A System for Total Environmental Management (STEM) of the oral cavity, and its application to dental caries control.

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Abstract

The STEM approach 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. While applicable to a range of orodental diseases, this paper focuses on the STEM approach for dental caries, which 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. The clinical step-by-step implementation of the STEM process is described, with reference to supporting literature. Two cases which illustrate the application of the STEM approach are presented: a teenager undergoing orthodontic treatment, and an older adult with permanent salivary dysfunction.

Introduction

In general dental practice, much of clinical practice is dominated by the treatment and retreatment of dental caries, particularly from the restorative viewpoint, since most restoration failure is due to recurrent caries. On a day-to-day basis, it is easy to focus more on repairing cavitations (the end result of the disease process), rather than evaluating and treating the early pre-cavitation stages, or tackling the critical risk factors that fuel the disease process itself.

Minimum intervention dentistry (MI) is the modern medical approach to the management of caries. The concept incorporates both maximum intervention as well as minimally invasive treatments. The core principles of MI are evidence based, and 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 these risk factors in order to help prevent caries, through altering fluid balance, the intake of dietary cariogenic foods, addressing habits such as smoking and the intake of caffeine, and increasing the oral pH.

3). Regeneration: To arrest and reverse incipient (white spot) lesions, aiming to regenerate enamel subsurface lesions and arrest root surface lesions using appropriate protocols with Recaldent ™ and fluoride.

4). Repair: If cavitation is present and surgical intervention is required, as much as possible of the tooth structure is conserved using conservative approaches to caries removal, while 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.

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To implement minimal intervention dentistry effectively, each of these elements must be integrated into patient assessment and treatment planning. By approaching the clinical situation from a biological standpoint, the process can be terminated, and therefore failure of restorations is unlikely to be a recurring problem. Restorations are not the "final solution" for dental caries.

Despite the sizeable literature which underpins MI dentistry, there remains a need for a straightforward and systematic approach to its use in clinical practice. This paper describes the System for Total Environmental Management (STEM) which has been developed and refined over the past two decades in the author's specialist clinical practice, and which has resulted in a range of clinical kits, products tools and publications (Figure 1). The underlying concept of STEM is that the oral environment has physical, ionic and microbial elements which can be measured, manipulated, and then monitored over time (Table 1). The components of STEM are summarized in Table 2 and are outlined below.

Structured Interview

The clinical tools and strategies which are available for assessing and monitoring changes in caries risk include the following:

1. Exploring medical, social and dental history. Past history and current levels of disease are good predictors of future disease, if underlying risk factors have not altered. Key aspects comprise: medical conditions or medications (prescribed, over-

Table 1. Aspects of the Oral Environment

Physical	Ionic	Microbial
• Flow of saliva at rest • Stimulated salivary flow (oral clearance) • Lubrication from salivary mucins • Temperature • Blood flow	• pH • Ions for buffering (predominantly bicarbonate) • Ions for remineralization (predominantly calcium, hosphate, fluoride)	• Redox potential • Composition of the salivary microflora • Composition of dental plaque biofilms at individual sites • Synergistic interactions between species • Bacteriocins and inhibitory interactions

the-counter, natural or otherwise) related to salivary dysfunction; past use of home care products; and past dental treatments.

2. Clearly identifying the patient's awareness of their caries problem, and their motivation for adopting long term solutions. Listening to the patient's description of their past dental history, and the success or otherwise of past treatments is critical.

3. Analyzing current symptoms which may be indicative of underlying salivary dysfunction, including oral dryness at various times of the day and night; lack of salivary lubrication during eating, talking and swallowing; salivary web formation during swallowing; altered taste perception; impaired retention of full upper dentures; reduced lubrication of full lower dentures; mucosal irritation from foods and home care products; and other potentially related complaints such as halitosis [1,2]. The duration and severity of symptoms should be noted, as well as any exacerbating or relieving factors.

4. Analyzing 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 (Figure 2) [3]. Key parameters to explore are: the patient's work

Figure. 1. Printed resources to support the STEM approach address screening using saliva (C) and dental plaque (H), risk assessment summaries (F), lifestyle prescriptions (E), clinical strategies for addressing dry mouth (B), recognizing and reversing white spot lesions (D), and using topical Recaldent (Tooth Mousse and Tooth Mousse Plus) (G and A).

and recreation habits; lifestyle stresses; dietary patterns, and use of legal and illicit substances. Because of their dominant role in the caries process, a lifestyle analysis must examine carefully the frequency of intake of carbohydrates, particularly sucrose, particularly between means, and 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. Frequent intake of acidic floods and drinks can cause an aciduric oral flora to emerge.

• The patient's water intake should be assessed since this can dramatically effect the production of saliva at rest. Certain occupations are linked with chronic dehydration. An assessment of the patient's water intake and fluid balance should be undertaken where the patient is doing any strenuous or exerting activity either at work or for their recreation. Patients who undertake physical training or a sports exercise program are particularly prone to losing fluid because of sensible or insensible perspiration. The impacts of this negative fluid balance and subclinical dehydration is that anti-diuretic hormone is released as part of the body's water saving processes. The trigger for the release of anti- diuretic hormone is an increased osmolality and a decreased blood volume, as the water level in the body falls. Anti-diuretic hormone reduces dramatically the flow rate (and thus 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 [3].

• Specific questions should be asked regarding the patient's intake of caffeine, for example, from coffee, tea, cola drinks or energy drinks. Many adults are under the influence of caffeine as a physiological addiction. Because of its potent diuretic actions, caffeine can affect fluid balance and thus resting salivary parameters [3].

The level of caffeine in a can or large glass of black cola softdrink is approximately 35 mg. The level is twice this, 70 mg, in a cup of regular instant coffee. The level of caffeine in coffee which has been drip-filtered or percolated is much higher at

Table 2. Components of STEM

Structured interview
^
Structured clinical assessment
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Systematic personalized advice regarding home care
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Targeted regeneration
^
Hard tissue repair
^
Recall and monitoring

125 mg, while an espresso coffee can be greater than 140 mg. Energy drinks typically have twice the caffeine concentration of black cola softdrinks.

• Patients should always be questioned regarding their use of alcohol and nicotine.

Ethanol is a diuretic and when taken in significant amounts can cause negative fluid balance. The vasoconstrictive actions of nicotine suppress resting salivary flow. Smoking can also change the oral ecology through providing an anaerobiotic (low oxygen) influence on the oral microflora, driving an increase in facultative anaerobes including the caries-initiating mutans streptococci.

• The various lifestyle and medical factors can then be sorted into those which increase "attack" by changing the pathogenicity of the dental plaque biofilm (high sucrose frequency in the diet, a grazing pattern of eating, acidic foods in the diet, low fluoride exposure, transmission of pathogens from parents or siblings, and irregular oral hygiene), and those which reduce "defence" by predominantly affecting saliva (smoking, caffeine, inadequate fluid intake, a stressful lifestyle, salivary gland diseases and medicines) (Figure 2). A useful further breakdown (in terms of patient education) is to separate those factors affecting saliva into those which impairing the supply of raw materials (water and electrolytes) to the salivary glands (dehydration, caffeine, smoking and alcohol) and those which can influence the nuclei within the brain that provide the parasympathetic signals for salivation (stress, medications, drugs, and hormonal changes) (Figure 3) [4]. If patients suffer from salivary dysfunction, there is reduced clearance of cariogenic substrates or exogenous or endogenous acids. There will be a lower salivary pH at rest and a reduced buffer capacity. These two factors mean there will be less remineralization of surfaces, and also greater potential for direct mineral loss.

Structured Clinical Assessment

Time-efficient clinical examination of patients for caries risk assessment involves the following steps:

1. Measuring the resting salivary flow rate prior to reclining the patient or performing any manipulations of the oral soft tissues. This can be done within 60 seconds using the microdroplet method for minor labial salivary glands [2,5].

2. Collecting samples of dental plaque for fermentation testing upon challenge with sucrose or glucose (e.g. using the GC Plaque-Check+pH test) [6,7]. When exposed to these substrates, cariogenic plaque will produce a number of organic acids, particularly lactate, which will cause a rapid drop in pH. This Stephan curve can be followed in real time using pH-sensitive dyes. As the maximum pH depression in the Stephan curve occurs after 5 minutes, taking the plaque sample at this stage allows for fermentation to reach completion whilst completing other parts of the clinical assessment. Plaque sampling is undertaken using intact plaque, collected using a disposable plastic collection instrument. In the mandible, the normal plaque pH will be lower in approximal sites than on buccal surfaces, and therefore the proximal areas between molars are sampled. In the maxilla, if any thick plaque is present on labial surfaces in the anterior maxilla, this should be sampled because these sites consistently give a lower pH than any matched sites in the mandible because of their relatively limited exposure to resting or stimulated saliva. Over a period of five minutes, as organic acids are produced, the indicator will change from green through to orange to yellow and to red, and this can be equated to a pH scale. After five minutes, the final colour can be seen, and the result which will later trigger a discussion with the patient regarding acid production in the caries process.

3. Completing a through assessment of salivary parameters, including resting salivary viscosity and pH, and stimulated salivary flow rate, pH and buffer capacity. These tests allow delineating 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. 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). The GC manual "Saliva Testing: Good Practice Good Sense" [5] and other literature by the author [2,4] provide a

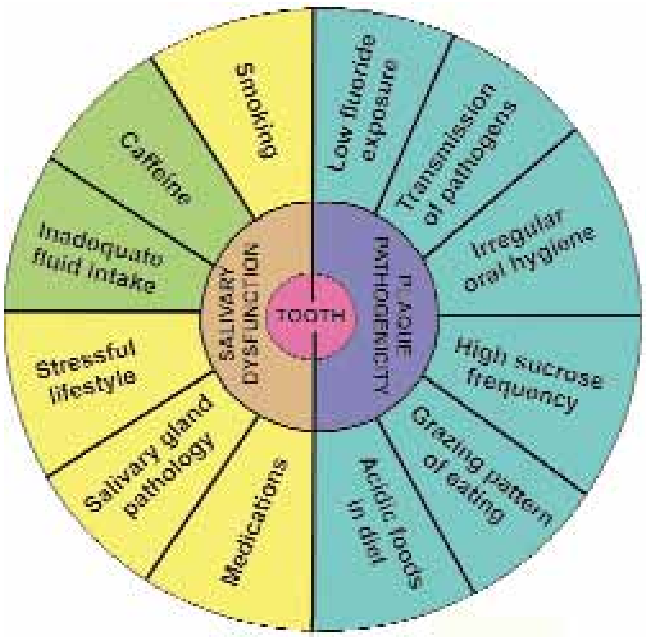

Figure 2. Schematic of medical and lifestyle factors which influence caries risk, based on their major action effect being either on salivary parameters or on the dental plaque biofilm. Modified from Ref. 3.

comprehensive coverage of the interpretation of saliva tests. Saliva testing can be repeated several weeks after giving lifestyle advice in order to monitor compliance, as well as at longer recall examinations.

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 or Streptococcus sobrinus) using monoclonal antibodies (e.g. GC Saliva-Check SM), and immunoassays for salivary antibodies to cariogens (as an indicator of host immune response).

Salivary samples can also be used for culture-based tests for mutans streptococci and lactobacilli, although these tests have less specificity than monoclonal antibody-based tests [8], and do not provide results in the same timely or costeffective manner as the more modern antibody-based testing technology. The use of rapid testing methods such as fermentation tests and solid phase immunoasssays provide information in a 5 minute time period so that advice to the patient can be personalized, based on the data obtained. Data from clinical trials demonstrate that Streptococcus mutans chairside immunoassay provides greater specificity than existing culture-based tests which use selective media [9-11]. Moreover, clinical studies have also shown a correlation between mutans streptococci levels in dental plaque and its acidogenicity, as reported by fermentation testing using the GC Plaque Check test [9].

5. Examining the oral cavity for specific soft tissue changes indicating salivary dysfunction, including dryness of the vermilion border (with zippering of the angles of the mouth by salivary mucins), general dryness of the oral mucosa, loss of filiform papillae of the tongue and cratering of its ventral surface, high levels of plaque formation on the tongue, and oral fungal infections from Candida albicans [1]. A general oral mucosal screen for soft tissue pathology completes this step.

6. Undertaking a high level screen of the oral hard tissues, paying attention to patterns such as: ringbarking 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.

7. Staining supragingival plaque with 2-tone disclosing dyes, to indicate areas of immature and mature plaque biofilm and persisting oral hygiene problems. The dye solution contains both erythrosin, the conventional pink coloured plaque disclosing dye, and fast green, a larger dye molecule which is retained within mature plaque. This two-tone method provides a clear delineation between old and new plaque, with the old plaque staining blue and the new plaque (< 24 hours) staining pink. Note that patients with highly acid-producing mature plaque may also produce a faint green colour which is superimposed within the blue, indicating de novo acid production within the plaque [6,12]. Any areas where patients miss frequently, e.g. interdental areas, will show up because of the intense blue stain. At this stage, the status of the gingival tissues and periodontium should also be assessed, since the plaque maturity data from the 2-tone dyes is also directly relevant to gingivitis. The same periodontal probe used for this assessment will later be used in caries detection.

8. Once these steps have been completed, consideration should be given to removing all plaque and stain (including dye

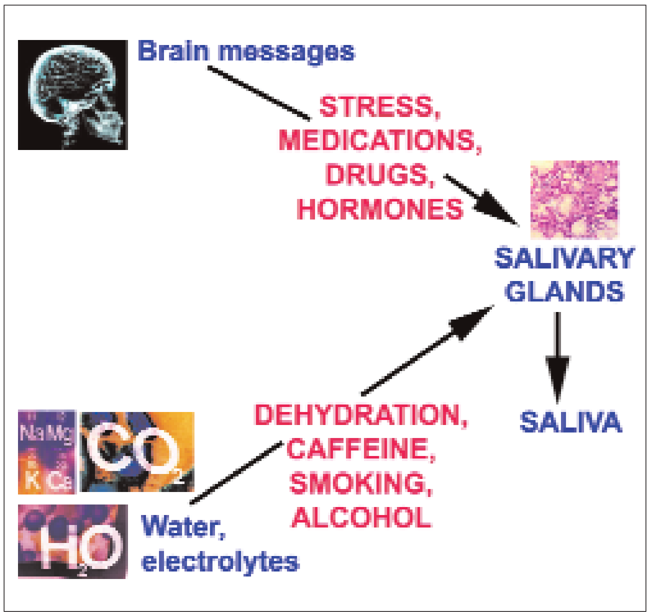

Figure 3. Simplified scheme of how medical and lifestyle factors can influence resting salivary parameters. Modified from Ref. 4.

stain from the previous step) so that the accuracy of clinical caries recording is increased. Occlusal surfaces are accessible for examination, but are often obscured by plaque and extrinsic stains.

The enamel is damaged by forceful probing with sharp sickle probes, so 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 the surface details. The presence 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.

9. The next step is to classify each tooth surface as to being sound, sealed, restored, crowned, or missing. It is important to differentiate between fully and partially sealed tooth surfaces, since partially sealed tooth surfaces may be at a higher risk of developing caries compared with sound or fully sealed surfaces.

Carious lesions now should be charted. The author's preference is to use the most recent (2007) version of the "International Caries Detection and Assessment System" (ICDAS) [13]. The ICDAS approach categorizes six stages in the carious process: ranging from the early clinically visible changes in enamel caused by demineralization, through to extensive cavitation, as follows [14]: Code 0 = Sound. This includes those with developmental defects such as enamel hypoplasia; fluorosis; tooth wear (attrition, abrasion and erosion), and extrinsic or intrinsic stains. Code 1 = First visual change in enamel. These lesions are not present when the tooth surface is wet, but become evident after air drying for 5 seconds. Code 2 = Distinct visual change in enamel (white spot lesion). At this stage, the lesion is non-cavitated, and can be seen when the tooth surface is wet with saliva. On pits and fissures, these lesions are wider than the confines of the pit or fissure area. For proximal lesions, when viewed from the occlusal direction, the opacity or discoloration may be seen as a shadow confined to enamel, seen through the marginal ridge. Active lesions will be in a plaque stagnation areas, e.g. near the gingival margins, and approximal surfaces below the contact point.

The surface of the enamel feels rough when the tip of a blunt (periodontal) probe is slid gently across the surface. Code 3 = Localized enamel breakdown (without clinical visual signs of dentinal involvement). To confirm the visual assessment of a code 3 lesion in a fissure, a periodontal probe can be slid gently across the tooth surface, noting if the probe tip drops into the surface of the enamel cavity/discontinuity (note that sharp probes such as sickle probes are not used). Code 4 = Underlying dark shadow, indicating that the carious demineralization has progressed into dentine, the dentine is discolored, and the enamel surface is unsupported. The shadowed appearance is often seen more easily when the tooth is wet. The darkened area has an intrinsic shadow which may appear as grey, blue or brown in colour. Code 5 = Distinct cavity with visible dentine. Note that there will often be visual evidence of demineralization at the cavity margins (opaque/white). Code 6 = Extensive distinct cavity with visible dentine, which destroys at least one half of the tooth surface involved.

10. Fluorescence and other optical adjuncts to caries detection can now be used. A conventional high intensity visible blue light used for curing resin composite materials (using LEDs, plasma arc or quartz tungsten halogen lamps) is used to irradiate the tooth, and the emitted yellow fluorescence of normal enamel is viewed through an orange protective Perspex shield (or orange protective glasses). Both pre-white spot lesions (code 1) and white spot lesions (code 2) will be seen as dark areas which lack yellow fluorescence. LEDs emitting in the ultraviolet A region (315-400 nm, also termed black light, long wave or near UV) can also be used, in a similar way, using UVA-selectable sources such as the GC G-light, although the pattern of fluorescence emitted differs somewhat. UVA light generates green 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 [15]. Thorough removal of plaque and extrinsic stains is essential if ultraviolet A light-induced (Inspektor ™, VistaProof ™) or visible red laser-induced fluorescence (DIAGNOdent ™) is to be used as an adjunct to conventional blunt probe/mirror

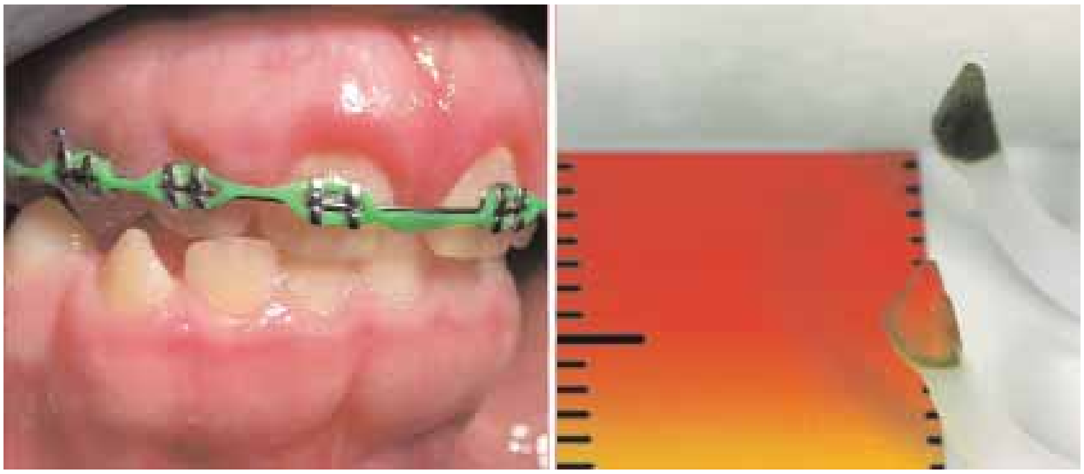

Figure 4. Teenage patient undergoing fixed orthodontic treatment. The patient has been struggling with oral hygiene. Fermentation testing indicates a high level of acid production from the plaque biofilm when exposed to fermentable carbohydrate (causing a red colour in the pH indicator; compare to the control indicator (rear) which shows green, indicating pH 7.0).

examination for dental caries, since stain and plaque will give positive fluorescence readings which can confuse the interpretation of these adjunctive technologies. Fluorescence arises because of the presence of porphyrins compound, particularly protoporphyrin-IX, in oral bacteria. Actinomyces odontolyticus (found in dentine carious lesions) is a strong emitter of such fluorescence. Once fissures that have been cleaned of plaque and stains, the use of quantitative laser fluorescence for the presence of bacteria (DIAGNOdent) allows an estimate of the extent of occult caries to be gained – since lesions which have reached the dentine give strong fluorescence signals (above 30-35). While the use of DIAGNOdent for detecting occult occlusal carious lesions is well described, it is also noteworthy that in white spot lesions, small amounts of protoporphyrin-IX are trapped in surface porosities and remain after professional cleaning, and can be detected because of its fluorescence properties. A recent large scale clinical trial of this using the DIAGNOdent (which has a detection limit of 1 picomole [16]), showed detectable fluorescence in buccal white spot lesions on deciduous teeth. [17]

11. Attention must now be paid to approximal smooth surfaces. These pose a number of challenges – the plaque biofilms environment ecologically is more amenable to the development caries than other smooth surfaces, because of low pH, low oxygen tension, and poor access to saliva. It is difficult to access proximal surfaces for mechanical oral hygiene, and for visual examination or tactile exploration. Augmentation of clinical mirror/blunt probe examinations with bitewing radiographs is commonplace, however one must remember that the correlation between radiographic appearance and the histological extent of caries on proximal surfaces is imperfect. Adjuncts to digital or conventional radiography such as software enhancement of images, and radiographic contrast media appear promising. As well, devices such as conventional or enhanced fiber optic illumination (DI-FOTI) and the DIAGNOdent pen (with its periscope tip) can play a valuable role in assessing proximal surfaces, particularly when making decisions about how to manage radiolucencies which extend to or just beyond the DEJ (code 3 and 4 lesions) [18].

12. The twelfth and final step is to collating the information collected regarding the patient's history, their particular risk factors, and the clinical findings, to gain an overall view of the existing situation to be gained, for explanation to patient (Figure 5). This step involves both an assessment of disease activity at particular sites (where plaque samples were taken from), and a prediction of future susceptibility to dental caries based on the composite of risk factors measured.

With an aggressive pattern of dental caries, it is critical to identify and control the risk factors by modifying the oral environment [19-21]. Put another way, the sequence is to recognize the problem, stabilize the situation, and remineralize tooth structure. Where extensive destruction of the dentition has already occurred, and there is limited restorable tooth structure, or aggressive periodontal disease, then prosthodontic options should be considered in the overall approach to the patient.

Systematic Personalized Advice

The clinician is now in a position to provide personalized oral health advice, which aims to target one or more aspects of the oral environment. A convenient way of doing this is to use an Oral Health Prescription form, such as the one produced by GC (Figures 6 and 8).

This provides specific options under the following categories: daily toothbrushing routine; selection of fluoride toothpaste; use of other fluoride products; choice of proximal cleaning device; use of GC Tooth Mousse™ or GC Tooth Mousse Plus™ (also termed MI Paste™ or MI Paste Plus™ in some countries); use of antibacterial agents; and the need for special devices or

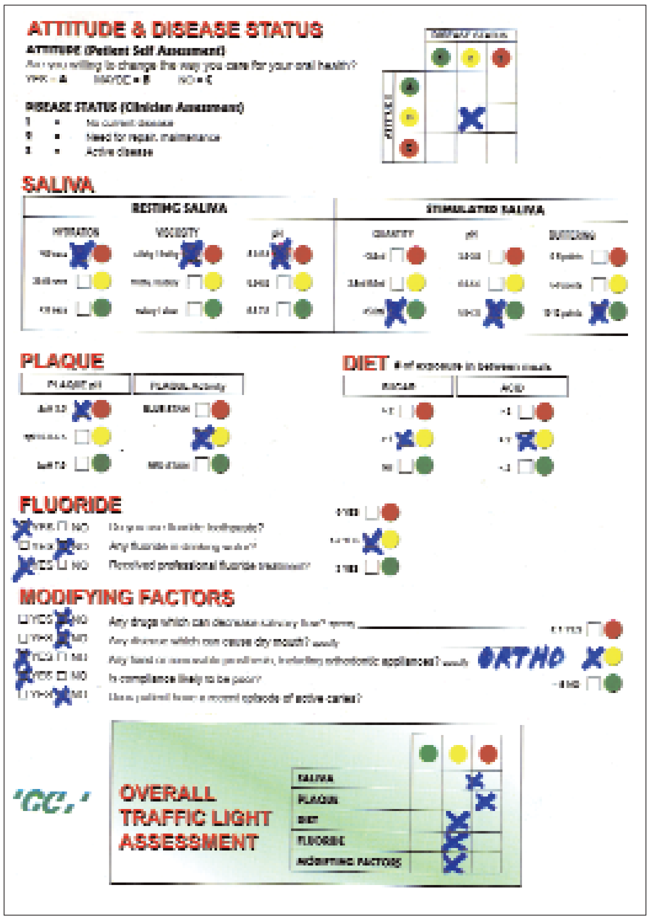

Figure 5. Completed risk assessment sheet from this orthodontic patient. The results indicate normal salivary gland function but compromised salivary parameters at rest because of lifestyle factors. The patient's overall assessment combines results for saliva, plaque, diet, fluoride and modifying factors. The risk assessment sheet is based on Ref.59

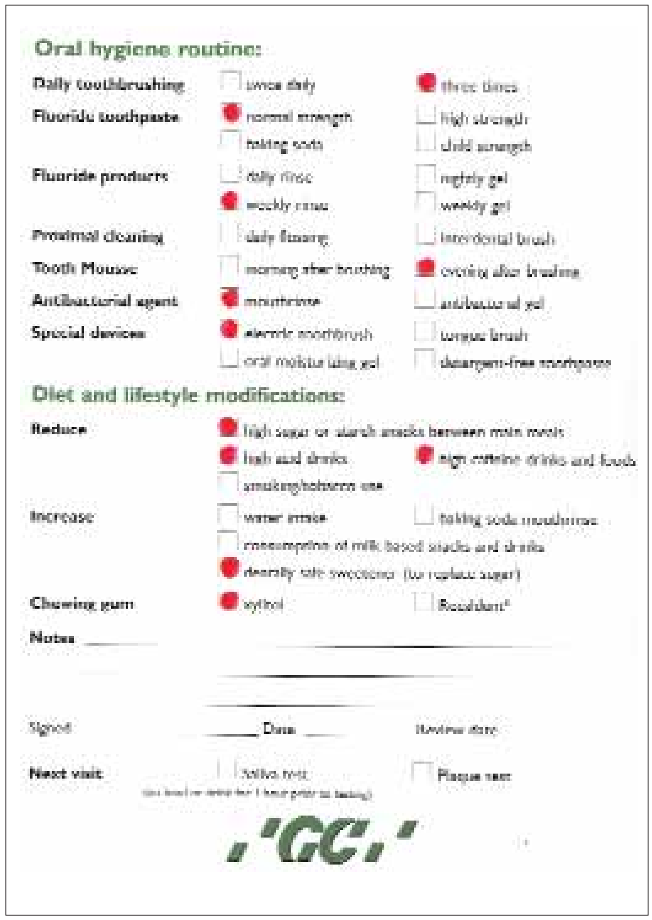

Figure 6. Lifestyle and home care prescription sheet for the orthodontic patient, which includes a number of lifestyle and home care modifications.

products, such as oral moisturizing gels. The lower section of the prescription form includes advice regarding food choice and lifestyle modifications, e.g. reducing the intake of high caffeine foods and drinks, or using sugarfree chewing gums to elevate stimulated (and resting) salivary outputs. The form also provides an opportunity for notes to be made, and prompts the clinician to determine an appropriate recall date, with the suggestion for follow-up plaque and/or saliva tests. This formalizes the continuous assessment and monitoring philosophy used for caries management, which is the final element of the STEM concept.

Targeted Regeneration

Because cavitation is a late stage in the 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 [13].

White spot carious lesions are typically found beneath mature deposits of dental plaque, which produce organic acids through fermentation. A fermentation test (GC Plaque Check + pH™) is useful for assessing plaque cariogenicity at a particular site. White spots and pre-white spots (e.g. seen with fluorescence but not visible under normal lighting conditions) can be screened for, paying particular attention to known risk sites, such as adjacent to brackets in patients with fixed orthodontic appliances. These areas can then be treated with topical preparations of casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) (GC Tooth Mousse ™) or casein phosphopeptide-amorphous calcium fluoride phosphate (CPP-ACFP) (GC Tooth Mousse Plus ™) to reverse the subsurface mineral loss, and achieve a normal enamel translucency [22]. This technology was developed in Australia at the University of Melbourne, especially to capitalize upon the anti-caries properties of milk [23]. When placed on the surface of a tooth, Recaldent interacts with hydrogen ions and forms the neutral ion species calcium hydrogen phosphate, which along a diffusion gradient, can enter into the tooth, react with and consume subsurface water, and produce enamel mineral, thereby eliminating sub-surface mineral defects. This very

Figure 7. Patient with Sjogren's syndrome, with depressed salivary pH at rest (A) and when stimulated (B), and with reduced buffer capacity (C), a pattern typical of damaged salivary glands.

effective technology is both safe and ingestible. The same technology has been put into chewing gums, lozenges, rinses and a range of other materials. A regeneration approach using Recaldent is indicated for all non-cavitated enamel lesions on smooth surfaces – including proximal surfaces [24-26]. Once 80-85% regeneration of mineral has occurred, the enamel will appear optically normal. This means that the appearance of the white spot lesion also disappears (a reversal of caries diagnosis).

A recent large scale clinical trial conducted in Melbourne, Australia, has demonstrated the value of CPP-ACP for lesion arrest and reversal, even in patients who live in fluoridated areas and who are already using traditional preventive approaches, including a fluoride dentifrice, and access to professional dental care [27]. In this trial, the radiographic progression and regression of dental caries was tracked in 2720 adolescents who used a chewing gum containing 54.4 mg CPP-ACP (Recaldent ™ gum) over a two-year period. The control group received an identical gum without CPP-ACP. Subjects were instructed to chew their assigned gum for 10 minutes three times each day.

Standardized digital radiographs taken at the baseline and at the completion of the trial using the Dexis™ digital X-ray system were scored by a single examiner, and assessed for proximal caries at both the enamel and dentine level. The CPP-ACP gum slowed the progression of carious lesions compared with the control gum, while fewer surfaces experienced caries progression, relative to the normal sugar-free gum used as the control.

Hard Tissue Repair

The final component of the STEM approach is to follow tooth structure preserving methods such as atraumatic restorative technique (ART), chemo-mechanical caries removal (Carisolv ™), fluorescence-assisted caries excavation (FACE) [15,28], and similar, to reduce iatrogenic injury during tooth restoration, and maximize the repair potential of the dental pulp. This tooth conservative approach should be combined with the use of a high fluoride-releasing bio-mimetic adhesive restorative material as a base, to promote dentine remineralization, such as GC Fuji VII or Fuji IX Extra. There is growing appreciation of the process of dentine internal remineralization which can occur when such materials are used [29,30]. If used as a bulk restorative, any tendency for glass ionomer cement restorations to erode can be obviated by the pH elevating effects of the bicarbonate rinse and Tooth Mousse. For stress-bearing areas, application of a resin coating with a completely dispersed nano-filler (GC G-Coat ™) is useful and minimizes the possibility of compressive fracture, wear or erosion of the restored occlusal surfaces.

The remaining sections of this paper will be used to provide two short case scenarios to illustrate the application of the STEM approach in clinical practice.

Case 1. Orthodontic treatment

Increasing numbers of both teenage and adult patients are being treated orthodontically by specialists and general practitioners. As a direct consequence, the potential for iatrogenic damage to the teeth and supporting structures has also increased [31].

Decalcification during orthodontic treatment is a significant and common complication of fixed orthodontic treatment. In the literature, the reported overall prevalence amongst orthodontic patients ranges from 2 to 96 per cent [32]. The teeth most commonly affected are molars, maxillary lateral incisors, mandibular canines and premolars [33].

Considering the orthodontic situation from the standpoint of STEM, the insertion of fixed orthodontic appliances provides new retention sites in the oral cavity. This opportunity is exploited by several facultative cariogens, in particular mutans streptococci and lactobacilli, which proliferate rapidly within


Oral hygiene routine:
Daily toothbrushing — twice daily — three times
Fluoride toothpaste — normal strength — high strength
baking soda — child strength
Fluoride products — daily rinse — nightly gel
weekly rinse — weekly gel
Proximal cleaning — daily flossing — interdental brush
Tooth Mousse — morning after brushing — evening after brushing
Antibacterial agent — mouthrinse — antibacterial gel
Special devices — electric toothbrush — tongue brush
oral moisturising gel — detergent free toothpaste
Diet and lifestyle modifications:
Reduce — high sugar or starch snacks between main meals
high acid drinks — high caffeine drinks and foods
smoking/tobacco use
Increase — water intake — baking soda mouthrinse
consumption of milk based snacks and drinks
dentally safe sweetener (to replace sugar)
Chewing gum — xylitol — Recaldent
Notes
Signed — Date — Review date
Next visit — Saliva test — Plaque test

Figure 8. Lifestyle and home care prescription sheet for an adult patient with permanent salivary compromise, e.g. from Sjogren's syndrome or from head and neck irradiation. Such patients are at high risk of future caries and require a comprehensive preventive program.

weeks of bracket cementation [34-36] This increase in biomass increases the pH-lowering and cariogenic potential of plaque. At the same time, the physical and ionic environment alters, with an increase in resting salivary flow rate (accompanied by increases in pH and buffer capacity) [36-38]. The balance between these "attack" and "defence" factors over time will influence the intra-oral demineralization-mineralization balance, and thereby determine whether decalcification occurs in an individual patient, and at which sites [36]. Maxillary incisors are at greater risk than mandibular incisors because of less salivary defence. Of note, plaque from the maxillary anterior region of the dentition exhibits a greater pH drop after sucrose exposure than plaque from the lower anterior or upper posterior regions of the dentition, where exposure to saliva is much greater because of proximity to major salivary gland ducts [39]. In the case in point, a teenage female patient was undergoing orthodontic treatment (Figures 4 and 5). The presence of orthodontic attachments made tooth cleaning more difficult, and predisposed to plaque accumulation on the tooth surface both around the attachment, and between it and the gingival margin. The problems were complicated by inflammatory gingival enlargement, creating more anaerobiotic niches and thus increasing the progression of the plaque towards an aciduric, fermenting type. Plaque samples taken from the maxillary incisor and mandibular incisor labial surfaces were examined for fermentation, and the contrast between the two was stark (Figure 4). This is not surprising as the literature has shown dramatic increases in mutans streptococci and lactobacillus counts on gingival margins and on the edges of brackets and orthodontic bands on teeth [36,40].

Several authors have advocated objective assessment of caries susceptibility prior to orthodontic treatment. In order to identify patients most at risk of decalcification, microbial monitoring using salivary mutans streptococci and lactobacillus counts, or lactobacillus counts in combination with salivary flow rate have been suggested [41,42]. In this case, which was referred for assessment mid-ay through treatment, a comprehensive risk assessment revealed that the patient's low daily water intake but high daily intake of black cola drink contributed to low salivary parameters at rest, thus tipping the balance away from salivary defence [43]. Although clinicians generally advise patients who are undergoing fixed orthodontic treatment to avoid excessive sugar consumption and sticky foods, this patient had a modest intake sucrose and acids through her cola drink habit, even though she did not take confectionery. Unless her underlying dietary pattern can be addressed, the risk of demineralization around the brackets will be high, even though such lesions are in her case yet to form. The home care/lifestyle prescription developed for her stressed oral hygiene, dietary changes, and the use of remineralizing therapies (GC Tooth Mousse each night and a weekly fluoride rinse) to ensure than the ionic balance was maintained in favour of remineralization. A conservative KTP laser gingivoplasty was also undertaken to restore normal gingival contours and thereby assist her efforts with mechanical oral hygiene.

It is anticipated that the strength of the carious attack will reduce following removal of the fixed appliances [44,45]. This arrest should be primarily because of' physical removal of the overlying mature acid-producing plaque [46,47]. If white spot lesions develop during orthodontic treatment, only limited surface remineralization will occur from using fluoride products alone [45]. Regular use of fluoride toothpastes has been shown to be insufficient to inhibit lesion development around orthodontic brackets [48].Visible white spots on facial surfaces which develop during orthodontic treatment should not be treated topically with concentrated fluoride agents since this procedure may prevent complete repair [49].

In fact, the surface layer in these cases forms a diffusion barrier against uptake of minerals from saliva, with the subsurface region remaining hypo-mineralized and waterrich [47]. Such lesions do not disappear, but remain an aesthetic problem for years after treatment [45,50,51]. Fortunately, using topical Recaldent treatments such as GC Tooth Mousse, full subsurface regeneration of white spot lesions can be achieved after bracket removal and an acid etch-pumice micro-abrasion treatment [22,52,53], however of greater importance is their prevention in the first instance by using Recaldent during treatment to sustain levels of bio-available calcium in the saliva. Explaining to patients the rationale behind the components of their home care program is simpler when a prescription form is used. Diet advice, oral hygiene, and remineralizing therapies are the basic elements of any preventive regimen during orthodontics, but these need to be individually tailored for each patient [54].

An ideal approach to is follow the comprehensive STEM assessment prior to commencing treatment, using the results of lifestyle assessments, saliva and plaque tests to develop a thorough home care plan, or what has been termed an "optimized prophylaxis" [55]. The prevalence of decalcification during orthodontic treatment can be markedly reduced by using a treatment regimen that targets the decalcification risk factors and uses a systematic, individualized home care program [55].

Case 2. Sjogren's syndrome

This second case illustrates the application of STEM principles a typical clinical presentation and pattern of diagnostic test results. The patient, a female in her mid-50s, noted a sudden onset of oral and ocular dryness, which was followed by a dramatic increase in dental caries as well as in tooth wear and sensitivity. Dryness of the mucosa was very marked. Her clinical examination disclosed a full range of the signs and symptoms of depressed salivary flow rate. She also had mild enlargement of the parotid salivary glands with localized hyperthermia from inflammation in the glands and vasodilatation of blood vessels. The saliva testing results (Figure 7) show a resting salivary pH near the critical value of 5.5, a stimulated pH that does not reach neutrality, and depressed buffer capacity as shown by red or blue on the buffer test pads.

A primary objective in a patient who will have compromised salivary output for the remainder of her life will be to first stabilize the oral situation, before undertaking any definitive oral care (such as complex restorative dentistry) [20,43]. The dramatic reduction in resting salivary flow rate and pH has caused a significant alteration of the oral microflora, with a predominance of acid tolerant microorganisms occurring. These include not only the caries initiating mutans streptococci, but also Candida albicans.

Thus, recurring problems with dental caries and oral fungal infections are likely in such patients if an effective preventive program is not instituted, monitored, enforced and reinforced. Taking the STEM approach to the oral environment, changing the physical attribute of salivary flow will not be practicable, so replacement for the protecting and lubricating action of saliva will be required. At the same time, the problem of a lack of bicarbonate ion must also be addressed. For this reason, using a near-neutral pH oral moisturizing gel (GC Dry Mouth Gel) in combination with home-made sodium bicarbonate mouthrinse, both ad libitum, will be an essential part of environmental control. The gel will provide symptomatic relief of oral dryness, whilst maintaining a safe oral pH at rest. It can also be placed on the teeth and gingival areas just before bed to reduce disturbances to the sleep pattern from oral dryness. Patients can make their own alkalinizing mouthrinse by dissolving a teaspoon of baking soda in a glass of tap water, and using this quantity in total during the day, rinsing their mouth before and after meals [1]. The rinse must not be swallowed, and must be prepared fresh each day, to prevent overgrowth of waterborne bacteria.

To support the pH elevation effect on aciduric pathogenic microorganisms, intermittent use of a biocide is recommended, albeit without an alcoholic vehicle which would otherwise irritate the oral mucosa. Both mutans streptococci and Candida albicans are responsive to treatment with 0.2 or 0.5% chlorhexidine gluconate gel, used once or twice per week [20,56,57]. Such a product would be used in the morning, at least fifteen minutes following brushing with toothpaste. The separation is important because of the potential for ionic interactions between chlorhexidine and fluoride ions which will inactivate the chlorhexidine [57,58].

The next major aspect of ecological management will be to elevate the bio-available calcium ion level within the saliva, and thereby increase the critical pH, preventing dissolution of apatite mineral from tooth structure. Using fluoride products alone in such patients is insufficient to cause remineralization or to prevent severe demineralization occurring, because the critical pH of enamel relates strongly to the calcium concentration in the saliva and the plaque fluid [53]. To maintain as high a level of calcium in the plaque fluid as possible, the patient will apply GC Tooth Mousse Plus to their teeth each morning and again each night, immediately before retiring. This contains and releases calcium, phosphate and fluoride ions in the correct ratio (5:3:1) for optimal remineralization of tooth structure. It can be safely used in combination with GC Dry Mouth Gel.

The next aspect of environmental management is to suppress plaque levels and simultaneously suppress plaque fermentation. To achieve this, the patient will use a detergent free normal strength toothpaste morning and night, but a high strength (5000 ppm) fluoride toothpaste or gel (9000 ppm) in the middle of the day, in order to exert antibacterial effects, and to prevent potential problems with sequestering calcium ions [58].

In terms of restorative management, the inability of patients with Sjogren's syndrome to wear conventional (not implant supported) complete dentures [43] means that preservation of the dentition is paramount. Thus, applying MI principles to the restorative treatments required in such patients is essential.

The future of STEM

In considering the limits of existing technologies to "recognize, remineralize, and restore", it is clear that the STEM concept can take on board new and emerging technologies for caries prevention, diagnosis, and treatment. 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 derived from natural sources has great potential, both in topical agents and in dental sealing, 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. There is preliminary evidence of the benefits of Recaldent (as a remineralizing agent) and reactive oxygen species (as a bio-oxidizer of organic acids) in such situations, and this will be an area of attention for the coming decades.

Disclosure:

The author was involved in the development of the chairside diagnostic kits and treatment approaches described in this article, and authored the series of clinical guidebooks and resources mentioned in this paper.

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