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Early Caries Detection:

An Evolution in the way we Diagnose and Treat Dental Caries

The treatment of dental caries has not changed radically since the time of GV Black. Detection of carious lesions depended upon locating mineral loss on bite wing radiographs, examining stain and discoloured areas on the tooth surface or probing lesions with a sharp explorer. Until very recently, surgical intervention was considered the cure for dental caries. The dental profession has been trained in a wide range of operative techniques to "cure dental caries" and restore lesions. Granted, restorations have become more conservative with the introduction of bonding but detection and treatment was done once the lesion was fairly large. There are a number of new and exciting technologies that can locate and monitor early small carious lesions. When combined with new technologies for remineralization of these lesions we can treat carious lesions or remineralize without the need for surgical intervention.

Dental caries, according to the United States Surgeon General report on Oral Health in America, is one of the most common chronic diseases among five to seventeen year olds. In their study, it was more common than asthma, hay fever or chronic bronchitis. Although we do not have this type of data available in Canada, one can assume that dental caries is extremely prevalent in the population. A great deal of a general practitioner's time is spent treating dental caries. The dental profession's understanding of caries and treatment approach has been evolving as new diagnostic devices and preventive techniques are introduced to our practices. In 2001, the National Institute of Health's (NIH) Consensus Conference on the Diagnosis and Management of Dental Caries throughout Life concluded:

> "Dental caries is an infectious, communicable disease resulting in destruction of tooth structure by acid-forming bacteria found in dental plaque, an intraoral biofilm, in the presence of sugar. The infection results in the loss of tooth minerals that begins with the outer surface of the tooth and can progress through the dentin to the pulp, ultimately compromising the vitality of the tooth."

This statement combines a number of new components from the traditional approach taught over the last twenty years in dental schools. Our patients assume that tooth decay is caused by eating sugary foods, not that dental caries is an infectious communicable disease caused by acid forming bacteria. One can place a number of restorations in a mouth, without treating the underlying disease. The bacteria remain in the plaque biofilm on the remainder of the teeth capable of creating new areas of decalcification and cavitation. Patients are beginning to expect that we can treat this disease or at least provide them with a reason as to why they or their children continue to develop carious lesions.

What is Dental Caries?

Dental caries arises from an overgrowth of specific bacteria that can metabolize fermentable carbohydrates and generate acids as waste products of their metabolism. Streptococci mutans and Lactobacillus are the two principal species of bacteria involved in dental caries and are found in the plaque biofilm on the tooth surface. When these bacteria produce acids, the acids diffuse into tooth enamel, cementum or dentin and dissolve or partially dissolve the mineral from crystals below the surface of the tooth. If the mineral dissolution is not halted or reversed, the early subsurface lesion becomes a "cavity". These early subsurface lesions are not detectable with our current technology but can be detected and monitored with some of the new emerging techniques.

These bacteria along with others colonize tooth surfaces as plaque which researchers have now come to recognize as a biofilm. A biofilm is a well organized cooperating community of microorganisms. Microorganisms in a biofilm are not evenly distributed. They are grouped in micro colonies surrounded by an enveloping intermicrobial matrix. Bacteria in biofilms communicate with each other by sending out chemical signals that can trigger the release of proteins and enzymes. This type of environment may contribute to some of the resistance to anti-microbials. One of the best methods for dealing with plaque biofilm is its meticulous removal by brushing or professional cleaning. The use of some anti-plaque agents such as chlorhexidine, hexetidne amine fluoride / stannous fluoride, triclosan and others may inhibit biofilm development and maturation as well as affect bacterial metabolism and thus help in the prevention of caries and periodontal disease. One of the

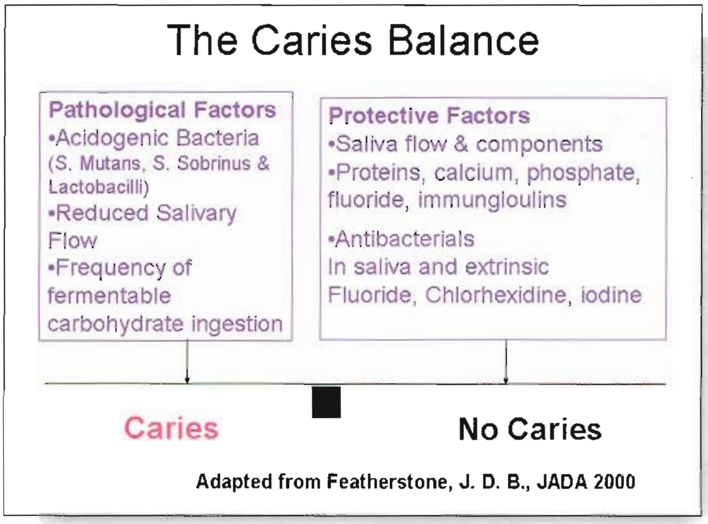

Fig. 1: The Caries Balance.

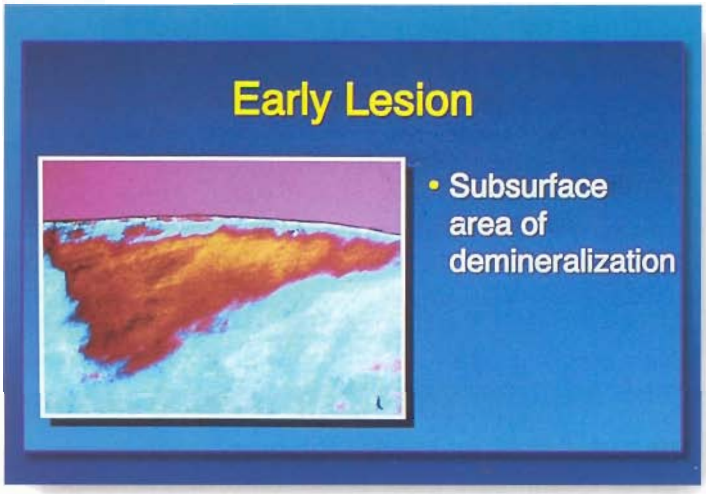

Fig. 2: Early demineralized lesions from Crest.

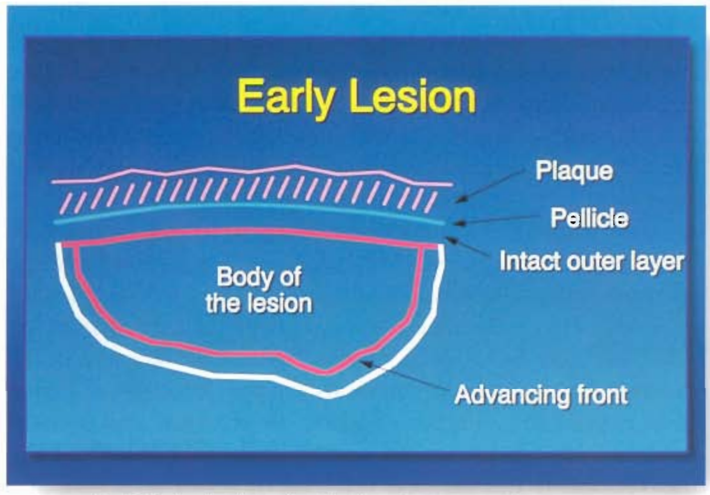

Fig. 3: Early demineralized lesions from Crest line drawing.

new emerging techniques, Prevora, involves application of a coating of chlorhexidine to root surfaces to reduce bacterial growth and prevent lesion formation.

The tooth surface undergoes demineralization and remineralization continuously, with some reversibility. When exposed to acids, the hydroxyapatite crystals dissolve to release calcium and phosphate into the solution between the crystals. These ions diffuse out of the tooth leading to the formation of the initial carious lesion. The reversal of this process is remineralization. Remineralization will occur if the acid in the plaque is buffered by saliva, allowing calcium and phosphate present primarily in saliva to flow back into the tooth and form new mineral on the partially dissolved subsurface crystal remnants. The new "veneer" on the surface of the crystal is much more resistant to subsequent acid attack, especially if it is formed in the presence of sufficient fluoride. The balance between demineralization and remineralization is determined by a number of factors. Featherstone describes this as the "Caries Balance", or the balance between protective and pathological factors (see Figure 1).

These early lesions (both enamel and root surface) typically have an intact hard outer surface with subsurface demineralization. The tooth surface remains intact because remineralization occurs preferentially at the surface due to increased levels of calcium and phosphate ions. Figure 2 shows a cross-section of an early carious lesion using polarising light microscopy. The line drawing in Figure 3 shows the various layers in an early lesion. The clinical characteristics of these early carious lesions include:

- Loss of normal translucency of the enamel resulting in a chalky white appearance particularly when dehydrated,
- Fragile surface layer susceptible to damage from probing, particularly in the pits and fissures,
- Increased porosity, particularly of the subsurface, with increased potential for uptake of stain,
- Reduced density of the subsurface, which may be detectable radiographically (depending upon mineral loss and location) or with transillumination (depending upon location and loss of mineral),
- Potential for remineralization with increased resistance to further acid challenge particularly with the use of enhanced remineralization treatments.

Radiographic and Visual Examination of Carious Lesions

Up till now we have been using visual and radiographic examination in order to detect and monitor lesions. These techniques are satisfactory if there is a substantial cavitated carious lesion. Detecting early pit and fissure caries is very difficult. Radiographic imaging is of minimal diagnostic value because of the large amounts of surrounding enamel. A number of studies have found the dental explorer inefficient for the diagnosis of occlusal caries. There are a number of the concerns with the use of the explorer in detecting pit and fissure caries:

- Since cavitation in pit and fissure caries occurs late in the disease process, using an explorer stick to detect caries only finds larger lesions,
- Probing an occlusal pit or fissure could convert a small lesion into a larger one,
- The probing could produce irreversible traumatic defects in areas that have the potential to remineralize,
- Probing can inoculate the fissure with microorganisms from other intraoral sites ,
- A stick or catch with an explorer may be due to fissure morphology or probe pressure rather than a carious lesion.

Radiographs do perform well in detecting carious lesions in between teeth (interproximal areas), especially if the area of decay is at least half way through the enamel into dentin In terms of early lesion detection, radiographs are not able to detect small lesions in the order of 50 – 100 μ (microns) in the interproximal areas, which could remineralize if detected early and suitable preventive measures instituted. An extensive review of the literature by Dove found that "overall the strength of the evidence for radiographic methods for the detection of dental caries is poor for all types of lesion on proximal and occlusal surfaces". He further stated that "it is beneficial only if the intervention is the surgical removal of tooth structure and detrimental if it is used for non-invasive remineralization methods". Pretty and Maupome in their review of radiographic diagnostic procedures concluded that "for interproximal lesions a clinician using radiographs can be very certain of the lack of disease in apparently sound surfaces (97% specificity) but not as certain that disease is indeed present in suspect interproximal surfaces (54% sensitivity)". As dentistry moves to a preventive model for treating dental caries the need for early lesion detection and non-surgical intervention becomes critical.

Over the last number of years, a number of new technologies have come on to the market that will aide in early caries detection. Each one of these new technologies can locate and monitor these early carious lesions to some degree.

DIAGNODent

Kavo first introduced DIAGNODent to the dental market place over ten years ago. DIAGNODent uses laser excitation to distinguish between carious and healthy tooth structure. The device is based upon the fluorescence caused by porphyrins (chromophores or coloured protein molecules) present in carious tissue and not the amount of enamel demineralization. Porphpyrins are also found in a number of oral bacteria but not the prime bacteria found in dental caries (Strep mutans and Lactobacilli). Porphyrin fluorescence lead to false positives since porphyrins are also found in stained, healthy fissures. A

Fig. 4: DIAGNODent on tooth.

number of studies were performed to assess the feasibility of using this device , and it has been evaluated as having the potential to improve occlusal caries assessment compared to visual examination and radiographs. Nevertheless, a validity study involving the DIAGNOdent concluded that it was not statistically significantly different from visual inspection. Furthermore, it was concluded that the DIAGNOdent was suitable for detecting small superficial lesions, rather than deep dentinal lesions. There are various sensitivity and specificity values obtained for the DIAGNOdent and they differ widely among different researchers, 0.76 ~ 1.00 for the sensitivity and 0.47 ~ 0.94 for the specificity.

Some clinicians advocated using DIAGNODent for detecting and restoring early carious lesions. Other clinicians advocated using the device for monitoring early carious lesions. Ongoing research discovered that certain dental polishing pastes that became trapped in the occlusal grooves also luminesced when exposed to the DIAGNODent light creating a false positive signal In addition, plaque, calculus and composites also created a false signal.

QLF (Quantitative Laser Fluorescence)

QLF or Quantitative Laser Fluorescence was developed by Inspektor Research in the Netherlands. A laboratory device has been developed and introduced to the market place. QLF in co-operation with 3M have introduced a clinic model to the market place North American market place. QLF™ is a dental diagnostic tool for in-vivo and in-vitro quantitative assessment of dental caries lesions, dental plaque, bacteria activity, calculus, staining, and tooth whitening. With QLF real-time fluorescent images are captured into the computer and stored in an image database. Optional quantitative analysis tools enable the user to quantify parameters like mineral loss, lesion size, stain size and severity with precision and repeatability. Several studies have demonstrated the ability of the QLF system to detect and monitor caries over time, both in children and adults. The

Fig. 5: QLF showing computer and monitor.

principle behind it relies on the fact that the enamel surface will fluoresce under certain optical excitation conditions. If the enamel is demineralized, the enamel fluoresces less and this loss of fluorescence is detected and quantified by QLF. QLF does look promising but there is need to develop the capability to probe lesion depths. At times QLF can not distinguish between caries, stains and white spots due to fluorosis. It may not be able to detect interproximal lesions deep within the contact area.

D-Carie from NEKS Technology

The D-Carie detector from NEKS Technology detects reflected light from the tooth surface. Using an incident beam from an LED, the device measures the reflectance. Healthy enamel is more translucent than demineralized enamel so the device is able to measure and quantify the change in reflectance. D-Carie is able to detect early caries on smooth surfaces, interproximal areas and occlusal fissures. There may be false positives associated with the following conditions :

- teeth with growth malformations in enamel or dentin such as amelogenesis imperfecta
- teeth with dark stains
- hypermineralization
- hypocalcification
- dental fluorosis

The D-Caries is not made to be used:

- on or at the interface of dental restorations or for residual drilling caries detection
- on buccal and lingual areas of anterior and posterior teeth
- on dark brown stains, calculus and intense plaque,
- on restorations and sealants
- on primary teeth.

Since the technology is based upon reflectance and not luminescence the device can not detect lesions below the surface and can be fooled by dark stain and surface topography. The technology was just introduced in 2006 with very little published background research initially.

Photothermal Radiometry and modulated Luminescence (PTR/LUM)

In our laboratory we are in the final phases of developing a laser based device for detection of early carious lesions. Our approach has been to not only look at the luminescence or fluorescence (reflected laser light) but to also look at the heat that may radiate back from the tooth. PTR/LUM sends pulses of one wavelength of light in the near infrared (but still visibly red) range of the spectrum at fixed repetition rate (frequency) to the tooth and gets back two different signals. One is ac fluorescence. The other is infrared radiation (heat). Part of the near-infrared light that hits the tooth enamel and dentin gets converted into heat and raises the temperature of the tooth by about one degree Celsius while the intermittent light shines on the tooth. This slight oscillating increase in temperature should have no effect on the health or integrity of the dental pulp or nerve of the tooth. An infrared detector captures the emitted thermal radiation and measures how far that heat travels to

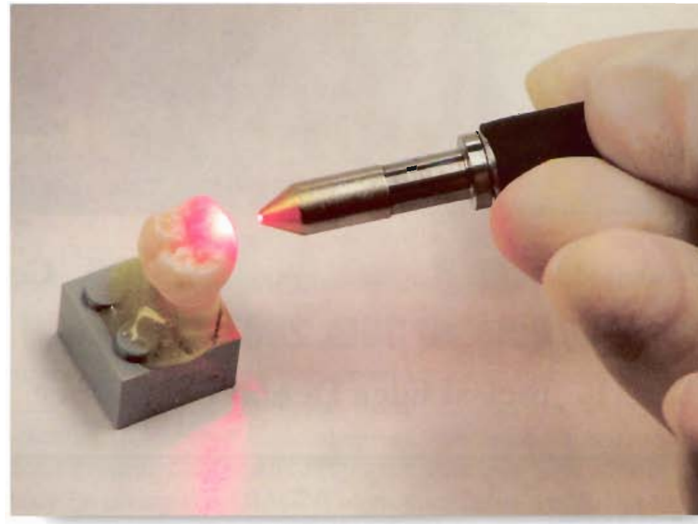

Fig. 6: PTR device.

give information about the deeper regions of the tooth. Although it is possible to see down about 4-5 millimetres (the average depth of tooth enamel), the depth is controlled by the cycling on — off frequency of the light that is used. Low frequencies about 5 Hertz, are deep probes because the heat that is generated pulses up and down very slowly and so it penetrates very deeply into the tooth. Whereas high frequencies, around 1,000 Hertz are shallow probes because there is not enough time for the heat to move up and down between the pulses of light. Therefore, by changing the cycling frequency of the laser pulse, a dentist can probe different depths inside enamel or dentin, a unique feature of the method called dental depth profilometry.

In addition to heat, part of the laser energy is converted to visible pink luminescence, which can be measured using simple inexpensive commercial detector devices called photodiodes. Luminescence is limited, however, by the optical scattering

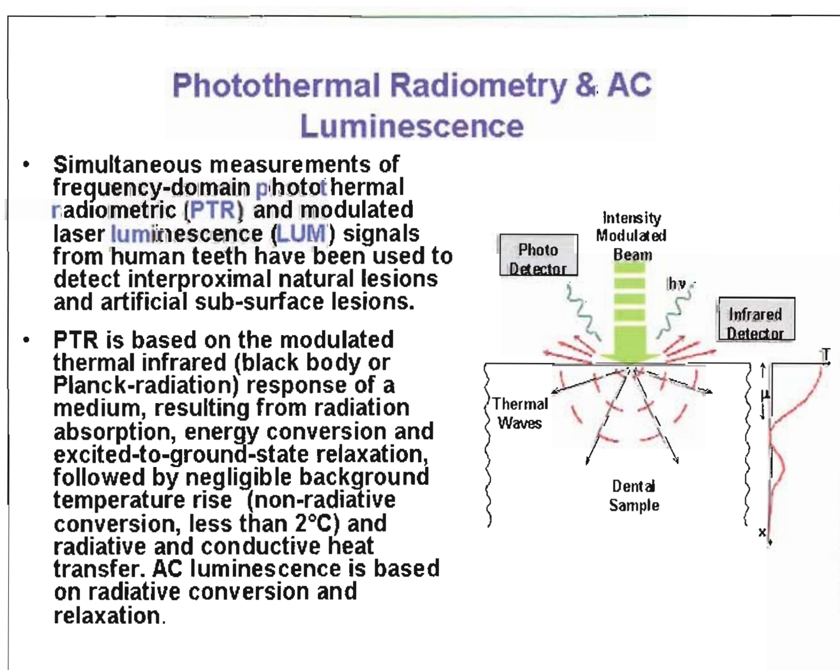

Fig. 7: Photothermal Radiometry & AC Luminescence.

process of the original light inside the tooth. We found that ac luminescence decays differently depending upon the degree of demineralization of the tooth enamel. Therefore the technique has an important advantage over continuous luminescence, such as that monitored by the DIAGNODent in that an appropriate frequency compatible with the luminescence decay rate can be used to highlight demineralized and healthy areas of the tooth. The integrity of the tooth surface can be mapped, for instance by means of scanning the laser across the tooth surface. This would allow a dentist to outline the extent of the tooth decay in a tooth much like a dental x-ray currently does without the danger of radiation exposure.

Over the last several years we have published a series of papers outlining the ability of PTR/LUM to detect dental caries. We have shown that PTR/LUM can detect:

- Occlusal Pit and fissure caries
- Smooth Surface Caries
- Acid Erosion Lesions
- Root Caries
- Interproximal carious lesions
- Demineralization and Remineralization of early carious lesions

PTR/LUM has demonstrated that it is able to detect small early lesions in order of 50 microns in depth even in the interproximal regions of teeth.

Detecting Secondary Caries Around Restorations

This is one of the most challenging clinical situations for all these new technologies. Restorative materials including amalgam and composite resin, at times, mask the ability of laser light or other forms of energy penetrating the material. Radiographs can show us defects along the gingival seats of Class II restorations but they can not examine the walls of the restorations nor the occlusal surfaces. DIAGNODent, D-Carie and QLF have problems with caries detection although QLF is able to monitor the margins of composites and sealants on the occlusal, buccal and lingual surfaces.

We are in the midst of a study on the detection of early carious lesions along the visible margins of the tooth using PTR/LUM. Our preliminary unpublished reports indicate our ability to detect and monitor these lesions. More data will be forthcoming in the next few months.

Summary

Early caries detection and monitoring is the next step in the evolution of the treatment of dental caries. With our expanding ability to detect and monitor early carious lesions we can also monitor the effects that various preventive therapies have on these lesions. Remineralization of a lesion by the application of a compound is preferable to the placement of filling. This non-invasive approach to the treatment of dental caries is becoming a reality and we can finally detect and treat lesions at an early stage in the caries process without the need for operative or surgical intervention.

Disclosure:

Dr. Stephen Abrams is a partner in the development of PTR/LUM technology for the detection and monitoring of early carious lesions. He has not received any compensation for the preparation of this article.

About the Author

Stephen Abrams is a general dental practitioner with over 26 years of clinical experience. Upon graduation from the University of Toronto Faculty of Dentistry in 1980 he established a group practice in Toronto Canada which has grown to involve general dentists and dental specialists. Dr. Abrams is the founder of Four Cell Consulting, Toronto Ontario, Canada, which provides consulting services to dental companies in the area of new product development and promotions. Dr. Abrams recently founded Quantum Dental Technologies, a company developing laser based technology for the early detection and ongoing monitoring of dental caries. He is a fellow of the Pierre Fauchard Academy and the Academy of Dentistry International, member of the Canadian Academy of Esthetic Dentistry, International Academy of Dento-Facial Esthetics, European Association for Caries Research and International Association of Dental Research. He has published over 80 articles in various international publications on topics ranging from early caries detection, prevention, removable prosthetics and restorative dentistry. He has developed the "Triple Laminate Technique for utilizing soft tissue undercuts when fabricating complete and partial dentures. Dr. Abrams was awarded the Barnabus Day Award from the Ontario Dental Association for 20 years of distinguished service to the dental profession. He is one of the founding board members of ACCERTA Claim Corporations, a dental and pharmacy claims management company. He can be contacted at 416-265-1400 or e mail; dr.abrams4cell@sympatico.ca

References available upon request.