum oxide - none of which is physically capable of causing microfractures.<sup>4</sup>

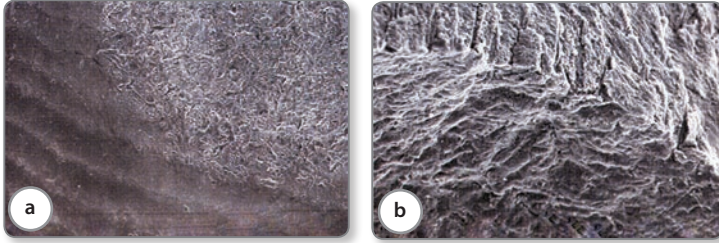
\*Nearly 90% of patients will report little or no discomfort when 27 micron aluminum oxide is utilized with air pressures in the 40-120 psi range (Figures 5a and b).<sup>4</sup>

### ***Air abrasion treatment can increase bond strength***

There are a number of factors which have been shown to reduce bond strengths to both enamel and dentin such as smear layer and surface contaminants.<sup>5</sup>

No smear layer is created on an air abraded, interfering with bonding. No contaminants such as handpiece lubricant, which are not utilized in air abrasion units. The abraded structure has an even micro-roughened surface, and the excess aluminum oxide is easily removed with an air-water spray. Etching enamel is required for maximum bond strength. Etching air abraded dentin will loosen the compacted collagen fibers.





**Figure 6** (a) Photomicrograph of air abraded dentin, Note flattend appearance of collagen fibers; (b) Raised collagen fibers and tubule openings after acid etching with phorphoric acid. (Courtesy: American Dental Technologies)

Acid etching dentin will open the odontoblastic tubules thus increasing the sensitivity of the surface somewhat until a bonding agent has polymerized in the hybrid zone (**Figure 6**).

Major indications for the use of air abrasion in microdentistry:

- Pit and fissure caries
- Interproximal lesions
- Hypocalcification preparations
- Gingival third abrasions/erosions/abfractions
- Pit and fissure sealant preparation
- Aid in repairing existing restoratives for maximum retention
- Application of regenerative powders to dentin (SYLC)
- Generalized stain removal

### Contraindications

- Large crater like lesions with large amounts of soft dentinal caries
- Removal of any metallic restorations
- Subgingival lesions
- Avoiding gingival third lesions wherever there is immature epithelial attachment (erupting teeth, periodontally broken down attachment)
- Lesions proximal to granulomatous gingiva (without proper precautions)

### Appropriate precautionary measures (**Figure 7**)

- Rubber dam - with a tight seal approximating the tooth structure
- Liquid rubber dam extending from the tooth structure covering adjacent soft tissue
- Metal matrices with wedges to protect both the adjacent hard tissue and gingival complex
- Instruments - separating the soft and hard dental tissues - hand-held while needed
- Polycarbonate materials such as class V hand-held matrices
- Cotton rolls placed to protect oral soft tissues

## Pit and fissure caries treatment

Natural failures in complete fusion of tooth buds during embryonic development (in both the primary and secondary dentition) result in the formation of deep pits and fissures of enamel. This often creates voids in the integrity and continuity of the enamel. Bacteria and food can collect in these areas during and after function creating acid demineralization of the enamel. These pits and fissures are most often narrower than a single toothbrush bristle, making brushing an inadequate management strategy for the patient.

It is now known that many different bacterial species can inhabit the pit and fissures. Many of which convert fermentable carbohydrate to lactic acid. Dental hard tissues are demineralized by the lactic acid and other bacterial secretions. Enamel decay can progress at the base of these areas and eventually progress toward underlying dentin and the pulp. Some research indicates that more than 85% of all new caries locations are within the pit and fissure defects.<sup>6</sup> Due to fluoride and other factors, there has been a reduction in the occurrence of smooth surface caries for most populations in the past few decades.

It becomes obvious that more emphasis needs to be brought to the treatment of pit and fissure lesions. Preventive and infiltrative resins have helped to some degree in this effort. However, there is generally a lack of knowledge with regard to the appropriate preparation and application for sealants. This has caused a reduction in the expected longevity of pit and fissure sealants.<sup>7</sup>

When surgical intervention is required due to the dentinal involvement of the lesion, it behooves a conscientious practitioner to utilize the least damaging treatment system.



**Figure 7** Methods of soft tissue protection from air abrasion use. (a) rubber dam; (b) light cured rubber dam; (c) Metal matrix and wedge.

Air abrasion systems offer such a minimally invasive technique.

Whether shrouded within water or used 'dry' aluminum oxide can easily open pits and fissures for caries exposure and removal. To avoid over-preparation, it is good technique to use caries visualization stains on the entire pit and fissure system prior to initiating treatment. The visualization of the stain removal will aid the operator in the removal of the minimum amount of sound structure as well as differentiating areas which should not be treated, require sealants, or dentin penetrating treatment (**Figures 8a to d**).

Air pressures generally between 40 psi and 160 psi are quite efficient at opening up areas of partially demineralized enamel. The abrasion will tend to remove partially calcified structure faster than surrounding intact enamel. Once the dentin is exposed, a lesser pressure will adequately and painlessly remove hardened carious dentin. Aluminum oxide average particle size 50 micron is somewhat more aggressive than 27 micron

powder. However, 27 micron powder is more comfortably tolerated by vital dentin. Dentin is best abraded by utilizing air pressures in the 40–100 psi range. This will help reduce unnecessary removal of sound structure especially as the pulpal floors and axial walls of the preparation extend nearer the pulp.

The addition of a water shroud surrounding the air/powder stream has a major effect on reducing sensitivity during treatment, increasing the width of the abrasion and markedly reducing powder escape (extraoral mess). In most systems, the water source will be at room temperature (68–72°F) warming the water in the source container will allow more pressure to be utilized with the same or less sensitivity. Additionally, the final rinse of the cavity once etched should be warmed near body temperature to further reduce patient sensitivity.

The addition of helium or nitrogen gas to the air supply can increase the efficiency of the abrasive action due to the lighter than air



**Figures 8a to d** Occlusal caries air abraded, completed with bonded flowable and standard filled composite resin; note that each lesion/sealant lesion was treated individually with no connections contrary to the GV Black system. (Courtesy: John J. Graeber)

property of the helium and nitrogen. This is available on some commercially available units. Systems operating only with operatory air supply are enhanced by the addition of helium. Some teeth (especially exposed to optimal fluoride or with thick enamel) will be abraded more quickly if a lighter than air gas is utilized to supplement the compressed room air.

### 3 Step technique: Expose decay, remove decay, bond restoration

1. *Carefully re-examine the tooth to be restored:* Images, visual and tactile inspection of the surface(s), drying the tooth and staining the pit/fissure system if appropriate. Determine with proper instruments (i.e. DIAGNOdent,

explorer, etc.), which areas are likely to have penetrated the dentino-enamel junction (**Figure 9**)

2. *Consider the over flow of abrasive particles:* adjacent teeth, mucosa, soft tissue and gingiva. Apply tissue protection: metal matrix bands or strips with wedges, cheek protection disks (Dry-Angles R), rubber dam, paint-on resins, and cotton rolls, etc. (**Figure 10**)
3. Place high-velocity vacuum in the abrasive stream exhaust path

Position any extraoral vacuum devices in front of the patient (**Figure 11**)

4. Most preparations can be air abraded without the need for local anesthetic. Patients who are unusually sensitive and teeth with hyperemic symptoms, or respond negatively to syringe air flow, should be offered local anesthetic or analgesia



**Figure 9** Fissures can penetrate through the enamel layer into the dentin. A single toothbrush bristle or any other commonly available home care device is too large to remove biofilm within the fissure.

(Courtesy: John J. Graeber DMD)



**Figure 10** Paper triangular disks (Dry-Angles) are convenient protectors of oral mucosa when rubber dam is not utilized for air abrasive techniques and the expended stream may contact cheeks or tongues.

(Courtesy: John J. Graeber DMD)



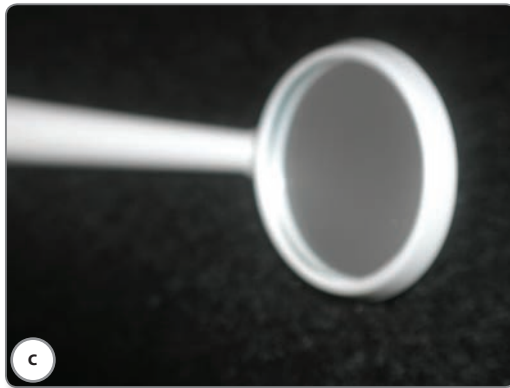
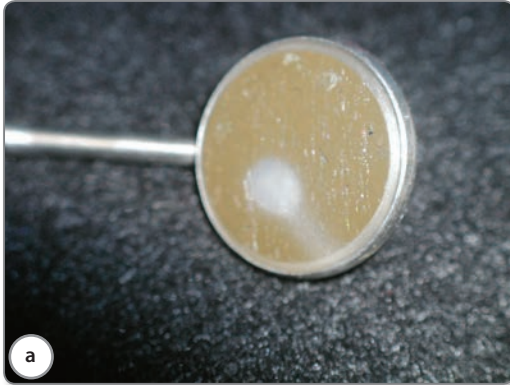
**Figure 11** The operator should position the high speed evacuation in the expected exhausted stream path.

(Courtesy: John J. Graeber DMD)

5. Utilize plane-surface mirrors as front surface mirrors will be abraded within seconds of exposure to the air abrasive (disposable mirrors work best). A stream of water directed to the mirror surface can aid in continuous visualization. There are durable plane-surface reusable mirrors available – see instrument/supply list. Magnification with loupes or an operating microscope should be utilized when abrading preparations (**Figure 12**)
6. Since tactile feedback is not possible with an air abrasive nozzle, the operator must position himself/herself for full visibility

of the operative site. The nozzle tip-to-surface angle needs to lean away from the absolute perpendicular ( $\approx 15^\circ$ ) – to facilitate the ‘exhaust’ stream of particles. If fully perpendicular, the exhaust stream can block the primary stream. Failure to allow spent particles to ‘escape’ decreases efficiency of the primary stream significantly

7. Abrade the entire pit and fissure system of the surface to be treated. However, stop abrading as soon as any stain present ‘disappears’ and move to the next area. The pulpal floor of each area will not necessarily finish at the same depth. This is a major departure from the GV Black system, wherein the pulpal floor is generally left at a consistent depth. This was necessary to create a uniform thickness of metallic restorative material. Bonded composite material does not require this consistent depth as do metallic restorations such as silver amalgam. Additionally, separate carious lesions on the same surface (usually occlusal) should not be joined as the Black system required for bulk restorative strength and retention
8. Prior to etching, the cavity preparation is restained to determine complete caries removal from infected dentin and enamel
9. *Soft caries*: cannot be efficiently removed with air abrasion. Hand instrumentation will be required. If the practitioner wishes to refrain from rotary instrumentation, the preparation



**Figure 12** Normal front surface mirrors will frost when exposed to the abrasive stream (a). Alternates are frost proof mirrors (CrystalMark) (b) or plane surface disposable mirrors (c).

is retained and small remnants of decay can be removed with air abrasive (with or without water). The use of polymer round excavating burs (SS White) can also be utilized at low revolutions to avoid heat production and resultant sensitivity

10. Consider the use of glass powder (SYLC) to aid in remineralization of the dentin especially for deep and/or active caries.
11. Plan the restorative material placement. Etch enamel and dentin simultaneously. Etching of dentin is indicated to raise flattened collagen fibers due to the action of the air abrasive systems
  - a. Fill areas which do not extend into dentin with a pit and fissure sealant or suitable flowable composite (this can aid in subsequent recall examinations in being able to visually distinguish caries versus preventive only treatment)
  - b. Utilize a self-leveling flowable composite or resin reinforced glass ionomer according to manufacturer directions to

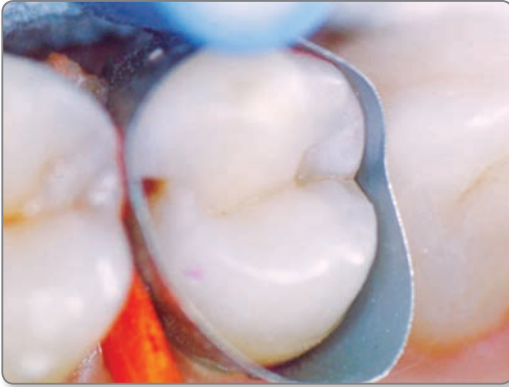
cover the dentin completely, preparation irregularities and any narrow fissures which are not amenable to restoring with thicker, putty-consistency composite resin

- c. Complete the restoration with appropriate strength composite resin which has greater strength and wear resistance than flowable materials
- d. Finish and polish as usual. The narrower diameter restorations will require far less time in finishing/polishing/occlusal adjustment steps

## Interproximal lesions

Due to the proximity of adjacent hard and soft tissue, protection of these structures is essential to appropriate care regardless of minimal or maximal treatment.

A matrix needs to be placed prior to abrading. Metal materials will resist perforation better than plastic films; however, continuous air abrasion of a small area will perforate even a stainless



**Figure 13** Photo of incipient Class II interproximal caries/ preparation with metal matrix (generic pediatric width) spool (Kerr) and wedge in mid-preparation stage. (Courtesy: John J. Graeber DMD)



**Figure 14** Lower central incisors displaying hypocalcification, cause unknown.

steel matrix. Gingival collars are especially prone to hemorrhage unless protected during abrasive treatment (**Figure 13**).

Contact restoration is also a critical factor in interproximal restoration. However, the smaller the interproximal opening of the preparation, the easier it is to maintain adequate contact.

Unlike preparation for amalgam under the Black system, it is generally unnecessary to carry interproximal preparations through the fissure pattern of the entire occlusal surface unless caries or existing restorations (which need replacement) have extended there.

It is only necessary to engage enough enamel within the preparation to provide adequate retention form through bonding. Care should be exercised in not extending further than necessary buccally and/or lingually to expose the margins for the purposes of detection of post-treatment marginal integrity.

It is often difficult to access decay for removal in many interproximal lesion preparations. The overlying enamel still needs removal to allow straight line access to the caries. Both lasers and air abrasive techniques offer only a straight line access – this departs from rotary instrumentation which can be applied at angles to the surface being removed. Fusayama has shown that it is not necessary to remove all unsupported enamel when bonding using the

all etch technique. A more important factor is the avoidance of placing margins at the point of heavy occlusal contacts.<sup>8</sup>

The choice of restoratives is also more critical particularly in the posterior where occlusal forces are the greatest. Thus, consideration of resistance bulk and material strength is essential for long-term success. The amount of etchable enamel should be maximized in cavity design as well. Beveling the cavo-surface margins can increase the surface area of bondable enamel.

## Smooth surface lesions

The majority of smooth surface lesions that occur close to or at the gingival third of teeth and are caused by inadequate biofilm control, diet, and/or acid erosion. Additional contributing factors include the use of orthodontic brackets. Lesions such as these may range from simple hypocalcifications to frank cavitations. The decision to intervene surgically must be weighed against remineralization or resin infiltration efforts (**Figure 14**).

Once the decision is made to surgically treat, the same principles apply: consider tissue protection first, and then use the air abrasive to remove all hypocalcifications to minimum depth in enamel and/or dentin. Pre-applying caries detecting agents greatly enhance the visualization

of infected dentin and will result in maximizing the resulting distance to the pulpal chamber.

## Root surface lesions

As the population ages and more teeth are being retained well into senior and elderly years and beyond, the need for root surface caries treatment will continue to increase. Conservative preparations are critical in maintaining root strength and pulpal protection. Any removal of unnecessary structure will compromise tooth retention. Unlike coronal caries with thick enamel margins, these root lesions have little to no areas of enamel to bond to. This fact will necessitate choosing materials which rely less on etch/resin bonding and more on ionic bonding and fluoride retention and release. A good example is the class of restoratives called 'glass ionomer cements'. While high bond strength is achieved by these cements, they lack the same compressive strength as traditional composite resins and therefore should be restricted to non-occluding areas in adults.

Root surface lesions are nearly always located near the gingival collar or are completely or partially subgingival. Gingival tissue adjacent to carious lesions is usually edematous, and will bleed easily if disturbed. It becomes virtually mandatory in these cases to perform gingivectomy/coagulation of the inflamed tissue prior to the caries preparation. The Ideal instrument to perform this function is the diode laser (810–1064 nm wavelength). The laser not only removes the overlying tissue but will



**Figure 15** Partially subgingival lesion. Diode laser (810 nm) used to perform gingivectomy to expose apical extent of caries.

coagulate deeply enough to reduce or eliminate intraoperative bleeding, the main cause of initial restoration failure and recurrent decay (**Figure 15**).

## Resurfacing composite resin restorations

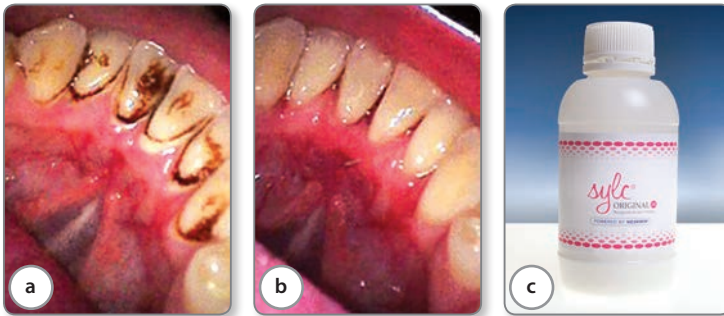
Composite resin restorations often appear stained on their surfaces while the dentinal and enamel bond appear unstained. This can easily be checked with the use of caries detecting dyes (red or green) or fracture detecting dyes (blue). If there appears to be no gross bond compromises, then the operator should consider just abrading away the stained outer layer and resurface with new resin of matching shade. Abrading the composite will aid in retention and the use of a porcelain etch and coupling agent will increase the bond strength of the new to old composite.<sup>9</sup>

## Repairing restorations

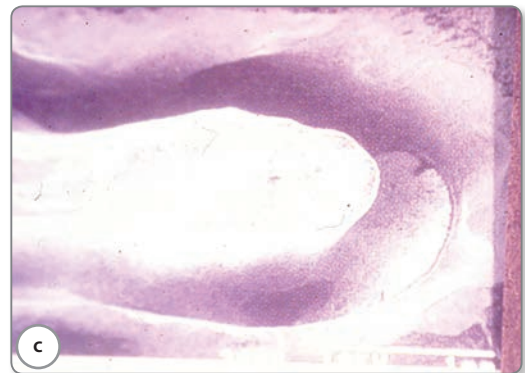
It has been traditionally taught that defective restorations need to be removed in their entirety. While this may be true for failing, non dentin-bonded amalgam restorations, it is much less true of other materials. With the advent of dentin-bonded composites, it is usually not necessary to remove restorations which are failing only in part. Adding an interproximal section to an existing occlusal surface should not normally entail full removal of the existing composite. A dove-tail can be abraded into the existing composite and the majority of the existing restoration is not disturbed. This likely be in the best interest of the patient. The innate ability of air abrasion to enhance the bondability and adaptability of new to older material is well understood and should be weighed by the operator.

## Additional uses of air abrasion

- *Remineralization:* Air propulsion of spheres of coated glass has shown to be effective in causing remineralization of affected dentin (SYLC). Another use of this material is in the preparation of enamel for bonding - it leaves the surface pristine of biofilm and extrinsic stain thus enhancing the effectiveness of acid etch on the enamel with much less abrasivity than aluminum oxide (**Figure 16**).



**Figures 16a to c** Photos pre- and post-exposure to SYLC abrasive polishing/remineralization powder. (Courtesy: John J. Graeber DMD)



**Figure 17** Amalgam can be removed in most cases by “trenching into sections which can be removed by pressing from the margin toward the trench with a sharp hand instrument. Most pulpal floors are less sensitive due to sclerotic dentin and/or base materials. (Courtesy of John J. Graeber DMD). Figure c is a photomicrograph of surrounding enamel and dentin being removed unnecessarily by the air abrasive in the attempt to remove the more resistant amalgam. (Courtesy: American Dental Technologies)

- **Stain removal:** SYCL powder is an effective extrinsic stain remover and leaves the enamel far smoother and less plaque retentive than traditional abrasive powders such as sodium bicarbonate or aluminum oxide (Figure 17)
- **Indirect restorations:** All dental indirect material whether they be gold, non-precious alloy, porcelain or zirconia show enhanced bond strengths if air abraded prior to cementation/bonding. Extreme care must be

taken not to abrade areas of the restoration which are glazed or the thin margins. It is highly recommended to use magnification and adequate lighting when abrading restorations

- **Contraindications:** Young patients being treated generally will object to the use of abrasives intraorally. Children often exhibit texture issues with food. They tend to be less tolerant of powdery substances than adults.



While aluminum oxide is inert, it is also tasteless. With some children, it is helpful to gain acceptance by suggesting that the abrasive is like no-taste toothpaste

When no local anesthesia is utilized, the use of rubber dam clamps on non-fully erupted teeth may be contraindicated. This may make the use of air abrasives less than optimum. The alternatives, especially hard tissue lasers may be more appropriate in these circumstances. Use of a mouth prop device may also be helpful.

## Operator objections to the use of air abrasion

### 1. *Slower removal of tooth structure*

Air abrasion removes far less structure than high speed rotary instruments per unit of time. This can create a less favorable attitude among practitioners. The speed of removal is similar to low speed rotary and most erbium and CO<sub>2</sub> (9300 nm) hard tissue lasers.

While air abrasion is less efficient than conventional instruments, the ability to begin treatment without waiting for the onset of local anesthetics, often makes up for lower cutting efficiency

### 2. *Air abrasion cannot remove soft decay*

Once soft decay is encountered, it can be

efficiently removed with various sized spoon excavators. A less desirable (due to vibrations and potential sensitivity) is the use of plastic decay removal burs. With either methodology, the use of caries detection dyes or systems greatly facilitate the efficient and thorough removal of carious dentin

### 3. *The objectional mess*

The small size of the aluminum oxide particles (averaging 27–50 microns) and the speed of propulsion cause the particle to be suspended in the ambient air for a period of time. Room air currents can carry particles yards away from the source. Aluminum oxide does have a strong affinity for moisture, temporarily sticking to moist oral membranes and other surfaces such as countertops and electronic devices. The addition of the water shroud as well as high speed vacuum use can greatly reduce the spread of discharged particles into the operator air

## Addendum: Current Air abrasive device

- Aquacare
- Velopex international
- Velopex.com
- Prepstart,
- Danville manufacturing
- Zestdent.com

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*Manaf Agha*

Since the development of laser devices in the 1960s, dentists and scientists have tried to find a laser which would replace the dental handpiece in the treatment of caries. Innovators such as Goldman, Sognaes and Stern tried to use the two wavelengths available in the early 1960s to remove tooth structure, but these attempts ended in failure because the structure charred significantly and little of it could be removed efficiently.

Laser physical properties and tissue interaction were poorly understood at the time, but since then, both the CO<sub>2</sub> (10,600 nm, far infrared) and ruby (red, visible, 690 nm) lasers had shown effective removal of soft tissue both intra- and extraorally. There were few studies available at the time to explain the various absorptive properties of living tissue.

Over the next few decades, more research concerning the interaction of various (old and newer) wavelengths led to the development in the late 1990s of the mid-infrared laser, named after its chief element, erbium. This particular wavelength is 2,940 nm. At nearly the same time a proprietary second wavelength of 2,780 nm was developed utilizing a doped erbium, chromium, yttrium, scandium, gallium, garnet crystal (Er,Cr:YSGG). Both erbium lasers are solid state doped crystals and the unique invisible light produced has a very short pulse time and very high peak powers, often exceeding 2,000 watts. The very short duration of these bursts of infrared energy have an ablative effect on dental hard tissues. The main chromophore in teeth (a substance which absorbs a particular wavelength of light) is water, both interstitial and intracellular. The secondary chromophore is the hydroxyl-ion (OH<sup>-</sup>).<sup>1</sup>

Hard dental tissues include enamel, uninfected dentin, carious dentin and pulpal soft tissue. Photons of the mid-infrared wavelength range are highly absorbed by water molecules,

and as water within the hard dental tissues absorbs photons, it increases in temperature and expands. The expansion of this 'trapped water' causes the hydroxyapatite molecule to expand and then disintegrate. This is known as the photoacoustic effect.

Tissues with a higher water content (dentin and carious dentin) ablate more efficiently than enamel, which has a water content of approximately 3–5%. Bone has similar water content to dentin (40%) and ablates at a similar rate. Soft tissues (gingiva, connective tissue, diseased tissue and pulpal tissue) contain nearly 90% water and ablates even more efficiently. However, this chapter concentrates on the effects of the erbium family of lasers as they relate to cavity preparation (see **Figure 1**).

## Laser physics terminology

**Photoablation:** It is the use of light energy to remove or cut tissue. The mechanism of action is a rapid thermally induced expansion of intra- and extracellular water. This rapid expansion causes the water to boil, resulting in the vaporization of the water and cellular components. The photonic energy must be focused on a small spot (a square millimeter) and is highly absorbed by the superficial layers of the tissue (see **Figure 2**).

**Photoacoustic:** It is the use of supersonic shock waves to remove of tissue. The shock waves cause the tissue volume to increase, and the resulting pressure changes cause micro-explosions within the structure of the tooth.

**Thermal effect:** This wavelength range (2000–3000 nm) is only superficially absorbed by teeth, so heat dissipates into the surrounding air. A water stream dissipates the heat generated during ablation and flushes the field of laser debris so the laser energy is absorbed by the next available layer of hard tissue.

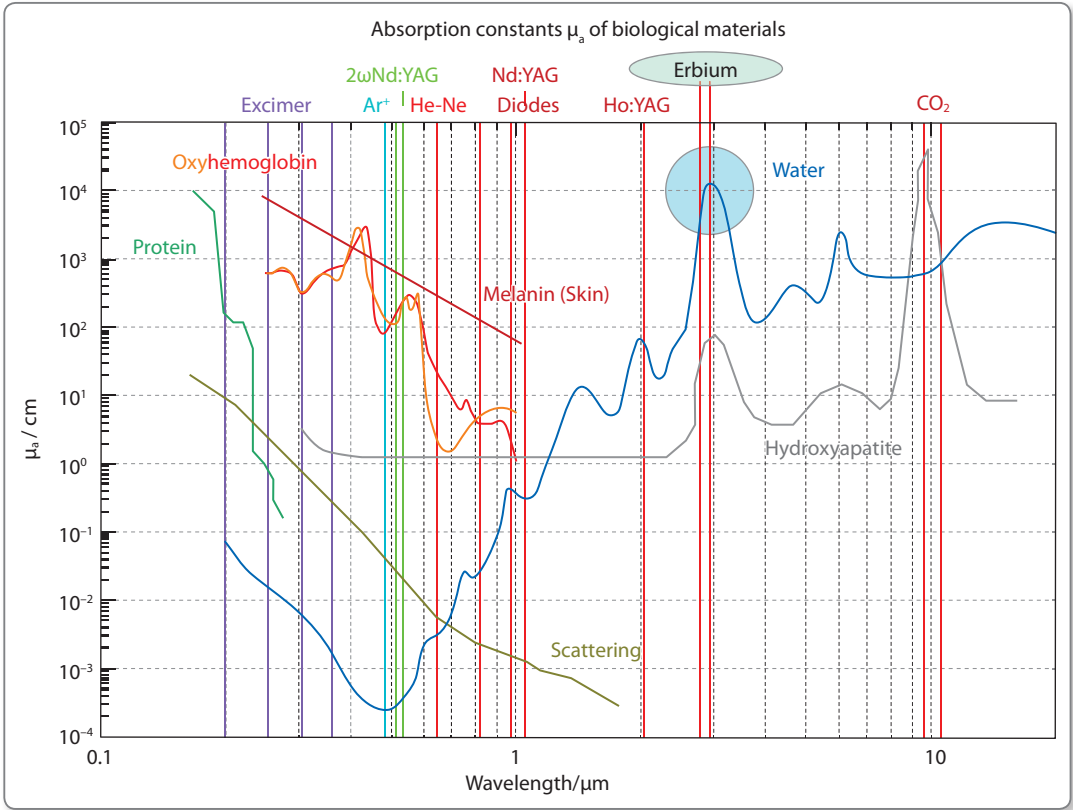


Figure 1 Absorption constants of the biological tissue compounds.

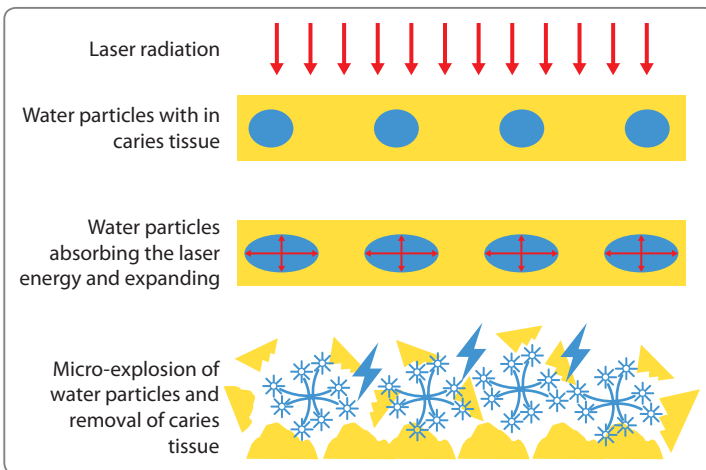


Figure 2 Ablation.

## Laser parameters

**Energy density:** The amount of energy per unit of irradiated area. This is measured in joules per square centimeter ( $J/cm^2$ ). For most laser devices the diameter of the tip of the laser handpiece defines the diameter of the treatment beam. Also of consideration is the actual focal point ahead of the handpiece tip. For example, the typical focal point of the laser beam is 0.5–1.0 mm beyond the tip end. The focal point of a tip-less handpiece is much longer and is set by the individual device manufacturer. The most important consideration for the clinician is to avoid using more energy than necessary to accomplish the treatment objective. Excessive heat causes unintentional injury to tissue but does not increase the ablation or vaporization rate.

**Pulse duration or time:** It is the length of time that a laser emits energy during a single pulse. The time between each pulse permits a period of thermal relaxation and allows for dissipation of the absorbed heat internally into the surrounding tissue. Erbium lasers are usually pulse in micro-seconds.

Pulse duration is measured in units of hertz (Hz). A pulse per second (PPS) is also used synonymously.<sup>2</sup>

## Average power and peak power

Peak power refers to the maximum energy discharged during each single pulse.

## Frequency or pulse repetition rate

This term refers to the pulse's individual rate. It is usually expressed in watts (W). The average power of a laser is the pulse energy multiplied by the pulse repetition rate. A higher average power usually leads to a greater effect on the tissue being ablated, while the peak power is a measure of the energy of each pulse.

## Advantages of erbium cavity preparation

- *Selectivity:* caries has a high water content, which leads to a faster ablation of infected tissue while aiding in less removal of healthy

tissue with less water content within the same parameters

- *Laser ablation does not create a smear layer:* one of the factors that negatively affects the bonding is the presence of a smear layer, whether on enamel or on dentin<sup>3,4</sup>
- Bacterial decontamination of the irradiated area, because the laser has the ability to virtually eliminate the bacteria extending nearly 1 mm into the dentinal tubules<sup>5,6</sup>
- No friction is created, therefore, there is no possibility of micro-cracks in remaining structure
- There is minimal need for anesthesia because little heat is produced. Tips of the delivery system should not touch the tooth structure during laser emission. The pulse time is much shorter than the nerve impulse time, so the patient rarely senses pain

## Disadvantages

- Initial cost of device: about 30–85K (US)
- Special training needed on each device
- All laser devices have specific techniques particular to them
- Cost of disposable supplies (Sapphire/zirconium handpiece tips)
- Cost of maintenance (beam alignment, trunk fiber replacement, etc.)

## Indications

- Carious fissures, pits, and smooth surface caries removal (class I, II, III, IV, V)
- Superficial enamel conditioning or 'laser etching'
- Removal of composite restorative materials (not metal)
- Porcelain crown and veneer removal with resin luting cement (Rechman, et al.)
- Fissure sealant preparation

## Limitations and contraindications

- Metal, dental alloys cannot be removed
- Cannot be used for crown or inlay/onlay preparations, due to the microscopic irregular surfaces created
- Slower operation compared to high speed handpiece
- Cannot ablate porcelain or zirconia
- Will not ablate traditional dental cements

## Handpieces and tips

There are two basic designs of erbium laser handpieces are supplied by erbium laser manufacturers; handpieces which are designed to be used with insertable tips and those which emit a treatment beam without the use of tips.

### Handpiece with tips

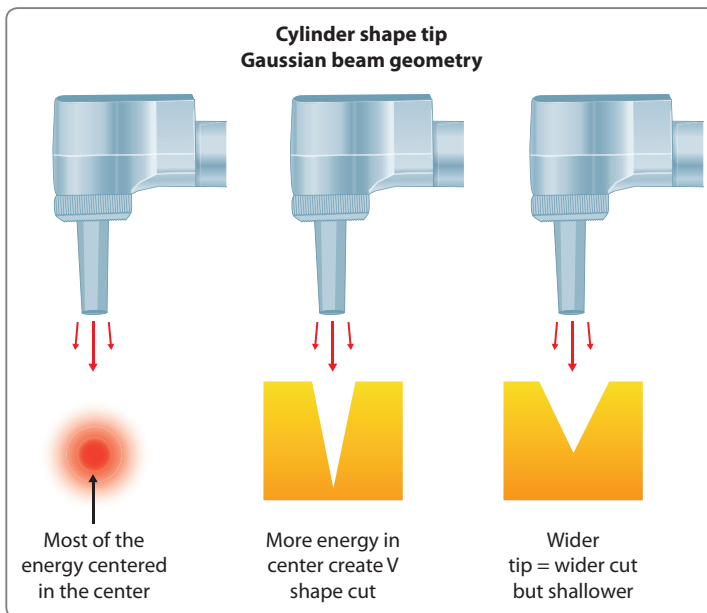
The tips are either disposable or autoclavable reusable; the reusable tips mostly are made from sapphire or zirconium. Disposable tips are made from glass, which are less expensive. The tip shape plays a role in the final shape of the cut of the tooth structure. Cylinder shaped tips create a Gaussian beam geometry wherein most of the energy is in the center of the spot with a decreasing energy level toward the periphery of the beam diameter. This leads to a V-shape cut. The larger diameter tips produce wider margins and shallower cuts with the same energy setting (Figure 3). A chisel shape tip leads to a convex from the sides. The laser beam energy decreases when increasing the distance of the surface of the preparation from the tip. The typical focal distance from tip to ablating surface is within 0.5–1.5 mm (see Figures 4 to 7).

### Handpiece without tips

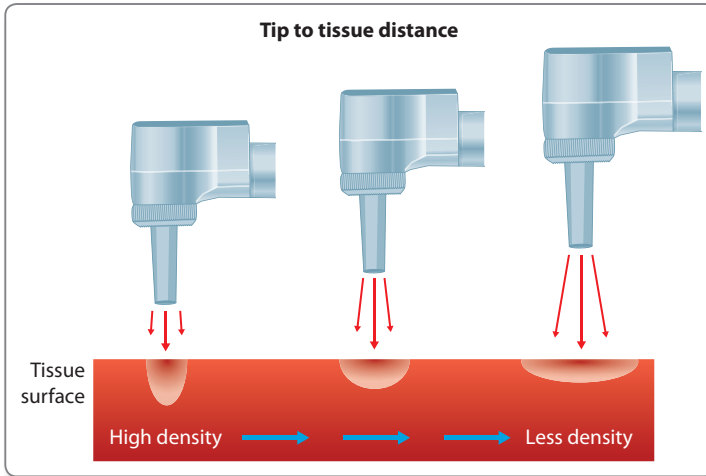
Many companies offer the tip-less handpiece design. The head of this type contains a lens that condenses the beam to a very small focal point spot to increase the energy density and help in faster ablation and a narrower cut. Figure 7 illustrates the need for adjustment of the distance from the handpiece to the radiated area. The purpose of the lens to produce the smallest and the maximum density for the beam. The focal distance is approximately 3–4 mm from the edge of the handpiece. Allowing the handpiece to come closer to the ablating surface will defocus the beam and reduce the ablation rate (Figure 8).

## Bonding to laser prepared dental surfaces and microscopic findings for the lased enamel and dentin

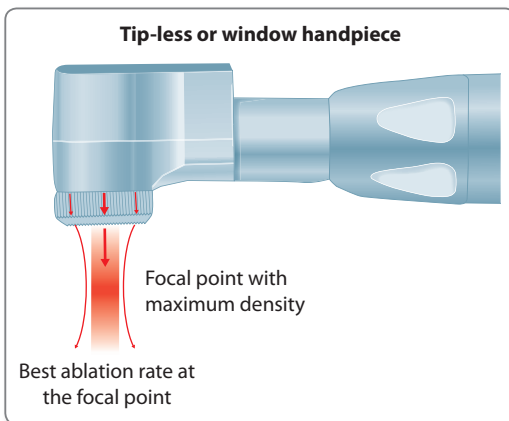
The bonding technique is essential to successful composite restorations. The composite is chemically bonded to the tooth structure, and unlike silver amalgam which depends solely on



**Figure 3** Left image represents the higher energy of the typical Gaussian beam in the center of the beam cross section. Center figure shows a typical cut with a narrow diameter tip and the right figure depicts a cut from a larger diameter tip.



**Figure 4** As the tip distance to target increases the width of ablation widens but becomes more shallow.



**Figure 5** Focal distance where is the maximum density of laser beam.



**Figure 6** Different diameter of disposable tips.



**Figure 7** Different handpieces with tips.



**Figure 8** Different tip less handpieces.

mechanical retention. Bonding strengths depend mainly on the relation between the bonding agent and the tooth surface, i.e. enamel and dentin. Well-prepared enamel or dentin promotes higher bonding strength. In general, bonding of the composite or resins to the tooth structure is a result of one or a combination of the following mechanisms:

- *Mechanical*: Penetration of the resin and the formation of the resin tags within the dentinal matrix absorption. The chemical bonding to both organic and non-organic components – hydroxyapatite and/or collagen
- *Diffusion*: Condensation of the substances on the tooth surfaces to which the resin monomers can bond mechanically or chemically

In order to have good bonding results the surface should be clean and free of debris, and the adhesive should be spread evenly on the tooth structure and have a firm and intimate adaptation to the adjacent 'tooth structure'. Complete polymerization of the bonding agent is required to finalize the bond. A sufficient thickness of bonding agent is needed to cover all the rough surfaces of the enamel and dentin, but a very thin layer of bonding agent will not be totally cured because the surface remains non-polymerized due to oxygen inhibition.

## Bonding to enamel

In 1955, Buonocore introduced the acid etching technique. He suggested applying an acid to an irregular roughened enamel surface and creating a micro-porous layer which is between 5–50 microns in depth.<sup>7</sup> When the bonding agent is applied after etching, it penetrates into the roughened surface with the capillary action, monomers then undergo polymerization and the material becomes interlocked within the enamel surface. The formation of these tags is the fundamental mechanism of resin/enamel adhesion 'bonding'.

The newest generations of self-etching bonding agents do not approach the bond strength of conventional acid etching enamel. However, the self-etching technique improves dentinal bonding strength. Later studies show that etching achieves a better bonding to enamel.<sup>8</sup> Laser treatment without acid etching alone is insufficient to establish the desired bond strength with enamel.

## Bonding to dentin

Bonding to dentin is much more complex, because the bonding strength is always less than enamel due to the different organic/inorganic matrix of dentin. Approximately 45% of dentin consists of the mineral hydroxyapatite, 33% of organic material, and 22% of water, and has dentinal tubules arranged in a three-dimensional maze which comprises 30% of the total dentin volume. Dentinal tubules extend from the dentinoenamel junction (in the crown) to the pulp chamber. Each tubule is between 1–3 microns in diameter, and is continuously filled with fluids. Cutting dentin with burs creates a smear layer which covers the dentin surface and plugs up the dentinal tubules with debris. This makes bonding to dentin more complicated than enamel bonding and, therefore, requires a different approach. Many materials have been suggested to bond with dentin since Buonocore introduced his technique. Older generations of materials suggested bonding to the smear layer without removing it. The next few to be introduced were found not to achieve the desired bond strength. Later generations (4th, 5th) showed better results with higher bond strength values between 13–18 MPa. The 6th generation is a self-etch adhesive system with a self-etching primer and a separate adhesive resin material, which make the application simpler than the previous generations of materials. The primer acidity treats the minerals in the smear layer and both the bonding resin and primer will infuse the altered smear layer and reaching the intertubular dentin to form the hybrid layer (layer resulted from the combination of resin, collagen fibrils, and the residual of the smear layer) and the resin tags in the dentinal tubules. The latest 7th generation, or all-in-one material became an easy application by combining all the three components; dentin conditioners, primer, and adhesive resin in one bottle, unfortunately the results of the 7th generation have shown less bonding strength than the 6th generation.<sup>9,10,11</sup>

It should be noted that when ablating the tooth structures with an erbium laser the microscopic findings appear to be different than after bur caries removal. All studies showed much different microscopic findings on enamel and dentin when ablated with erbium lasers. The absence of smear layer and chemical changes due to the

## Achieving better results on laser enamel and dentin suggestions

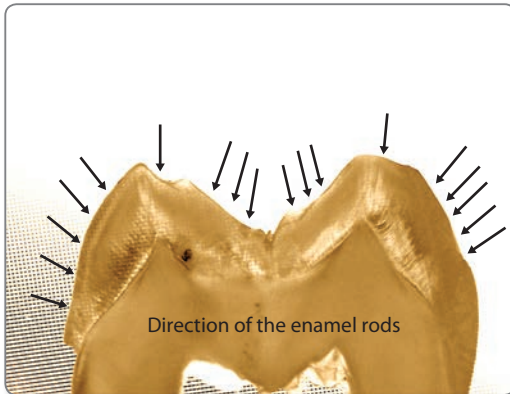
- Etching is always required on enamel<sup>20</sup>
- Selective etching is recommended; etch the enamel alone with 35–37% phosphoric acid for 15–20 seconds, followed by rinsing with water. Then air dry and chalky appearance of enamel
- Using the self-etch 6th generation ‘two step’ bonding by applying the primer on enamel and dentin and rub vigorously for 15 seconds, then air thin until it stops flowing, followed by application of the adhesive ‘bonding’ layer which is left to penetrate the hybrid layer and the dentinal tubules, then light cure. Some suggest the use of the 7th generation one step directly after the enamel selective etching, the material should be rubbed on enamel and dentin the left for 10 seconds for penetration into hybrid layer and dentin then air thinned and light cured. In both suggestions always follow the manufacturer instructions for the time of exposure to the curing light source
- Apply composite filling material in increments to guarantee maximum polymerization for each layer (oblique layering is recommended to minimize shrinkage forces on the dentinal walls), unless using flowable bulk materials and then covering it with composite several millimeters thick
- Adjustments and good finishing and polishing are needed to produce the best possible restoration

thermal effect of laser depends mainly on the pulse duration and cooling.<sup>12,13</sup> The resulting compounds after laser exposure is more acid resistant and less acid soluble,<sup>14–17</sup> and as a result of the thermal effect of the laser the collagen can potentially denature it which could alter the dentin permeability.<sup>18,19</sup> Moritz has suggested that the dentinal tubules be further exposed by a final step of adjusting the angle of the tip to the dentinal surface to 45°. This step should enhance dentinal tubule permeability and penetration.

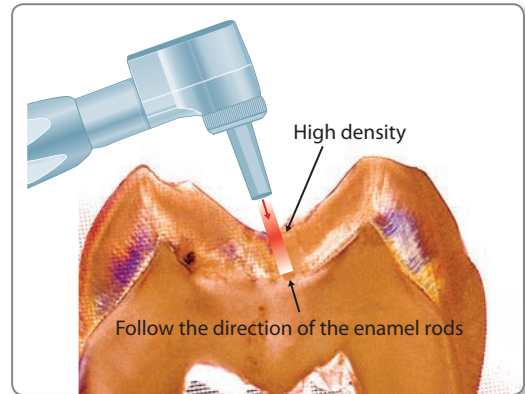
## Clinical techniques and pitfalls to avoid

- The direction and distance of the tip is essential in achieving an efficient ablation. The focal distance should be maintained to achieve maximum energy density. In the fissure area, the beam should not be perpendicular to the fissure but should be tilted in an oblique direction to ablate the adjacent enamel to the fissure more efficiently (**Figures 9a and b**). The fissure will widen as the adjacent enamel is ablated
  - In class II cavities, the starting in the enamel requires a higher power setting due to the thickness of the marginal ridge enamel. When reaching the dentin and carious tissues, less power is needed. Adjustments to the parameters are necessary because the prep floor deepens nearer the pulp
  - The power should be lowered to prevent the destructive thermal effects on pulp and to maintain patient comfort. If starting the preparation on enamel with 5 W and pulse frequency of 15 Hz. Then preparation in dentin and will be lowered to the 2.0–2.5 W range and 15–20 Hz
  - The air/water coolant stream must be focused on the ablation spot. Care must be taken not to bring the high speed evacuation to close to this coolant stream, much unlike the evacuation of conventional rotary high speed
- Use the manufacturer’s laser parameters to avoid any undesirable changes in tooth structures ‘enamel, dentin, and pulp’
  - As the erbium laser target the water content in the caries and result in faster ablation of the decay, use caries detector dyes to help facilitate the selective removal of carious tissue especially in deep and undercut areas
  - The caries detection dyes should be utilized on carious suspected areas prior to irradiation by a laser because laser ‘exposed’ collagen will yield a false positive and could lead to unnecessary removal of uninfected dentin





**Figure 9a** Direction of the enamel rods.



**Figure 9b** Direction of the laser beam on the occlusal surface. The tip surface should be parallel to the surface as well as the enamel rods.

equipment. It is suggested to use a more passive evacuation system such as a saliva ejector next to the tooth being prepared

- Some studies suggest the application of laser energy in defocused mode and low intensity on the tooth surface before starting caries removal, with the assumption that this causes an analgesic effect enhancing patient comfort and acceptance. Margolis suggested the use of 1.5 W and 20 Hz in a defocused mode for 30 seconds radiating the labial surface of the anterior teeth or the occlusal surface of the posterior teeth. Olivi, in his book, suggests the use of 20–50 MJ for 40–60 seconds and 10–15 Hz radiating the neck of the tooth then gradually increasing the energy to 75–80 MJ prior to radiating the carious dentin<sup>21</sup>
- According to Olivi et al. (2011) dentin laser conditioning or analgesia is accomplished with a reduced energy of 40–50 MJ with 600 micron tip diameter. This conditioning is applied directly after finishing the caries removal to enhance the cleaning and aid in smear layer removal. He proposed reducing both the thermal effect on collagen fibers and reducing the underlying dentinal thermal damage<sup>22</sup>
- It is recommended to use the manual excavator to remove the dentin flakes or 'loose dentin particles' that exist in the whitish layer in the cavity. These loose or weakened etched collagen fibers and hydroxyapatite structure are removed to enhance the bonding to stronger structures<sup>23</sup>

- Some studies suggest the application of 5% NaOCl on the laser prepared dentin to improve bonding and partially remove the denatured collagen layer caused by the thermal effect of the erbium laser. The suggested technique is to rub the dentin with a cotton pellet or soft applicator with NaOCl<sup>24,25</sup>
- Both mechanical and chemical preparation of dentin surface is essential to achieve the desired bonding result
- Existing amalgam alloy must be removed first with rotary handpieces before laser caries removal. This can be accomplished without the need for anesthesia if the operator can section the alloy without touching the sensitive dentin adjacent to the restoration. It is very important to determine if the dentin if it is either a tattoo or a residual carious tissue. Leaving stained dentin or enamel may cause esthetic failure of the composite restoration

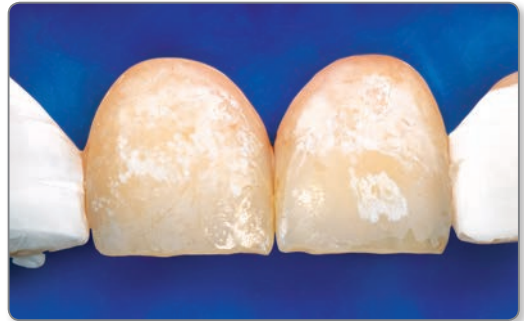
## Clinical cases (see below)

**Addendum:** list Erbium devices available in the world market and manufacturer contacts

- Biolase, Erbium, Chromium:YSGG, Biolase.com
- Oral Health, Er:YAG, oralhealthgroup.com
- Fotona, Er:YAG, Lightwalker, Fotona.com
- Doctor Smile, Er:YAG, doctor-smile.com
- Litetouch, Er:YAG, light-inst.com

**Case 1 Demineralization lesion**

**Figure 10** Demineralization on centrals.



**Figure 11** Enamel laser conditioning.



**Figure 12** Enamel acid etching.



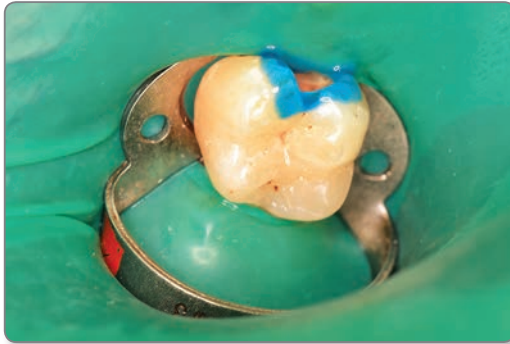
**Figure 13** Composite material in place.

**Case 2 Class II Molar caries**

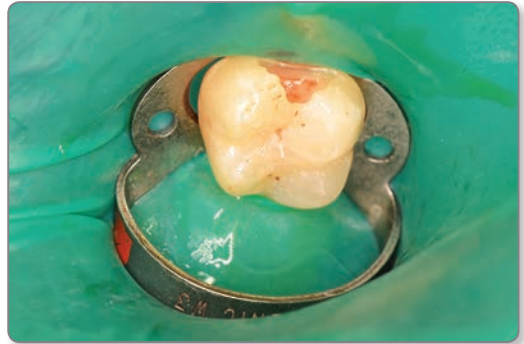
**Figure 14** Class II caries present on mesial surface of maxillary molar.



**Figure 15** Laser preparation and conditioning.



**Figure 16** Selective etching.



**Figure 17** Curing the bonding agent.



**Figure 18** Composite restoration.

### Case 3 Class III caries



Figure 19 Class III lesion mesial to right central incisor.



Figure 20 Caries removal and laser conditioning.

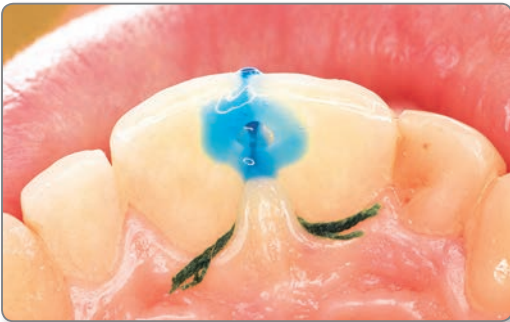


Figure 21 Selective etching.



Figure 22 Bonding agent curing.



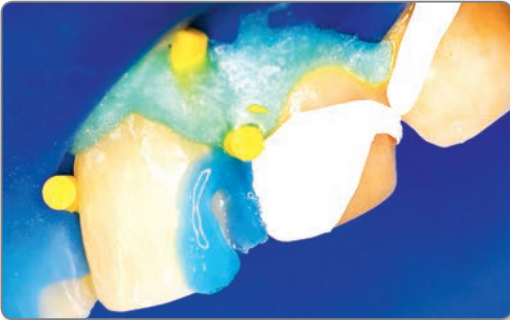
Figure 23 Composite restoration.

**Case 4 Class IV maxillary incisor**

**Figure 24** Broken filling with leakage.



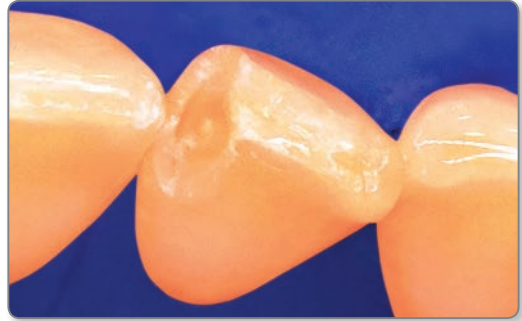
**Figure 25** Laser composite and caries removal.



**Figure 26** Selective etching.

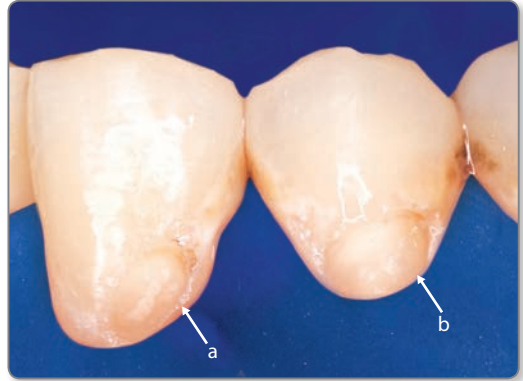


**Figure 27** Composite restoration in place.

**Case 5 Class IV lower incisor****Figure 28** Class IV lesion.**Figure 29** Laser conditioning.**Figure 30** Selective etching.**Figure 31** Bonding agent after curing.**Figure 32** Composite restoration.

**Case 6 Class V lesion**

**Figure 33** Class V lesion.



**Figure 34** (a) Laser conditioning, (b) applying bonding agent.



**Figure 35** The composite restoration.

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Lawrence Kotlow

## Introduction

Society sensationalizes going to the dentist as a painful agonizing experience and a basic part of life where the thought of having teeth repaired invokes fear and avoidance, occasionally, leading to catastrophic results. Most people can survive with having some degree of stress and anxiety about visiting a dentist, however, for those with dental phobia the thought of a dental visit is terrifying. Dental anxiety, or dental fear, is estimated to affect approximately 36% of the population, with a further 12% suffering from extreme dental fear.<sup>1</sup>

The introduction of the local anesthetic, Novocain, by the German chemist Alfred Einhorn in 1904 change dentistry dramatically by reduced the discomfort when repairing hard and soft tissue of the oral cavity, but still required the use of needles, numbing and post-treatment discomfort. The fear of numbing, needles, vibrations of the dental handpiece and the smell of tissue removal all became fear factors giving both children and adults reasons to avoid routing dental care.<sup>2</sup>

## Development of the 9300 nm CO<sub>2</sub> laser

In December of 2013, Convergent Dental introduced a completely new laser, the carbon dioxide (CO<sub>2</sub>) laser operating at a new wavelength of 9300 nm (Solea) (Figure 1).<sup>3</sup> This isotopic C<sub>12</sub>O<sub>18</sub> laser was developed with the promise of making the restoration of decayed teeth almost completely anesthetic free and allow for minimally invasive conservative restorative dentistry techniques with minimal peripheral thermal or mechanical damage to surrounding tissues and without damage to pulpal tissue.<sup>4,5</sup> When caring for the dental needs of children

as well as adults, this would make going to the dentist less stressful, by removing the most common fear factors thus taking the anxiety out of going to the dentist.

Experienced users of both erbium (Er) and the CO<sub>2</sub> lasers and most importantly, patients confirm the effect of this new laser wavelength is to be able to quickly and comfortably perform caries removal, cavity preparation, and a wide range of intraoral soft tissue procedures without the need to numb the treatment areas, along with no age restrictions on patient use. Clinicians with years of chairside experience in the use of Er and other dental lasers now regard the 9.3 μm CO<sub>2</sub> laser as a truly revolutionary development.



Figure 1 Artist rendering of Solea 9300 nm laser.

This laser (Solea), manufactured by Convergent Dental Needham, mass can be viewed as the culmination of more than 27 years of scientific research devoted to this specific wavelength. The 9.3  $\mu\text{m}$  laser brings speed and efficiency to enamel and dentin cutting not experienced heretofore using  $\text{CO}_2$ , a medium that many considered to be the gold standard of soft tissue surgical lasers.

The difference is the new carbon dioxide laser wavelength, 9.3  $\mu\text{m}$  versus the traditional 10.6  $\mu\text{m}$  that  $\text{CO}_2$  is known for is that it is an all tissue laser, not just a soft tissue laser. This super pulsed  $\text{CO}_2$  laser allows for dental hard tissue modifications and ablation.<sup>6</sup>

I initially used Er:YAG lasers in my practice, from the year 2000 until the initial concept and development of the isotopic  $\text{CO}_2$  laser. I was fortunate to be asked to become involved in its development, became an investor and is presently on the company's dental advisory board. Due to convergent's ongoing goal of creating the perfect laser for dentistry, I remain an active beta tester of the unit as it continues to grow and become available to the dental profession. The laser is continuously being improved by periodic Wi-Fi software updates.

## Unique characteristics of the 9300 nm laser

### Laser delivery system

The laser energy is delivered to the target by means of an articulated arm containing optics of 12 mirrors and 4 lenses.

### Analgesia

As indicated earlier, the computer-generated beam size allows for multiple beams to be placed with a designated spot diameter, thus the computer creates a beam sequence which allows for maximum thermal relaxation time between pulse bursts and laser creating an effective, predictable analgesic effect.

### *Using the isotopic $\text{CO}_2$ laser for caries removal and tooth preparation*

Once the pediatric dentist or family dentist make a decision to invest in a laser, the obvious choice should be an all tissue laser. The first choice of which laser to invest will be the isotopic  $\text{CO}_2$  laser

@9300 nm. Due to this wavelength being highly absorbed in both hydroxyapatite and water, it has the ability to vaporize, bone, tooth structure and soft tissue. Due to its high absorption in collagen, it excises or ablates soft tissue extremely well with little to no bleeding and often without the need for local anesthetics.

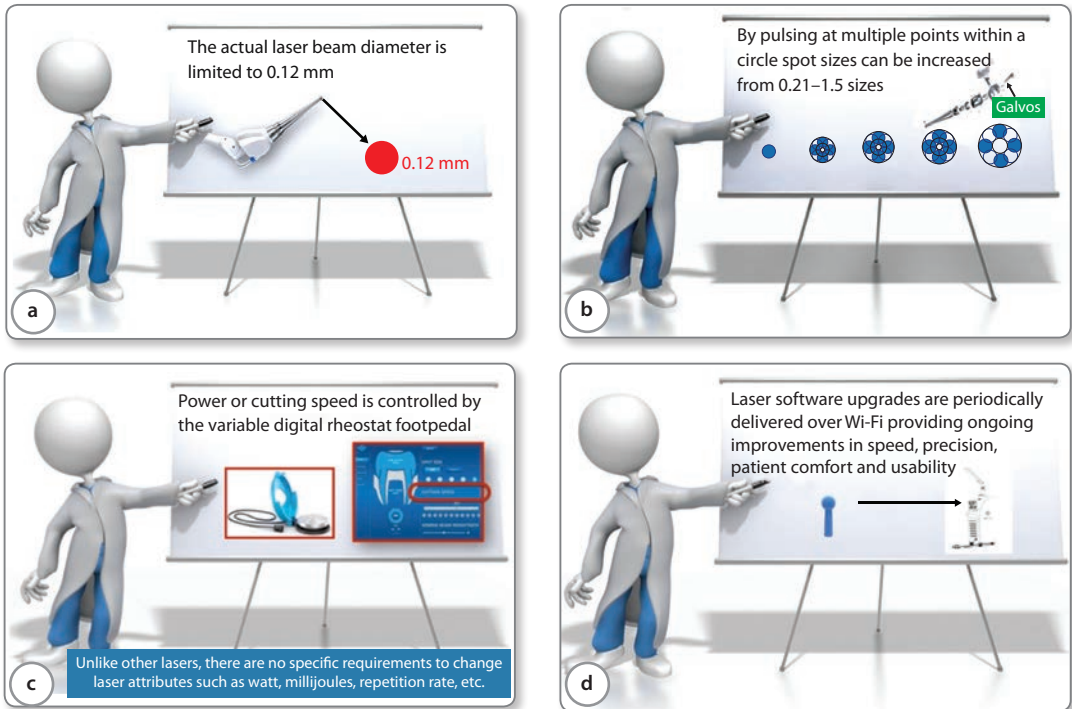
**NOTE:** Due to the continued improvements in all lasers efficiency and power, specific settings will not be discussed in the context of this book. See the manufacturers suggested settings as well as information available at each manufacturer's introductory courses.

The Solea laser is a very consistent and dependable laser for speed and tooth analgesia. This 9300 nm  $\text{CO}_2$  dental laser takes laser dentistry to a whole new level. It raises the bar over previous all-tissue lasers and delivers what it promises. Lasers continue to change dentistry in ways we never thought possible and make dentistry less stressful for both the dentist and patient. Since the introduction of this laser clinical results by over 400 units being used by dentist have provided consistent positive results.

Presently there are few published papers on the use of this new laser (Figure 2).

## Advantages of using the 9300 nm $\text{CO}_2$ laser

- Over 95% anesthesia free in primary teeth
- Over 90% anesthetic free in permanent teeth
- Tooth isolation can be achieved using either the isolite system of tooth isolation or a rubber dam using a supragingival # 3-winged clamp rubber dam
- When needed the dentist can restore all four dental quadrants during one appointment
- Eliminate postoperative lip and tongue biting
- Reduced time lost from school for children and teens
- Reduced time for parent and other adults for time out of work to receive dental care
- Children and adults to return to all normal activities immediately after restorative care since they are not numb
- Eliminates many of the fear factors which have people avoid getting needed dental care such as; numbing, smell, vibrations
- In permanent teeth I, III, V, restorations anesthesia free
- Permanent class II restorations majority can be anesthesia free



**Figure 2 The laser beam size and spot size.** (a) Multiple spot sizes are generated by using a computer-controlled focused spot positioning system through a series of galvanometers (small motors located at the base of the handpiece holder) to move the 0.12 mm beam in specific patterns and achieve a larger spot size without changing the amount of laser energy or joules per square centimeter ( $J/cm^2$ ) also known as fluence. (b) Laser energy or power is not controlled by focusing or defocusing the laser beam but by the digital rheostat foot pedal which controls laser energy and power by adjusting pulse duration. The use of this 'accelerator' foot pedal allows the dentist to have precise control over laser energy without the need to focus and defocus the laser beam. The tipless handpiece allows the laser beam to be changed by a simple tap on the laser screen to create spot sizes of 0.25, 0.50, 0.75, 1.0 and 1.25 mm without the need to change tips or handpiece. (c) All presently available lasers control power by altering and adjusting hertz, millijoules and in some cases pulse duration. In addition, these lasers are either on or off. The 9300 nm  $CO_2$  laser controls power by the use of a digital variable rheostat foot pedal, thus altering settings it eliminated. (d) Regular software improvements and upgrades.

- Reduction in the need for sedation, less anxiety and excellent patient cooperation
- Increased productivity

### Disadvantages: 9300 nm and erbium lasers

- Cost
- Slower than conventional handpieces slight odor

### Disadvantages, conventional handpiece

- Microfractures
- Pain due to friction and heat creates smear layer

## Types of preventive, interceptive and restorative dental preparations

### Using the 9300 nm $CO_2$ laser

#### Sealant preparation

Dental enamel consists of carbonated hydroxyapatite [ $Ca_{10}(PO_4)_6(OH)_2$ ] is maximally absorbed by the hydroxyapatite, however, the key word is carbonated, since this is the most soluble portion of the tooth surface. The 9300 nm  $CO_2$  laser removes the carbonate portion during lasing and etching procedure without any significant enamel ablation, the remaining enamel surface is carbonate free, making the remaining tooth

structure less soluble and with the addition of fluoride makes the remaining enamel surface even less soluble. In the future, it is quite likely the 9300 nm CO<sub>2</sub> laser may be used to prevent dental decay similar to sealants or in conjunction with sealants and fluoride applications. Carbon dioxide lasers are used at low-energy densities to fuse enamel, dentin and apatite. This laser treatment caused surface fusion and inhibition of carious lesion progression and improved the bonding strength of a composite resin to dentin (see Chapter 16 for more information).<sup>7</sup> Caries removal produced by the 9300 nm CO<sub>2</sub> laser produces a cavity surface morphology with marked resistance to artificial secondary caries as compared to conventional caries removal.<sup>8</sup> Since the wavelength of this laser is in the invisible range of the human eye, an additional aiming beam in the visible light spectrum of 532 nm (green) is incorporated into the system.

#### *Enamel etching for sealant placement*

The process of CO<sub>2</sub> laser etching the enamel surface is achieved by the using the lowest power setting causing the lased enamel to turn whitish during the lasing process and not without any significant sound enamel. Preventive resin restorations are also easily completed by combine minimally invasive caries removal and sealing non-carious grooves, pits and fissures. Using CO<sub>2</sub> laser in enamel grooves where small pits show small areas of decay allows for conservative tooth cavity preparation with sealing unaffected areas of the occlusal pits and fissures (Figure 3).

An excellent device which can enhance the diagnosis of decay is the SOPRO caries detector, which can be attached to your chairside computer for use in any digital radiographic capture program and photo capture program.

All bonding still requires the use of chemical etching with adhesives or a self-etching adhesive to achieve maximum retention, the laser removes any remaining smear laser on the area to be restored.

#### **Caries removal (Figure 4)**

The use of this specific laser (Solea) allows the dentist to prepare the teeth with small conservative caries removal techniques and, therefore, preventing the removal of healthy tooth structure by efficient use of computer-assisted laser beam and caries removal due to the galvos located at the base of the dental handpiece.



**Figure 3** (a) Pre-etch enamel surface. (b) Post-etch surface.



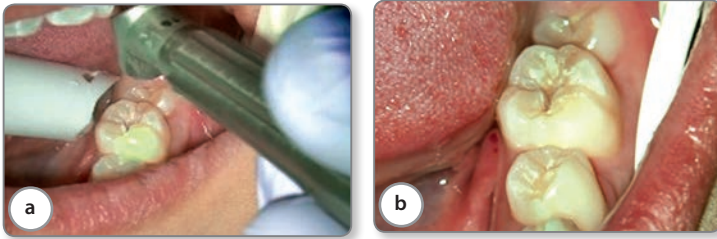
**Figure 4** Restorative contra-angle Solea handpiece.

## **Class I cavity preparations and preventive resin restorations**

Patients rarely require any local anesthetics for class I restorative procedures using the isotopic CO<sub>2</sub> lasers. During laser ablation, however, it is important to remember that the laser is end cutting only (Figure 5).

#### *Ablating not allowing water to pool around the tooth*

The CO<sub>2</sub> laser ablates dental hard tissue by means of a photothermal action with significantly high absorption and efficiency in removing hydroxyapatite. It is important to keep in mind that since this wavelength is absorbed in water



**Figure 5** (a) Class I caries, (b) Laser preparation of class I cavity preparation.

as well as hydroxyapatite when ablating a tooth, water should not be allowed to pool in around the area ablating or the laser may appear to not be working, since the water can absorb a portion of the laser energy.

### **The laser plume**

When using the 9300 nm CO<sub>2</sub> laser the laser plume contains vaporized hydroxyapatite, therefore, is extremely important to make sure the plume is removed using high velocity suctions to remove the plume as well as any toxic particles contained within the plume.

When placement of an alloy restoration is required, it may be advantageous to use the high-speed handpiece to smooth walls and floors of the cavity preparation.

The analgesia produced by this wavelength is more than adequate to allow this without any concerns of causing patient discomfort.

This laser induced analgesia is in part due to the computer-generated pattern spot size pattern of the ablating tooth structure by the galvos contained within the head of the articulated arm and their movement and location controlled by the onboard computer. Dental pulpal tissue is innervated by non-myelinated C fibers. The photobiomodulation (PBM) affect reduces the conduction of A and C fibers which transmit nociceptive pain or in other words, the nerves that are stimulated into transmitting the pain message to the brain. In addition, PBM stimulates the release of endogenous B-endorphins. The actual mechanism of pain relief is not well understood.<sup>9,10</sup>

### **Class II cavity preparations**

In the primary dentition, since the 9300 nm CO<sub>2</sub> laser is quite efficient when ablating enamel and almost completely anesthetic free, multiple quadrants are able to be completed in a short period of time. I recommend completing the

ablation process for each quadrant, and then go to the next quadrant and placing a small wooden wedge slowly and carefully interproximally before beginning the procedure, to prevent hitting the laser energy from hitting the gingival interproximal tissue, which could bleed and/or cause the patient discomfort.

Each patient, adult or pediatric, has his/her limitation for setting in the dental chair.

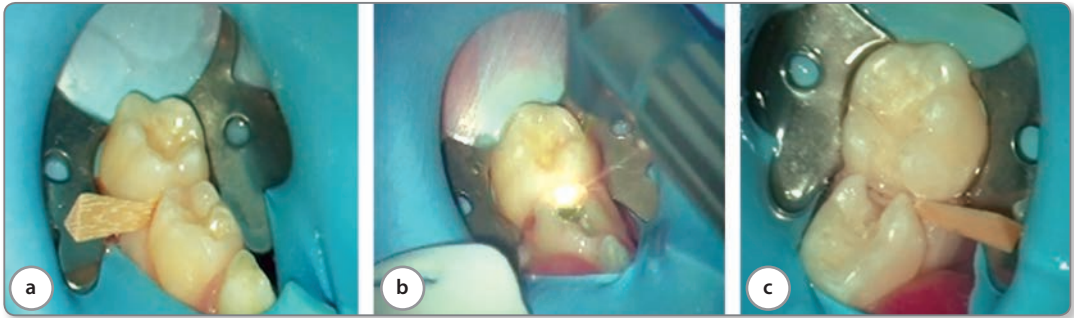
When treating the pediatric patient, lasers can be used safely with light oral conscious sedation and or nitrous oxide, allowing the completion of as many as four quadrants in one appointment.

During the removal of decayed tooth structure and cavity preparation, the hard tissue laser usually provides adequate analgesia to allow the dentist to complete most class II preparations as well as using a conventional dental drill without creating any pain or introducing any fear factors to our little patients. The time it takes to seat a patient, place a topical anesthetic, give the patient a numbing agent by means of the dreaded needle, complete the procedure and send the patient home, can take considerably less time once the dentist masters the technique of using the all tissue CO<sub>2</sub> laser.

Operative dentistry has changed, the patient experience has changed, and our practices have changed with the laser-centered practice. Our patients require less time missed from school, our patient's parents lose less time away from work and everyone's stress levels are reduced, especially after treatment since the patient, the parent as well as the dentist no longer have to worry about patient induced injuries from post-anesthetic lip or tongue biting (Figures 6a to c).

### **Class III, IV, V, VI cavity preparations**

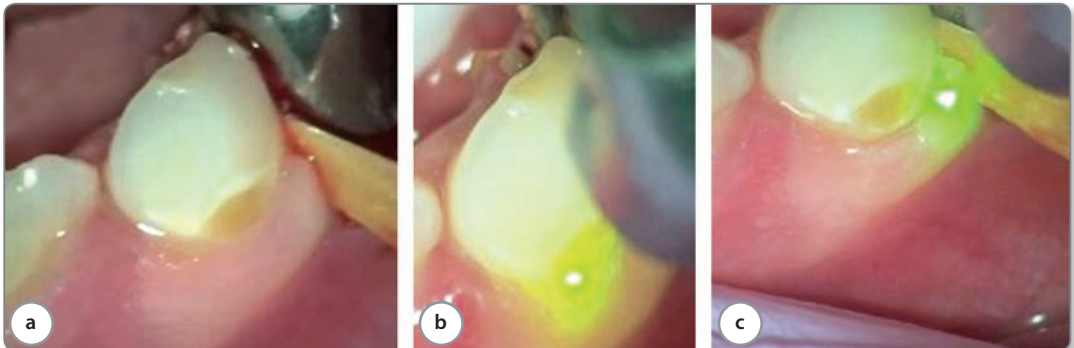
The majority of all permanent and primary teeth presenting with class III, IV, V, VI dental decay



**Figure 6** (a) Placement of rubber dam and wedge prior to preparation of class II cavity. (b) Laser initiating cavity preparation, (c) Completed preparation of class II.



**Figure 7** (a) Class III decay, (b) Laser preparation of class III lesion, (c) Completed class III restoration.



**Figure 8** Removal of gingival tissue covering access to buccal decay. (a) Class V caries with overgrowth of gingival margin, (b) Laser removal of overgrown gingival tissue, (c) Immediate postoperative of gingival ablation showing no hemorrhage.

require little or no local anesthetic and usually do not require any conventional dental drills for cavity preparation (Figures 7 and 8).

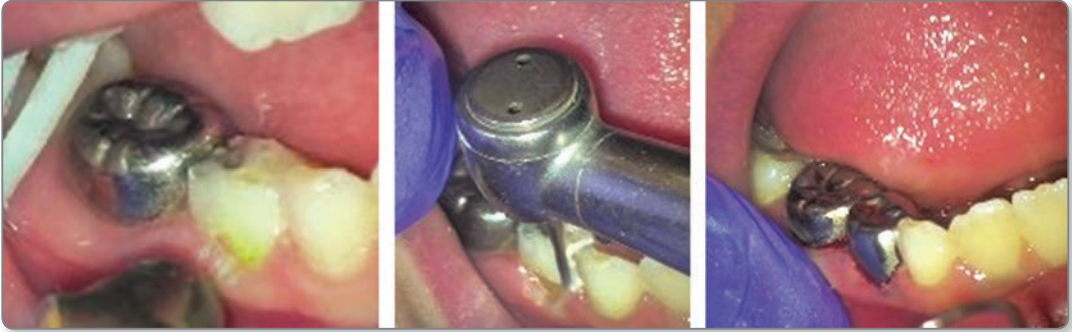
### ***Removal of soft tissue to expose dental caries***

During cavity removal, it is often necessary to remove tissue covering the occlusal surface of an erupting posterior permanent molar or a facial lesion-extending subgingival occurs. This laser is

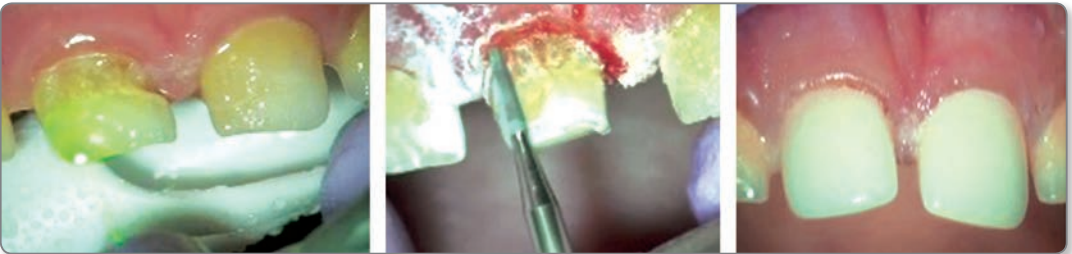
able to remove this tissue by using low settings to desiccate tissue and prevent bleeding.

### **Placement of primary tooth crowns**

Anterior and posterior pediatric crowns can be prepared using CO<sub>2</sub> @9300 nm in conjunction with a conventional high-speed handpiece without the need for any local anesthetics (Figures 9 and 10).



**Figure 9** Posterior stainless steel crown prepared using CO<sub>2</sub> @9300 nm for analgesia.



**Figure 10** Anterior crown preparation using CO<sub>2</sub> @9300 nm for analgesic effect.

### ***Removal of old alloys and repairing the tooth***

It is not recommended to directly laser the alloy but by going around the old filing it is possible to both achieve good analgesia and then use the conventional high-speed to cut into the alloy and then elevate it out followed by completing the restoration (**Figure 11**).

### ***All tissue CO<sub>2</sub> laser @9300 nm***

In addition to the benefits of using this wavelength and laser (Solea) for minimally invasive hard tissue procedures. It is also a very effective tool in the treatment of most soft tissue dental procedures such as; frenectomies, biopsies, gingival recontouring or gingivectomies, aphthous ulcers, herpes labialis, crown lengthening, operculectomies, and in the adult patient, periodontal treatments and implant recovery. All this can often be completed using topical anesthetics.

## **Conclusion**

Since the introduction of the Er laser in the late 1990s restoring permanent and primary teeth has become easier using lasers.

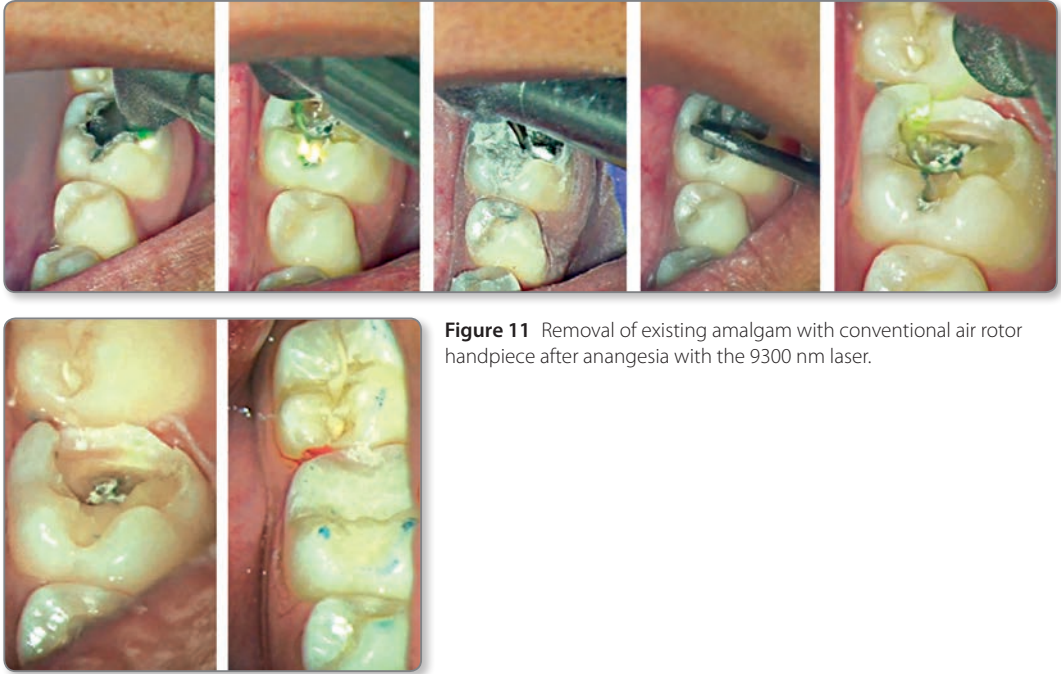
With the introduction of the isotopic CO<sub>2</sub> laser @9300 nm the success rate for achieving anesthetic free restorative procedures has reached over 95% success.

All classes of restorative dentistry, including crowns are now within the scope of the laser dentist's abilities as well as a significant number of soft tissue treatments.

## **Addendum: Convergent dental**

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- Needham, MA 02494
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- info@convergentdental.com
- Facebook: @ConvergentDental





**Figure 11** Removal of existing amalgam with conventional air rotor handpiece after anesthesia with the 9300 nm laser.

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John C Comisi

## Introduction

Dentin is often thought of by many as that structure just below the enamel, which is so extraordinarily difficult to get a reliable long-term bond to in our restorative processes. Dentin is the living part of the tooth which is capable of regeneration. The technical definition is 'the most voluminous structural component of human tooth. Dentin protects pulp tissue from microbial and other noxious stimuli. It also provides essential support to enamel and enables highly mineralized and thus fragile enamel to withstand occlusal and masticatory forces without fracturing. Furthermore, it is the first vital tissue to meet external irritation, and instead of being merely a passive mechanical barrier, dentin may in many ways participate in dentin-pulp complex defensive reactions.'<sup>1</sup>

It is all too easy to think of the tooth structure, as a whole, of being an inert crystalline structure, not unlike a mountain, hill or rock. However, it is a vibrant dynamic responsive structure with its own set of defensive mechanisms. Each part of the tooth is entwined in a never ending system of defense against the pH, bacterial and acidic challenges that are encountered in the oral cavity almost every moment of every day. One part, the odontoblasts, are dentin-secreting cells that survive throughout the entire life of a healthy tooth. They are critically involved in the transmission of sensory stimuli from the dentin-pulp complex. Odontoblasts are responsible for secondary and reactionary dentin secretion when needed, in the cellular defense against pathogens.<sup>2</sup> This defensive response is almost immediate, even before we might notice a white spot lesion on the coronal tooth or on an exposed root surface. This acid attack in dental caries creates a changes in the overall composition of the dentin by degrading the collagen fibers that

make up the bulk of the dentin structure resulting in a reduction in hardness.

According to Fusayama,<sup>3</sup> there are two types of carious dentin - infected and affected. Infected dentin, which is forever changed, is necrotic and can often be leathery in consistency. It is contaminated with the bacteria that can advance the carious lesion. It is denatured due to the loss of calcium and phosphate and structural integrity. Once dentin has become infected, it is irreversibly demineralized. Affected dentin is the part of the dentin structure that has responded successfully by the dentin-pulp system to the bacterial assault. This structure is often dark brown in color and is partially demineralized but the collagen fibers are not fully denatured and often contain minimal-to-no bacteria. Affected dentin has been mistaken as infected dentin as traditionally taught in prior years by clinicians eager to remove all discolored dentin before restoring the tooth, sometimes referred to as called complete caries removal cavity preparations. This process, unfortunately, can could create pulp exposure requiring endodontic procedures.

In recent years, we have discovered that this process of complete caries removal does more harm than good.

Studies have determined that 'incomplete caries removal', a relatively new technique, which is defined as removal of the infected dentin and maintaining a layer of the affected dentin when managing decay in tooth preparations, successfully maintains pulp vitality.<sup>4-6</sup> Interestingly, when you combine this incomplete removal of the caries-affected dentin with the odontoblasts' ability to protect the dental pulp structure, especially when in the presence of materials containing calcium and phosphate ions, this affected dentin then has the ability to remineralize via a secondary dentin

deposition. Furthermore, incomplete caries removal significantly reduces the occurrence of pulp necrosis when compared with stepwise excavation, which supports partial removal of caries as a single-visit technique to manage deep caries lesions in permanent teeth.<sup>7</sup>

Let's explore this remineralization process further. Odontoblasts, in the dentin-pulp complex, control the process of collagen synthesis. This involves a cascade of events, including the interaction of calcium ions with the acidic residues created in the demineralization process, which leads to the remineralization of collagen-based tissue.<sup>8</sup> This complex then combined with available phosphates to initiate a nucleation process. The collagen matrix provides a template upon which the mineral crystals deposit and ultimately help to remineralize and heal the damaged dentin.

However, how can we in dentistry assist this natural healing process? We have attempted to do so over the years with various materials such as calcium hydroxide [Ca(OH)<sub>2</sub>], glass ionomers, composites and calcium silicates. Calcium hydroxide has been the gold standard in this process. It stimulates the formation of reparative dentin by extracting growth factors from the dentin matrix.<sup>8</sup> Additionally, Ca(OH)<sub>2</sub> is bactericidal because of its high pH, which neutralizes the acid produced by bacteria. It is also an effective pulp capping agent. This effectiveness is based on the ability of CaOH to act with water from the tooth moisture to release calcium from the material into the tooth structure. This hydrophilicity is a critical factor in the natural mineral transfer process, but it plays havoc with the overall physical ability of Ca(OH)<sub>2</sub> materials to deal with compression forces. When hydrophobic resin is added to improve the physical properties of regular Ca(OH)<sub>2</sub>, the calcium release no longer takes place. Since these resins do not allow significant water absorption, by design, water sorption will damage the physical properties of these materials and lead to catastrophic failure of the restorative material. Other materials, like calcium silicates are also effective in releasing calcium from their matrices. However, the mechanism of calcium availability if from calcium leaching out as CaO<sup>+</sup> [a stable form of Ca(OH)<sub>2</sub>] which then reacts with water to form Ca<sup>+2</sup> and OH<sup>-</sup>. It becomes obvious

from this that water transfer becomes critical in the calcium availability to 'feed' the damaged dentin structure. This leads us to the subject of bioactivity and biomineralization.

## Bioactivity

The concept of bioactive materials was first introduced in 1969 and later defined as follows: A bioactive material that elicits a specific biological response at the interface of the material which results in the formation of a bond between tissues and the material.<sup>9</sup> This definition was and is a center focus for describing bioactivity in previous years. This eliciting of a biological response is the basis for many products such as glass ionomer and other ion releasing materials as they have been marketed and sold to the dental profession. However, it has recently been suggested that the term bioactivity should be redefined as 'a bioactive material is one that forms a surface layer of an apatite-like material in the presence of saliva or a saliva substitute.'<sup>10</sup> These materials, like the previously described Ca(OH)<sub>2</sub> and calcium silicates, deliver minerals that are beneficial to the tooth structure because of their ability to work with the moisture in the tooth and the mouth to stimulate mineralization and the formation of chemical bonds that seal the tooth and prevent microleakage.<sup>11</sup>

These materials are active, playing a dynamic role in the overall responsiveness of the tooth and the dentin-pulp system in its protective process and perform favorably in the oral environment. Bioactive materials have the potential to reduce sensitivity,<sup>12</sup> marginal leakage and marginal caries,<sup>13</sup> and since they favorably work with the moisture present in the mouth and tooth, can be significantly less technique sensitive.<sup>14</sup>

The first bioglass compound, calcium sodium phosphosilicate (CSPS), was developed for use in the development of bone regeneration materials.<sup>15</sup> A composition of this bioactive glass, which is an amorphous, melt-derived glass compound containing calcium, sodium, phosphate and silica, is being used for dental applications such as the reduction of dentin hypersensitivity.

Prior to the introduction of bioglass materials, all materials used in medical applications within

the human body were inert, so as to not to cause unwanted interactions. However, because bioglass materials create a direct chemical bond to bone tissue,<sup>16</sup> the use of inert materials has waned. Bioglass materials bridge a gap when a section of bone is missing and firmly secure the sections together. This discovery allowed medical researchers to focus on developing materials that could positively interact with the body and allow healing to occur.

The mechanism of action of CSPS materials consists of a series of reactions at the surface of the material, which both changes the composition and structure of the the surface of the CSPS material and release ions into the surrounding structures.<sup>17</sup> For example, the interaction at the interface between the CSPS and bone structure causes that CSPS particles to become negatively charged which facilitates the absorption of proteins, calcium and phosphates that form hydroxycarbonate apatite (HCA). The HCA acts as a bonding interface between the bone and the implant containing the CSPS, enabling biomineralization to occur. Additionally, CSPS has antibacterial and transient anti-inflammatory properties.<sup>18-20</sup>

Bioglass materials were first used in the treatment of dentin hypersensitivity. Abrasion and erosion (the two main causes), remove the cementum and also the smear layer from of the tooth root surface. This causes an exposure of the dentinal tubules to the oral cavity environment. Tactile, thermal or fluid flow over this exposed area can then cause an excitation of the odontoblasts sending a 'pain response' to the dental pulp. The number and diameter of open tubules on these exposed root surfaces determines the type and intensity of the hypersensitivity.

Commonly used chemical agents, such as potassium nitrate or potassium chloride, penetrate into the dentinal tubules and depolarize the nerve synapse. This reduces the sensitivity by preventing conduction of pain impulses.<sup>21</sup> This unfortunately can often take a long period of time for the patient to perceive a benefit. Other chemical agents used include potassium oxalate, ferric oxalate, and strontium chloride which physically occlude the dentin tubules, reducing the fluid flow and reducing sensitivity. Although effective, the symptoms often reoccur

due to physical abrasion of the root surfaces, acid challenges in the mouth and degradation of the materials themselves over time.

The bioactive glass particles in 45S5 (bioactive glass), in contrast, bind to the exposed dentin tubules, and also physically fill the open tubules. Then when exposed to an aqueous environment (water or saliva), this bioglass immediately releases sodium ions and lowers the pH of the local environment. This acidity feeds back to create a more rapid release of sodium ions, and a precipitation of the other ions present (calcium and phosphate), to form an amorphous calcium phosphate (ACP) layer within minutes of its application. The calcium phosphate layer creates an HCA layer. Even in the absence of external calcium and phosphates, a calcium HCA layer forms.<sup>22</sup>

In the dental field, glass ionomer cements (GIC) are useful because of their ability to form an ionic bond to tooth structure, and for their fluoride releasing and recharging properties. The calcium fluoroaluminosilicate glass and polyacrylic acid mixture fuses to the tooth as a result of the transfer of the ions contained in the glass. Water plays an important role in this process, since without it, GICs cannot fully mature and transfer ions to the tooth surface. The caries preventive effect of the fluoride released from GIC materials is mainly attributed to demineralization/remineralization at the tooth-oral fluids interface. As long as there is a small sustained increase of fluoride in the oral cavity there can be an effective in shifting the balance from a demineralization to a remineralization process. Numerous other indirect reports of artificial caries remineralization have been found in the literature. However, if this therapeutic level is not maintained, low levels of fluoride have been shown to be ineffective in preventing or slowing down the growth and metabolism of bacteria, and do not result in a significant reduced dissolution of tooth mineral as a result of fluoride incorporation.<sup>23</sup>

Studies have looked at strontium-based GIC to determine if they could completely remineralize demineralized dentin by nucleation of new apatite crystallites within an apatite-free dentin matrix and found that no apatite deposition could be identified in completely demineralized dentin that were immersed in three types of remineralization media, even with TEM/EDX

evidence of diffusion ions specific to the GIC material tested.<sup>24</sup>

Another important study illustrated that GICs cannot close a 50 micron gap in their investigations nor form apatite.<sup>11</sup> However, this study did show that calcium aluminate and calcium silicate did close the artificial gap created in his study and formed apatite. The 50 micron control gap used in this study showed that calcium-based bioactive dental cements could seal or reseal artificially created gaps in simulated aqueous physiological conditions. This is clinically significant and demonstrates that there is an ability of these types of calcium containing bioactive materials significantly improved the marginal stability of the tooth-restorative material interface and could significantly improve the long-term survival and serviceability of dental restorations.

## Biom mineralization

Biom mineralization is the process by which living organisms selectively extract inorganic materials from their environment and incorporate them into functional structures under strict biologic control.<sup>25</sup> The formation of biological apatite is a biologically controlled process, and requires nucleation sites to be present. Nucleation is the first step in crystalline formation, and requires calcium and phosphates to be present to create a complex from which there can be a continuous growth of crystalline structures.

If this is accurate, then does crystalline formation equate to biom mineralization? This has been called into question by some authors. Camilleri has stated that just because material forms crystal, doesn't mean it is doing what you think. She continues to suggest that we must question what is the material contributing and what is happening to the material.<sup>26</sup> Her work has lead to the thought process that "your material is changing and change is to be expected, but may not be as predictable as you would expect". This is quite an important statement. Laboratory results may not always translate to the clinical applications. Creating experimental models that are closer to what we find in nature, if possible, would enable a more true resultant that can yield a more effective clinical result which is certainly a needed direction. However, that model is

more difficult to create than we might imagine currently.

So, if we look at the previously described testing that showed no mineralization in the 50 micron gap with glass ionomers, we must ask, is the crystalline formation of calcium silicates and calcium aluminates ability to fill a 50 micron gap between a test material truly dentin biom mineralization? To answer that we must first look at the work done in a paper studying the interaction between bioactive glass and collagen, where it was noted that there are 40 nm gaps between the ends of tropocollagen subunits (approximately equal to the gap region) probably serve as nucleation sites for the deposition of the HA mineral components.<sup>27</sup> To further expand on this, we need to review a subsequent study which states that if any calcium phosphate crystals are larger than 40 nm they may not 'fit' into demineralized collagen...the most recent research suggests that amorphous (non-crystalline) calcium phosphate enters collagen fibril in a biomimetically stabilized 'fluidic' state.<sup>28</sup> Based on this information, then larger gap closer and particle creation may not qualify as true biom mineralization as defined and is more likely closer to the type of occurrence described by Camilleri, crystal formation. But it is biom mineralization?

It has recently been illustrated that there is a hierarchical nano-apatite assembly mechanism associated with collagen mineralization. A complex combination of phosphorous-based templating analogs of extracellular proteins in conjunction with polycarboxylic-acid stabilized ACP create nano precursors (nucleation). This process creates a highly ordered intrafibrillar apatite crystallite assembly within collagen fibril and that this assembly recapitulates the gap and overlap arrangements of collagen molecules.<sup>29</sup> This is a cell precisely controlled process and the exact mechanism of action remains elusive. However, it is the ACP stabilized by polyacrylic acid (PAA) that is most important in the development of collagenous mineralized tissue.<sup>30</sup> This has been shown to be a step-by-step process that enables the ACP to form a biomimetic, and biologically incorporated biom mineralization process.

Further research determined that it is possible to prefabricate intermediate precursors of

calcium phosphate acid stabilized ACP solution loaded with amine functionalized mesoporous silica nanoparticles, to create nucleation sites, and enable intrafibrillar remineralization. This proof of concept study represented an important advance in the translation of biomineralization concepts into regimes for in-situ remineralization of bone and teeth that can lead to clinical use.<sup>31</sup>

Further work has shown that the use of biomimetic analogs of dentin, phosphoproteins PAA and/or sodium trimetaphosphate (TMP), in combination with resin-based materials that can release ionized calcium and phosphate ions in a neutral to alkaline water rich environment, and can induce intrafibrillar collagen remineralization.<sup>32</sup> This research has illustrated that if demineralized dentin is covered with a flowable resin composite containing an ACP, and is immersed in biomimetic polyanions they can slowly diffuse through any water-filled porosities within adhesives and hybrid layers (i.e. residual water in un-infiltrated dentin), so that it would be possible to 'back-fill' such defects with apatite crystals and fossilize all dentin proteases as the matrix collagen remineralize. This approach decreases enzymatic breakdown at the interface between the material and the tooth structure, reduces nano-leakage, and showed phosphate uptake and deposition of needle-like crystallites at the intrafibrillar level.

Finally, a new model for collagen intrafibrillar mineralization that supplements existing collagen mineralization mechanisms has been proposed.<sup>33</sup> This model challenged a paradigm that electrostatic attraction is responsible for polyelectrolyte-directed intrafibrillar collagen mineralization. This work showed that calcium phosphate precursors infiltrate the intrafibrillar compartments of collagen in demineralized dentin to compensate for the contraction of collagen structures. Infiltration of calcium phosphate particles into the contracted collagen fibrils by molecular dynamics simulations and the establishment of something called a Gibbs-Donnan equilibrium between the intrafibrillar and extrafibrillar water compartments of collagen gives ACP the ability to infiltrate into fibrillar collagen and enables a remineralization process to occur.

The net result of the Gibbs-Donnan effect is that more water moves into the extrafibrillar compartment than would be predicted on the

basis of oncotic pressure of poly(allylamine) hydrochloride (PAH) molecules alone. This work provides insights to the driving forces for infiltration of polyelectrolyte-stabilized prenucleation clusters into the water compartments of collagen to initiate intrafibrillar mineralization. A simple way to look at this is thinking about fog as it moves into the San Francisco Bay. As the warm air rises, it leaves a void that is filled by the cold ocean air that creates the vapor associated with fog creation.

The research work that as described here, and the work continuing today helps provide one more rung on the ladder to creating materials that can be translated into products that have the ability to work within the environment of the mouth to help us provide improved long-term restorative outcomes.

## Current bioactive materials

An effort has been made recently in the industry to promote the concept of bioactivity. Several companies have released products stating that they are bioactive. As of this writing, we have products in the dental marketplace like NovaMin, mineral trioxide aggregate (MTA), Biodentine, TheraCal LC, Ceramir cement and the Activa family of products.

**NovaMin (Sylc)** is marketing name for the 45S5 bioactive glass (**Figure 1**) described earlier in this chapter. It creates a union with the tooth structure and aids the formation of new dentin-like structure. Its use prior to the placement of a restorative material decreases



**Figure 1** Aquacare by Velloplex international. Ideal device for applying the bioglass powder. Powder is provided in separate canisters for ease in changing abrasives.



**Figure 2** Aquacare dual chamber device (Velopex International).



**Figure 4** Biodentin restorative material (Septodont).



**Figure 3** Sylc bioglass powder provided in easy to change canister (Velopex International).



**Figure 5** Bioactive flowable material (Bisco Dental).

dentin permeability and remineralizes the tooth structure.<sup>34</sup> The application is carried out using some of the newer air polishing systems (Figures 2 and 3). Best use currently would be before placement of glass ionomer and resin modified glass ionomer materials. Restorative materials such as Activa Bioactive restorative may be considered for use since the use of a resin bonding agent with placement is not needed for its use.

The MTA (Dentsply, Angelus, and others) and Biodentine (Septodont) (Figure 4) are calcium silicate materials which are effective dentin replacement materials. They form an intimate union with dentin. The application of these materials in very deep carious affected dentin has been shown to help healing and remineralization of dentin structure. These are indicated for direct and indirect pulp capping and dentin replacement. Other indications are pulpotomy, root and furcation perforations, internal/external resorptions, specification and retrograde surgical filling. The average initial setting time for these

materials is between 9–12 minutes, however, in some reports the complete setting time is much longer.<sup>35</sup> This setting time makes the use of these materials in a clinical setting somewhat problematic, but it is a very effective dentin replacement. Again, a restorative material must be used over these materials for final restoration of the dentition.

**TheraCal LC (Bisco)** is a resin modified calcium silicate material, indicated for direct or indirect pulp capping (Figure 5). It is a very opaque material that can only be used in 1-mm increments. If used in thicker placements, the risk of not achieving full cure of the material is very high and could prevent any benefit this material could potentially provide. Its ease of use and ability to be light cures makes it a very popular product. However, there is some concern as to the hydrophilicity of the material and its ability to effectively release the calcium needed for healing the dentin.<sup>36-39</sup>

**Ceramir Crown and Bridge Cement (Doxa AB)** is a calcium aluminate luting cement



**Figure 6** Ceramir Crown and Bridge Cement (Doxa AB).

supplied in both a powder/liquid form and a Quickcap capsule form (**Figure 6**) indicated for conventional cementation of all of the current types of indirect restorations. It contains a glass ionomer powder along with the calcium aluminate which when mixed with water creates, what has been reported to be a high pH final setting cement. Its high calcium content is a benefit in the initiation of a union with the tooth structure. There is concern that the bond strength takes time to fully achieve because of the lack of phosphates in the material. The creation of a potential hydroxyapatite interface is therefore reliant on the phosphate derived from the tooth itself and this ability does take time (7 days) to achieve.<sup>40</sup>

The **Activa** (Pulpdent Corp) family of products (**Figure 7**) includes a restorative material, a lining material, a pediatric restorative material and luting cement. The unique ionic hydrophilic resin combined with what the company calls a 'rubberized urethane' component to provide resiliency, and calcium, phosphate and fluoride ion content has made this product unique and groundbreaking. The various formulations are essentially the same, with minor differences in viscosity and opacity. Investigations into the material indicate that it holds great promise in its use in dentistry. The hydrophilicity of these materials enables them to work well with moisture and it is the hydration of the material that enables the formation of hydroxyapatite via the release of calcium and phosphate ions from the material without degradation of the material's physical properties and structure. Its high compressive strength and its ability to significantly reduce micro-leakage as compared to traditional resin based composite materials, and evidence that the Activa products are able to inhibit secondary decay as compared to



**Figure 7** Activa Brand of base, restorative and cementation products (Pulpdent).

conventional composite resins makes these materials an exciting addition to the clinical armamentarium.<sup>41-43</sup>

## Conclusion

The formation of a crystalline structure at the restorative/dentin interface is very attractive as a means of overcoming the challenges manifested in resin bonded adhesives. However, it is important to remember that hydration and activity of materials *in vivo* may not be similar to those displayed *in vitro* because of insufficient fluid available in contact with dentin.<sup>36</sup> Second, as we apply the current research, we see that crystalline formation of our materials must be associated with water and osmotic forces which allow the transmission of the necessary ions (calcium and phosphate) to act as nucleation sites and the effective penetration of these ions into the fibrillar and intrafibrillar collagen. The presence of water is critical, so the demineralized collagen structure can accept the needed ions to rebuild. This cannot be accomplished with traditional hydrophobic materials and methods.

Next, this crystal formation must also be of the correct size and in the correct proportions since crystals too large may not be usable by the tooth structure and too much apatite may prevent true biomineralization. Too much crystal formation may overwhelm the surfaces that need to be remineralized by preventing the collagen fibrils from using the material in a manner that will enable proper nucleation and remineralization. This could lead to unintended side effects such as over-whitening of the restorative-tooth interface.



Materials used to restore the dentition must be able to withstand the hostile forces of the oral cavity, and enable the tooth to 'breathe' in the oral environment so that it can create a 'heal and seal' effect. This would be the creation of a bioactive/biomimetic interface that releases calcium and phosphate ions which 'feed' the mineral starved tooth structure by initiating crystalline formation, and enable and create appropriate biologic biomimetic remineralization processes, so the elastic modulus, structure and hardness of collagen fibrils is completely recovered.

There must be a mechanism by which we translate the information gathered here into clinical application. We must embrace water. Water is not the enemy that it has been portrayed. It is the enemy of hybridization, which cannot occur without water, yet also cannot be done well with water; a complicated relationship indeed.

Furthermore, in order to biomimetic collagen and tooth structure, water is essential for the osmotic gradient to set up and enable expansion of the collagen. This will enable ion transfer and preserve proteins in that structure. The presence of water enables the nucleation of calcium and phosphates into the collagen.

The work of all of the researchers mentioned in this chapter and countless others have shown that we can translate the dreams from the laboratory bench to use in the clinical environment. The development of materials, such as NovaMin, MTA, Biodentine, TheraCal LC and the Activa family of products, are leading the way, and others that follow will enhance this process. Ultimately, there is a need for further development of other restorative materials that work within the moist oral environment, protect the tooth surfaces they are applied to and enable long-term success.

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## Introduction

Management of caries without removal of tooth structure is one of the most striking advancements of contemporary dentistry. Areas growing in popularity for treating caries include the use of pharmaceutical agents such as silver diamine fluoride and/or ozone. This could reduce the extent of conventional caries treatment by reducing drilling and filling and could potentially improve patients' acceptance and compliance with caries treatment.

Ozone is considered one of the pharmaceutically least invasive methods used to prevent and treat dental caries. It can be used solely or in conjunction with other methods to manage dental caries. Ozone treatment is conservative and requires less treatment time and of course less mouth opening periods.

## Safety and healing potential of using ozone

The use of the healOzone (CurOzone Germany) (see **Figure 1**) has been proven to be safe; however, other systems which blow out ozone into the patient's mouth have not been considered safe, since ozone can be toxic to lung tissue. Ozone gas is applied to the tooth surface



**Figure 1** HealOzone (CurOzone Germany).

using the various sizes of disposable silicone cups supplied by Curozone, and these ensure an absolute seal to avoid ozone leakage. Each cup is pressed against each tooth so that the maximum ozone is delivered into the tooth. The healOzone and healOzone X4 machines provide ozone after the cup allows an absolute seal; this characteristic permits the appliance to be safe to utilize for humans.

Experiments investigating whether ozone exerts any cytotoxic effects on human oral epithelial cells and gingival fibroblasts compared with established antiseptics (chlorhexidine digluconate, sodium hypochlorite, or hydrogen peroxide) or with antibiotics (metronidazole) revealed essentially no cytotoxic signs for aqueous ozone; the latter is how ozone would become in contact with the pulp after dissolving in the dentinal tubules fluids. Aqueous ozone revealed the highest level of biocompatibility of the tested antiseptics.<sup>1</sup>

Moreover, ozonized media have been shown that immunoregulatory activities (NF- $\kappa$ B) in oral cells and in periodontal ligament tissue from root surfaces of periodontally damaged teeth were inhibited. Under this treatment, proteolysis and cytokine expression were prevented. Specific ozonized amino acids were shown to represent major inhibitory components of ozonized medium, and to exert anti-inflammatory capacities.<sup>2</sup> An indirect assessment of the healing potential of ozone has been shown with the treatment of recurrent aphthous stomatitis (RAS). Application of ozone on RAS lesions for 60 seconds reduced pain levels and improved ulcers' healing by reducing ulcers' size and duration.<sup>3</sup>

Ozone applied using the healOzone device is superior to many other ozone or other pharmaceutical application methods as it only acts locally and not on large areas like mouth washes and therefore does not have any effect on the oral cavities resident protective microflora. In

addition, a side benefit of the use of the healOzone is that it does improve the color of teeth.

## Ozone's ability to kill microorganisms within carious lesions

Ozone has been proven to be effective against both gram-negative and gram-positive bacteria, as well as against viruses and fungi in dentistry, especially when referring to the healOzone device. Ozone as a gas or ozonated water was found successful to achieve a significant

reduction of the number of cariogenic microorganisms (including *Streptococcus mutans* and *Streptococcus sobrinus* and lactobacilli) in both *in vivo* and *in vitro* conditions.

Consequently, ozone has been well documented to be used for the prevention as well as for the treatment of caries.

## Which cavities are best to treat with ozone?

Ozone is a highly reactive molecule and, therefore, is capable of penetrating carious lesions. However, there will be a limit as to how

### Mechanism of action of ozone

Ozone is an energy-rich and highly unstable form of oxygen. Ozone is created by an energetic reaction that results in an oxygen molecule ( $O_2$ ) being split into singlet oxygen ( $O_1$ ). A singlet oxygen then combines with a diatomic oxygen ( $O_2$ ), thus forming ozone ( $O_3$ ). Healthy (mammalian) cells have antioxidant enzymes in their cell membranes, such as superoxide dismutase, catalase and glutathione peroxidase. There are also antioxidants such as vitamin C and vitamin E present in the extracellular matrix fluids and plasma. These antioxidants protect healthy cells from being oxidized by ozone. In contrast, pathogens such as bacteria, viruses and yeasts have little or no antioxidant enzymes in their cell membranes, and this lacking property makes them vulnerable to oxidants. Ozone destroys the cell membrane of the pathogen resulting in a strong disinfecting (or even sterilizing) effect. Ozone leaves no toxic by-products like other antimicrobials such as chlorine compounds (e.g. trihalomethanes, etc.). The final breakdown product of  $O_3$  is oxygen.

Biofilms are a complex aggregation of structurally and genetically diverse microorganisms growing on a solid surface. Biofilms are found in dental plaque, carious lesions, root canals, periodontitis and dental waterlines. Ozone has been proven in several studies to kill microorganisms in biofilms

by damaging the microbial cell walls and cytoplasmic membranes.

[http://www.drnicolevane.com/san\\_diego\\_tooth\\_decay\\_ozone\\_therapy\\_dentist.html](http://www.drnicolevane.com/san_diego_tooth_decay_ozone_therapy_dentist.html)

Ozone has been well documented to be the most powerful antimicrobial agent we can use in either dentistry or medicine. In addition, ozone is an extremely powerful oxidant, much more powerful than even hydrogen peroxide. Ozone therefore oxidize carbohydrates, proteins, glycolipids and acids in saliva and within carious lesions, and the latter probably contributes to limiting the depth of its penetration into deep caries.

Hardness of open single surface shallow carious lesions was found to improve following treatment with ozone using the healOzone, thus clearly reflecting the remineralization process to be favored over demineralization in the dental carious process. This remineralization is also supported by the strong oxidative capability of ozone consuming the molecules usually leading to demineralization and preventing remineralization, such as many organic (including lactic, formic, and pyruvic) acids. Ozone might also affect surface wettability of dentine via a reaction with organic components making cariogenic bacteria unable to form a biofilm on dentine after the use of the healOzone device.

far it can penetrate. Clearly, lesions of a depth of 1 mm (such as shallow root carious lesions) or 1 mm of deep caries overlying the pulp or for cavity disinfection after preparation before placing a restoration are all highly suitable sites to apply ozone, and have been proven to be capable of becoming arrested using ozone produced by the healOzone machine.

## Ozone's effects on early fissure carious lesions

Some researchers reported that ozone is capable to reduce the number of bacteria in cavitated occlusal fissure carious lesions, but not in non-cavitated ones; this would suggest that direct ozone application into open cavities in occlusal pits and fissures is required to achieve the desired effects of ozone. A highly significant reduction in numbers of cariogenic microorganisms and arrest of caries lesions occurred in small shallow carious lesions but not in very large deep carious lesions. Longer durations of ozone application are associated with even greater reductions in the counts of cariogenic bacteria.

When assessing the effectiveness of ozone with or without an additional remineralizing solution on non-cavitated fissure carious lesions in permanent molars, ozone treatment either alone or combined with a remineralizing solution was found to be effective for remineralization of initial fissure caries lesions.<sup>4</sup> Using the healOzone device, others reported an improvement in the clinical status of non-cavitated fissure carious lesions among high caries risk patients. The healOzone-treated lesions showed significantly more caries reversal or reduced caries progression if compared to the untreated control lesions within the group of patients at high current caries risk. It was concluded that healOzone application significantly improved non-cavitated initial fissure caries in patients at high caries risk over a 3-month period.<sup>5</sup> It should be noted that the authors of this chapter prefer sealing in caries after ozone treatment.

## Ozone treatment of smooth surface enamel caries lesions

When assessing the antibacterial efficacy of ozone therapy in the treatment of caries at the white spot stage,<sup>6</sup> it is strongly advisable to include ozone in

the protocol of non-invasive treatment of initial dental caries.

## Cavity disinfection before restoration

Microorganisms might remain in dentinal tubules and on cavity surfaces, regardless of attempts by many clinicians aiming for the full removal of carious tissues depending on clinical judgment. Residual bacteria have been reported to possibly lead to pulp inflammation, recurrent caries, and/or failure of the restoration. To remove the remaining bacteria following caries removal, the use of pharmaceutical agents such as sodium hypochlorite, iodine, hydrogen peroxide, disodium ethylenediaminetetraacetic acid (EDTA) or chlorhexidine has been recommended. As a viable alternative, many dentists routinely use the healOzone for this purpose for cavity disinfection.

## Ozone treatment of deciduous carious lesions

Ozone has also been used to treat and prevent caries in deciduous teeth. Open carious lesions in anxious children have been treated by means of the healOzone device in a prospective controlled clinical study to determine whether the treatment of dental caries with ozone was possible in apprehensive children and to ascertain whether ozone reverses caries in open single-surface lesions. Ninety four percent of the children were treatable and 93% lost their dental anxiety. The hardness values improved significantly in the ozone-treated test lesions after 4, 6, and 8 months compared with baseline while the control lesions had no significant change in hardness at any recall interval.<sup>7</sup>

When assessing the antimicrobial activity of ozone and NaF-chlorhexidine on early childhood caries, ozone has been shown to inhibit all bacteria tested, and it has been concluded that ozone seemed to be a good alternative for controlling progression of carious lesions. It should be emphasized that the number of microorganisms killed by ozone was 99.9% for all species in such situations.<sup>8</sup> Moreover, the healOzone device has been used for deep caries treatment in primary teeth in a retrospective study,<sup>9</sup> evaluating the effects of incomplete removal of carious dentine tissue, the use of

ozone for the disinfection of carious dentine, and the creation of a peripheral seal in healthy tissues for adhesive bonding procedures with rubber dam isolation. The success rate at 12 months was 93.62% ( $n = 88/94$  restorations), similar to success rates reported in the literature for pulpotomy. The deciduous teeth considered for this study, if treated conventionally, would have probably been subjected to pulpotomy, because of the extension of the carious lesions. The proposed minimal invasive conservative protocol, by means of the healOzone device, proved to be an excellent alternative, with the fundamental advantage of saving dental tissue and preventing the invasion of the pulp chamber.

### Management of root caries using ozone

The clinical reversal of root caries using the healOzone device was assessed in a double-blind, randomized, controlled 18-month trial. This study assessed the effect of the healOzone combined with the daily use of a remineralizing patient kit, on the clinical severity of non-cavitated leathery primary root carious lesions in an older population group.<sup>10</sup> A total of 89 subjects, each with two leathery primary root carious lesions were recruited, and the two lesions in each subject were randomly assigned for treatment with healOzone or air. Subjects were recalled at 3, 6, 12 and 18 months, and lesions were clinically recorded at each visit as soft, leathery or hard and scored with a validated root caries severity index. After 3 months, in the ozone-treated group, 61 primary root carious lesions (69%) had become hard and none had deteriorated, whilst in the control group, four primary root carious lesions (4%) had become worse. At the 6-month recall, in the ozone group, seven primary root carious lesions (8%) remained leathery, the remaining 82 (92%) primary root carious lesions had become hard, whilst in the control group, 10 primary root carious lesions had become worse (11%) and one had become hard. At 12 and 18 months, 87 subjects attended; in the ozone group at 12 months, two primary root carious lesions remained leathery, compared to 85 (98%) that had hardened, whilst in the control group 21 (24%) of the primary root carious lesions had progressed from leathery to soft (meaning they became worse), while 65 primary root

carious lesions (75%) were still leathery, and one remained hard. At 18 months, 87 (100%) of ozone-treated primary root carious lesions had arrested, whilst in the control group, 32 lesions (37%) of the primary root carious lesions had significantly worsened from leathery to soft, 54 (62%) primary root carious lesions remained leathery and only one of the control primary root carious lesions had reversed. It was concluded that leathery non-cavitated primary root caries can be arrested non-operatively with the healOzone and remineralising products. This treatment regime indeed is an effective alternative to conventional 'drilling and filling'. It should be noted, however, that these lesions would all have been relatively shallow carious lesions which of course would allow the penetration of the ozone to the depths of the lesions.

Primary root caries lesions were significantly reversed and arrested by the use of the healOzone in a further double-blind randomized clinical trial.<sup>11</sup> Non-cavitated root carious lesions have more potential to harden and reverse than cavitated root carious lesions following healOzone treatment which probably reflects the fact the cavitated root carious lesions are deeper than non-cavitated root carious lesions (and do constitute a major biofilm trap). This is probably due to the ozone having the ability to more easily penetrate these shallower (non-cavitated) lesions and thereby eliminating the ecological niche of acidogenic and aciduric microorganisms, thus contributing to the remineralization process.

### Management of deep caries approaching the pulp

One of the main challenges in caries management is to treat deep caries approaching the pulp. Many dentists tend to remove all carious tissues which often ends up with tooth sensitivity and/or pulp exposure, and might require indirect pulp capping, direct pulp capping, pulpotomy or pulpectomy. Other protocols have been suggested to manage deep caries, such as conservative and ultraconservative approaches that include stepwise caries excavation and partial caries removal. Complete or minimal (ultraconservative) removal of caries ended up with similar rates of caries progression and restoration longevity.<sup>12</sup> However, only few randomized controlled trials are currently

available to reach this conclusion, and further studies are still necessary to establish such recommendations. It should be emphasized that if one is to leave some deep caries in an attempt not to expose the pulp, it would certainly seem more logical to aim to kill this ecological niche of acidogenic and aciduric microorganisms in the deep caries before placing any restoration.

Assessing gaseous ozone effects on microbes in deep occlusal carious lesions using a stepwise excavation method was found to reveal significant antimicrobial effects in deep class I occlusal carious lesions.<sup>13</sup> Mutans streptococci, lactobacilli and *Candida* counts were significantly reduced immediately after ozone application. After 12 months, this could be confirmed; still, mutans streptococci and lactobacilli were significantly reduced in the ozone treated caries. The *Candida* counts were also significantly reduced in the ozone treated caries at the 6 and 12 months recall visits. Regarding caries reversal, it has been shown that the clinical effects of ozone on dentine of deep carious lesions using a stepwise excavation technique lead to significantly reduced DIAGNOdent values 6 and 12 months following ozone application.

Regarding the role of ozone in the management of symptomatic, deep, almost cariously exposed pulpal lesions, ozone has been shown to have beneficial effects on the pulp, and this might be attributed to the neutralization of endotoxins; the latter are known to potentially irritate the pulp. Moreover, ozone treatment of deep caries might allow for a less invasive management strategy. Therefore, following partial removal of caries, ozone was used to disinfect remaining leathery dentine caries before placement of a restoration.<sup>14</sup> The ozone method only differed from the traditional method by leaving the deep leathery caries on the pulpal floor and then treating this with 10 seconds of ozone from the healOzone X4. The aim was to leave approximately 1 mm of caries in the deep part of the cavity in the ozone group whilst the control group used a traditional method of caries removal whereby the aim was to remove all the infected dentine. A conventional glass ionomer cement was placed followed by amalgam in each cavity. Ozone treatment was associated with less pain and less needs for root canal treatment (RCT). This study concluded that ozone treatment

of symptomatic teeth with deep, carious lesions almost reaching the pulp shows promise for a more conservative approach to treat deep caries as well as being associated with less postoperative sensitivity and less need for RCT compared to a traditional method.

Another protocol for management of deep caries is photodynamic antimicrobial therapy (PAD); here, a sensitizer is applied to the lesion to be taken by bacteria, then the lesion is exposed to light of special wavelength, leading to formation of cytotoxic agents that damage bacteria. However, there are concerns about how deep this antimicrobial therapy can penetrate the lesion. In addition, there are some concerns that this technique is sensitive to the amount of dye used. PAD is also not capable of the additional benefits accrued when ozone is used such as the powerful oxidation and neutralization of toxins such as the organic acids and endotoxins.

All in all, there are no reported deleterious effects of applying ozone on deep caries, nor on exposed pulp. In contrast, many papers have actually reported many beneficial effects associated with the contact of ozone with blood such as endogenous interferon release. Ozone has an antihypoxic effect. Ozone improves the transportation of oxygen in blood. Ozone improves the metabolism of inflamed tissues by increasing their oxygenation and reducing total inflammatory processes. Ozone has an immunostimulating effect and improves blood circulation, stimulates proliferation of immunocompetent cells and synthesis of immunoglobulins, as well as activates the function of macrophages and increases sensitivity of microorganisms to phagocytosis. Moreover, ozone causes the synthesis of biologically active substances, such as interleukins, leukotrienes and prostaglandins which are beneficial in reducing inflammation and wound healing.

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## Ozone and its effects on dental hard substances

### Ozone does not reduce bond strength of composite resin adhesive to tooth tissues

Unlike bonding problems associated with the use of hydrogen peroxide, ozone does not reduce



bond strength of composite resin adhesive to tooth hard substances. Direct high-dose gaseous ozone application from the healOzone on both dentine and enamel did not impair shear bond strengths, and this has been confirmed for shear bond strengths of orthodontic brackets. Thus, adhesive restoration placement should be possible immediately after healOzone application for cavity disinfection. Moreover, ozone gas did not compromise the mechanical properties of dentin adhesives. Thus, its application on dentine prior to bonding procedures is possible, without impairing the performance of the final restoration.

### Ozone treatment before the placement of fissure sealants

Ozone using the healOzone can also be used in fissures before application of fissure sealants to kill microorganisms and reduce the chance of caries.

### The effect of ozone on microleakage and fissure penetration of different sealing materials

The preventive effect of sealing materials depends on ability to penetrate into the fissures. Microleakage absence, resulting in better clinical success, must be assured, and this is particularly important as most dentists use ozone and then seal the lesion. The influence of ozone on microleakage and penetration of nanoparticle fissure sealing resins and flowable composites has been shown to be negligible, with no effects either on microleakage or penetration ability of flowable composites or sealing resins.

This has been confirmed with studies on sound enamel physical properties. Ozone was shown to dehydrate enamel, and, consequently, enhanced its microhardness, which was reversible; possible effects of ozone on sealant tag length, microleakage and unfilled area proportions could not be revealed. Moreover, contact angle and acid resistance tests obviously did not reveal any differences between ozone and air.

### Use of remineralizing agents after ozone application

Some researchers advocated the use of remineralizing agents directly following ozone

application to obtain best results and help reversal of pit and fissure carious lesions.<sup>4</sup> Ozone applied to non-cavitated fissure carious lesions in permanent molars revealed remineralizing effects, and this was independent from the additional use of a remineralizing solution.

## Future directions

Some studies have shown that sealing in caries can be successful but there are also investigations revealing that sealing in caries is associated with progression of the carious process. Of course, restorations do not completely seal, and, in addition, the microorganisms in the deep caries can receive continuous nutrition from the pupal fluid. Further studies are required to reach undisputed conclusions regarding whether proper sealing of a cavity would end up with death of viable bacteria left to tooth filling. Moreover, leaving soft dentine under the restorations could cause pulp problems and affect restoration longevity. In addition, to explore whether we need to disinfect dentine before restoration and which are the best methods to disinfect remaining dentine should be worth evaluating in the future.

## Conclusion

By attacking microorganisms in their niches, where hitherto they have been able to survive, the use of ozone opens new horizons. It appears reasonable to expect enhancements of minimal invasive treatment procedures or even new synergies between traditional treatment regimens and prevention. The ozone generating device represents an important tool in the medical treatment of dental caries, thus shifting dental medicine from a symptom-driven (reparative) discipline to a prevention-oriented speciality, taking care of the cause(s) of disease. Ozone treatment is a very useful support for minimal invasive dentistry as it clearly helps to treat the cause of dental caries and in addition has been shown to have numerous other benefits which can in fact help the pulp to recover and allow dentists to avoid root canal therapy in many cases. Meanwhile, ozone is being used by around 100,000 dentists worldwide, and these are daily using its clear evidence-based clinical benefits most successfully.

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*John J Graeber*

## Introduction

The failures associated with direct placed restorations can be attributed to many causes. This chapter will outline many of these with the aim of elimination of as many of them as possible.

## Earlier diagnosis

Obviously, the key to minimal invasion is the earliest possible diagnosis! One factor which dental professionals do not have is controlling when the patient decides to seek care. However, any efforts by the profession to inform the public and parents of young children as to the need for early intervention will have positive results. Educational efforts directed toward the benefits of early care for children and adults will help to change and elevate the population toward seeking diagnostic care before symptoms of caries become apparent to them. The chapters on new diagnostic instrumentation have been part of this book. The recommendation from pediatric dental organizations is that parents should establish a dental 'home' for infants as early as 1 year old.<sup>1</sup>

## The restorative prescription

After arriving at a diagnosis of caries presence, the restoration of a tooth should begin with an individual tooth restorative prescription: a surgical plan on accessing the decay, removing the infection (caries), and adequately restoring the tooth while disinfecting it, remineralizing the dentin, and restoring both function and esthetics.

## Ways conventional treatment fails

### ***Failure #1 Rote adherence to the black system***

The GV Black system for direct restorative dentistry was intended for low speed rotary

preparation a century ago! The main outdated concept is a pre-ordained shape of the preparation. This system was designed for use with low-speed rotary instrumentation and amalgam as the restorative system. It features undercuts for retention, sufficient bulk and depth to provide resistance form, and inclusion of all enamel fissures. Strict adherence to this preparation system all too frequently results in unnecessary over-cutting of tooth structure.

The introduction of high speed rotary handpieces in the 1950s has also contributed to the over-preparation of cariously involved teeth. The ease and speed of cutting contributes to excess removal of sound tooth structure.<sup>2</sup>

The inherent eccentricity of the burs causes microfracturing of the crystalline structure of the enamel when used intracoronally. Enamel margins also suffer chipping during the preparation process regardless of the type of bur or diamond employed. Micro-fractures lead to leakage surrounding the restorations, regardless of type. Under load, and over time, the microfractures propagate, often leading to catastrophic fracturing of marginal ridges and cusps.<sup>3</sup>

The shape of the preparation also has been shown to be of significance in catastrophic failure. An MOD restoration which is continuous across the entire occlusal surface including marginal ridges in molars and bicuspid has been associated with fracture.<sup>4</sup>

Fractures have been identified as the third most common loss of teeth in industrialized countries. While the thrust of this textbook is on minimal restorative treatment, the use of cuspal protection should be considered when significant tooth structure has been lost or when marginal ridges are missing (**Figure 1**).<sup>5</sup>

Under the GV Black principles of preparation, every restorative material required



**Figure 1** Fractured buccal cusp of bicuspid previously prepared with high speed rotary handpiece and restored with silver amalgam.



**Figure 2** Fractured mesio-buccal cusp of maxillary first molar.

its own preparation features. Cast gold, gold foil, porcelain, silicates and amalgam preparations were decidedly different due to the accommodation of each material's physical properties.

Fast forward to the 1970s, composite resin restoratives were introduced and came into common usage in the next two decades. About the only accommodations made to the 'rules' of preparation were rounding internal line angles and enamel bevels. The over cutting of teeth has continued along with the disadvantages of high-speed instrumentation. Many of the preparation shortcomings have continued to plague the integrity and longevity of composite resin restorations.

### ***Failure #2 Heat and friction***

All high speed rotary handpieces create heat and friction when cutting tooth structure. This is an inherent side effect which may be minimized by higher quality of each device and may be maximized by lesser quality instruments. The individual bur or diamond design and grit size can also impact the amount of heat generated while cutting (**Figure 2**).

### ***Failure #3 Aspiration of odontoblasts***

As rotary instrumentation contacts the dentinal surfaces, the odontoblastic processes within the tubules are aspirated by the centrifugal forces created by the direction of a rotating bur or diamond. This has the potential of causing

postoperative sensitivity and possible pulpal necrosis if enough processes are irreversibly damaged. Postoperative sensitivity has long been a frequently reported as a consequence of initiating tooth preparation and/or preparation methods.

### ***Failure #4 Lubricant contamination***

Virtually all rotary handpiece require a lubricant for normal operation. Usually silicone or oil based, these lubricants will escape the handpiece at the moving mechanism end. Invariably there is residual lubricant sprayed onto the tooth surface which may interfere with bonding or polymerization. Solvents appropriate for the lubricants could be harmful to the delicate dentinal tissues and cause undesirable effects.

### ***Failure #5 Pulpal injury***

Besides the damage done by heat and friction to the dentinal surfaces and micro-structures, pulp tissue can become exposed mechanically or cariously, resulting in physical or biological infection.

The aggressive nature of high speed cutting can lend itself to this type of injury. Less aggressive methods such as air abrasion and hard tissue lasers can be helpful in reducing the tendency to over cut preparations.

### ***Failure #6 Smear layer***

The smear layer is formed by the melting of organic material onto the dentinal surface during

high speed rotary cutting procedures (**Figure 3**). While considered sterile, the presence of the smear layer could complicate bonding material adherence and bond strength. Some bonding agents are intended to attach to the smear layer but most are designed to be used with acid etching of the dentin in order to create a hybrid layer of the bonding agent, dentinal tubule penetration and collagen fiber envelopment. Clinicians must be aware of which technique applies to the bonding agent type being utilized. If no smear layer is created by the preparation system, the choice of bonding agent type becomes self-evident. Neither air abrasive nor lasers currently in recommended use are capable of creating a smear layer.

### ***Failure #7 Disinfection of the prepared cavity***

New evidence indicates that no materials are effective in effective disinfection of a cavity preparation (see Chapter 7).

It is not yet known what agents or techniques may be necessary to effect sufficient disinfection to prevent recurrence of decay post-treatment. Apparently, entombment of bacteria is not effective since nutrients from the pulpal side of the dentin may be supportive of bacterial growth. A disinfecting agent itself must be found safe for use on dentinal structure. Laser energy may be shown to be effective in bacterial decontamination in the future. Studies in endodontic decontamination may be pertinent



**Figure 3** Fractured mesio-lingual cusp of mandibular molar.

toward designing appropriate investigations. Air abrasives currently available do not have antibacterial properties. It is not known how effective fluoride addition to restorative materials may have on disinfection of the dentinal structures (**Figure 3** and **4**).

### ***Failure #8 Bonding failures***

While some of the failures listed above will adversely affect the ability to bond composite resins to tooth structure, there are some other inherent factors which must be minimized to achieve optimal results. Higher bond strengths are reached if enamel is dry, and dentin is 'wet' with water or by not overdrying. How dry? How wet? Is there salivary or blood contamination? Have other chemicals been left on tooth structure to interfere with bonding or enhance it? Can resin be bonded to cariously affected dentin or enamel? Will the bonding agent be the best match for the composite resin? How strong will the bond be to other materials such glass ionomers? These questions are some of the factors which may explain why there are differences in reported bond strengths.

### ***Failure #9 Noise and vibration***

Many a patient has complained about the excruciating noise a high speed device creates. The noise has been associated with pain especially if patients have previously experienced pain along with the noise. How many patients have made this complaint to their dentist?



**Figure 4** Outline form which only includes carious areas of occlusal surface. There is no sound reason to further weaken the tooth by connection of the individual preparations.

Associated with the noise objection is the associated vibration.

This cannot be minimized by technique as teeth are connected to bones which are then connected to hearing apparatus. Air abrasion and lasers create no vibration and no noise. This can eliminate one of the main causes of dental fear in patients.

### ***Failure #10 The need for local anesthesia***

The second most reported distaste of operative treatment is the discomfort of the 'shot' of local anesthetic. While some older patients do not require local anesthetic for many operative treatments with a dental handpiece, most do. The reason is that it causes PAIN! Besides the need for local, many patients require conscious sedation or more for routine restorative dentistry.

### ***Failure #11 Reading manufacturers' directions***

The list of variables is far longer and more complex with every succeeding study. Perhaps the greatest failures come from dentists' failure to read manufacturers' directions - even though they are included in every package of material.

### ***Failure #12 Iatrogenic damage***

Many studies have focused on damage to adjacent surfaces of teeth being restored.<sup>6</sup>

Unless protected most adjacent surfaces are damaged unintentionally with rotary instrumentation. The obvious problem is the creation of voids in these surfaces which aid in the potential formation of new decay. These same studies have concluded that both low and high speed handpieces are equally contributory. Air abrasion techniques must be associated with deliberate protection adjacent structures due to the residual kinetic energy of the abrasive particles after they come into contact with the primary target.

Lasers are much less likely to cause adjacent structure harm because of the end cutting nature of the photonic beam.

### ***Failure #13 'Do no harm'***

The Hippocratic Oath requires doctors to do no harm to patients! Harm can be physical and/or psychological. Many of the procedures traditionally performed by the dental profession

do one or both. Finding less invasive, less harmful, quieter, methodologies should be the goal of every dentist, dental researcher and dental manufacturer. Fear of treatment continues to keep so many patients away from care.

The oral cavity is the source of more pleasure than any other part of the human body. It is the instrument of nourishment, taste, communication, and love. No wonder that patients are so protective of it. It is also a very private place. Only the dental professional is allowed in. The professional must be respectful, and kind to it. If the profession is dedicated to serving all, it must find less invasive methods of treatment and preservation.

### ***Failure #14 Class V 'Mud Flaps'***

One of the most frustrating aspects of restorative care are the poor retention of the class V cervical restorations repairing noncarious root attrition. The term 'Mud Flap' refers to a strong bond to adjacent enamel and a much weaker bond often resulting in a loose restoration only held in place by a thin area of enamel bond.

There have been many theories put forth to account for the attrition of the exposed cervical portion of the root. The traditional cause was the overuse of a hard bristle toothbrush. Since the widespread of soft toothbrushes, however, the incidence of root attrition has seen a dramatic increase. In the near past, these abfractions were blamed on occlusal disharmonies. Like everything in Biology, there is hardly ever just one cause for a given pathology.

Recently, an update of the ADA and ISO abrasivity values suggests a third possible cause: an increase in abrasivity of major brand (especially newly formulated multipurpose) toothpastes. The RDA values are available on the internet.<sup>7</sup>

Regardless of cause, these lesions are sterile, usually quite smooth macroscopically and frequently have dentinal tubules sclerosed closed. In order to create a strong bond to the dentin, more preparation may be required.

Gross roughening with a diamond is one approach. Better approaches could include air abrasives, or laser roughening.

Traditional phosphoric acid etching of both the treated dentin and beveled adjacent enamel will increase the potential longevity of these restorations.

## Additional information

**Table RDA**

0–70	low abrasive
70–100	medium abrasive
100–150	highly abrasive
150–250	regarded as harmful limit

Toothpaste makers regularly measure their product's abrasivity. It's necessary for FDA approval, and usually is not required to be disclosed on the label. Abrasivity measurements are given by what's known as an RDA value which stands for radioactive dentin abrasion or relative dentin abrasivity.

The maximum value for FDA approval is 200. Toothpastes that claim whitening properties appear to have a higher abrasiveness index. Here is how to interpret the RDA values:

- From 0 to 80 = low abrasion
- 70 to 100 = midrange abrasion
- 100 to 150 = highly abrasive
- 150 to 250 = considered harmful to teeth

The lower the number, the less enamel/dentin it is likely to be worn away. The higher the number – the more wear on your dentition. The ideal toothpaste would not have a RDA index higher than 7; therefore dentifrices with a low abrasivity index are desirable.

RDA	Toothpaste brand	Source
07	straight baking soda	Church & Dwight
08	Arm & Hammer Tooth Powder	Church & Dwight
30	Elmex Sensitive Plus	Elmex
35	Arm & Hammer Dental Care	Church & Dwight
42	Arm & Hammer Advance White Baking Soda Peroxide	Church & Dwight
44	Squigle Enamel Saver	Squigle
48	Arm & Hammer Dental Care Sensitive	Church & Dwight
49	Arm & Hammer Peroxicare Tartar Control	Church & Dwight
49	Tom's of Maine Sensitive (given as 40's)	Tom's
52	Arm & Hammer Peroxicare Regular	Church & Dwight
53	Rembrandt Original (RDA)	Rembrandt
54	Arm & Hammer Dental Care PM Bold Mint	Church & Dwight
57	Tom's of Maine Children's, Wintermint (given as mid-50's)	Tom's
62	Supersmile	Supersmile
63	Rembrandt Mint ('Heffernan RDA')	Rembrandt
68	Colgate Regular	Colgate-Palmolive
70	Colgate Total	Colgate-Palmolive
70	Arm & Hammer Advance White Sensitive	Church & Dwight
70	Colgate 2-in-1 Fresh Mint (given as 50-70)	Colgate-Palmolive
79	Sensodyne	Colgate-Palmolive
80	AIM	Unilever
80	Close-Up	Unilever
83	Colgate Sensitive Maximum Strength	Colgate-Palmolive
91	Aquafresh Sensitive	Colgate-Palmolive
93	Tom's of Maine Regular (given as high 80's low 90's)	Squigle (Tom's)
94	Rembrandt Plus	Rembrandt



Continued...

94	Plus White	Indiana study
95	Crest Regular (possibly 99)	P&G (P&G)
101	Natural White	Indiana study
103	Mentadent	Squigle
103	Arm & Hammer Sensation	Church & Dwight
104	Sensodyne Extra Whitening	Colgate-Palmolive
106	Colgate Platinum	Indiana study
106	Arm & Hammer Advance White Paste	Church & Dwight
107	Crest Sensitivity Protection	Colgate-Palmolive
110	Colgate Herbal	Colgate-Palmolive
110	Amway Glistler (given as upper bound)	Patent US06174515
113	Aquafresh Whitening	Indiana study
117	Arm & Hammer Advance White Gel	Church & Dwight
117	Arm & Hammer Sensation Tartar Control	Church & Dwight
120	Close-Up with Baking Soda (canadian)	Unilever
124	Colgate Whitening	Indiana study
130	Crest Extra Whitening	Indiana study
133	Ultra brite (or 120-140)	Indiana study (or Colgate-Palmolive)
144	Crest MultiCare Whitening	P&G
145	Ultra brite Advanced Whitening Formula	P&G
145	Colgate Baking Sode & Peroxide Whitening (given as 135-145)	Colgate-Palmolive
150	Pepsodent (given as upper bound)	Unilever
165	Colgate Tartar Control (given as 155-165)	Colgate-Palmolive
168	Arm & Hammer Dental Care PM Fresh Mint	Church & Dwight
200	Colgate 2-in-1 Tartar Control/Whitening or Icy Blast/Whitening (given as 190-200)	Colgate-Palmolive
200	recommended limit	FDA
250	recommended limit	ADA

### **Failure #15 Use of amalgam**

When it was developed in the 1800s, this material was a marvel: metallic, relatively inexpensive, easy to mix and place, hard enough to resist deformation, and very forgiving in the oral environment.

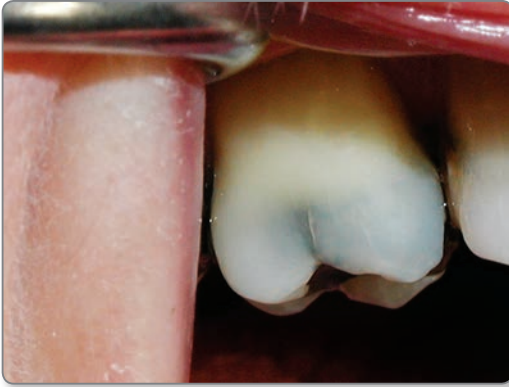
For the considerations in this text, it has no place. It must be mechanically retained by undercuts in the preparation. Undercuts undermine dental structures aiding in the propagation or initiation of fracturing. It is nearly impossible to prepare undercuts in cavities with lasers or air abrasives. Many of the preparations are so small or have inadequate access to properly place and condense the alloy.

There is no innate adhesion to tooth structure. One goal of any restoration is to utilize adhesion to the cavity walls to help prevent fracture under load. Amalgam is of no benefit to resulting tooth strength.

Amalgam will expand and contract with temperature change.

Expansion could be a factor in causing or at least aiding propagation of fractures. Contraction has the potential of causing shrinkage of the restoration, potentially opening a gap between the alloy and enamel walls.

Amalgam 'seals' itself by corrosion products. These products cause staining of the tooth structure (**Figure 5**).



**Figure 5** Prominent fracture line in maxillary molar with amalgam restoration replacing all of the dentin supporting the buccal cusp.

Amalgam, containing mercury has been banned by Public Health Authorities in certain countries. While controversial, and probably does no harm in the set state. Intraorally, however, removal and regulated waste mishandling can cause release of mercury into the environment.

### ***Failure #16 Properly placing and handling of composite resin***

Composite resin is a polymer which undergoes a chemical reaction caused either by chemical and/or light catalyst. Any contamination of the components may interfere with polymerization and its resultant physical properties. Salivary or hematologic contamination is clearly contraindicated.

Composite resin materials have definitive shelf lives. Storage temperatures outside of manufacturers' recommendations can negatively impact its physical properties. Resins also dry

with age and exposure to air impeding handling characteristics.

Composites must be handled with care. Most have a paste-like consistency. They do not respond to excessive force while being placed. They stick to packing instruments with the potential of being pulled from cavity walls. Use of unfilled resins as an instrument lubricant help in packing, but excessive unfilled resin can dilute the packable resin and reduce its physical properties. They must be a chemical match to the bonding agents being used.

Warming the composite just prior to use may assist in more favorable handling characteristics. Sonic assisting placement units can also aid in reducing air entrapment leading to porosity in the final restorative. Air entrapment can result in voids, which could entomb bacteria causing stains or voids.

The introduction of flowable resins added to the choices for clinicians. So now, it is necessary to choose the type of resin for special circumstances: smallest restorations are best filled with flowables to reduce the potential of voids. Since they are not as filled as packables, they are not as strong or abrasion resistant. Covering the dentin with flowable reduces contraction stresses compared to paste types. Using bulk-flowable may not be as strong as a packable.

The confusion of this area is always changing as newer materials are introduced. One of the most reliable sources on the best currently preferred techniques are Clinical Research Associates in Provo, Utah.

For long-term success, the use of composite resins require strict adherence to details, isolation and finishing.

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# Section IV

## Future caries diagnosis and management

Chapter 19 Enamel regeneration

Chapter 20 Photobiomodulation



## Introduction

Enamel is the hardest known human structure composed predominantly of the mineral hydroxyapatite. The superior wear-resistant mechanical property of this mineralized tissue structure is attributed to its significant mineral density and densely-packed mineral crystal arrangement. The functional implications of these properties enables a wide range of oral functions, especially processing foods and fluids with varying temperature, texture and hardness. Besides its dental functions, enamel has a key role in the esthetics of tooth form and facial features.

It is important to note tooth enamel represents an unusual biological scenario where a hard tissue forms within soft tissue, and is programmed to eventually erupt outside its original site of conception. This process also results in some of the unique anatomical, physiological and immunological aspect of oral-dental structures. Most importantly, cells that form enamel, the ameloblasts, are ultimately lost following tooth eruption. This results in an irreversible loss of enamel throughout life. Thus, a major cornerstone of clinical dentistry is aimed at restoring enamel while dental research has zealously explored approaches for enamel regeneration.

## Embryonic development of enamel

A logical approach to engineer a biological structure is to precisely understand its normal developmental program.<sup>1,2,3</sup> There has been significant effort, even among the earliest embryologists, to better understand the process of embryonic tooth development. Following the initial formation of the craniofacial complex, a primitive oral cavity termed the stomatodeum is evident. The lining of this primitive oral cavity is formed predominantly by the ectoderm,

along with minor contributions from the endoderm in its most posterior extent. The underlying connective tissue is primarily formed from the mesoderm with contributions from specialized cells in the para-axial neural crest, called the neural crest cells. This primitive oral lining is termed competent epithelium, and it undergoes precise downward invaginations into underlying connective tissue to form tooth buds or germs. These epithelium invaginations undergo proliferation and organization leading to a two discrete cell layers termed the inner and outer enamel epithelium. Further cell proliferation and morphological patterning results in two additional layers termed the stellate reticulum and stratum intermedium. At this point, the epithelium begins to communicate with the surrounding mesenchymal (connective) tissue and leads to condensation and cellular differentiation of the dental papilla (eventual pulp) and follicle (eventual periodontium). It has been noted that there is a clear shift in the competency of the developmental information at this point from the epithelium to the mesenchymal tissues there is active communication between the two components termed reciprocal induction. This exchange of information leads to further cellular differentiation and patterning (morphological) differentiation. One of the key events involves differentiation of the innermost epithelial cells to form elongated cells with pyramidal extensions and are termed ameloblasts that give rise to enamel. These cells progressively lay down the enamel organic matrix that include amelogenin, sheathlin, enamlin and ameloblastin among others. These organic constituents are used as scaffolds for deposition of inorganic calcium hydroxyapatite mineral crystals. The process of mineral deposition requires active degradation and remodeling of the organic matrix mediated by specific proteases such as enamelysin (also known as MMP-20) and kallikrein-4. Once enamel development is complete, the cells

fuse to the overlying surface epithelium and form the residual enamel epithelium. This layer degenerates as the tooth erupts into the oral cavity and hence, cells that form enamel are permanently lost during this process.

Changes to any of these key constituents, as evident from transgenic animal studies, have been shown to result in enamel defects and resulting in clinical manifestations such as amelogenesis imperfecta, hypoplasia and anodontia among others. Lack of a few or complete tooth structure is also clinically evident and has been attributed to the disruption of the exquisitely regulated developmental tissue interactions during tooth development.<sup>4</sup> These interactions have narrowed down the key cellular players to the developing tooth germ epithelium and specialized cells within the mesenchyme, the neural crest cells. The epithelium is known to form a signaling competent node termed the enamel knot. These foci of cells are known to be capable of coordinating developmental signals for cell proliferation and migration as well as instructing eventual tooth crown morphological patterning resulting in incisors, molars and premolars. A lack of effective signaling competency in this epithelial structure, that eventually dictates enamel formation, can disrupt reciprocal inductive tissue formation resulting in defects in other tooth structures including pulp–dentin complex, cementum, periodontal ligaments and bone.

## Limitations of strategies for enamel regeneration

Ameloblasts, cells that synthesize the enamel matrix during amelogenesis, are not present after tooth eruption. The lack of such cells dictates that native enamel structure cannot be replaced or repaired by physiological means as no new ameloblasts are formed from the dental epithelium after the epithelial root sheath has been formed. Animal studies, who have tooth forming tissue throughout life, have noted a potential source of enamel forming stem cells in the stellate reticulum.<sup>5</sup> However, humans do not have these cells available. Combining the competent dental epithelium and mesenchyme has been noted to generate tooth-like structure. Efforts in engineering teeth focused on *in vitro*

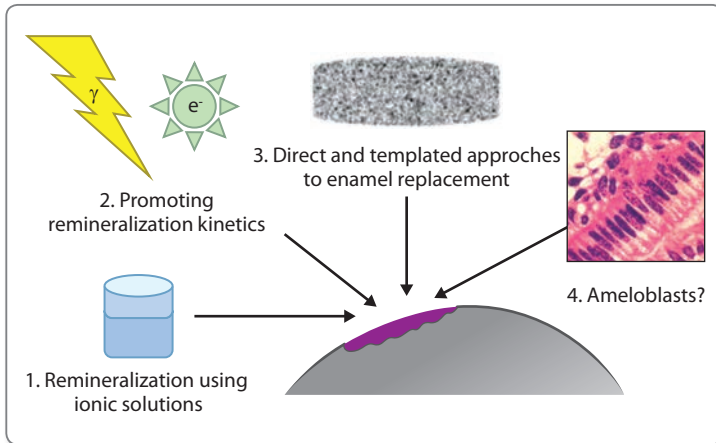
growth of tooth bud explants transitioned into a focus on characterizing teeth stem cells in dental pulp tissue. More recently, there has been a broad recruitment of different sources of enamel forming cells, ranging from co-cultured bone marrow cells to inducible skin epithelial cells as a means to potentially grow tooth tissue.<sup>6,7</sup> However, the need to replicate the natural processes of tooth development, including a large number of complex epithelial-mesenchymal reciprocal interactions has been difficult to precisely recapitulate.<sup>8</sup>

## Current approaches to enamel replacements

Tooth decay affects the enamel surfaces and progressively involves deeper layers extending past the dentinoenamel junction (DEJ) into dentin, ultimately involving the tooth core containing the pulp. Clinical symptoms such as pain and thermal (hot or cold) sensitivity are evident when microbial infection reaches the DEJ and the odontoblast extensions are able to perceive these injurious agents. Further ingress of microbiological and biochemical mediators invoke a strong immunological reaction within the pulp, usually resulting in a progressive, irreversible damage and necrosis. Current clinical strategies for clinical management of enamel decay are based on the extent of disease and levels of structural damage. Broadly these approaches can be divided into routine bulk enamel replacements or surface remineralization approaches (Figure 1). These approaches are briefly discussed below with an emphasis on the biological rationale of the individual approaches.

### 1. Bulk replacement

Current restorative strategies are mainly limited to the use of metals, composites, and cements. Amalgam, the widely popular biomaterial used in the past, is in the midst of being transitioned out due to concerns on its mercury content on individual health and the environment as well as continuing improvements newer dental materials. Dental composite materials provide a durable, esthetic restorative alternative to amalgam. However, such materials are reliant on a resin binding to the surface of etched enamel or dentin, the failure of which is often implicated



**Figure 1** Three strategies for restoring lesions within enamel using enamel remineralisation. Strategies 1 and 2 target small-to-moderate lesions, and strategy 3 targets large lesions. Strategy 4 involves the generation of ameloblasts (enamel-forming stem cells), but this remains hypothetical.

in secondary caries and crack formation. These materials are also 'passive' biologically, predominantly mostly characterized on the basis of biocompatibility alone. On the other hand, polyalkenoate or popularly called glass ionomer cements (GICs) are a class of materials that provide the advantage of binding to enamel and dentin surfaces without the use of a bonding agent. These materials also are capable of 'actively' aiding both antimicrobial and dentin-pulp healing responses. Recent modifications have further enhanced their clinical attractiveness. However, a major limitation of GICs are the lack of esthetics afforded by dental composites and their relatively weak mechanical properties.

### **Bulk-fill composites**

Current resin composites compared with other direct placement materials, such as amalgam, are very technique sensitive. This implies clinical performance and durability of restorations is strongly operator dependent. A critical step in composite restorations is the adhesive application involving multiple steps with ample opportunity for operator errors. Also, the incremental layering technique necessary for proper composite curing is time-consuming and introduces additional variables in the treatment regimen. With the aim of simplifying clinical procedures and addressing these shortcomings, bulk-fill and self-adhesive materials were developed. Bulk-fill resin composites comes in both flowable and conventional, sculptable viscosities, with the advantages of having simplified application

and ensuring adequate depth of cure. This has been achieved for different commercial materials via different routes that include optimization of initiator system (increased concentration of conventional photoinitiators or novel photoinitiators), modifications of the filler system (larger fillers or more translucent fillers), or inclusion of different chemistries in the composition. In general, the utilization of bulk-fill resin composites in posterior restorations has been shown to reduce cuspal deformation and polymerization, as well as increase the fracture resistance. A few commercially available examples are outlined below (**Table 1**).

**Flowable bulk-fill materials:** In addition to the lower filler content, the use of a novel high molecular weight (849 g/mol) urethane dimethacrylate (UDMA) monomer results in reduced material shrinkage. The novelty of this monomer consists of a polymerization modulator that has photoactive groups embedded with backbone of an oligomeric species. The rationale here is that photocleavage of these groups will result in oligomer chain breakdown to accommodate stress and further generate free radicals that increase overall polymerization. This material has been noted to have improved polymerization conversion and reduced shrinkage, eliminating the need for incremental filling.

**Conventional/sculptable bulk-fill materials:** One of these materials uses a novel photoinitiator systems containing a germanium-based light initiator, Ivocerin has a greater quantum yield conversion (more reactive species for same



**Table 1 Modified composites and glass ionomer cements that provide additional functionalities such as mechanical strength, an aesthetic finish and improved adhesion**

Restorative material	Functions	Commercially available products
<b>Composites</b>		
Flowable bulk-fill	Low viscosity	SureFil SDR Flow (Dentsply) HyperFIL - DC (Parkell) Venus Bulk Fill (Heraeus Kulzer) X-tra Base (VoCo)
Conventional bulk-fill	Sculptable, bulk filling	Tetric EvoCeram Bulk-Fill (Ivoclar Vivadent) Filtek Bulk-Fill (3M-ESPE) Alert (Pentron) QuiXX (Dentsply Caulk) Sonic Fill (Kerr) X-tra fil (VoCo)
Self-adhesive	Adhesives added	Vertise Flow and Dyad Flow (Kerr) Fusio (CE)
Ormocers		Admira Fusion (VoCo) Admira Fusion X-tra
<b>Glass ionomers</b>		
Compomer	Polyacid modified composites	MagicFil (Zenith Dental)
Resin-modified	Resins added	Fuji plus, FujiCem II (GC)
Zirconomer	Zirconia added	Zirconomer (Shofu)
High viscosity	High powder to liquid ratio	Equia Fill (GC) Equia Forte (Ge)

amount of incident light). This enables this material to be more efficiently polymerized in depth despite the use of a shorter wavelength. This material also used pre-polymerized resin filler particles that further reduce material stress and shrinkage. Another material uses a monomer capable of addition-fragmentation chain transfer – a mechanism known to accommodate strain via covalent breakage and reformation without net loss of crosslinking via an allyl disulfide bond. This has been shown to improve mechanical properties of the material with up to 30% reduction in polymerization stresses.

**Self-adhesive resin composites:** These have been developed to simplifying the composite restorative procedure by eliminating its most technique-sensitive step – the adhesive application. The resins in these composites contain glycerol phosphate dimethacrylate, a self-etching, dimethacrylate monomer capable of crosslinking and copolymerization with other methacrylates as well as the potential for chemical bonding with the tooth. There is also some evidence for micromechanical interlocking between polymerized monomers and partially demineralized collagen fibrils.<sup>9</sup>

**Ormocers:** This class of materials was developed by the Fraunhofer Silicate Research Institute, Würzburg, Germany. The term Ormocer represents ORGANICALLY Modified CERamic that refers to a 3D cross-linked copolymer that has a large backbone functionalized with polymerizable organic units and filler particles. These materials have been shown to have minimal volume shrinkage (<1.97%) and have excellent biocompatibility and superior strength and esthetics compared to conventional composites.<sup>10</sup>

### **Recent advances in glass ionomer cements**

The polyalkenoate or glass ionomer cement was originally invented by Wilson and Kent in 1969 and has been widely used for many years due to their desirable properties. Several key benefits include its ability to bind chemically with tooth structures via chelation of carboxyl group of acid polymeric chains and calcium ions ( $\text{Ca}^{2+}$ ) in the apatite of enamel and dentin. In addition, GICs have acceptable translucency, color and may exert an anti-cariogenic effect due to release of fluoride ( $\text{F}^-$ ) ions. Several modifications have been developed that continue to improve GIC properties. Broadly,

mechanical properties of GICs have been shown to be improved by grafting unsaturated carbon-carbon bonds onto the polyalkenoate backbone, incorporating dimethacrylate monomers or both into the composition.<sup>11</sup>

**Compomer:** This material represents a combination of a 'composite and glass ionomer and has two main constituents namely, the dimethacrylate monomers with carboxylic groups and a filler similar to the ion-leachable glass present in GICs. The ion-leachable glass is partially silanized to ensure partial bonding with the matrix. These material undergoes free radical polymerization but do not bond to hard tooth tissues or release  $F^+$  to same extent as conventional GICs.<sup>12</sup>

**HAInomers:** A new class of bioactive GIC with hydroxyapatite filler has been developed predominantly for maxillofacial surgery and retrograde fillings.<sup>13</sup> These bioactive materials actively participate in the cyclic exchange of ions between tooth and saliva. Their material strength, esthetics and physical properties are similar to composites while they can release more fluorides than conventional GICs. Another advantage is their ability to chemically bond and seal tooth surface to protect against bacterial leakage and secondary caries.<sup>14,15</sup>

**Zirconia-reinforced GIC:** A new bioactive hybrid material combining nonparticulate hydroxyapatite and zirconia within GIC was developed to improve the biocompatibility and bioactivity of the GICs with the surrounding bone and connective tissues. This material is processed by heat treatments at 700–800°C for 3 hours to enable development of crystallinity of composite powders and suitable mechanical properties.<sup>16</sup>

**High viscosity GIC or condensable GIC:** A material specifically developed for the atraumatic restorative technique (ART) has a high powder to liquid ratio and fast setting reaction. This enable the quick setting requirements for this technique and has good physical properties as a definitive restoration.<sup>17</sup> Newer modifications in restorative materials for ART have focused on addition of antimicrobial agents.<sup>18–20</sup>

**GIC with chlorhexidine hexametaphosphate (CHX-HMP):** Besides the disinfection effects of fluorides released from GICs, several attempts at incorporating antimicrobial agents have been attempted. GICs have been supplemented with CHX-HMP resulting in sustained (upto 14 months)

soluble chlorhexidine release.<sup>19</sup> This was shown to inhibit growth of *Streptococcus mutans* adjacent to material placement without compromising the mechanical properties of the restoration.

## 2. Surface replacements

Loss of the mineralized enamel surface leads to clinically evident white spot lesions initially. This is eventually followed by further loss of structural integrity and clinically visible, frank cavitation. Based on the major themes of this book on microinvasive dentistry, the remaining part of this chapter will focus on the three major approaches to minor, surface enamel replacement (**Table 2**). We have broadly divided these approaches into three major strategies:

1. Remineralization using ionic solutions
2. Promoting remineralization kinetics
3. Direct and templated approaches to enamel replacement

### Remineralization using ionic solutions

Based on the rationale that key constituents of highly mineralized enamel contain calcium and

**Table 2 Agents to improve remineralization**

Surface remineralization agents	Commercial products available
Conventional fluoride	Colgate, Crest, 3M, Toms, Himalaya
Silver diamine fluoride	Advantage arrest (Elevate Oral Care)
Nanosilver fluoride	SilverSol (MRSA medical)
Calcium carbonate carrier	Cavistat, DenClude, ProClude (Ortek Therapeutics)
Amorphous calcium phosphate	Arm and Hammer Complete Care Enamel
Casein phosphopeptides amorphous calcium phosphate	MI paste, (GC) Recaldent (GC)
Tricalcium phosphate	SensiStat (SensiStat Technology)
Bioactive glass	SoothRx (OMNII) Denshield (NovaMin Technology)
Infiltration resin technique	Icon (DMG)
Electrically-accelerated and enhanced remineralization	Reminova*
Laser-based technique	Biolase* (Er, Cr; YSGG), Morito* (Er;YAG)

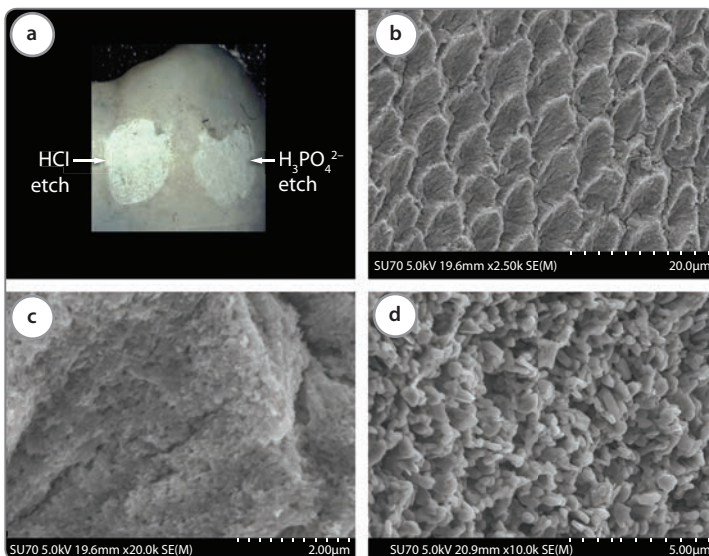
\* These technologies are available but clinical protocols based on rigorous human studies are lacking.

phosphate, various remineralization approaches have attempted to provide these key elements (Figure 2).<sup>21,22</sup> These remineralization mechanisms rely on epitaxial growth of residual apatite seed crystallites in the partially demineralized carious lesion.<sup>23–25</sup> These results in parts of their collagen matrix with remnant seed crystallites that can be effectively remineralized usually deeper, basal part of carious lesions. It is worth pointing out that while substitution of normal carbonated hydroxyapatite to fluorapatite makes it more acid resistant, fluoride enhanced surface hypermineralization prevents remineralization of deeper lesions.<sup>21,26</sup> Hence, to engineer superior remineralized enamel properties, several combinations of ionic replenishment approaches have been attempted.

**Conventional fluorides:** The fascinating history of the early 19th century inquiry into the Colorado brown stains in teeth led to the eventual realization of the protective effects of fluorides against tooth decay. Several studies examined the precise dose relationship of fluorides in various preparations where excessive levels result in mottled enamel versus low doses forming fluorapatites. The use of fluorides in preventing surface caries and effectively remineralizing early lesions has been well established. The precise mechanism of its anti-caries activity is based on the increased acid resistance of fluorapatite as compared to normal hydroxyapatite. This

has led to the formal public policy on fluoride supplementation in foods and drinking water to professionally applied topical gels and varnishes on teeth.<sup>27</sup> Some effects of  $F^+$  on inhibiting bacterial plaque were noted that has led to development of several new formulations.

**Silver diamine fluoride:** Among some of these multi-targeted formulations, silver diamine fluoride (SDF) is a non-invasive treatment method that aims to control the active growth of small, caries lesions and prevent further progression in younger patients.<sup>28</sup> SDF has a long history of testing in multiple clinical trials. In fact, SDF has long been utilized as a treatment plan in Japan since its introduction as early as the 1970s. SDF treatment is capable of arresting caries in primary teeth and permanent molars, as well preventing root caries lesions.<sup>29</sup> Clinical studies using SDF have noted its ability to arrest caries in 80–90% of patients.<sup>30</sup> Studies utilizing a 38% SDF solution either every 6 or 12 months have noted its effectiveness is comparable to flowable, high fluoride-releasing, glass ionomer fillings. The major benefit cited for SDF benefits is that a single annual application reduces susceptibility of tooth acid demineralization and possesses antibacterial properties that prevent collagen degradation. Prior studies have also shown that SDF can be safely combined with other treatments such as modified glass ionomer filling to improve treatment effectiveness.<sup>31</sup> However, a limitation



**Figure 2** Enamel ultrastructure examined via acid ( $H_3PO_4^{2-}$  or HCL) etching and scanning electron microscopy. (a) Acid-etched molar buccal surface. (b) Enamel rod structure following 12N HCL treatment for 1 hour. (c) Phosphoric acid-etched fibrillar surface at low power. (d) Phosphoric acid-etched fibrillar surface at high power.

of SDF treatments have been the dark-brown or black staining when applied to caries lesions. Ongoing efforts to mitigate this staining side-effect, such as with potassium iodide solutions, have shown limited efficacy.<sup>32</sup>

**Nano-silver fluoride:** A recently developed alternative that circumvents the undesirable staining effects of SDF, is called nano-silver fluoride (NSF).<sup>33</sup> It consists of a mixture of silver nanoparticles, chitosan, and fluoride. It has antimicrobial properties against the primary pathogens responsible for dental caries development and is effective at arresting active dental caries. NSF provides similar levels of effectiveness of arresting caries as SDF when applied once a year.<sup>34</sup> NSF provides another inexpensive and non-invasive treatment source for treating dental caries, especially in underprivileged areas challenged with the ability to provide proper, preventative dental care.

**Calcium carbonate carrier:** Various attempts at utilizing suitable peptide carriers led to exploration of arginine highly soluble arginine bicarbonate by Israel Kleinberg, New York.<sup>35</sup> This involved a reaction of highly soluble arginine bicarbonate surrounded of the poorly soluble calcium carbonate component. The adhesive properties of this composition enable formation of a paste-like consistency that fills open dentinal tubules and adheres to the walls. Because of its high alkaline pH, this material reacts with calcium and phosphate ions in the dentinal fluid promoting remineralization and protecting it from further acid demineralization. This product has also been used to treat early surface demineralization effectively.

**Amorphous calcium phosphate:** Mixing a high concentration of calcium chloride with sodium acid phosphate results in a glassy, non-crystalline precipitate due to double decomposition reaction in buffered pH solution called 'amorphous calcium phosphate' (ACP). This complex was first described by Posner and Eanes as a biologically relevant biomineral complex.<sup>36,37</sup> ACP undergoes hydrolysis in aqueous solution under physiological temperature and pH to form octacalcium phosphate. This serves as an important intermediate compound in both *in vitro* and *in vivo* hydroxyapatite formation. ACP can form complexes with a broad range of proteins and ions that increase its stability as

evident in blood and urine preventing its routine precipitation to form calcific deposits. This facilitated stability is also utilized in formulations to harness its role in remineralizing enamel. ACP is incorporated into toothpastes as two salts calcium sulfate and dipotassium phosphate. When the two natural salts are mixed together, they rapidly form ACP that can precipitate onto the tooth surfaces. ACP compounds are considered main ingredient for remineralization therapy due to their high solubility under oral conditions and ability to rapidly hydrolyze to form apatite.<sup>38</sup> However, the dual phase product significantly gets compromised during prolonged storage and has limited self-life and hence various other formulations with other protein complexes have been explored as described in the following sections.

**Casein phosphopeptides-amorphous calcium phosphate (CPP-ACP):** Casein in an abundant milk protein and has been shown to be responsible for the high bioavailability of calcium from milk and other dairy products.

Prof. Reynolds at the School of Dental Science at the University of Melbourne in Australia described the combination of CPP-ACP.<sup>39</sup> It contains the sequence Ser-Ser-Ser-Glu-Glu produced from tryptic digestion of the milk protein casein, then aggregated with calcium phosphate and purified by ultrafiltration. Under alkaline (pH 5–9) conditions, calcium phosphate is present as an alkaline amorphous phase complexed with CPP. These form a nanocomplex where CPP stabilizes calcium and phosphate ions forming that are supersaturated metastable solutions. CPP have the ability to bind and stabilize calcium and phosphate in solution, as well as to bind to dental plaque and tooth enamel. Calcium phosphate is normally insoluble as it has a crystalline structure at neutral pH.

When CCP-ACP nanocomplexes are generated, the calcium and phosphate are made available in an amorphous, noncrystalline state. In this amorphous state, calcium and phosphate ions can enter the tooth enamel and reduce the risk of enamel demineralization as well as actively promote remineralization of tooth enamel. The CPPs have also been shown to keep fluoride ions in solution, thereby enhancing the efficacy of the fluoride as a remineralizing agent.<sup>40</sup>

**Tricalcium phosphate:** A new hybrid material has been developed that fuses  $\beta$ -tricalcium phosphate with sodium lauryl sulfate or fumaric acid called 'tricalcium phosphate' (TCP). The addition of the latter chemical forms a protective surface layer preventing the TCP from aggregating. When this material is in contact with the tooth surface and moistened by saliva, the protective barrier breaks down releasing calcium, phosphate and fluoride ions to promote tooth remineralization. This material has also been used in combination with fluorides (950 ppm) in a paste form that has been shown to significantly increase tooth surface microhardness of eroded enamel. Other formulations of TCP include combinations with silica and urea that can be used along with fluorides to increase its anti-erosion benefits.

**Trimetaphosphate:** Another formulation of phosphate developed to promote remineralization is trimetaphosphate.<sup>41-43</sup> This material acts a biomimetic remineralization agent by diffusion of  $\text{Ca}^{2+}$  to the inner surface of enamel, particularly in areas devoid of seed crystallites and prevents calcium loss in acidic solutions. Multiple toothpaste containing 3% sodium trimetaphosphate studies have demonstrated a statistically significant reduction in DMFS index in a 3-year trial.

**Bioactive glass:** It is considered a break-through advance in remineralization technology.<sup>44</sup> It consists of a synthetic mineral containing sodium, calcium, phosphorous and silica or sodium calcium phosphosilicate. This unique material has numerous novel features, including the ability to act as a natural scaffold to promote mineralization. When in contact with saliva or water, this material first releases sodium ions that elevates the pH (pH 7.5-8.5) that is essential for hydroxyapatite formation. Calcium and phosphate ions are then released to further supplement normal levels in saliva. This increased ionic concentration combines with the increased pH resulting in precipitations of the ions onto the tooth surface forming calcium hydroxycarbonate apatite. This leads to a remineralization of the surface and protects the teeth from further acid damage.

### **Promoting remineralization kinetics**

Biom mineralization is generally regulated through interactions between hydrophobic components and hydrophilic molecules that regulate crystal

nucleation and growth.<sup>45,46</sup> The sapce occupying template proteins such as collagen interact with specific matrix proteins such as amelogenin (enamel) or dentin phosphoprotien (dentin) regulate crystal nucleation and growth that regulate crystal nucleation and growth.<sup>47-49</sup> This process emphasizes the dynamic nature of biomineralization involving a sequence of kinetic factors that modulate phase transformation and selective crystal structure and composition.<sup>50</sup> The conversion of ions to hydroxyapatite, the most thermodynamically stable calcium phosphate phase, involves a phenomenon termed the Ostwald-Lussac law of stages.<sup>51</sup> This process is pH dependent and involves mulple phase transfromationthat depend on the free energy of activation of mineral crystal nucleation and growth.<sup>52-54</sup> Hence, attempts have been made to promote biomineralization by directly modulating the reaction kinetics by providing external energy sources have been attempted.

**Laser-assisted remineralization:** An elegant recent review outlined the rationale for combination of fluorides with non-ablative laser treatments.<sup>55</sup> The authors highlight the increased temperatures (100-400°C) is capable of reducing crystalline water and carbonate ( $\text{CO}_3^{2-}$ ) in enamel and concomitant increase in structural hydroxide (OH) induces formation of pyrophosphates, tricalcium phosphate or tetracalcium phosphates.<sup>56,57</sup> Repeated heating and cooling effects facilitates fluoride incorporation into the mineralized crystal structure, hydroxyapatite resulting in generation of fluorapatites.<sup>58</sup> Mid-infrared laser-induced photothermal effects in the presence of fluorides have been noted to significantly increase the resistance to acid dissolution. However, the effects of with visible (He-Ne), visible and near-infrared (diodes) lasers remain to be fully investigated. The authors emphasize that while there are no gross structural changes, as melting point of enamel is not achieved, high resolution changes in lattice crystals are apparent via ultrastructural analyses.<sup>59,60</sup> These compositional and ultrastructural changes essentially increase the enamel resistance to acid demineralization.

**Electrically-accelerated and Enhanced Remineralization (EAER):** This is a novel approach aimed at remineralizing initial or

early stages of tooth decay being pioneered by Reminova, a spinout company of King's College London (Reminova). This non-invasive technique is based on the use of an iontophoretic electric field to electrically accelerate remineralizing agents at the site of a caries lesion. The process involves preconditioning the tooth by removal of decayed material followed by addition of a pool of remineralizing agents in a paste or fluid formulation. This is followed by placing electrodes on either sides of the lesion and applying a low electrical charge. Early experimental results demonstrated single treatment of EAER was able to significantly increase (up to 16% compared to remineralizing agents alone) mineral levels density and reduce total volume and depth of small lesions. These areas had increased hardness and were structurally similar to non-lesional enamel as apparent on electron microscopy.

### 3. Direct and templated approaches to aid enamel replacement

Biom mineralization involves physical-chemical process regulated by cells and intra- and extra-cellular matrices that increases local concentration of its component ions, a change in temperature or pressure, or lowers surface activation energy for initial mineral formation.<sup>61</sup> Potential delivery systems of treatment in clinic may require a secondary, protective scaffold such as calcium, chitosan/agarose hydrogels to withstand immediate mechanical washing within the oral cavity.

**Infiltration resin technique:** A recent development of a light cured composite infiltration technique has been shown to be effective for white spot lesions.<sup>62,63</sup> The appearance of WSL is attributed to reduced refractive index (1–1.3) by loss of mineralized enamel. The major rationale for this infiltration resin technique is to use low viscosity, low contact angles, high surface tension flowable composites to occlude white spot lesion porosities. The physical occlusion of the porosities with the resin results in increased refractive index (1.46) of the WSLs restoring the normal enamel (1.6) appearance. The presence of porosities also allows for WSLs to progress to frank cavitation due to poor hygiene and continued assault by microbial and

biochemical agents. Restoration of the physical enamel integrity by the infiltrative resin technique results in improved microhardness and prevents further demineralization within the WSLs.<sup>64</sup>

**Natural enamel proteins as scaffolds:** Common approaches to utilizing natural proteins as a means to mineralize enamel have mainly utilized Amelogenin. Experiments utilizing an Amelogenin scaffold have used a chitosan-hydrogel base mixed with calcium and phosphate, incubated in a solution of artificial saliva.<sup>65,66</sup> Amelogenin scaffolds have shown the capability that such biomimetic approaches can promote new enamel growth on etched enamel surfaces. Results of these studies have shown the formation of newly-organized apatite crystal growth in nearly parallel fashion along the C-axis, with similar thickness and diameters to native enamel. In the presence of Amelogenin, etched enamel surfaces also showed a significant increase in hardness and elastic modulus.<sup>67</sup> In addition to delivery in a hydrogel scaffold, Amelogenin has also been used to mineralize etched enamel in calcium-phosphate solutions mixed with fluoride.<sup>68,69</sup> Another biomimetic approach that utilizes natural enamel proteins, is the use of enamel matrix derivative (EMD). Treatment of demineralized enamel with an EMD-agarose hydrogel showed denser, thicker, and more organized hydroxyapatite crystal growth in comparison to treatment without EMD.<sup>70</sup>

**Synthetic enamel-analogs as scaffolds:** Among common approaches to remineralize the enamel surface, protein analogs have also been successfully used to mimic the mineralizing function of natural proteins. Native enamel matrix proteins are difficult to extract and store.<sup>71</sup> The major advantages of protein analogs include ease of synthesis, wide range of modifications and ease of storage. However, the full functions of amelogenin are still not yet completely understood. Therefore, it is unlikely protein analogs can fully provide the variety of secondary functions amelogenin may be responsible for. The most common protein analog-biomimetic approaches utilize a range of peptide sequences with discrete functionalities.<sup>72–76</sup> Such peptide solutions have shown the ability to provide nucleation sites and markedly increase hydroxyapatite on the surface of etched enamel. A number of recent studies have also utilized

modifiable, polyamidoamine (PAMAM) dendrimers in order to promote new enamel growth on the surface of etched enamel.<sup>77–79</sup> PAMAM dendrimers with varying carboxyl and phosphate terminating ends have shown the ability to bind well to the surface of etched enamel and induce the formation of organized hydroxyapatite nanorod structures. Similarly to Amelogenin, these dendrimers have also been shown to aggregate in a progression of smaller monomers and into larger microribbon structures *in vitro*, supporting the claim that such analogs can mimic the mediation role of natural proteins in order to induce new hydroxyapatite crystal growth.<sup>77</sup>

**Abiotic enamel:** The conserved structure of tooth enamel comprised of parallel microscale and nanoscale ceramic columns or prisms interwoven by a soft protein matrix suggests there is functional necessity to its structure. The columnar motif maximizes interfacial macroscale deformations providing superior load-bearing material properties. A recent attempt at replicating enamel structures by sequential growth of nanowire carpets and gradual deposition of a surrounding polymeric matrix is termed ‘Abiotic’ tooth.<sup>80</sup> This composite structure was generated by a layer-by-layer (LBL) deposition of polyallylamine and polyacrylic

acid adsorbed onto zinc oxide nanowires. This approach simulated the unique parallel and columnar shape of natural enamel and also recapitulated mechanical properties of natural enamel such as hardness, viscoelasticity and low weight. It is hoped this novel approach will lead to development of new biomineral-inspired restorative materials.

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## Conclusion and future directions

There are several exciting developments enabling enamel replacements using a minimally invasive approach. Besides surface remineralization strategies that are already clinically available, future developments for moderate to large lesions is ongoing. A formidable challenge in true enamel regeneration has been the lack of ameloblasts. Progress in induced pluripotent stem cell technologies along with sophisticated biomaterial scaffold systems offer promising future avenues.

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## Introduction

Photobiomodulation (PBM) is the application of monochromatic, non-thermal, low-intensity light at specific wavelengths typically in the range 400–1064 nm, from a laser or light-emitting diode (LED) over diseased, and injured tissue to promote healing, accelerate inflammation and reduce pain.

Photobiomodulation has been widely used for over four decades throughout the world as both primary and complimentary therapy and employed by many medical specialties and subspecialties, including physical therapy, osteopathic medicine, chiropractic medicine, dentistry, and acupuncture. However, the therapy remains controversial and has yet to become a mainstream treatment modality even though it has been proved to be a very effective non-invasive form of treatment. It can be applied locally and has both local and systemic effects but has no known side effects.

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## Photobiomodulation mechanism of action

The mechanisms are not completely understood but absorption of light by cytochrome c oxidase (COX) in mitochondria has been shown to increase in ATP production and reduce oxidative stress<sup>1</sup> leading to faster tissue repair, reduced inflammation and increased lymphatic flow, as a biostimulatory effect whilst higher power density lasers have been shown to reduce pain by the inhibitory effect, therefore, PBM concept describes the effect of light on cells more accurately. Lasers have also been shown to reduce the tenderness and irritability of myofascial trigger points. Cells under oxidative stress respond more favorably to the effects of light.

Primarily when cells are irradiated the photons are absorbed by chromophores in the mitochondria with COX being the photo acceptor and reactive oxygen species (ROS) are produced.<sup>2</sup> These act as signaling molecules that lead to a cascade of events which include the release of nitric oxide and triggers the production of ATP. The release of nitric oxide and other growth factors such as transforming growth factor- $\beta_2$  is also implicated in the promotion of angiogenesis.<sup>3</sup>

Secondly there is a change in the cell membrane potential that enables exchange of ions with more oxygen available for cellular activity and release of growth factors, endorphins and cell proliferation of fibroblasts and macrophages to promote repair.

There is also an inhibitory effect of the C-fiber and A-delta pain fibers thereby producing effective and non-invasive analgesia.<sup>4</sup>

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## Potential applications of photobiomodulation

In practice, the PBM concept is used for pain management, repair and regeneration of tissues, during and after simple and complex restorative, periodontal, orthodontic, endodontic, pedodontic and surgical procedures. Some diagnostic and therapeutic applications are being investigated and researched currently and this could widen its uses and become a mainstream modality in the future.

## Photoactivated disinfection

Light-based technology is not new to dentistry, in the early seventies the first dental curing light (Nuva light) was used for polymerization of composite resin, an ultraviolet in the visible blue wavelength spectrum, however, due to its

lack of depth of penetration in the materials it was succeeded by Tungsten halogen, plasma arc curing (PAC), lasers and now LED which are now commonly used. There are numerous materials that can be used with these lights for various applications routinely in dentistry.

With advances in light-based technology it is now possible to target the bacteria that can cause dental caries and periodontal breakdown and other common bacterial invasions in and around the oral cavity. With a specific wavelength of light source and a specific photosensitive dye the bacteria can be targeted and destroyed. This concept uses the principle of photodynamic therapy (PDT) where a dye is absorbed by the target cell and a light source specific to this dye upon activation causes the destruction of the cell. Use of PDT in cancer is very well known and the concept of light therapy has been used in ancient times by Egyptians (photochemotherapy), Greeks (heliotherapy) Chinese (phototherapy) and in Rome and India, where the sun was used as the light source.

Photodynamic therapy, phototherapy and photochemotherapy all use a photosensitive dye that is activated with a specific wavelength of light in the presence of oxygen. On absorption of this light energy, the molecule of the photosensitizer goes into an excited triple state, which can undergo photochemical reactions of two types:

- Type 1 - The molecule reacts directly with biological molecules generating free radicals
- Type 2 - An excited photosensitizer molecule reacts with an oxygen molecule resulting in singlet oxygen which is a strong oxidant, and is cytotoxic to the targeted cells or cellular structure. In dentistry, this could be used for antimicrobial disinfection and the use will increase as bacterial, fungal and viral infections can be targeted<sup>5</sup>

This concept has been adapted for bacterial disinfection in dentistry and can be implemented for caries, periodontics and endodontics,<sup>6-9</sup> implantology and restorative procedures in fact anywhere an anti-bacterial field is required.<sup>10</sup>

There are several commercial units available today with various devices either as laser or LED-based and these have different wavelengths and specific photosensitizers. Wavelengths in the 600–800 nm range is the optical window and the photosensitizers used in dentistry can be methylene blue, toluidine blue, medical grade

tolonium chloride, indocyanine green with iodine, indocyanine green without iodine.

The main benefits of photoactivated disinfection (PAD) are that it is safe, does not affect healthy tissue and there is no staining of the teeth or gingiva with most of the higher quality units which is important for esthetics. It is also quick and simple to use with only a 60 seconds contact time with tolonium chloride solution 60–120 seconds light activation time and easily integrated into normal treatment procedures and modalities. This proven LED technology is effective in eliminating all oral bacterial species including *Enterococcus faecalis*.

The concept of alternative antimicrobial agents is welcomed rather than pharmacological agents particularly in view of the increasing bacterial resistance to antibiotics and as chances of super infection and sensitizations are on the increase worldwide.<sup>11</sup> The chances of resistance to bacteria from PAD is greatly reduced or non-existent as the photosensitizer does not enter the cell transport system, it tags to the cell wall.

One of the significant advantages of having an effective antimicrobial agent is to aid in the repair of initial demineralized enamel or carious lesions and promote healing and remineralization sometimes seen in young adults or children with pit and fissure lesions. These lesions start in enamel as an invisible defect and then turn in to a white spot that progresses to dentin, the speed at which this happen could depend on the environment. There is a zone of partially demineralized dentin which is infected with bacteria which precedes the demineralized zone which is targeted to eliminate the bacterial niche and enable repair and remineralization.<sup>12,13</sup>

Photoactivated disinfection can be used for, caries disinfection, restorative, endodontic, surgical and periodontal cases, etc.

### **Photoactivated disinfection and replacement of sealant restorations**

Fissure sealants provide the most effective and minimally invasive treatment for the prevention of caries in the permanent dentition.<sup>14</sup> However, bacteria left under the sealant is a concern. Materials with an antimicrobial effect have been considered and used to mitigate this problem.<sup>15</sup> The use of PAD and appropriate hard tissue lasers prior to fissure sealants and sealant restorations

ensures that there are no viable bacteria that can colonize and re-infect the site (Figure 1).

### ***Photoactivated disinfection of carious lesions and remineralization of decalcifications***

Minor decalcifications in interproximal areas can also be treated in a similar way. Destruction of the bacteria colonizing the decalcified areas is followed by a mineralization program with remineralization paste, using custom trays to aid in the interproximal areas and oral hygiene maintenance and reinforcement (Figure 2). Any restoratives required can also be provided using the concept mentioned above.

### ***Multiple applications of lasers with photoactivated disinfection***

Disinfection of periodontal pockets with PAD helps to reduce the bacterial load in the pockets to accelerate and enable healing and recovery of gingival health (Figure 3). Root canals can also be treated using the same concept to ensure effective disinfection prior to sealing the canals. This is also applicable for internal and external whitening

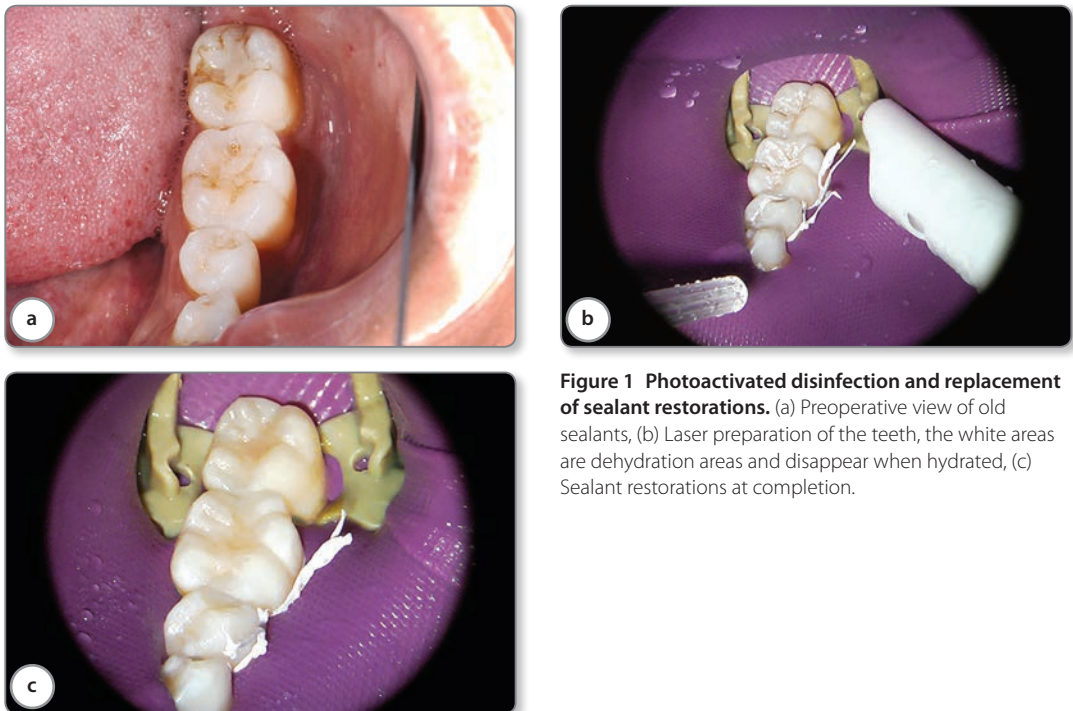
procedures in conjunction with a specific diode laser 810 nm wavelength and chromophore targeted whitening gel.<sup>16</sup>

## **Trauma**

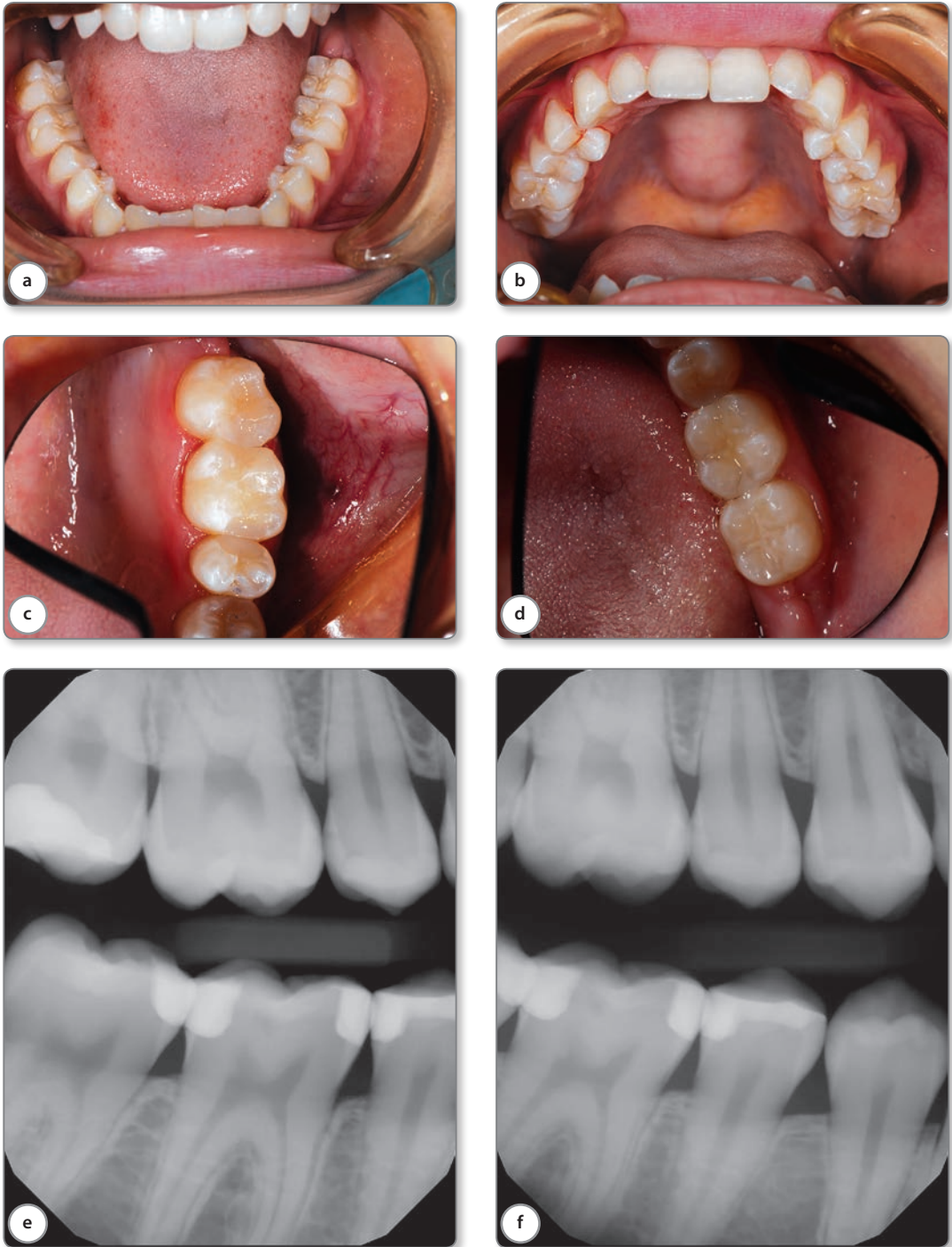
Accidental injuries to the anterior teeth occur in both the child (Figure 4) and adult (Figure 5) population and their management using a minimally invasive technique with the aid of lasers using the PBM concept to get the best outcomes are discussed.

The main complications of trauma to the anterior teeth are loss of hard tissue tooth structure, pulp death, pulp calcification, ankylosis and external root resorption.<sup>17</sup> In a luxation injury when the neurovascular supply to the tooth has been severed or damaged through trauma, some innate mechanisms for the revascularization and reinnervation are present. However, 43% of extrusive luxation lead to pulp death within the first year with some calcification and root resorption while 85–95% of intrusive luxation lead to pulp necrosis.<sup>18</sup>

These cases treated with laser therapy did not require any endodontic intervention which



**Figure 1 Photoactivated disinfection and replacement of sealant restorations.** (a) Preoperative view of old sealants, (b) Laser preparation of the teeth, the white areas are dehydration areas and disappear when hydrated, (c) Sealant restorations at completion.



**Figure 2 Photoactivated disinfection of carious lesions and remineralization of decalcifications.** (a) Lower arch occlusal view which appear normal but X-ray show the defects, (b) Upper arch view, (c) upper arch restorations completed at distal of first molar and mesial of second molar, (d) Lower first and second molar restorations completed. (e, f, g, h) Patient's bite wing X-rays show all the decalcifications and carious lesions. *Continues opposite...*

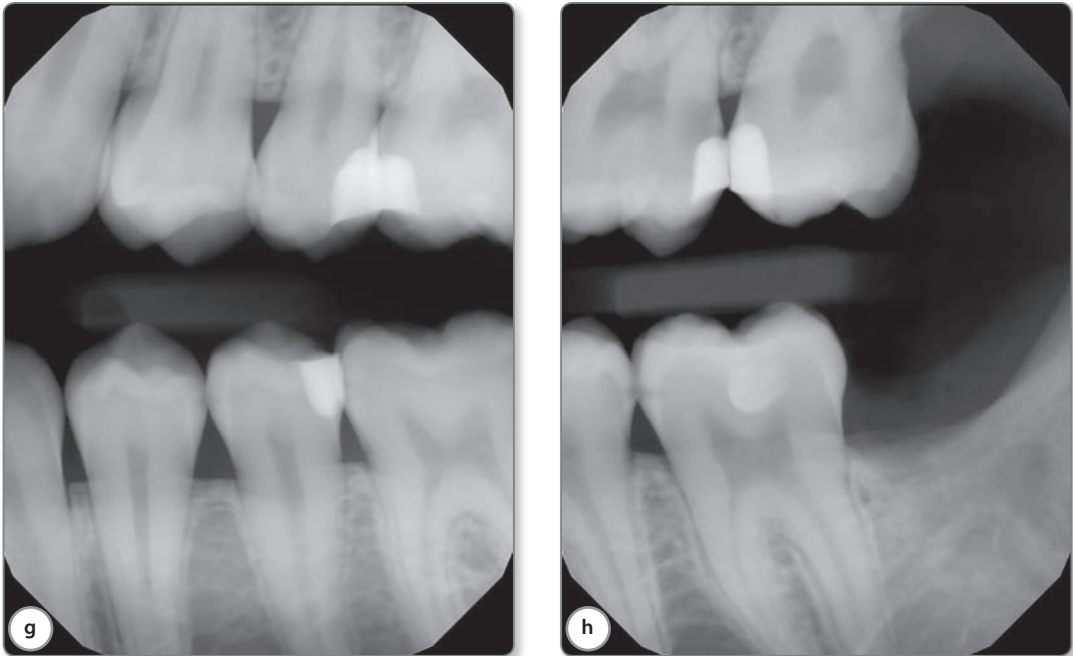


Figure 2 Continued...



**Figure 3 Multiple applications of lasers with photoactivated disinfection (PAD).** (a) Patients smile and concerns about the upper right central incisor, (b) Isolation of tooth for internal walk in bleaching, (c) Patients smile restored on interim basis, (d) Periodontal issues – presence of exudate from the pocket, (e) PAD of the site, (f) Immediate postoperative after removal of the spicule with a laser, (g) Final result and healing of the defect. *Continues overleaf...*

kept the treatment minimally invasive.<sup>19</sup> The preservation of vitality also reduced the need for any intervention which reduces the complications of coronal leakage.<sup>20</sup>

### Laser analgesia

The tooth is a highly sensitive organ and responds to a variety of stimuli, mainly tactile

during tooth preparation procedures, and thermal. As hard tissue lasers are used in a non-contact mode, there are no unpleasant vibrations unlike with a drill. Apart from that, analgesia during tooth preparation is achieved by inhibiting C-fiber and A-delta pain fibers by blocking depolarization with using high irradiance lasers.<sup>21</sup>



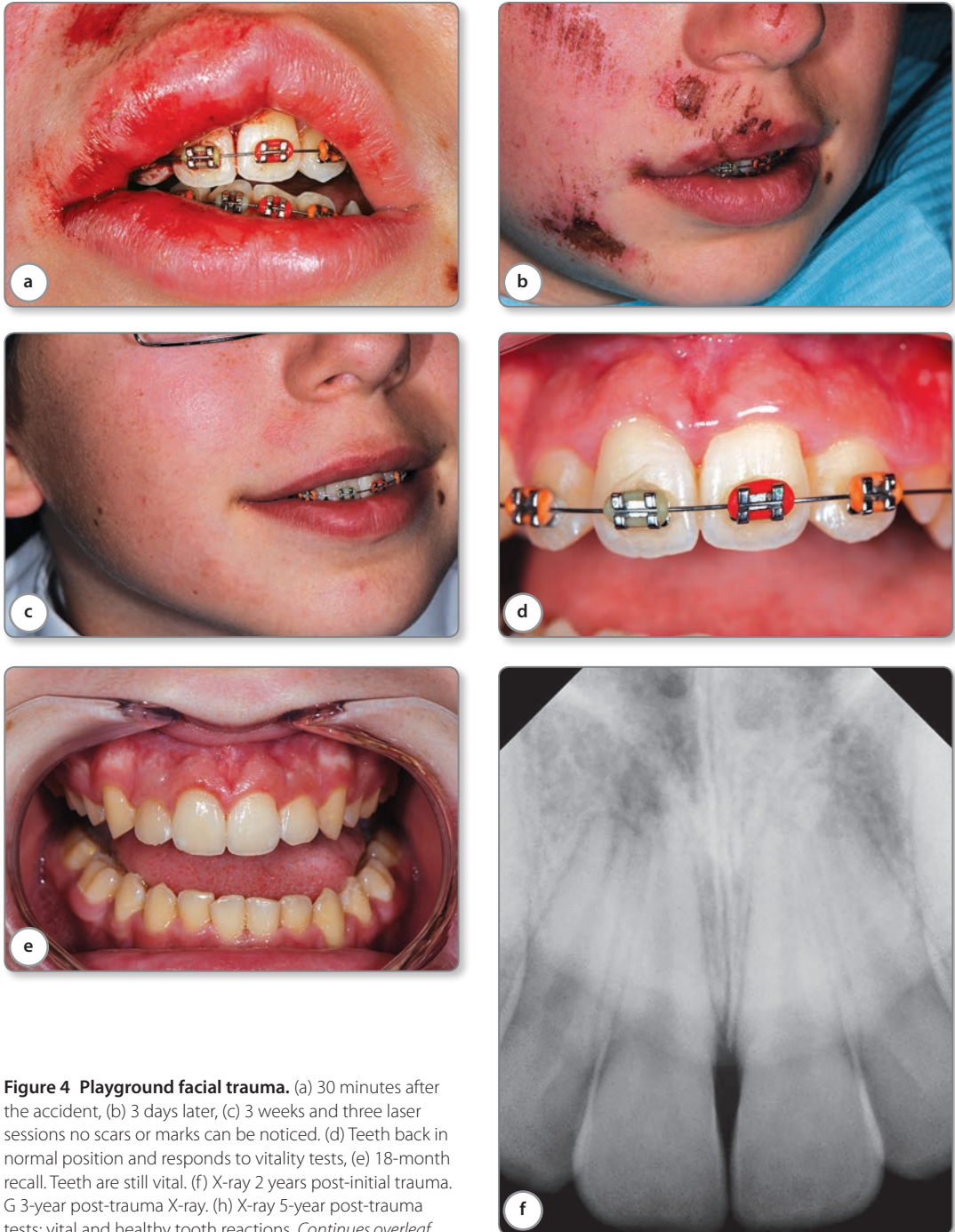


Figure 3 Continued...

Low level laser therapy (LLLT) has also been shown to relieve pain and is not only minimally invasive but also has no side effects. Studies note that an increase in urinary serotonin and opioid release occurs with LLLT irradiation, signifying the potential for pain reduction.<sup>22</sup> Laser irradiation also decreases the release and expression of tumor necrosis factor-alpha (TNF- $\alpha$ ).<sup>23</sup> Laser analgesia can be achieved by most diode lasers currently used in dental practice.

In clinical practice, laser analgesia has been shown to be effective with most high intensity

lasers, both hard tissue (Er:YAG, Er,Cr:YSGG, CO<sub>2</sub>) and soft tissue (diodes of various wavelengths and Nd:YAG), along with dedicated low level lasers. Many techniques have been advocated and even though these vary there is some overlap in their use in relation to the power density outputs. The high intensity lasers are used in pulsed modes and away (non-contact mode) from the tooth being treated and repeated exposures on different surfaces of the tooth usually starting with occlusal aspect at higher powers then on the lingual or palatal and buccal surfaces pointing toward the pulp, it is believed



**Figure 4 Playground facial trauma.** (a) 30 minutes after the accident, (b) 3 days later, (c) 3 weeks and three laser sessions no scars or marks can be noticed. (d) Teeth back in normal position and responds to vitality tests, (e) 18-month recall. Teeth are still vital. (f) X-ray 2 years post-initial trauma. G 3-year post-trauma X-ray. (h) X-ray 5-year post-trauma tests; vital and healthy tooth reactions. *Continues overleaf...*

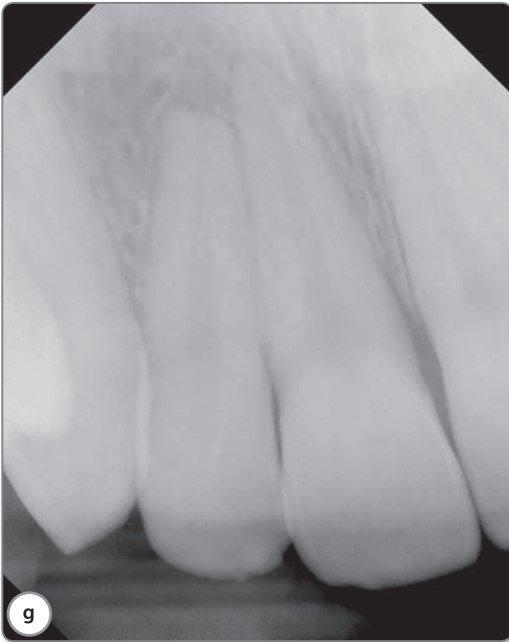


Figure 4 Continued...

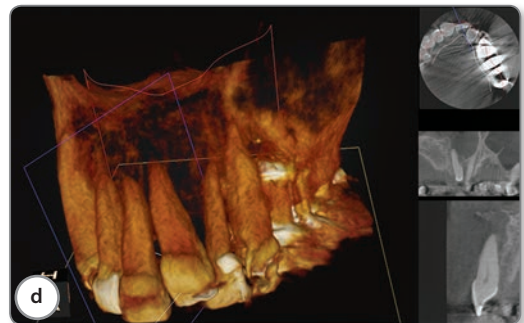


Figure 5 Facial trauma in an adult. (a) Pre-treatment assessment appointment, (b) retracted view of the damaged tissue and level of intrusion, (c) Laser preconditioning and with brackets *in situ*, (d) 3D cone beam CT (CBCT) scan, (e) Tooth back in its original position, (f) Recall appointment and teeth respond to vitality, (g) Postoperative 3D CBCT scan. *Continues opposite...*

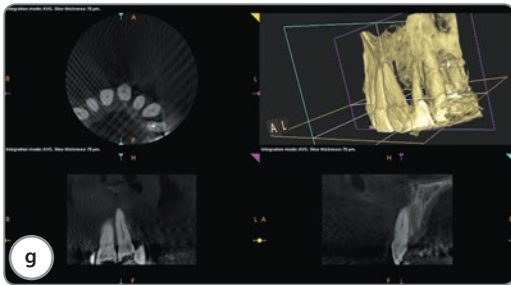


Figure 5 Continued...

that this effect is also produced continuously while treating the tooth for cavity preparation. The diodes are generally used in a continuous mode. The times vary from 90 seconds to few minutes depending on manufacturers protocols. Nd:YAG and even Argon lasers<sup>24</sup> have produced similar analgesic effects, the irradiation is just below the pain threshold of the tooth or the patient, usually this is provided in the inhibitory part of the PBM concept. Energies in the range of 18–20 J/cm<sup>2</sup>. On each buccal and palatal/lingual surface of the tooth and apical areas is used and sometimes occlusal surface as well (Figure 6). The effect is said to last about 15–20 minutes producing adequate analgesia for most patients. Again, this helps patients with phobias and is minimally invasive.

## Gag reflex

The gag reflex, also known as laryngeal spasm, is a reflex contraction at the back of the throat evoked by touching the lateral border of the tongue or the palate. Some patients have a hypersensitive gag reflex and dental treatment for them can be challenging or even impossible. Lasers are known to activate the acupuncture points that are

conventionally used with needles. Low level lasers are shown to be effective as they are non-thermal, non-invasive and have a good penetration in the red and near-infrared wavelengths. In our practice, we commonly use the acupuncture point L14-Hegu point which is a coin-sized spot on the top of the hand located between the thumb and the forefinger (Figure 7a). The laser is applied in contact mode delivering 4 J/cm<sup>2</sup> to the fleshy part between the thumb and the forefinger, and can give relief for up to 20 minutes. The other point commonly used is the CV24 which is a point under the lower lip in the midline (mentolabial groove) between the chin point and the lower lip (Figure 7b). Using a dedicated PBM laser with preprogrammed settings and right tip size makes this modality easy, fast and effective. In most jurisdictions auxiliary personnel can administer the PBM dose.

## Preconditioning

Preconditioning is a concept that is used in daily life but has not yet been translated in dentistry to improve outcomes prior to treatment by preparing the tissues for the assault of any intervention which can range from something



**Figure 6 Laser analgesia.** (a) Laser position on occlusal area of the molar, (b) Buccal position which can be on the cervical and toward the apical regions, (c) Lingual position cervical and toward the root apex.



**Figure 7 Gag reflex.** (a) Laser used on L14-Hegu point, (b) Laser used on CV 24-point in the chin area.

simple we do daily, to complex surgical procedures with the purpose of protection and survival.

Preconditioning has been used for centuries in the sports field where athletes travel to train in the climatic and geographical environments they may eventually face in the actual competitions.

Laser therapy now has an established role in improving treatment outcomes following surgery. Animal studies show that pretreatment with low level laser irradiation reduces the side effects of ionizing irradiation.<sup>25</sup> The pain and edema are also reduced in animals pre-treated with low level light therapy.<sup>26</sup>

In practice, this concept is applied before treatments such as endodontics, orthodontic appliance adjustments and any soft tissue surgery. This modality is also useful when treating patients with angular cheilitis and herpetic lesions which can be quite painful and made worse with stretching of the lips for access. Following dental treatment, local anesthesia reversal is another application that is most useful both for patient comfort and safety particularly in children who are more likely to chew a numb lip.

## Pulpitis

It is possible to use a PBM device or low level laser to help in diagnosis of the painful tooth. As there are no direct studies for this modality published yet, but in practice it is possible to locate a tooth that could be the one that's involved. Obviously thorough history and standard protocols need to be followed to identify the tooth in question whether it is reversible or irreversible pulpitis. Using a laser tends to increase the blood flow and circulation microscopically almost immediately; hence, placing laser at the suspected tooth root apex will do the same and in a pulpetic tooth will elicit a pain response in the tooth concerned and withdrawing of the laser for few minutes will ease the pain as the increased circulation dissipates and repeat of the laser action could help identify the suspect tooth, as a normal tooth will have no reaction to such a low energy.

Depending on the patient expectations sometimes a reversible pulpetic tooth when

treated with removal of the etiology along with PBM will tend to heal faster. In irreversible pulpitis a tooth once opened and caries removed and pulp exposed to relieve the pressure and if the pulp is not necrotic can be disinfected with PAD and pulp capped to try to maintain vitality but patient psychology and expectation may dictate the ultimate treatment provided. We have treated such cases in the practice with good outcomes.

## Conclusion

Use of PBM as a modality is becoming well accepted with numerous publications and research and considering it has virtually no side effects nor contraindications and helps patients to be comfortable, less apprehensive with ability to heal faster which they prefer compared to our conventional tools has to be something as a profession we should be able to offer all our patients with this standard of care.

## List of devices

- Thor laser with multiple wavelengths and handpicks in both lasers and LED lights.
- Lasersmile laser
- Lasotronix lasers
- Quantum Led light device
- Medx laser and LEDs
- Ezlase laser
- Sirona Siro Blue laser
- Zolar laser

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# Index

Note: Page numbers in **bold** or *italic* refer to tables or figures, respectively.

## A

Acid etching dentin 110, 110  
Acteon 55  
*Actinomyces* species 91  
Activa (Pulpdent Corp) 149, 149  
A-delta pain fibers 188  
Affected dentin 143  
Air abrasion 99  
    and acid conditioning of tooth structure 102  
    advantages 103–104, 108–110, 109  
    bond strengths, increase in 109  
    clinical applications 103–104  
    contraindications to use of 103, 110, 117–118  
    devices 118  
    history and scientific principles 99–100, 107–108  
    indications for use of, in microdentistry 110  
    interproximal lesions and 114–115, 115  
    interproximal restoration and 115–116  
    methods of soft tissue protection from 111  
    no harm to enamel and dentin by 109  
    operator objections to use of 118  
    other uses of 116–118, 117  
    particle delivery system 101–102  
    pit and fissure caries treatment 110–112  
    precautionary measures 110, 111  
    reappearance of new devices 101  
    remineralization of affected dentin by 116, 117  
    resurfacing composite resin restorations 116  
    root surface lesions and 116, 116  
    safety considerations and precautions 103  
    scientific research on 102  
    steps in technique for 112–116, 113–115  
    technique 107–118  
    types of particles 102  
    variables affecting 102  
Air-abrasive cavity preparation devices 104, 104  
Airdent 100, 107  
Aluminum oxide 101, 102, 109, 111  
Anorexia 20  
Autofluorescence of enamel 55

## B

Bioactive glass 178  
Bioactive glass powder 102  
Bioactive materials 144–146  
Bioactive product  
    Activa (Pulpdent Corp) 149, 149  
    Cerami Crown and Bridge Cement (Doxa AB) 148, 148–149  
    Gibbs–Donnan equilibrium 147

    NovaMin (Sylc) 147, 147–148  
    TheraCal LC (Bisco) 148, 148  
Bioglass materials 145  
Biomineralization process 146–147  
Bonding technique 122  
    bonding to dentin 124–125  
    mechanism of resin/enamel 124  
Bruxism 20, 21  
Bulimia 20  
Bulk-fill composites 173

## C

Calcium sodium phosphosilicate 102  
Calculus and plaque/biofilm 79  
Canary patient report 48  
Canary Scale 47  
Canary System 45  
    advantages 51  
    in clinical practice 45–48, 49, 50, 50–51  
    disadvantages 51  
    energy conversion technology 45  
    procedure 46–48  
    users of 48  
Caries detection technologies 35.  
    *See also* Canary System; Near-infrared (NIR)  
    transillumination; SoproLife  
    approaches 46, 46–47  
    CariVu 36, 36–37, 41–42, 42, 43  
    DIAGNOcam 36, 36, 42  
    methods 36–37, 37–38  
    use of VDDS and TWAIN interface 36  
Caries detector dye 103  
Caries lesions  
    acid solutions for removal of surface layer 11  
    classification of 11  
    clinical staging of 11  
    determination of treatment 11  
    radiographic evidence of 11  
    surgical treatment of 11  
Caries Management by Risk Assessment (CAMBRA)  
    protocol 22  
Caries prevention  
    anticaries preparations 8  
    bacterial control 6  
    diet 6  
    fluoridation of drinking water 3, 6–7  
    fluoride supplements 7–8  
    tooth brushing techniques 6  
    using silver diamine fluoride 8, 8  
    using topical fluoride preparations 7



Caries risk assessment 19–22  
 bacterial load 22, 23  
 questionnaire 19–22, 20–21  
 screening of cariogenic bacteria and future decay 22–23

Casein phosphopeptides-amorphous calcium phosphate (CPP-ACP) 177

Case study  
 class III caries 129  
 class IV lower incisor 131  
 class IV maxillary incisor 130  
 class V lesion 132  
 demineralization lesion 127  
 molar caries 128

Cavitation of enamel 11

Ceramir Crown and Bridge Cement (Doxa AB) 148, 148–149

Chromophore 119

CO<sub>2</sub> laser, 9300 nm  
 for caries removal and tooth preparation 137  
 class I restorative procedures 138, 139  
 disadvantages, conventional handpiece 137  
 laser beam size and spot size 136, 137  
 laser delivery system 136  
 laser plume 139  
 occlusal pits and fissures 138, 138  
 progress 135–136  
 sealant preparation 137–138

Composite resin restorations 116

**D**

Demineralization 12, 20–22, 35, 51

Dental caries 83  
 caries removal 138, 138  
 class II cavity preparations 139, 140  
 class III, IV, V, VI cavity 139, 140  
 contaminated tooth preparations 89–90, 90  
 crown preparation with small knitted cord 72  
 detection and treatment 72, 72  
 diversity of bacteria identified within 90–94, 91–94  
 endodontic therapy 74, 74  
 glass ionomer restoratives 96–98, 97  
 inactivating invisible microbes 84–87, 86, 87  
 infected and affected layer in 87–89, 88, 89  
 laser plume 139  
 methods for harvest of microbes present *in vivo* 84, 85, 86  
 microbes in 83  
 old alloys and repairing the tooth 141  
 posterior pediatric crowns 140, 141  
 silver diamine fluoride application 94–96, 95–96  
 support and training 74  
 tooth disinfection 85, 87

Dental decay 3, 4

Dental explorer 77, 77

Dental mirrors 77–78

Dentin 143  
 defined 143  
 overview 143–144  
 secreting cells 143  
 types 143

Detection dyes 77

DIAGNOdent value 61

Digital Imaging Fiber Optic Transillumination (DIFOTI) 35–36, 36

Dust issue 108

**E**

Ecological plaque hypothesis 92

Electrically-accelerated and Enhanced Remineralization (EAER) 178–179

Enamel, abiotic 180

Enamel matrix derivative (EMD) 179

Enamel regeneration  
 developmental program 171  
 enamel replacements 172–173  
 limitations of strategies 172–173, 173

Enamel replacement  
 abiotic enamel 180  
 infiltration resin technique 179  
 natural enamel proteins as scaffolds 179  
 synthetic enamel-analogs as scaffolds 179–180

Energy density measurement 120

Erbium laser handpieces  
 with tips 122, 123  
 without tips 122, 123

Etching 11–12, 14–15

**F**

Facial trauma 187–193, 191–193  
 complications 187

Fiber optic transilluminator (FOTI) 35

Fissure stain removal 62

Fluorescence 46

Fluoridation 3, 6–7

Fluoride mineral  
 exposure history 4, 5  
 sources 3, 7  
 therapeutic uses 3–4

Fluoride varnish 8

Fluorosis 3, 8

Fractured teeth 31, 33

Frequent polishing 92, 94

**G**

Gag reflex 193, 194

Gaussian beam geometry 122, 122

Gauze squares 103

Gibbs–Donnan equilibrium 147

Gingival collars 115, 1115  
 Gingival recession 3  
 Glass ionomer cements (GICs) 173  
   with chlorhexidine hexametaphosphate (CHX-HMP) 176  
   flowable bulk-fill materials 173  
   HA ionomers 175  
   self-adhesive resin composites 174  
   surface remineralization agents 175  
 Gluma Desensitizer treatment 89, 90

## H

Halogen operating light 78  
 HealOzone 153, 153  
 Helium gas 111–112  
 Hydrochloric acid 12, 14, 15

## I

Icon (resin infiltrant) 11–12, 16–17  
 Illumination, adequate 78, 78–79  
 Infected dentin 143  
 Infiltration resin technique 179  
 International Caries Classification and Management System (ICCMS) 11  
 International Caries Detection and Assessment System (ICDAS) coding system, for decay 23, 23–24  
 Interproximal caries 11  
   resin infiltration for 12  
 Interproximal coronal caries 79, 79  
 Interproximal restoration 114–115, 115  
 Intraoral video cameras (IOVC)  
   benefits 29, 32–33  
   best practices 30–31, 30–31  
   in case presentation 32  
   commercially available units 33  
   consultation room setup 32  
   development of 29–30  
   disadvantages 32–33  
   equipment 32, 32  
   images 30–31  
   models 29, 29–30  
   procedure 30–32  
   role in patient education 32

## K

KaVo-Kerr DIAGNOdent 62–63  
   advantages 64  
   disadvantages 64  
   failed amalgam margin 64, 64  
   measurement of the lesion 63, 63  
   ‘moment’ and ‘peak’ ports 63, 63  
 Kinetic cavity preparation (KCT) 101

## L

Laser-assisted remineralization 178  
 Laser delivery system 136  
 Laser devices 119

Light-based devices  
   CariVu 79, 79  
 Light-based technology 185  
 Light emitting diodes (LED) 78  
 Low level laser therapy (LLLT) 190

## M

Material seal 96  
 Microscope  
   advantages 67  
   components of 68, 70  
   crown preparation with small knitted cord 71  
   history 67  
   labeled parts of 67  
   levels of magnification 69, 70  
   magnification changer 70  
   mounting configurations 70  
 Minimal invasive conservative protocol 156  
 Mouth rinses 5–6

## N

Nano-silver fluoride 177  
 Near-infrared (NIR) transillumination. *See also* Caries detection technologies  
   band width 38  
   benefits 38–44  
   for caries detection 35  
   case example 41, 41–42  
   disadvantages 44  
   images 37–39, 40, 41–43  
 Nuisance dust 102

## O

Oral cavity abrasive polishing agent 102  
 Orthodontic separator 13–14, 13–14  
 Ozone therapy 153  
   ability to kill microorganisms 154  
   antibacterial efficacy 156  
   deciduous carious lesions treatment 155–156  
   effects on dental hard substances 157–158  
   effects on microbes 157  
   future 158  
   mechanism 154  
   safety and healing 153–154  
   smooth surface enamel caries lesions 155

## P

Paper triangular disks (Dry-Angles) 112, 113  
 Peak power 121  
 Pen Model DIAGNOdent 61–62, 62  
 Photoablation 119, 120  
 Photoacoustic 119  
 Photoacoustic effect 119  
 Photoactivated disinfection 186  
 Photobiomodulation (PBM) 185  
   applications 185

lesions and remineralization of decalcifications 187, 188  
 mechanisms 185  
 with photoactivated disinfection 187, 189  
 replacement of sealant restorations 186–187, 187

Photochemical reactions  
 type 1 186  
 type 2 186

Photothermal radiometry and luminescence (PTR-LUM) 45

Pit and fissure caries treatment 110–112

Preconditioning 193–195

Pulpitis 195

Pulse duration 120

Pulse repetition rate 121

## Q

Quantitative light-induced fluorescence (QLF) 23, 67

## R

Recaldent (phosphopeptide-amorphous calcium phosphate (CPP-ACP)) 7

Remineralization 7, 47, 51, 116, 117  
 of brown spot lesions 48–50, 50  
 products 7

Resin infiltration 11  
 commercially available 12  
 effectiveness of 13  
 for demineralized smooth surface lesions 17, 17  
 for interproximal lesions 12  
 for white spot lesions 17, 17  
 initial steps 12  
 principle of 12  
 procedure 13–16, 13–16

Restorative prescription  
 aspiration of odontoblasts 162  
 composite resin 167  
 disinfection of the dentinal structures 163, 163  
 heat and friction 162, 162  
 iatrogenic damage 164  
 lubricant contamination 162  
 Mud Flaps 164  
 no harm to patients 164  
 noise and vibration 163–164  
 pulpal injury 162  
 smear layer 162–163  
 use of amalgam 166–167, 167

Root surface lesions 116, 116

Rotary instruments 108, 109

Rubber dam 103, 110

## S

Salivary contamination, of infiltration process 12

Sandwich technique 97

Schick CDR 59

Screening of cariogenic bacteria and future decay  
 ATP screening 22  
 bacterial culture 23  
 CAMBRA process of determining risk profile 22  
 of gum line notching 22, 23  
 pH check 23

Sealant restorations, photoactivated disinfection and replacement 187, 187

Shallow root carious lesions 155

Silver diamine fluoride (SDF) 94–96, 95–96

SoproLife 55, 55–56  
 applications 57  
 blue fluorescence mode 56, 56, 58  
 operating portion of 56  
 white or daylight mode 56  
 working head of 56

Subgingival lesion, partially 116, 116

Subjectivity of tests 80

SYCL powder 116, 117

## T

TheraCal LC (Bisco) 148, 148

Therapeutic bandage 96–97

Thermal effect 119

Tooth desensitization, formulation for 89

Tooth disinfection 85, 87

Toothpastes  
 with fluoride 4  
 RDA value 24–25

Transillumination of teeth 35, 46  
*See also* Near-infrared (NIR) transillumination

Trauma 187

Tricalcium phosphate 178

Triethylene glycol dimethacrylate (TEGDMA) infiltrants 12

Trimetaphosphate 178

## V

VDDS interface 36

## W

Whisperjet 2000 107

White spot lesion 47

## X

Xerostomia 20, 21

