

Minimal Intervention Dentistry principles and objectives

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Abbreviations and acronyms: CPP-ACP = casein phosphopeptides-amorphous calcium phosphates; ICDAS = International Caries Detection and Assessment System; MID = Minimum intervention dentistry

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ABSTRACT

MID is the modern medical approach to the management of caries, utilizing caries risk assessment, and focusing on the early prevention and interception of disease. Moving the focus away from the restoration of teeth allows the dentist to achieve maximum intervention, with minimal invasive treatments. The four core principles of MID can be considered to be: (1). *Recognition*: Early identification and assessment of potential caries risk factors through lifestyle analysis, saliva testing and using plaque diagnostic tests. (2). *Reduction*: To eliminate or minimize caries risk factors by altering diet and lifestyle habits and increasing the pH of the oral environment. (3). *Regeneration*: To arrest and reverse incipient lesions, using appropriate topical agents including fluorides and casein phosphopeptides-amorphous calcium phosphates (CPP-ACP). (4). *Repair*: When cavitation is present and surgical intervention is required, conservative caries removal is carried out to maximize the repair potential of the tooth and retain tooth structure. Bioactive materials are used to restore the tooth and promote internal healing of the dentine. Effective implementation of MID involves integrating each of these four elements into patient assessment and treatment planning. This review paper discusses the key principles of MID as a philosophy of patient care, and the practical objectives which flow into individual patient care.

INTRODUCTION

In general dental practice, much energy and time is devoted to the restorative treatment and retreatment of dental caries. On a day-to-day basis, it is easy to focus on repairing cavitations (the end result of the disease process), rather than upon evaluating and treating the early pre-cavitation stages, or tackling the critical risk factors that fuel the disease process itself.¹ Given that recurrent caries is the most common reason for failure for restorations of any type, it is important to move the clinical focus away from the art and science of restoring teeth ravaged by dental caries to the prevention of disease and its early interception.

CORE MINIMUM INTERVENTION PRINCIPLES

Minimum intervention dentistry (MID) is the modern medical approach to the management of caries. The concept of MID has been promoted in the national and international dental literature over the past 20 years, having evolved from “more conservative caries removal methods” through to its current form as an integrated philosophy of patient management. While the term CAMBRA (Caries Management by Risk Assessment) summarizes one approach, the current conceptualization of the MID concept now incorporates both maximum intervention as well as minimally invasive treatments.

The four core principles of MID can be summarized as follows:

- 1). *Recognition*: To identify and assess any potential caries risk factors early, through lifestyle analysis, saliva testing and using plaque diagnostic tests.
- 2). *Reduction*: To eliminate or minimize caries risk factors, through altering fluid balance, reducing the intake of dietary cariogenic foods, addressing lifestyle habits such as smoking, and increasing the pH of the oral environment.
- 3). *Regeneration*: To arrest and reverse incipient lesions, regenerating enamel subsurface lesions and arresting root surface lesions using appropriate topical agents including fluorides and casein phosphopeptides-amorphous calcium phosphates (CPP-ACP).

4). *Repair*: When cavitation is present and surgical intervention is required, as much as possible of the tooth structure is maintained by using conservative approaches to caries removal. Bioactive materials are used to restore the tooth and promote internal healing of the dentine, particularly in cases of deep dentine caries where the risk of iatrogenic pulpal injury is high.^{1,2}

To implement MID effectively, each of these four elements must be integrated into the thought processes which underpin patient assessment and treatment planning. Recognizing that restorations are not the “final solution” for dental caries, clinicians should approach the clinical situation from a biological standpoint. A major benefit of this for both the patient and the practitioner is that the inevitable failure of restorations because of unending cycles of recurrent caries is prevented.

Dental caries is best thought of as a chronic multifactorial lifestyle disease in which patient compliance with professional recommendations regarding diet, habits, and oral self care procedures plays a major role.³⁻⁵ It is now recognized widely that dental caries is fundamentally an imbalance between the hard tissues of the teeth and the oral microbial and salivary environment. The concept of an ecological catastrophe, as first proposed by Marsh in 1995 forms the basis of the modern understanding of the disease process.^{6,7} Contributing factors to dental caries which affect the pathogenicity of the dental plaque biofilm include the frequency of oral hygiene, the types of oral hygiene products used, the pattern of eating (in terms of both fermentable carbohydrates and acid challenges), the level of fluoride exposure, and (particularly in infants and very young children) exposure to high levels of pathogenic bacteria through salivary contacts.⁸⁻¹⁰

A large range of factors are recognized as contributing towards the natural defense processes against the development of dental caries. Accordingly, a range of factors which reduce the protection afforded by the salivary system increase the risk of disease developing. Such factors include use of prescription medications or illicit substances which induce xerostomia, and medical conditions or medical interventions which reduce resting salivary flow (Fig. 1).^{4,5}

The diagnostic workup of patients with high levels of caries activity should explore medical, social and dental elements of their history. Key aspects include medical conditions or medications (prescribed, over-the-counter, illicit substances, natural /alternative medicines) related to salivary dysfunction. Past history of aggressive forms of dental caries and current levels of disease (e.g. active white spot

lesions and cavitations) are good predictors of future disease, if underlying risk factors do not alter.¹ The practitioner should gauge the patient's awareness of their dental caries problem, and their motivation for adopting long term solutions.

The patient workup should include an analysis of lifestyle factors which can affect caries risk, either by reducing the protection afforded by saliva, or by increasing the cariogenicity of the dental plaque biofilm (Fig. 1).³ Key parameters to explore include the patient's work and recreation habits, lifestyle stresses, dietary patterns, and use of legal and illicit substances.³⁻⁵

Because of its dominant role in the caries process, the lifestyle analysis must examine carefully the frequency of intake of carbohydrates, particularly sucrose, focusing on the periods between meals, and determining whether the sucrose is taken in the form of sticky solids or in liquids such as softdrinks or medicines. Sucrose is rarely consumed in pure form or in isolation. Modern diets can have surprisingly high intakes of softdrinks, "energy drinks" and other beverages. Frequent intake of acidic floods and drinks can cause an aciduric (acid tolerant) oral flora to emerge through ecological pressure.⁷

The patient's overall water intake should be assessed since this can dramatically affect the production of saliva at rest. Certain occupations (e.g. farming, construction industry, flight crew) are prone to chronic patterns of dehydration. An assessment of the patient's water intake should be undertaken where the patient is doing significant strenuous or exerting activity either at work or for recreational purposes. The impact of negative fluid balance and subclinical dehydration on caries risk occurs through the action of anti-diuretic hormone which is released as part of the body's water saving processes. This hormone reduces dramatically the flow rate and pH of resting saliva, with consequential aciduric shifts in the plaque microflora, favouring an overgrowth of cariogenic bacteria which can tolerate high levels of acid.
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Structured Clinical Assessment

Patients with numerous pre-cavitation (enamel white-spot) lesions should undergo a structured caries risk assessment, for which a range of chairside saliva and plaque assessment tools are available (Fig. 2). Rapid testing methods (such as fermentation tests and solid phase immunoassays) can provide information in a 5-minute time

period, so that advice to the patient can be personalized based on the data obtained in the same appointment.

A system for total environmental management of the oral cavity (STEM) has been described which is based on the ability to measure, manipulate and monitor key physical, ionic and microbial aspects of the oral environment, in order to reduce the risk for oral disease.¹ The STEM approach for dental caries includes the following components: a structured interview; structured clinical assessment; systematic personalized advice regarding home care; targeted regeneration or incipient lesions; hard tissue repair; and recall and monitoring. Using this as a template, a suggested method for caries risk assessment which is time-efficient in the setting of general dental practice can be summarized as follows: ^{1,3,4}

1. A thorough assessment of salivary parameters at rest and after stimulation. The greater the caries activity seen in an adult patient, the more likely that a deficit in salivary output at rest will be found.^{3,4,11,12} Measuring the resting salivary flow must be undertaken prior to reclining the patient or performing any manipulations of the oral soft tissues. A simple method which can be completed within 60 seconds using the visual formation of a single visible microdroplet from the orifice of each minor labial salivary gland in the labial mucosa of the lower lip within 30 seconds.^{3,13} The next steps should examine the resting salivary viscosity and pH. When anomalies in resting parameters are found, examination of stimulated salivary flow rate, pH and buffer capacity should be screened for, as the latter as a group will delineate between patients with damaged salivary glands (with deranged parameters both when stimulated and when at rest), and patients with intact normal glands but compromised salivary output at rest because of medication, hydration and lifestyle factors.⁴ Patients who have depressed stimulated parameters require further investigation, particularly for conditions where there is immune destruction of salivary gland acini (e.g. Sjogren's syndrome, connective tissue autoimmune diseases, diabetes mellitus, chronic hepatitis C infection, and HIV infection).⁴ Samples of stimulated saliva collected for pH measurement and buffer capacity testing can also be used for microbial analyses such as specific immunoassays for pathogenic bacteria (such as *Streptococcus mutans*) using monoclonal antibodies, or for culture-based tests for mutans streptococci and lactobacilli.

2. Examining the teeth, paying attention to patterns such as: ring-barking patterns of dental caries commencing on the cervical aspects; caries developing in unusual sites which normally have strong salivary protection (such as proximal surfaces of mandibular incisor teeth); and lack of plaque mineralization in the location of major salivary gland ducts. Because enamel is damaged by forceful probing with sharp sickle probes, probes used to examine occlusal surfaces should be blunt and the probing forces light. It may be necessary to use a powder abrasive cleaner to remove stains in order to see surface details of fissured surfaces. The presence of areas of opacity at the entrance to a fissure or pit (i.e. extending into the lateral fissure walls) is the anatomical equivalent to a white spot lesion on a smooth surface, but this feature cannot be seen unless the occlusal surface is clean and dry.

Active enamel carious lesions will normally be in plaque stagnation areas, e.g. near the gingival margins, and below the contact point. The surface of the enamel of an active lesion feels rough when the tip of a blunt (periodontal) probe is slid gently across the surface. Fluorescence and other optical adjuncts to caries detection can be used to improve the detection of white spot lesions. A conventional high intensity visible blue light used for curing resin composite materials (using light emitting diodes, plasma arc or quartz tungsten halogen lamps) can be used to irradiate the tooth, and the emitted yellow fluorescence of normal enamel is then viewed through an orange protective plastic shield or orange protective glasses. Both pre-white spot lesions and white spot lesions will be seen as dark areas which lack yellow fluorescence.

Gallium nitride light emitting diodes which generate light in the ultraviolet A region (315-400 nm, also termed black light, long wave or near ultraviolet) can also be used, in a similar way, as this generates green rather than fluorescence from enamel. Pre-white spot and white spot lesions will be darker compared to the adjacent green luminescent sound enamel. Red fluorescence will be seen from deposits of mature dental plaque on the surface of teeth, restorations, or dental appliances, as well as from bacteria within cavitations involving dentine. Thorough removal of plaque and extrinsic stains is essential if ultraviolet A light-induced (Inspektor™, VistaProof™) or visible red laser-induced fluorescence (DIAGNOdent™) is used as an adjunct to conventional blunt probe/mirror examinations.

3. Assessing dental plaque thickness and fermentation. ^{9,10} Supragingival plaque can be stained with 2-tone disclosing dyes, to indicate areas of immature and mature plaque biofilm and persisting oral hygiene problems. This two-tone method provides a clear delineation between old and new plaque, with the old plaque staining blue and the new plaque (present for less than 24 hours) staining pink. Any areas where the patient has missed frequently, e.g. interdental areas, will show up with intense blue stain. At this stage, the status of the gingival tissues and periodontium should also be assessed, since the plaque maturity information provided by 2-tone dyes is also directly relevant to gingivitis.

In 3-tone disclosing, the dye has additional chemistry included so that regions of highly acid-producing mature plaque in the mouth produce a light blue/green colour, indicating *de novo* acid production within the plaque following a substrate challenge (Fig. 3).

Systematic Personalized Advice

Having now gained an appreciation of major risk factors driving the patient's caries risk, and the site distribution of disease at the pre-cavitation and cavitation levels across the dentition, the practitioner is now in a position where they can provide personalized oral health advice to target one or more aspects of the oral environment. Such advice would normally address options under the following categories: daily toothbrushing routine; selection of fluoride toothpaste; use of other fluoride products; choice of proximal cleaning devices; use of CPP-ACP remineralizing agents such as GC Tooth Mousse Plus™; use of antibacterial agents; and the need for special devices or products, such as oral moisturizing gels. ^{1,3} Advice should be given regarding food choice and lifestyle modifications, e.g. reducing the intake of high caffeine foods and drinks, or using sugar-free chewing gums to elevate stimulated (and resting) salivary outputs.

Maximum interception

Early detection of multiple incipient carious lesions in an active state flags to the practitioner that the patient has a high risk for progression of these sites and development of disease at other sites. There is an urgent need to address the current

disease, but one should not lose sight of the longer-term situation. With an aggressive pattern of dental caries, it is critical to identify and control the risk factors by modifying the oral environment. This brings the situation into stability and provides every opportunity remineralization to occur. Once balance has been restored, minimal permanent restorations where required because of cavitation of the tooth surface tooth structure can be undertaken, giving these the most favourable conditions for long term service. As mentioned previously, restoration of the carious tooth surface without accompanying changes in lifestyle and behavioural risk factors cannot prevent further disease developing, nor will it eliminate ongoing disease at other sites. While it often may not be possible to wait until stability has been achieved before placing final restorations, this should always be regarded as the desired best approach. Indeed, the more complex and expensive the final restorations placed, the more important controlling the oral environment will be perceived by the patient as being a prudent measure.

Because cavitation is a late stage in the enamel caries process, there are opportunities to intervene in the process to arrest and reverse the lesion, before committing to restorative procedures. The number of pre-cavitation “white spot” carious lesions typically exceeds the number of clinically detectable cavitated lesions by a considerable margin, so one needs to have a high index of suspicion when discovering a frank cavitation, as it often represents the “tip of the iceberg” in terms of sites with disease present.

Restoration outlines

Restorative dentistry is a surgical intervention undertaken as a form of tertiary prevention to preserve the health of the dental pulp and maintain the longevity of the tooth. It does this by eliminating the cavitation which forms a protected environment for the dental plaque biofilm, thereby allowing the patient to carry out adequate plaque control of the site. Placing a restoration into a cavitated tooth surface also improves aesthetics and returns that tooth surface to normal function.¹⁴ As a surgical operative intervention, the decision to place a restoration is made when the surface has collapsed and no other less invasive forms of treatment will be able to retain the tooth surface. In other words, a restorative approach is only undertaken as a last resort, allowing the clinician to retain and maximize tooth strength and structure.¹⁵

Regardless of the extent or severity of the carious lesion, it is now recognized that the outline of the final restoration should follow the three-dimensional shape of the individual lesion and preserve as much tooth structure as practicable. Traditional preconceived outline forms for cavity preparations (often referred to as “GV Black dentistry”) are no longer regarded as appropriate. These older designs followed the principles of ‘extension for prevention’ and extending the margins of cavity preparations into so-called ‘self-cleansing’ areas.¹⁶ With the benefit of hindsight, it is clear that sound natural tooth structure was sacrificed to meet Black’s cavity design requirements when these were applied rigidly, even to small lesions. Cavity width and size correlate inversely with fracture strength and positively with the incidence of tooth fracture, respectively.¹⁷ Excessively wide cavity forms are now recognized to contribute to the higher frequency of cusp fracture seen in older adults.^{18,19}

A lifetime cycle of restoration and re-restoration increases the possibility of eventual tooth loss. Since people now enjoy longer lives, and expect to keep their teeth for life, the consequences of having teeth which have undergone multiple cycles of restoration assumes greater significance. With greater awareness of the biological factors which underpin dental caries, it is no longer appropriate to follow rigidly the GV Black cavity preparation principles which necessitate the irreversible loss of tooth substance and structure, even for small or questionable lesions. Instead, the emphasis is now placed on stopping the disease process from commencing, preventing demineralization, and promoting self-healing mechanisms. As yet, no restorative material can adequately replace the natural form, strength, anatomy or appearance of the natural tooth. Minimal invasive cavity designs minimize unnecessary destruction of tooth structure, and facilitate the use of adhesive and biomimetic restorative materials.¹⁴

MICROBIAL ASPECTS OF DENTAL CARIES

Demineralization of tooth mineral can occur from dental caries or dental erosion. While other physical processes such as wear, trauma and cervical flexure (abfraction) also contribute to loss of tooth structure; dental caries remains the major cause of tooth structure loss and of total loss of teeth across various age groups in the population.^{15,16,20} A key factor which distinguishes dental caries from these other conditions is the pre-eminent role of the dental plaque biofilm.

A thick highly structured cariogenic biofilm will develop when the ecological pressures on the dental plaque biofilm favour the growth of acid producing and acid tolerant bacteria. The period of risk commences as the oral flora first develops after birth prior to the eruption of teeth. This timeframe also allows a number of interventions to be undertaken to prevent the development of dental caries. Such interventions include selective suppression of key pathogenic organisms, blocking transmission of key pathogens from carers to infants, and selective decontamination of the dental plaque biofilm in the infant. The latter can be undertaken using conventional biocides such as chlorhexidine (delivered as a varnish or a gel), with selective antimicrobial peptides, and with agents such as CPP-ACP which change the levels of calcium and other key ions within the dental plaque biofilm itself.

While ecological pressures such as a diet with a high frequency of sucrose and acid challenges can cause the emergence of a dental plaque biofilm with high levels of acidogenic and aciduric bacteria, it is equally true that the same principles of ecological manipulation can be applied to reduce the pathogenicity of dental plaque.⁴ In this context, recent interest has focused on the potential role of topical products containing CPP-ACP. A series of clinical trials undertaken at the University of Queensland over the past five years²¹⁻²⁶ has demonstrated that daily use of GC Tooth Mousse™ can reduce severe forms of early childhood caries in infants from high risk communities, through a series of actions involving ecological manipulation at a number of levels (e.g. elevating dental plaque pH, calcium and fluoride levels; decreasing fermentation from bio-available calcium and fluoride ions; slowing diffusion of free calcium ions, and interfering with adhesion of mutans streptococci so that their levels reduce over time). Without a dramatic change in the patient's dietary profile, it appears that daily use of GC Tooth Mousse in infants and young children can cause a sufficiently large change in the ecology of the biofilm to render it largely non-cariogenic, resulting in an impressive reduction in dental caries risk.

The benefits of this approach are enhanced when supported by home visits with patient education and motivation by dental professionals. There are particular benefits in using oral health therapists for this caries prevention approach. Home visits provide excellent opportunities for health promotion because they provide an optimal setting for dental educators to give personal instruction in oral hygiene and motivate mothers to provide good infant oral care, including ensuring appropriate feeding and oral hygiene habits for the child. This explains why improving maternal

oral health behaviors can decrease the risks for caries development in infants. Home visits are an effective way to reach mothers of infants, particularly those in low socioeconomic status communities, as these parents lack the resources to obtain professional care. Using oral health therapists for this rather than dentists is advantageous for several reasons, including lower cost and thus greater cost effectiveness,²⁴ and because oral health therapists through their education have specific skills in health promotion.²⁷ The original intent of the OHT role was to address unmet community oral health need in a cost-effective manner, and the core of their education and their knowledge and proficiency is in oral health and public health promotion.^{27,28} In terms of dental caries, significant unmet oral health need persists, and this is especially urgent for the most disadvantaged, who suffer a greater burden of disease in terms of untreated cavitations and lost teeth.

If the dental plaque biofilm present on teeth produces organic acids over much of the waking hours, the net under-saturation of the plaque fluid will necessitate dissolution of the surface minerals, which will then be replaced by mineral from deeper within the enamel. Because the rate-limiting ingredient for mineral loss is the concentration of available calcium ions at acidic pH levels, much attention has been paid to assessing the chemistry of saliva and dental plaque. Today, a range of diagnostic aids are available to determine salivary parameters^{4,10,12} and the extent of fermentation which occurs within dental plaque after exposure to fermentable substrates.^{9,10} The various assessments gained from these chairside tests allow the clinician to compile a thorough profile of the patients caries risk status, by taking the results from saliva and plaque tests and adding to these and assessment of patient motivation and willingness to comply with recommendations from their dental professional. Such recommendations may include not only the elimination of certain foods, drinks, or habits, but their replacement with alternatives which reduce the risk of disease progression.

Chairside tests for plaque acid production have an important place in risk assessment and in patient education. These tests are based on the causal association between caries activity and the production of strong acids from plaque in response to sucrose, which was first identified by the work of Stephan more than 60 years ago.²⁹ Many dental plaque bacteria can ferment carbohydrate substrates, and this leads to the production of numerous organic acids (of varying potency for demineralization). Thus, it is logical to look at the intact plaque biomass and the net result of

fermentation, rather than to focus narrowly on just one species or just one organic acid (such as lactate).^{9,10} The most recently commercialized technology for assessing caries risk is 3 tone disclosing. As mentioned previously, this displays variations in plaque pH using colour changes to show the extent of the pH-drop which occurs in plaque at multiple sites in the mouth, when exposed to a supply of substrate. As fermentation occurs, a colour change occurs in a pH indicator.

In relation to dental caries risk, “good plaque” (formed in a low cariogenic environment) has limited fermentation capabilities, and produces primarily acetate, (with lesser quantities of propionate and butyrate). These weaker acids can effectively buffer plaque pH changes. In contrast, “bad plaque” (formed in a highly cariogenic environment) produces large quantities of lactate, formate and pyruvate, stronger organic acids that can readily demineralize enamel.^{9,10,30} The use of simple disclosing methods allows the dental practitioner and their chairside staff to extend a traditional discussion about oral hygiene to now include specific discussion about areas where they struggle with plaque control (where their plaque is “thick”) and where they have highly cariogenic plaque deposits. These same methods can be applied at subsequent visits to assess compliance with oral hygiene and lifestyle advice designed to reduce the cariogenic potential of dental plaque.^{9,10} Such advice could include, for example, replacement of sugar-containing drinks and confectioneries with “smart food” replacements. These direct replacements include both products with natural non-cariogenic sweeteners (such as xylitol and stevia), as well as those with modified carbohydrates which are rendered non-cariogenic through modification of their structure (such as Isomalt™, which is made from sucrose). There is also an interest in foods, dental products and chewing gums containing certain amino acids, peptides and proteins which produce urea when metabolized by dental plaque bacteria such as *Streptococcus salivarius* and *Actinomyces naeslundii*. The resting pH in plaque results from a delicate balance between alkali and acid generation, which is in turn dependent both on the bacterial composition of the plaque and on the supply of substrates and buffers from, and metabolite clearance into, flowing oral fluid.^{31,32} The resting pH also varies according to saliva flow at specific sites. Urea from natural sources (saliva and gingival crevicular fluid) as well as from exogenous sources (such as chewing gums and foods) will raise the resting pH of plaque and in so doing reduce the cariogenicity of the biofilm.³² A similar physiological strategy for oral biofilm manipulation is promoting alkali generation from arginine supplements and

arginine-rich proteins in the diet, because arginine-containing peptides as well as and urea in saliva can both be hydrolyzed to ammonia.³³ There is also interest in the amino acid proline which can act as an acceptor for protons from lactate, which could further reduce plaque acidogenesis, and in pyridoxine (vitamin B6), which may exert a cariostatic effect by enhancing decarboxylation activity in dental plaque.³⁴

There is some evidence from clinical trials that such strategies can be effective, for example, a sugarless mint known as BasicMint containing CaviStat® (an arginine bicarbonate calcium carbonate complex) was able to reduce caries in the primary molars and first permanent molars of 10 year-old children by 50%.³⁵ CaviStat is now used as an additive in toothpastes and well as in mints. There have been numerous studies of chewing gums supplemented with urea, and it is now clear that these best inhibit caries when chewed after consumption of fermentable carbohydrate, not before,³⁶ with a rapid rise in plaque pH within the first minutes of chewing,³⁷ resulting in lower plaque acid production. Examples of urea enriched chewing gums include V6®, Dirol®, and Endekay®.^{38,39}

THE PRE-CAVITATION LESION

If the loss of mineral from beneath the dental plaque biofilm is allowed to progress unchecked, the capacity of the enamel surface to remain intact by the re-precipitation of mineral from the deeper layers of the enamel is eventually overwhelmed, and the surface collapses, resulting in the formation of a carious cavitation. As such, the formation of a cavitation can be regarded as a late stage event in the caries process. Internationally used systems for classifying the stages of progression of dental caries recognize a pre-white spot lesion which is not visible when the enamel surface is wet, but can be seen once the overlying plaque is removed and the tooth surface is dried with compressed air. Pre-white spot lesions can also be detected using a number of fluorescence systems. The further progression of this pre-white spot lesion leads to a lesion which is detectable by the clinician on a wet enamel surface without the aid of magnification. Whilst its macroscopic surface structure remains intact, remineralization of such lesions can be a powerful means for preventing their cavitation. Practical methods include ensuring the patient is aware of the site and can gain adequate access to it for mechanical oral hygiene measures and for the

application of topical products which enhance remineralization, including fluoride dentifrices and CPP-ACP, thereby avoiding the need for a restoration.^{40,41}

A major challenge for caries prevention lies in the fact that enamel lesions begin in areas which are difficult to access, such as interproximal spaces and fissures. There is strong evidence to support the concept of simplifying the physical configuration of the tooth surface to make plaque accumulation less likely, and to provide a physical barrier between the enamel surface or root surface and the oral environment. Resin fissure sealants were developed in the 1960's, and today there is strong evidence to support the use in pits and fissures. There is accumulating evidence for low viscosity glass ionomer cements as fissure sealing agents, and for the use of such materials to protect the surface of erupting teeth, as an intermediate measure at a time when crevicular fluid and saliva prevent the use of a resin fissure sealant.

A recent development has been the concept of total tooth surface protection, as an extension of the original fissure sealant concept to incorporate not only approximal tooth surfaces but other accessible surfaces. The concept of tooth surface sealing has particular appeal for the prevention of dental caries on proximal tooth surfaces where access for mechanical cleaning will be challenging once the teeth have erupted to the point where contact areas touch. If successful, the concept of surface protection giving approximal caries elimination (known as "SP=ACE") would have considerable usefulness in school dental programs in high caries risk populations.

A particular concern with incipient enamel lesions on approximal surfaces is the difficulty in identifying and tracking the presence of disease, because of limited access. Bitewing radiographs will not show the earliest forms of the disease process, and for this reason a number of methods including electrical impedance, differential reflectometry, light-induced fluorescence and transillumination are attracting current interest. Lack of cavitation can be confirmed utilizing tooth separation techniques (orthodontic separators), and remineralization of white spot lesions on proximal surfaces can be enhanced with flossing, application of fluoride, and CPP-ACP. While there is constable evidence to support the ability of CPP-ACP delivered through chewing gums in arresting the progression of white spot lesions on proximal surfaces in children,^{42,43} for most situations the application of higher concentration CPP-ACP topical pastes will be more practical for at-home use. CPP-ACP products containing fluoride have been available for some years, as well as CPP-ACP delivery vehicles such as varnishes and glass ionomer cements which give sustained release of calcium,

phosphate, and fluoride ions. Regardless of which delivery system is chosen, there is the intriguing possibility of enhancing the uptake of ions into white spot lesions, by various surface treatment methods prior to the first application of CPP-ACP.⁴¹

Caries prevention approaches

Simply put, to stop the initiation of dental caries, it is necessary to reduce risk factors, in a series of increasingly smaller circles from the community, to the family, the patient, the plaque and finally the tooth. At the community level, the provision of fluoridated drinking water reduces but does not eliminate the social inequality in the burden of disease. Oral health education and promotion in neonatal, maternal health, preschool and school settings can be effective, with growing interest in interventions undertaken in the patient's own home rather than in the dental surgery setting. Clearly, there is benefit in risk profiling, so that support is given and programs are targeted to high risk cohorts and high risk individuals within those cohorts.^{23,24}

At the family level, there are opportunities for greater use of oral health therapists, dental hygienists and dental therapists for health promotion work, particularly using proven approaches such as motivational interviewing. By engaging with the total family, long lasting changes in diet and lifestyle may be more likely to occur. These dental professionals can also provide specific support to patients using dental products to reduce levels of key disease-related organisms.²⁴

At the patient level, the clinician can detect and track levels of key indicator organisms and how these respond to interventions. They can identify areas of plaque acid production for education and monitoring purposes. At the tooth level, pits and fissures can be sealed with resins or glass ionomer cements, while erupting services can be covered with surface protection materials, and the incorporation of fluoride into the tooth surface can be enhanced by light activation methods which have been shown to change the surface chemistry of enamel and increase fluoride uptake by more than threefold.⁴¹

At the level of the dental plaque, the ecology can be changed by selective suppression using chlorhexidine gels or varnishes, by CPP-ACP, by agents which elevate the redox potential (such as dilute hydrogen peroxide), and by agents which elevate plaque pH by metabolism, such as arginine or urea.^{35,38}

Documenting caries and restorative decisions

The goals of secondary prevention of dental caries are the early diagnosis of disease, so that the disease process can be arrested and if possible reversed. This is more difficult in deciduous teeth because the enamel contains more water and less mineral than permanent enamel, and caries progression occurs at a more rapid rate. In contrast, in permanent teeth, because the development of surface cavitation is a late stage in the caries process, there are often numerous opportunities to intervene in the process to arrest and reverse the lesion before committing to restorative procedures.

Once the clinician has uncovered a white spot lesion, all efforts should be made to educate the patient regarding the factors that are contributing to this. Uncontrolled progression of demineralization will lead to the eventual development of a cavitation, which will protect the plaque biofilm and further encourage growth of facultative anaerobic cariogenic bacteria.⁴⁴ If the cavitation involves a proximal enamel surface, the patient will be unable to disturb the biofilm even by flossing, and a restoration will be required. Radiographic contrast pastes have been developed to guide clinicians in making decisions as to whether or not to restore a proximal surface which shows some evidence of dental caries on a bitewing radiograph.

Restorations can be avoided in the following situations: (modified from E Kidd)⁴⁵

- Non-cavitated white spot lesions, such as hidden proximal lesions detected on a bitewing radiograph, if these are confined to within the enamel or are just into dentine (as they are unlikely to be cavitated)
- Root surface lesions, both cavitated and non-cavitated, if accessible for cleaning and application of topical remineralizing products.
- Recurrent lesions adjacent to restorations – if both small and cleansable.
- Large cavitated lesions accessible to plaque cleansing (no overhanging enamel) – where loss of function and aesthetics is acceptable.

To facilitate early lesion detection and documentation, and to encourage clinicians to avoid the constraints of the G.V. Black classification system, new uniform charting systems have been suggested. Such classification systems describe both the site and the severity of the lesion, and use visual identification of (wet and dry) surfaces, without the use of a sharp explorer.⁴⁶ In the late 1990's Mount and Hume introduced a

system based on the site of the lesion and the size of the lesion. (1 = pit and fissure, 2 = contact area, 3 = cervical) and size (from 0 to 4).⁴⁷

A more recently described classification system termed ICDAS II (International Caries Detection and Assessment System) (Table 1),⁴⁸ can be applied to individual tooth surfaces. ICDAS-II complements the Mount and Hume system by characterizing lesions linked to their histological depth. Studies investigating the ICDAS II methodology confirm its accuracy for predicting the penetration of caries lesions into dentine, with histologic validity.⁴⁹ Utilizing such classification systems allows appropriate documentation of lesions, and provides a sound basis for communication between dentists.

The ICDAS-II system distinguishes between a sound tooth surface, the first visual change in enamel (the pre-white spot lesion), the first distinct visual change in the enamel, the occurrence of micro-cavitation, and the progression of caries within the tooth to involve various levels of destruction. For root surface lesions, the progression is from a clearly demarcated area on the root surface or at the cemento-enamel junction (CEJ) that is discoloured (light/dark brown, black) but without cavitation, to a lesion with the same appearance but with cavitation (loss of anatomical contour greater than 0.5 mm). The characteristics of the base of the discoloured area on the root surface can be used to determine whether or not the root caries lesion is active or not. These characteristics include texture (smooth, rough), appearance (shiny or glossy, matte or non-glossy) and perception on gentle probing (soft, leathery, or hard). Active root caries lesions are usually located within 2 mm of the crest of the gingival margin.

When early (pre-cavitation) lesions are found, a decision should be made as to their likely activity. For active lesions, the surface of the enamel will be whitish/yellowish opaque with loss of lustre, and it will feel rough when the tip of a blunt probe is slid gently across the surface. Active lesions will be located on surfaces in plaque stagnation areas, e.g. near the gingival and approximal surfaces below the contact point. If cavitated, the cavity will feel soft or leathery on gently probing the dentine. For inactive lesions, the surface of the enamel can be whitish, brownish or black. The enamel may be shiny and feel hard and smooth when the tip of a blunt probe is slid gently across the surface. For smooth surfaces, inactive caries lesions are typically located at some distance from the gingival margin.

MID PRINCIPLES FOR RESTORATION

Once cavitation has occurred, the thought processes of minimal intervention dentistry now move firmly into the arena of tertiary prevention. The goals of tertiary prevention are to limit disability caused by disease or by using approaches which allow healing to occur.⁵⁰ Adhesive dental materials make it possible to conserve more tooth structure using minimally invasive cavity preparations, principally because adhesive materials do not require extensive use of mechanical retention features. Effective adhesion of the restorative material to both enamel and dentine reduces concerns regarding bacterial microleakage.²⁸

Of the two main types adhesive materials in use, resin based composites with micromechanical adhesion to enamel were first developed by Buonocore in the 1950's, while glass-ionomer (polyalkenoate) cements were introduced in the 1960's by Wilson and Kent.^{51,52} Composite resin bonding to enamel is very effective, but there is less reliable long-term micromechanical bonding to dentine. Bonding to dentine is technique sensitive.⁵³⁻⁵⁵

Glass-ionomers (GIC)

To achieve the goals of MID, an optimal requirement for a restorative material is to establish an effective seal, with long-term adhesion to enamel and dentine. GIC achieves chemical adhesion to tooth structure via an ion-exchange mechanism, creating a stable acid resistant "ion-exchange layer" interface, preventing microleakage and bacterial contamination of the pulp.^{55,56} Setting shrinkage is compensated for by water sorption and by the slow rate of the acid-base reaction, such that stress on the adhesive interface is minimized, unlike the situation in composite resin bonding. GIC are unique amongst dental restorative materials in being biocompatible and achieving long-term release of fluoride ions.⁵⁷ Fluoride, calcium, phosphate and strontium ions are released from GIC and taken up by adjacent enamel and dentine, resulting in hypermineralization of sound and demineralized enamel and inhibition of caries progression.⁵⁷⁻⁵⁸

GIC acts as a reservoir for fluoride ions and can be recharged with ions from topical fluoride treatments and dentifrices.^{57,59} Restrictions on successful restorative use of GIC for large surface area restorations in posterior teeth relate to the physical limitations of the material under high compressive loads due to its low compressive

strength, or to dissolution in highly acidic oral environments. Surface lamination of GIC with resin composite (sandwich restoration technique) overcomes both these drawbacks.

Fissure Sealants

The use of fissure sealants in occlusal pits and fissures is an important MID clinical procedure for prevention of occlusal caries. As discussed previously, the initiation of caries occurs in the stagnant biofilm which accumulates at the opening of a fissure.⁶⁰ Many systematic reviews of clinical trials confirm the effectiveness of resin sealants in occlusal caries prevention, particularly for permanent molar teeth.³⁵ Traditionally, resin-based sealants have been the material of choice, with higher retention rates than GIC fissure sealants. However, when the absence of occlusal caries on permanent teeth protected by either type of sealant material is compared, GIC appears to be as effective as resin for preventing dental caries in pits and fissures.⁶¹⁻⁶³ A key aspect of caries prevention by fissure sealants is the need for monitoring and long-term maintenance of the sealants.

Surface Protection Measures

Root Surfaces

Root surface exposure and development of root caries lesions is an area of concern for an aging population, with the caries risk situation complicated in many cases by hyposalivation.⁶⁴ Adequate plaque control and local chemotherapeutic measures (topical fluoride varnish, intense light activation of topical fluoride gels, CPP-ACP application) will enhance mineral levels and can harden the surface. The pH of the dental plaque biofilm can be elevated via regular daily chewing of sugar-free gums or through the use of alkalizing bicarbonate rinses in compliant patients. Surface protection of an exposed root surface with a glass-ionomer coating is an excellent preventive treatment option, to reduce the growth of surface biofilm and facilitate remineralization.

Erupting teeth

This use of a high fluoride releasing GIC as surface protection for erupting teeth has been shown in clinical studies in children aged 5-8 years in high risk populations. GC

FUJI VII applied onto erupting permanent molars reduced the relative risk of caries by 2.3 times during 48 months.⁶⁵

How much infected dentine must be removed?

GreeneVardiman Black's operative requirements treat all zones of dentinal caries as 'dental gangrene', i.e. total surgical removal of all affected tooth structure (softened by loss of mineral but still vital) and infected tooth structure (containing bacteria) was seen as essential. Removal of dentinal caries is traditionally judged on a visual /tactile basis, where all discoloured or soft infected material is to be removed until hard dentine is reached. The objective of this approach was the removal of all microorganisms, to avoid possible recurrence of caries.

In the 1960's, a new understanding of carious dentine emerged which was based on the identification of two separate carious dentine layers, an outer "infected layer" and an inner "affected layer" by Fusayama using fuschin dye.⁶⁶ This led to a more guarded approach to caries removal, targeting only the outermost infected dentine layer, which has a disrupted collagen structure, and is incapable of remineralization. In contrast, the inner (often sterile) demineralized, and softened affected layer retains its original collagen framework, and can be remineralized.

A further challenge to the wisdom of conventional caries removal has come from Edwina Kidd, whose work has shown that leaving small amounts of infected dentine in a cavity does not seem to result in caries progression, pulpitis, or pulp death provided the overlying restoration has a perfect seal.^{44,45,67} To quote directly from her 2004 publication, "There is no clear evidence that it is deleterious to leave infected dentine, even if it is soft and wet, prior to sealing the cavity. Indeed, this cautious approach may be preferable to vigorous excavation because fewer pulps will be exposed and sealing the dentine from the oral environment encourages arrest of lesion progression".⁶⁷

This suggestion is supported by a long-term clinical trial conducted by Mertz-Fairhurst et al. who placed well bonded and sealed composite restorations directly over frank cavitated lesions without removing infected dentine.⁶⁸ There was impressive restoration longevity at 10 years, and a lack of caries progression as determined radiographically. Like Kidd, they inferred that integrity of the restoration seal prevented caries progression under the restorations.

The benefits of a more conservative approach in terms of the health of the dental pulp were seen in a 2006 Cochrane review,⁶⁹ which compared the consequences of conventional “complete” caries removal with incomplete removal in symptomless teeth with deep lesions. There was a 98% study reduction in pulpal exposures for the incomplete caries removal technique, but there was no difference in the progression of decay and longevity of restorations between the two groups. Today, stepwise and partial caries removal is considered preferable to complete or aggressive caries removal in deep lesions, in order to reduce the risk of carious exposure of the dental pulp.^{44,45,67}

Internal Remineralisation

A prescient statement made in 2000 by Mount and Ngo was that GIC had the necessary properties including release of calcium, phosphate, and fluoride ions in a wet environment to allow for the remineralization and healing of underlying carious dentine.¹⁵ Compelling evidence for internal remineralization of dentine caries was presented in 2006 clinical trial using the atraumatic restorative technique with a strontium based GIC material (GC FUJI 9 GP).⁷⁰ The trial demonstrated that a substantial amount of both strontium (a calcium analogue) and fluoride crossed from the GIC into the partially demineralized dentine adjacent to the restorative material, to create a hypermineralized zone. The dynamics of this exchange were subsequently demonstrated in a number of laboratory studies.^{71,72}

Conservative Methods of Dentine Caries Removal

In addition to the atraumatic restorative technique, a number of methods for more selective and conservative removal of infected dentine have been described in the literature, including chemomechanical caries removal and pulsed middle infrared lasers.² Chemomechanical caries removal using Carisolv™ gel has been shown to be effective in selective removal of infected dentine,⁷³ but it is slower than normal rotary instrumentation. Various optical methods for giving the operator feedback on the amount of infected dentine remaining in the cavity have also been developed. Many of these use different wavelengths of light in the ultraviolet, blue or red regions to elicit fluorescence. Laser fluorescence guidance has been shown to be particularly effective for detecting infected dentine, and guiding the clinician or controlling an autopilot system with caries removal utilizing a pulsed erbium laser rather than a

rotary bur.^{74,75}

Optimizing MID Cavity Preparation Methods

The same principles of minimal invasive treatment relevant to early carious lesions, apply similarly to extensive cavities and replacement restorations. It is important to minimize unnecessary cutting and destruction of sound tooth structure, with sufficient access required only for clear vision and tactile sense. The clinician should attempt to limit the depth and extent of preparation, and to retain surrounding enamel, so as to maximize the adhesive bonding surface area for the final resin composite restoration. Achieving clean cavity margins free of caries is a key clinical objective, to ensure the integrity of the adhesive restorative seal.⁷⁶

As mentioned earlier, in deep lesions, demineralized soft dentine can be deliberately left over the pulpal floor (to retain pulp vitality), and optimally a glass-ionomer base would be used to allow ion-exchange adhesion and reduce the potential for restoration microleakage. Since resin composite is an anhydrous material, a 'total etch' composite technique cannot achieve the ion exchange events required for remineralization, nor can one expect long-term fluoride release. The material is considered technique sensitive and its placement is clinically demanding.

In extensive restorations under heavy occlusal load, the strength of the restorative material becomes an important consideration, and in this regard dental amalgam, zirconia ceramics and cast metal restorations have greater compressive strength than resin composite materials. It should be noted that despite its disadvantages, amalgam remains a useful and cost-conservative restorative option for the protection and overlaying of weakened cusps.

Key principles of minimal invasive cavity design are as follows:

- Minimize tooth structure removal with the aim of eliminating plaque accumulation or surface roughness, restoring normal tooth shape
- Cavity outline usually follows lesion outline - consistent with achieving adequate visual and instrument access to the caries.
- To achieve a predictable marginal seal, removal of demineralized dentine near cavity margins around the full cavity periphery.
- No flat cavity floor is required.

- Rounded internal cavity angles, with no occlusal keys or dovetails required. Some internal cavity resistance form or small proximal retention slots to reduce stresses on the bonding agent.
- Cavity size and position, occlusal load, as well as patient caries risk and patient preference, are all factors in determining the choice of adhesive restorative material used.

CONCLUSIONS

Despite dramatic advances in caries management methods over the past two decades, significant challenges and opportunities remain. Considering the microbial environment, the use of inhibitory compounds from bacteria and those derived from natural sources has great potential, both in topical agents and in dental sealing, surface coating and restorative materials. Effective discrimination between cavitated and non-cavitated lesions on approximal surfaces is a persisting challenge, and is important because of the inherently irreversible nature of a restorative intervention. Finally, with aging of the population, effective methods for arresting and/or reversing root surface caries are in great need. The need to better “recognize and remineralize” will drive the developments in methods and materials for caries prevention, diagnosis, and treatment for decades to come.

Disclosures:

LJ Walsh declares he is a co-inventor of salivary test kits, plaque biofilm tests (including 3 tone disclosing), radiographic contrast pastes and fluorescence systems for guiding caries removal. AM Brostek declares no conflicts.

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Figures

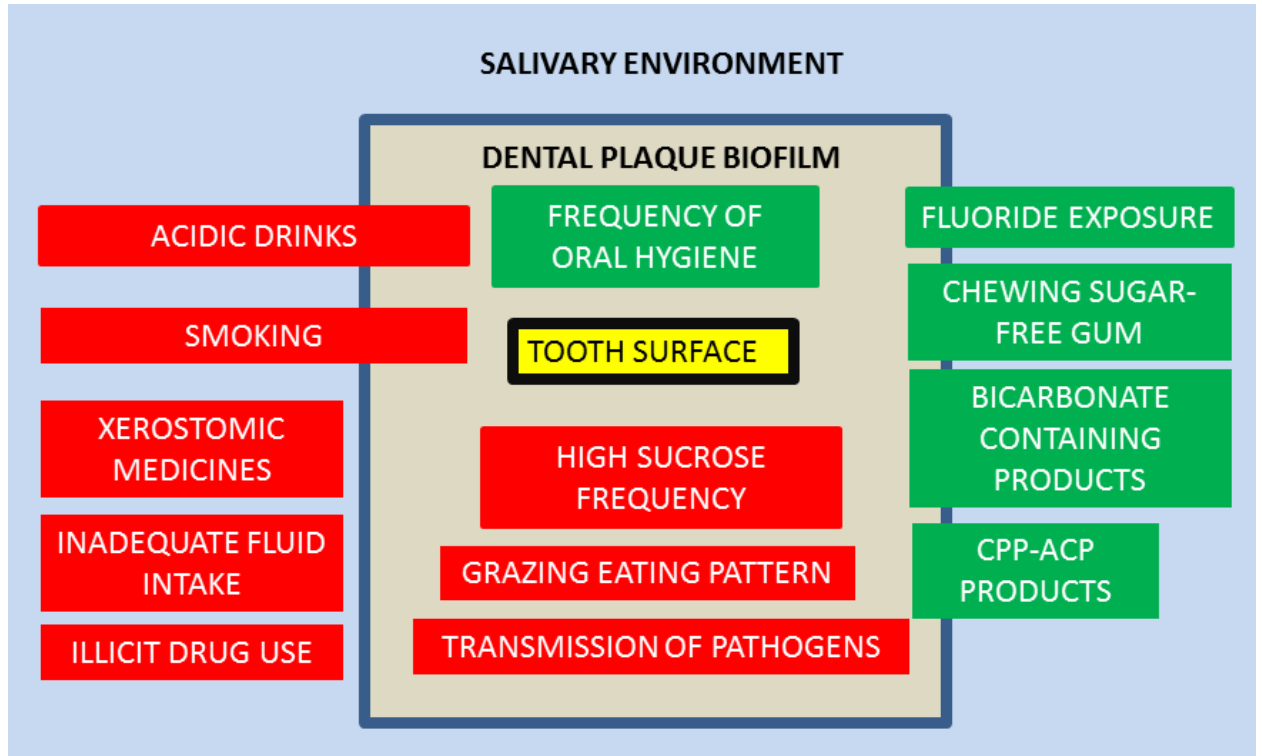


Fig. 1. Major factors contributing to dental caries risk in the individual patient. Based on the “wheel of misfortune” from Walsh.⁵

ATTITUDE & DISEASE STATUS

ATTITUDE (Patient Self Assessment)

Are you willing to change the way you care for your oral health?

YES = **A** MAYBE = **B** NO = **C**

DISEASE STATUS (Clinician Assessment)

- 1** = No current disease
- 2** = Need for repair, maintenance
- 3** = Active disease

		DISEASE STATUS		
		1	2	3
ATTITUDE	A	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	B	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
	C	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

SALIVA

RESTING SALIVA			STIMULATED SALIVA		
HYDRATION	VISCOSITY	pH	QUANTITY	pH	BUFFERING
>60 secs <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	sticky / frothy <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	5.0-5.8 <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	<3.5ml <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	5.0-5.8 <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	0-5 points <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
30-60 secs <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	frothy / bubbly <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	6.0-6.6 <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	3.5ml-5.0ml <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	6.0-6.6 <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	6-9 points <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
<30 secs <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	watery / clear <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	6.8-7.8 <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	>5.0ml <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	6.8-7.8 <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	10-12 points <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>

PLAQUE

PLAQUE pH	PLAQUE Activity
≤pH 5.5 <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	BLUE STAIN <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
≈pH 6.0-6.5 <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
≥pH 7.0 <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	RED STAIN <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>

DIET # of exposure in between meals

SUGAR	ACID
> 2 <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	> 3 <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
> 1 <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	> 2 <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
NII <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	< 2 <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>

Fig. 2. Profiling for caries risk using a “traffic light” approach.



Fig. 3. Multi-tone disclosing to show thin plaque (pink), mature plaque (dark blue) and cariogenic plaque which is producing acids in response to a sucrose challenge (light blue/green).

Table 1. ICDAS-II scoring system for enamel

Score	Descriptor	Stage
0	Sound	
1	First visual change in enamel	Early caries
2	Distinct visual change in enamel	
3	Localized enamel breakdown	Established caries
4	Underlying dentine shadow	
5	Distinct cavity with visible dentine	Severe caries
6	Extensive cavity with visible dentine	

This scoring system is updated periodically. See www.icdas.org