

An Update on Demineralization/ Remineralization



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Intended Audience: Dentists, Dental Hygienists, Dental Assistants, Dental Students, Dental Hygiene Students, Dental Assistant Students

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Conflict of Interest Disclosure Statement

- Robert V. Faller is a retired employee of P&G. He has no relevant financial relationships to disclose.

Introduction – Demineralization/Remineralization

This course was one of the first courses available on dentalcare.com. The course has been updated without changing the original content, which is still valid. The update includes information on new technologies emerging for caries detection and evaluation as well as information on the evidence-based approach for dentistry in the area of demineralization and remineralization. This primarily includes the use of fluorides with information and resources on how to approach evidence-based dentistry for clinical practice. This course begins with an historical perspective on caries as a concern in the 1940s as a major public health problem and moves to the clinical practice today...from cure to prevention. An up-to-date understanding of the caries process in both enamel and root caries are detailed through the discussion of demineralization/remineralization. This course has been widely used by clinical staff (dental assistants, hygienists, and dentists in clinical practice) as well as students from all over the world. This course is not meant to be a comprehensive cariology course but rather an introduction to the concepts of demineralization and remineralization and how they can and should be incorporated into clinical practice. Upon completion of this course, participants will understand the continued need for fluoride to help protect against the ongoing challenge to tooth structure, secondary lesions and root caries. Participants will also appreciate the need to examine the literature and evidence when applying clinical preventive techniques for caries prevention.

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Overview

Demineralization/Remineralization begins with an historical perspective on caries. Caries was identified as a major public health problem in the 1940s. At that time, caries was the single greatest reason for rejecting draftees from enlisting in the military services in the United States in World War II. From that historical view, this course moves to the clinical practice today...from cure to prevention.

An up-to-date understanding of the caries process in both enamel and root caries are detailed through the discussion of

demineralization/remineralization. Changes in approach using an “evidence-based dentistry” view of demineralization/remineralization are an integral part of this course.

Participants will understand the continued need for fluoride to help protect against the ongoing challenge to tooth structure, secondary lesions and root caries; and appreciate the need to examine the literature and evidence when applying clinical preventive techniques for caries prevention.

Learning Objectives

Upon completion of this course, the dental professional should be able to:

- Explain the process of demineralization/remineralization.
- Discuss the role of calcium and phosphate in the remineralization process.
- State where caries occurs first within the enamel structure.
- Compare and contrast enamel and root surface caries.
- Compare and contrast the remineralization process on permanent and primary teeth.
- Discuss elements in clinical examination vital to detection of (a) enamel caries and (b) root surface caries.
- Explain the current approach to evaluating the evidence in answering clinical questions regarding fluorides and caries prevention.
- Provide a scientific, literature-based rationale for the effectiveness of fluoride products in preventing dental caries.

History

Many years ago the JDHA carried this quote by L. S. Fosdick, “It is quite possible that in the not too distant future, mass control of caries may be achieved; but until that time, each dentist and hygienist should become acquainted with the fundamental mechanism of the caries process, and pass this information on to the patient, along with suitable methods of control.” We took Dr. Fosdick at his word and moved the management of dental caries from a personal concern to a national concern...developing sensitive scales for the measurement of dental caries. We have also continued to learn about the mechanisms of the caries process; building an understanding that caries is not a one-way process. Rather,

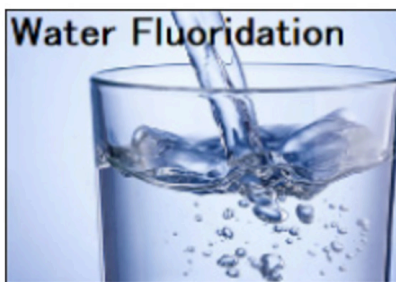


Draftee rejection due to poor oral health

early caries can be inhibited, and even reversed, through the process of remineralization.

The single greatest reason for rejecting draftees from enlisting in World War II was poor oral health. We saw a personal concern become a social concern and, ultimately, a significant concern for national security.

One of the primary responses to these challenges was the development of effective anticaries approaches, most notably in the form of fluoride. From water fluoridation to our professional recommendations of an OTC product, fluoride touches the lives of our patients on a daily basis. Unlike the concerns of the 1940s and 1950s, where the focus was on CURE, our focus today is on PREVENTION.



Fluoride

Today we face many questions about fluoride from well-informed patients. We are no longer simply asked, “WHEN will I get my fluoride treatment?”, but rather we face more complex questions such as “Who should get fluoride, when and how much...does fluoride affect permanent teeth, should we give a topical fluoride treatment to a caries-free child, and what do we do when we see rampant caries?” The evidence to support these decisions has become increasingly more important in the practice of dentistry today. Some basic background on “evidence-based dentistry” and how it applies to demineralization/ remineralization is an integral part of this course. What is the evidence supporting your clinical decision, and what is the strength of this evidence? These questions, in addition to those above, have been asked with increasing frequency by students and practitioners alike. In a world that allows both patients and practitioners to instantly access information over the Internet, we must be prepared to face these questions with scientific support. In that way, we can be fully prepared to work with our patients, sharing the most up-to-date knowledge with them in a way that enhances not only our role in providing dental health but also in their role of being healthier, more well-informed patients.

Epidemiology of Caries and the Role of Fluoride

The message we have been taught is caries is a disease of the past, and although the common perception is that kids no longer get much tooth decay, the most recent large-scale data continues to suggest that we have not eradicated the problem just yet. These data, from the 1999-2004 National Health and Nutrition Examination (NHANES) Survey, show that overall, dental caries in deciduous (baby) teeth of children ages 2 to 11 declined from the early 1970s until the mid-1990s. From the mid-1990s until the most recent survey, the trend has actually reversed: a small but significant increase in primary decay was found, with the trend being more severe in younger children.¹ Separate from the NIDR Survey, the US Surgeon General's report in 2000 confirmed caries remains the number one childhood disease among 5-17 year-olds.² Among this

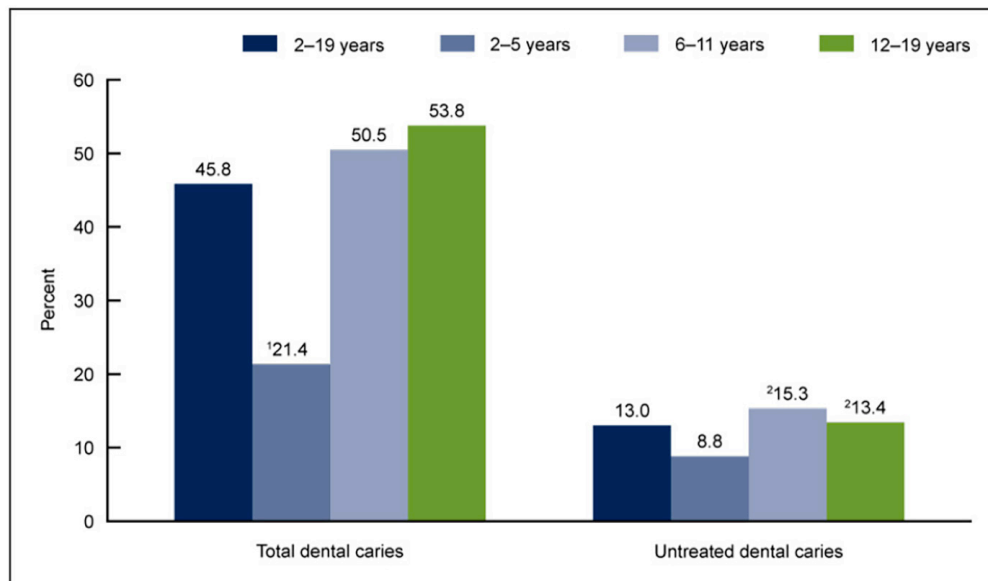


Figure 1. Prevalence of Total Dental Caries and Untreated Dental Caries in Primary or Permanent Teeth among Youth Aged 2-19 Years, by Age: United States, 2015-2016.

¹Significant linear trend with increasing age.

²Significantly different from youth aged 2-5 years.

NOTES: Total dental caries include untreated and treated caries. [Click here](#) for data table for Figure 1.

Source: NCHS, National Health and Nutrition Examination Survey, 2015-2016.

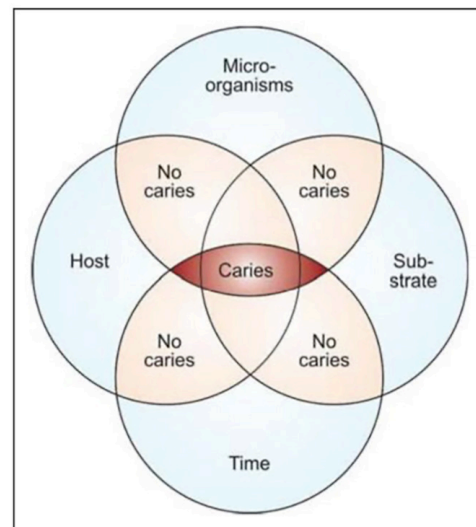
group, caries is 5X as prevalent as asthma and 7X as common as hay fever. These data highlight the ongoing need for fluoride therapy.

In addition to the levels of disease that we do see and treat, there is also a concern about the amount of caries that go untreated. National surveys in the United States have routinely reported the levels of untreated dental caries, in children ages 2-19 in the United States, during various time periods.

According to the most recent survey:

“A decrease was seen in the prevalence of total dental caries (from 50.0% to 45.8%) in youth from 2011-2012 through 2015-2016. However, this decline was not statistically significant. For untreated dental caries, the prevalence was 16.1% for 2011-2012, with the percentage increasing to 18.0% for 2013-2014, and then declining to 13.0% for 2015-2016.”

And then further: “For National Health and Nutrition Examination Survey (NHANES) period 2015-2016, the prevalence of total



and untreated dental caries in primary or permanent teeth among youth aged 2-19 years was 45.8% and 13.0%, respectively. For both total and untreated caries, prevalence was lowest among those aged 2-5 years. The prevalence of total dental caries was highest for Hispanic youth compared with other race and Hispanic-origin groups. The prevalence of untreated dental caries was highest for

non-Hispanic black youth. The prevalence of total and untreated dental caries decreased as family income levels increased. Youth in families with incomes greater than 300% of the federal poverty level had the lowest prevalence of both untreated and total dental caries. There was an observed decline in the prevalence of total caries in youth during the 6 years from 2011–2012 through 2015–2016; however, the trend was not statistically significant. The prevalence of untreated dental caries increased from 2011–2012 through 2013–2014, and then declined for 2015–2016.¹³

Over the most recent time frame reported for adults (1999-2004), 26% of adults 20 to 64 were reported to have untreated decay.⁴ Unfortunately, no newer data are available.

A broad review of the epidemiology has been published,⁵ which concludes “Caries is a worldwide problem associated with plaque, microorganisms, and the intake of carbohydrates. The presence of fluoride in the oral environment attenuates the process.” While we have made a lot of progress with the use of fluoride, there is still more work to do.



Examining secondary caries...it has been estimated approximately 50% of the amalgam restorations that need replacing are due to recurrent caries. You have heard it a thousand times... “My teeth are all filled; there is no room for more decay!” A filling, as we know, can be successfully replaced twice before a more permanent restoration is indicated. Again, the role of fluoride therapy here is clear.

And what about root surfaces? Kids are all grown up and out of the house; are Mom and Dad justified in using a non-fluoridated toothpaste? It has been estimated that by the age of 50 at least one-half of the population will have at least 1 root surface caries lesion.

The ongoing need for fluoride treatment is not limited to specific age groups. All patients can benefit from appropriate fluoride therapy.



Dental Caries Risks

The changes in caries distribution are important in understanding and planning for preventive approaches for all age groups throughout the world. Changes in the clinical management of the caries process and an emphasis on early treatment mean we now lack estimations for both non-operative and operative treatments. The understanding of the caries process, in terms of a dynamic continuum of demineralization and remineralization, means epidemiological studies will soon change in the level of caries information and detection. The visual-tactile examination using diagnostic criteria such as established by Radike⁶ may no longer be sufficient to collect caries data in light of changing technologies for early detection and the need to measure non-cavitated carious lesions. Pitts et al.⁷ discuss the current caries epidemiology with respect to an emphasis on diagnostic standards.

Demin/Remin Process

Saliva is the primary component for caries protection and neutralizes acids formed by plaque bacteria. In addition, saliva contributes the needed calcium and phosphate for

preventing demineralization and allowing remineralization to occur. Many patients are compromised by reduced salivary flow or saliva with reduced buffer capacity.⁸ Although many systemic diseases can cause hyposalivation or even xerostomia, the major cause comes from prescription and over-the-counter medications. More than 400 medications are known to have this impact on salivary flow. Many of our patients take these medications daily for the treatment of chronic conditions like hypertension and depression. Others may use them seasonally for allergies. The real clinical significance here is that the balance between remineralization and demineralization processes is most likely disrupted and patients taking these medications are at risk for net demineralization. These patients need to be clearly recognized. In addition to fluoride toothpastes, additional preventive measures and diet counseling for caries prevention should be provided.

Overdentures present a concern from a caries perspective. Plaque is retained more easily on the tooth surfaces with an overdenture residing over these surfaces. These areas are also less accessible to saliva and the protective effects of the oral cavity. A study that followed 296 subjects with overdentures over a period of 20 years found “that regular oral hygiene and regular dental care contribute to lower caries incidence in overdenture patients.”⁹

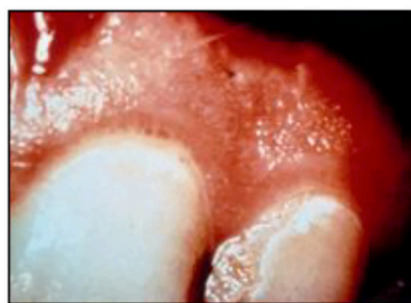
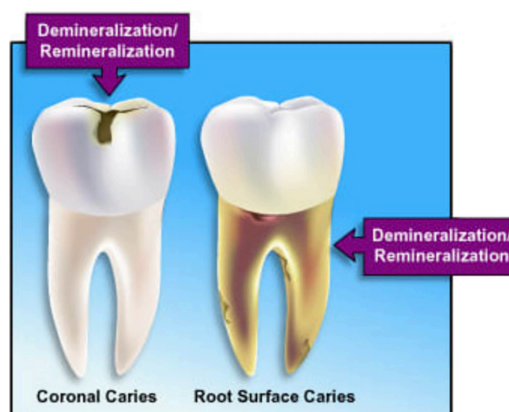
One additional area of concern requiring focused fluoride therapy is oncology patients who receive radiation therapy to the head and neck. Due to the impact of these treatments on salivary flow rates, rampant caries is often a significant issue. Once again, the ongoing need for fluoride therapies is clear.

Role of Fluorides

To examine the role of fluorides in the caries process, we need to understand the concepts of demineralization and remineralization and how they function in both coronal as well as root surface caries.

Our overall view of Caries and the Caries Process has changed over time:

Past View: Caries was a simple, continuous



Caries Process

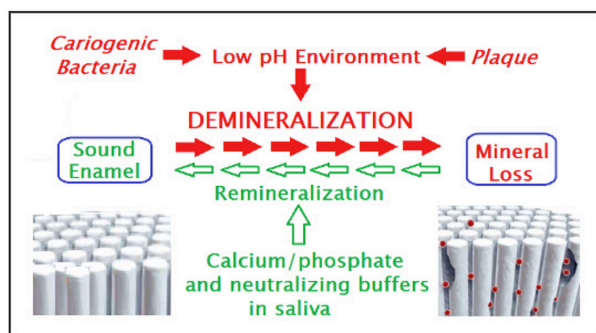
dissolution of the enamel by bacterial acids, beginning at the enamel surface and progressively destroying the tooth structure inward.

Current View: Caries is a **subsurface phenomenon**, with the earliest clinical evidence of the process being the white spot lesion, characterized by its chalky white appearance. When explored, it seems to be structurally intact.

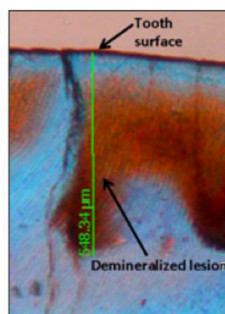
The surface layer is intact but the zone of demineralized enamel can be noted beneath the intact surface layer. Calcium and phosphate are lost from the tooth (enamel and dentin)

during the demineralization process and may be either precipitated together somewhere else in the tooth or lost to the mouth via the plaque and saliva.

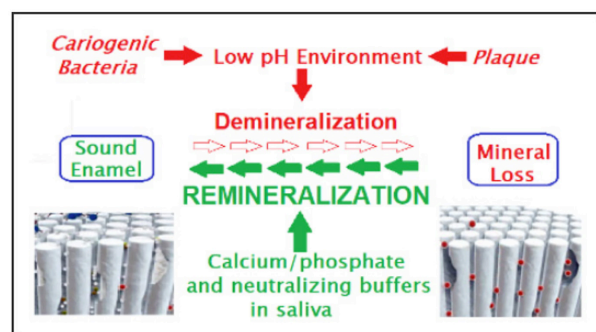
Although a dynamic process, when the negative (demin) outweighs the positive (remin), caries occurs. The surface layer is intact and the subsurface zone of demineralized enamel can be noted beneath the intact surface layer. Calcium and phosphate, lost from the tooth surfaces during the demin process, may re-precipitate in the tooth (likely at the surface of the lesion).



Source: Dentistry IQ



When the positive (remin) outweighs the negative (demin), caries can be reversed.



In the remineralization process, calcium and phosphate diffuse into the tooth from saliva and/or plaque fluid and precipitate as new material inside the early carious lesion. Remineralization is an enrichment of the partially demineralized tissue via formation of redeposited mineral. This re-deposited mineral is normal crystal growth on existing partially demineralized crystals but could also be new crystal formation within the subsurface regions of the enamel or dentin.

In the world of instant access to information via the Internet one can examine the caries process using sites such as the University of Illinois "[Dental Caries \(Cariology\) Treatment in the New Millennium](#)" site. This site provides an excellent background on the caries process and what it means for the clinical approach to treatment.

A landmark conference was held by NIH on March 26-28, 2001 entitled, "[Diagnosis and Management of Dental Caries Throughout Life.](#)" The bibliography for the conference "[Diagnosis and Management of Dental Caries](#)" was developed by the National Library of Medicine.

In the consensus conclusions it is stated: "Effective preventive practices, such as the use of fluoride, sugarless products, and dental sealants were reconfirmed, and clinical studies to identify more conservative but more effective non-surgical and surgical approaches are to be applauded. However, it was evident that current diagnostic practices are inadequate to achieve the next level of caries management in which non-cavitated lesions are identified early so that they can be managed by non-surgical methods." The conference also concluded after careful examination of the current evidence at that time that "In spite of optimism about the future, the panel was disappointed in the overall quality of the clinical data set that it reviewed. Far too many studies used weak research designs or were small or poorly described, and consequently, had questionable validity. There was a clear impression that clinical caries research is under-funded, if not undervalued. Moreover, incomplete information on the natural history of dental

caries, the inability to accurately identify early lesions and/or lesions that are actively progressing, and the absence of objective diagnostic methods are troubling.”

Conclusions drawn from the NIH Caries Management Consensus Conference in 2001 included the following findings regarding effective caries preventive treatments:¹⁰

1. **Fluoride.** The research data on fluorides in water and dentifrices support their efficacy. The data also support the use of fluoride varnishes. For rinses and gel applications, the evidence is promising but not definitive.
2. **Chlorhexidine.** For varnishes and gels, the data are promising. Research data showing effectiveness of chlorhexidine rinses are lacking.
3. **Sealants.** The use of pit and fissure sealants is supported by the data.
4. **Combinations.** Combinations of chlorhexidine, fluoride, and/or sealants are suggestive of efficacy.
5. **Antimicrobials.** Although *mutans streptococci* is recognized as part of the pathology of caries and, therefore, an antimicrobial approach would seem reasonable, current data are inadequate to support antimicrobial treatments other than chlorhexidine and fluorides, both of which have antibacterial properties.
6. **Salivary Enhancers.** Although there are indications that pathologically lower salivary flow, as a consequence of Sjögren’s syndrome or as an effect of head/neck radiation treatment or xerostomic medications, is associated with caries, there is no evidence that low normal salivary flow produces a similar outcome.
7. **Behavioral Modification.** Most interventions require patient adherence, and current data provide some support for the efficacy of office-based behavioral interventions.

It is important to note that the Consensus Conference also made the following statement, “In the development of caries treatment, dentistry has moved historically from extraction to surgical restoration. Identification of early caries lesions and treatment with non-surgical methods, including remineralization, represent the next era in dental care.” We

are clearly in an era of dental care in which prevention of demineralization and effective remineralization have taken the spotlight.

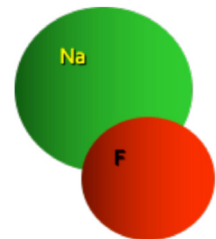
Later in that same year, 2001, another consensus report, “[Recommendations for Using Fluoride to Prevent and Control Dental Caries in the United States](#),” was published by a working group of the Centers for Disease Control that examined fluoride approaches for caries prevention; and it is evident from this working group’s recommendations that fluoride is an effective approach to caries prevention in a variety of forms.

When used as directed, brushing with fluoride toothpaste is safe and effective, and it represents one of the most cost effective means available for preventing and reversing the caries process. In the US, there are 3 fluoride sources that companies are allowed to use in formulating fluoride toothpaste. These are sodium fluoride (NaF), sodium monofluorophosphate (SMFP) and stannous fluoride (SnF₂).

One of the most widely used sources of fluoride in toothpaste is NaF, an ionic form of fluoride that is highly reactive. For this reason, NaF dentifrices need to be formulated with abrasive systems that are fluoride compatible.

Often referred to as the “simple” fluoride

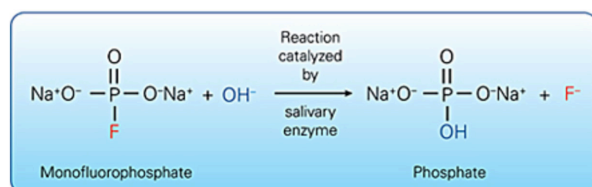
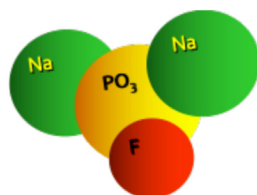
- Ionic form of fluoride
 - F is released upon contact with saliva
 - Available to react with tooth surface almost immediately
- Highly reactive species
 - Requires non-reactive abrasive system, such as silica
 - Long-term stability of F in a properly formulated product
 - Properly formulated products high levels of bioavailable F
- Contains 0.22 - 0.243% NaF (1000-1100ppm F)
- Clinical efficacy in the 25-50% range (vs. placebo)
 - Also demonstrated effective against root caries



SMFP is a covalently bound form of fluoride. In order to release the active fluoride ion from the SMFP, the covalent bond must first be broken by way of either acid or salivary enzyme hydrolysis. Although it is a bit easier to formulate stable toothpastes using SMFP, delivering the active F ion to the tooth surface requires a two-step process that makes this agent a bit less efficient than its ionic counterparts.

More complex than Sodium Fluoride

- Covalently bound form of F
 - Covalent bond must first be broken via acid or salivary enzyme hydrolysis before F can be available for reaction with tooth surface



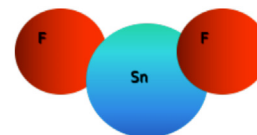
- Less reactive form of F
 - Can be formulated with a wide range of abrasives systems
 - Silica, CaCO₃, dicalcium phosphate dihydrate (DCPD)
 - Available levels of free F increase as product ages
- Products contain 0.76 - 1.14% SMFP (1000-1500ppm F)
- Clinical efficacy approximately 15-30% (vs. placebo)

Probably the most unique of all of the available F sources is SnF₂. Like NaF, SnF₂ is also an ionic form of fluoride. However, in addition to its fluoridating benefits, SnF₂ also provides efficacy against bacterial acids. The first dentifrice accepted by the ADA in 1960 as being clinically effective against caries contained SnF₂ (Original Crest® with Fluoristan®). However, toothpastes at that time were not stable for long periods of time (current products are generally stable for 2-3 years). The most effective of the modern day SnF₂ dentifrices are those that have been

“stabilized” using proprietary methods. Most importantly, the modern SnF₂ dentifrices, in addition to providing anticaries benefits, have also been clinically proven effective against plaque and gingivitis, dental erosion, sensitivity and halitosis.

A “double action” fluoride

- Ionic form of fluoride
 - Effective against bacterial acids and provides F benefits
 - Tin (stannous) provides a protective barrier against acid
 - F penetrates tooth surface to provide subsurface remin
- Highly reactive species
 - Difficult to formulate
 - Most effective formulations are those that are “stabilized” using various proprietary methods
- Products contain 0.454% SnF₂ (1100ppm F)
- Clinically proven effective against caries, plaque and gingivitis, dental erosion, sensitivity and halitosis



Fluoride supplemented with Calcium

No clinical trials have demonstrated the combination of F actives with calcium containing ingredients provides greater anticaries effectiveness than fluoride alone.

- “Supporting” data are almost always limited to *in vitro* studies
- Saliva is saturated with sufficient levels of calcium and phosphate to aid in remineralization processes; additional calcium and/or phosphate from toothpaste has little, if any, impact on salivary levels of these minerals
- Claims focused on specific calcium ingredients are generally considered to be marketing schemes

By definition, calcium is a necessary component of remineralization; whether it is there from previously demineralized mineral, plaque fluid, saliva, or from all

sources. There has been a considerable amount of research on the benefits of adding remineralizing agents, such as soluble calcium and phosphate, into oral care products in order to ensure that individuals with low levels of natural salivary minerals are afforded all the benefits of fluoride.¹¹ One of the more interesting approaches is the use of casein phosphopeptide, amorphous calcium phosphate (CPP-ACP) that has shown promise in initial testing as a potential adjunct to fluoride therapy;¹² although more work needs to be done to verify the clinical benefits of this type of approach. Fluoride plays a key role in this process by aiding the transformation through the mineral phases, enhancing crystal growth, speeding up the remineralization process, and inhibiting demineralization at the crystal surfaces.

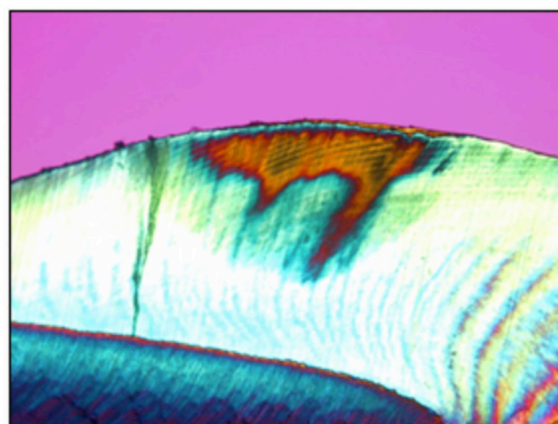
New mineral which is formed will be less soluble than the original mineral and will be either fluorapatite-like or hydroxyapatite-like, with much less carbonate and fewer impurities than the original mineral.

In summary, both calcium and phosphate are needed for remineralization. Importantly, both are generally present in sufficient quantities from endogenous sources, i.e., saliva, for this to occur. If not, supplementation of saliva with additional sources of these key minerals may be helpful; and fluoride enhances the overall process.

Microscopic Examination of the Demin/Remin Process

To understand the concept, we can examine this lesion that has been prepared for microscopic examination. We can easily note the outer layer, the surface layer, and the inner demineralized area termed a subsurface lesion.

The calcium and phosphate are dissolved from the crystals in a complex environment. The concept of a “critical pH” is the situation under which net mineral loss occurs. Previously this was thought to be a fixed value, but it is now accepted that it is rather a value that is inversely proportional to the calcium and phosphate concentrations in solution in the localized environment.¹³ Larsen and



Polarized-light micrograph (in water) of an early enamel subsurface lesion. Blue area is normal enamel and surface zone over lesion. Brown area is the early lesion.

Image provided by: Dr. James Wefel

Pierce¹⁴ developed a computer program for examining the solubility of enamel. Small pH changes around a pH of 4 were demonstrated to significantly impact the demineralization potential of enamel.

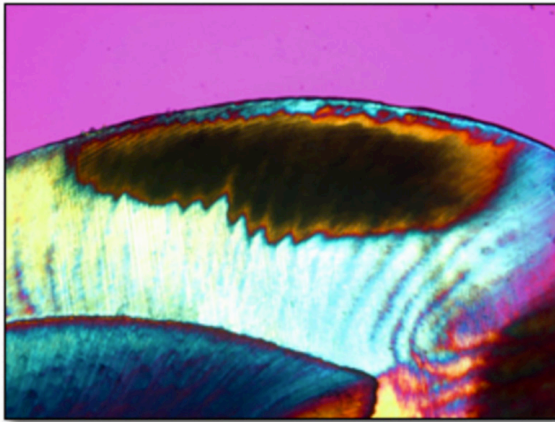
What has actually happened? Acids diffuse through the interprismatic rod substance and travel along the rod margin to an area of lowered fluoride content (Note: the outer 10 microns of enamel holds a higher concentration of fluoride.)

As the process of demineralization continues, the edges of the enamel crystal demineralize... that is, calcium and phosphate become dissociated in the small subsurface area.



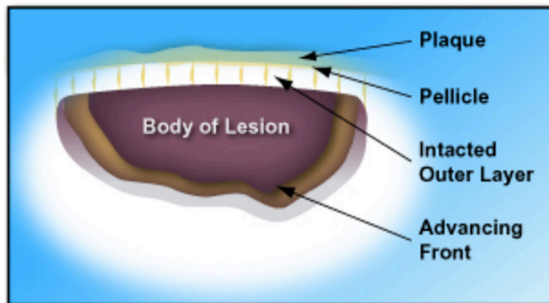
Partially Demineralized Enamel Crystals

This process results in the development of an early lesion (begins 10-15 microns beneath the surface) which has a relatively intact surface



Polarized-light micrograph (in water) of early enamel lesion (about half way through the enamel) showing the body of the lesion in brown with its advancing front and a blue surface zone at the enamel surface area as shown in the accompanying diagram.

Image provided by: Dr. James Wefel

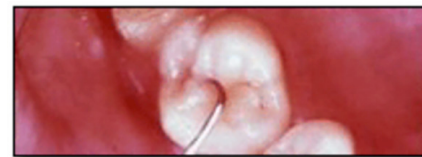


Early Lesion

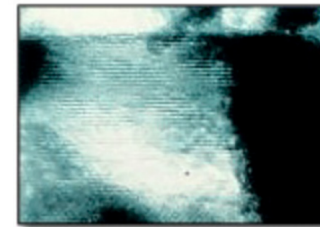
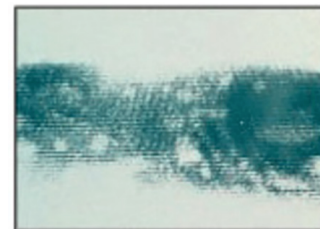
layer that cannot be penetrated with a dental explorer during the early stages of formation. If the acid challenge continues, greater amounts of subsurface enamel will be demineralized (or as it is sometimes called “decalcified”) and the lesion will continue to progress deeper under the intact surface layer.

The caries process is a dynamic situation which occurs as a result of substantial pH fluctuations taking place in the biofilm on the tooth surface. Kidd and Fejerskov¹⁵ describe this process and its histopathology and indicate the “Regular removal of the biofilm, preferably with a toothpaste containing fluoride, delays or even arrests lesion progression.” The processes of demineralization and remineralization can occur simultaneously or alternately. The high resolution transmission electron microscope

has been used to demonstrate how these crystals look in caries lesions.¹⁶ In very simple crystallographic terms, demineralization is crystal dissolution and remineralization is the restoration of partially dissolved crystals, growth of surviving crystals and the formation of new crystals within the carious lesion. If net demineralization continues, the outer layer of enamel will eventually become extensively undermined; with the clinical result being an area that is “sticky” or “soft” to the explorer coupled with visual evidence of demineralization. Larsen and Bruun¹⁷ describe this process in detail in their textbook chapter on “*Caries Chemistry and Fluoride – Mechanisms of Action.*” They discuss the theory which claims that when “...fluoride is present in the aqueous phase around the tooth, in saliva and in plaque fluid, enamel solubility is low, which tends to prevent it from dissolving.”



Advanced Lesion

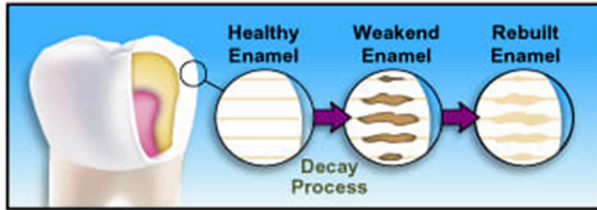


Remineralization

Remineralization of the subsurface lesion occurs when the dissociated ions of calcium and phosphate recombine to form an even stronger crystal. This reaction is enhanced in the presence of fluoride.

Fluoride and Caries Prevention

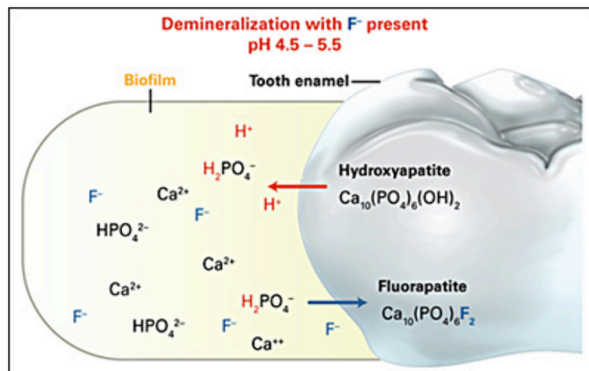
- The primary mechanism of action of fluoride in preventing dental caries is topical
- It inhibits demineralization of the teeth
- It enhances remineralization of the teeth
- It makes cariogenic bacteria less able to produce acid from carbohydrates



F Levels as low as 1ppm have been shown to be effective at reducing lesion formation, but F must be present at the time of the acid challenge

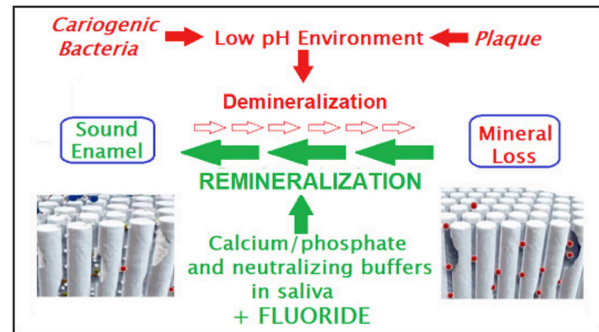
Elevated levels of F close to the tooth surface help change the dynamics of the demineralization process, preventing dissolution of HAP crystals

Fluoridated water and fluoridated dentifrice and mouthrinse help deliver low levels of F to the saliva, enabling residual F to build up in plaque, pellicle and calculus



Adapted from: Cury and Tenuta. Braz Oral Res 2009; 23 Suppl 1: 23-30.

Thus, fluoride changes the remineralization process by acting as a mineral growth catalyst. The action of fluoride accelerates the rebuilding of enamel and can stop or even reverse the progression of dental decay. More importantly, the incorporation of fluoride into the tooth mineral along with calcium and

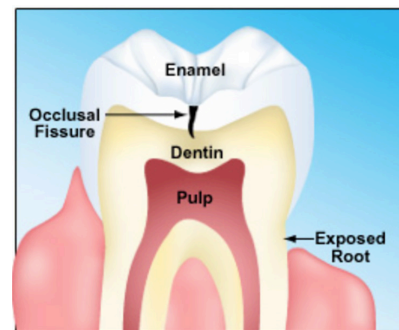


Fluoride significantly enhances the natural process of Remineralization.

phosphate makes enamel more resistant to acid demineralization than it was originally.

The processes of remineralization and demineralization are similar on any tooth surface upon which they are occurring (enamel pits, fissures, smooth surfaces). However, some surfaces tend to have higher incidence of lesion formation compared to others. This is primarily a function of a combination of tooth morphology and accessibility for cleaning, with pit and fissure along with interproximal sites experiencing the highest rates of lesion formation.

Surfaces at Risk for Caries

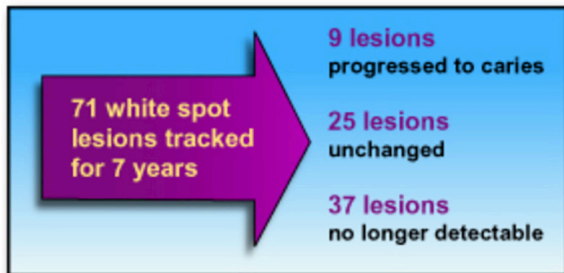


Enamel lesions are categorized according to where they are located. Smooth surface lesions occur on the buccal, lingual, and interproximal surfaces. Pit and fissure lesions occur in enamel pits or on occlusal fissures.

Primary and permanent teeth are affected in the same manner.

The concepts of demineralization and remineralization are not new. A study from

Backer-Dirks,¹⁸ for example, was done in 1966, prior to the widespread use of fluorides. In this study, 71 white spot lesions in 8-year olds were tracked for 7 years. All frank lesions were restored. At the end of the 7 years, the results demonstrated:



Mandibular left second premolar that has a buccal surface cavitation that cannot be remineralized and requires restoration. Note the additional distal surface caries that is visible upon preparation.



Early white-spot lesion on the buccal surface of a right mandibular first permanent molar.



White spot lesion on a left mandibular first permanent molar that has been partially remineralized and is stable without activity.



caries process, rather than individual pieces of the process. Caries is a complex biological process which involves an infectious agent (acid-forming bacteria), the host or patient, and the diet (fermentable carbohydrates). If the diet is balanced in such a way that the host protective factors (saliva) and fluoride can overcome the bacterial acid challenge, no net demineralization occurs. Increased frequency of foods that are acidogenic can tip this

Although it is interesting to look at demineralization and remineralization as independent processes, current approaches to caries are generally focused on the entire

balance in the direction of net demineralization. A human, intraoral, demineralization/remineralization model was used to evaluate various between-meal snack foods. The study demonstrated that certain foods can cause net remineralization while “acidogenic” foods can cause demineralization.¹⁹ Duggal et al.²⁰ used a slightly different human model to examine the frequency of carbohydrate consumption with and without fluoride toothpaste. When a fluoride free toothpaste was used and carbohydrate frequency exceeded 3 times per day, significant demineralization occurred. When subjects used fluoride-containing toothpaste, net demineralization was only seen when carbohydrate consumption exceeded 10-times/day. This study emphasizes the need for use of a fluoride toothpaste by all patients to help balance, prevent, and reverse the caries process on a daily basis. Hicks et al.²¹⁻²³ have provided a three-part series on the biological factors in the caries process with respect to demineralization and remineralization and also emphasize the role of low levels of fluoride on a daily basis.

In this example a 15-year old male had his orthodontic brackets removed and came directly to the general dentist’s office presenting as shown below. This illustrates an imbalance in the demineralization/remineralization process to the extent of developing many frank cavitated lesions which cannot be remineralized. This is a great example of the need for understanding the caries process. Had the lesions been recognized at an early stage, they could have been reversed through remineralization. In fact, they could likely have been prevented completely through the proper use of fluoride.



Case and photo credit to: Dr. Neil Millikin

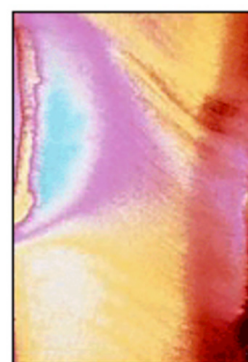
What about root caries?

We know the initial phase of root caries development requires recession of the gingival margin; the root surface is exposed and at risk for caries. The tissue may be normal but recessed for a variety of reasons—abrasion (e.g., over aggressive toothbrushing), aging, or periodontal conditions. These can result in exposure of a tooth surface that has previously not been at risk.

Phase II of root caries is similar to that of coronal caries; the process typically begins apical to the cemento-enamel junction, presenting a few clinical symptoms.

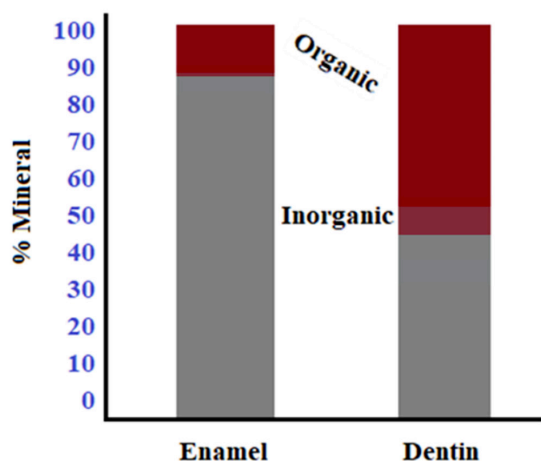
There appears to be a healthy intact layer of cementum, which quickly dissolves. It is important to note enamel is approximately 88% mineral (by volume) while dentin is only about 45% mineral (by volume). Due to its lower mineral content, the root surface has a higher demineralization potential relative to the enamel surface.

The question that faced researchers for a long time was, “Can a root surface remineralize since it is only approximately 45% mineral (by volume) to begin with?” The answer is absolutely...in fact it has been documented the root surface can remineralize to a higher mineral percent than it was initially (One study: 67% more remineralization vs. placebo).



Root Surface Caries

With respect to root caries, Leake²⁴ completed a review of published data using an evidence-based approach. This review concluded that



the accuracy of diagnostic systems at the time of the review was unknown, but the color of the lesion itself had little predictive validity. The use of “softness” to define active lesions has been validated with the presence of microbes in the lesion. The author noted: “For patients aged thirty and older, the prevalence of root caries is roughly 20 to 22 percent less than a person’s age. Severity reaches over one lesion by age fifty, two lesions by age seventy, and just over three lesions for those seventy-five and older. About 8 percent (odds of 1:11) of the population would be expected to acquire one or more new root caries lesions in one year.”

A more recent review by Gluzman and colleagues²⁵ focused on English language articles published between 1979-2010 that assessed the effectiveness of the seven leading root caries preventive agents (fluoride, chlorhexidine, xylitol, amorphous calcium phosphate, sealants, saliva stimulators, or silver diamine fluoride) to prevent or control root caries, and it provided recommendations for use of those agents in clinical practice with older adults and vulnerable elderly.

The conclusions from both of these reviews provided consistent support for the use of various fluoride therapies in the prevention and reversal of root surface caries.

Advancing Approaches for Clinical Caries Measurement

The standard methods for caries diagnosis in the past were the combination of the dental “visual/tactile” examination together with

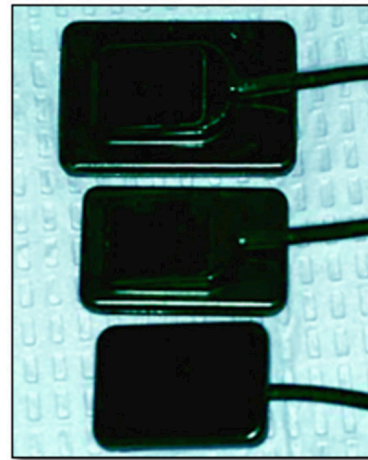
conventional film radiography. Slowly, fiber-optic transillumination became a regular clinical adjunct for caries examination in the clinical setting. The use of laser fluorescence for measuring pit and fissure caries has become a more commonplace clinical instrument. Fiber-optic transillumination advanced further with the use of the DIFOTI™ system, which stands for “Digital Imaging Fiber-Optic Transillumination.” Other caries detection methods include electrical resistance, laser detection devices such as DIAGNOdent and Quantitative Light-induced Fluorescence or QLF™. QLF, for example, is capable of following lesions over time, which can provide important information on both lesion progression and reversal. Conventional radiography is slowly giving way to various forms of digital radiography, and some advances in quantitative digital radiography may not be far off. The NIH caries management symposium cited earlier¹⁰ addressed various methods of early detection and caries measurement, but the evidence for implementing most of these fell short of expectations at the time. More recent research has demonstrated that many of these new approaches took the recommendations of the NIH conference to heart and are moving forward to generate more substantial data packages in support of these technical advances. The key concept of all of these approaches is to make early clinical assessments of lesions that can be stopped before they are irreversible and need restoration. It is even more exciting to consider the concept of being able to detect the caries lesions in their very early stages and have quantitative measurements of their condition. The object is then to apply “remineralization” therapy to reverse the lesions through products such as fluoridated toothpastes which are well documented to be clinically effective, while using quantitative early detection methods to assess the progress of our therapy. Specific recommendations for patients, or even specific lesions, could be made and monitored for effectiveness long before intervention with a restoration would be necessary.

Digital Radiography

Various digital radiographic instruments have been commonplace in clinical practice for many years. The various approaches will

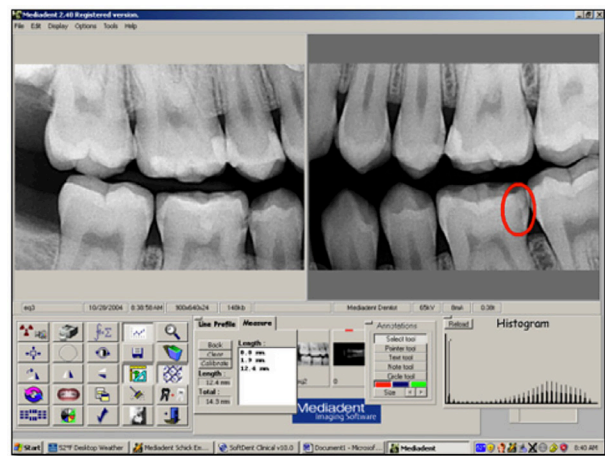
not be addressed in this course, but they are addressed in many publications and forums for “technology” in dental practice. An article by Parks and Williamson²⁶ reviews radiographic approaches using digital radiography. Publications continue to support the superiority of digital radiographic systems over conventional radiographic film. One such article²⁷ presents evidence that phosphor plates significantly improve the accuracy of caries diagnosis while reducing observer variability. Jacobsen et al.²⁸ compared four different digital radiographic systems using histologic measures as graded by 4 trained clinicians. Two of the systems were determined to be more accurate than the other two for caries depth measurement. More studies of this nature are needed to help guide clinical practitioners in the selection of the approach that they wish to use in diagnosis of early caries in the clinical setting. An example of a digital bitewing radiograph and the clinical sensor are provided below to illustrate the presence of carious lesions.

Images taken with digital radiography showing various stages of caries.



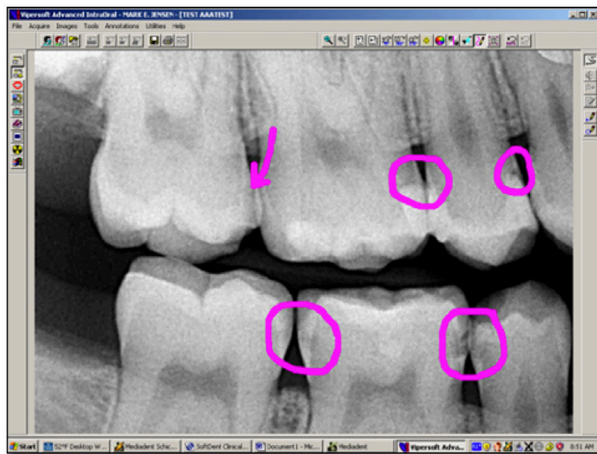
CCD Sensors for direct digital radiography shown as size #2, size #1, and size #0.

Different systems have various software functions for viewing the digital radiographs as shown here. The ability to change contrast, colorize, flip to a negative, measure density, measure lengths, and otherwise adjust an image for diagnosis greatly enhances the ability of the clinician to get information. The goal is to make the diagnosis of proximal caries at the earliest stage when remineralization can be achieved instead of surgical intervention and restoration.



The above screen capture illustrates bitewing radiographs taken and viewed using the Mediadent system. Note the one area circled

in red showing interproximal caries for the patient. Below the digital radiographs, the tools are shown for managing the images.



The screen capture above shows a digital bitewing radiograph using the Viperoft system. The highlighted areas were marked during a discussion with the patient. Toolbars for image management are seen on the left and at the top of the image.



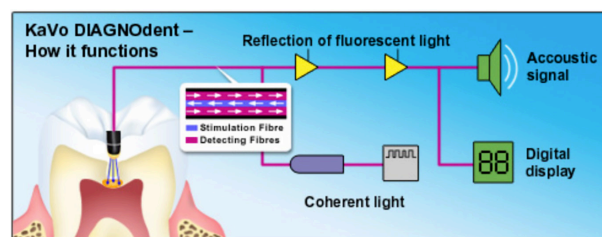
The screen capture above illustrates a digital peri-apical radiograph from the Schick system for digital radiography. The icons for image management are seen above the image.

In 2006, the ADA conducted and published an online professional product review of digital radiography systems "[ADA Professional Product Review - Digital Radiography Systems: ACE Panel Dentist Interviews](#)." One of the key findings of this review was: "Digital radiography has advantages and disadvantages, but once

the dentist and his or her staff conquer the learning curve, these dentists seemed to agree that digital radiography is an overall plus for them, their patients, and their practices."

DIAGNOdent

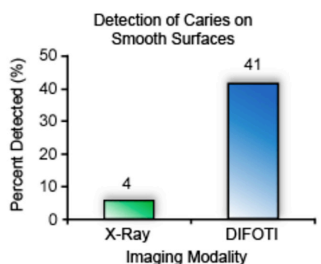
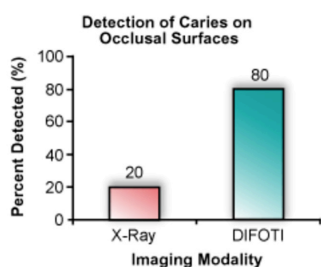
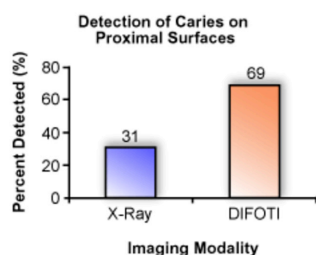
The small portable laser device manufactured by KaVo, called the DIAGNOdent, is available as a clinical adjunct in caries diagnosis of pit and fissures. It is a small, portable unit which can be easily moved from operator to operator during patient examinations. It works relatively simply by laser fluorescence feedback to provide a numerical readout. Although not a quantitative measurement, it indicates involved areas that often are not detectable visually or by radiographs. Various in vitro studies show reliability is still a concern, but the device has emerged as a commonplace adjunct in clinical practice for pit and fissure caries diagnosis and monitoring.²⁹ More recent studies have suggested DIAGNOdent may be useful for detecting secondary caries under composite restorations.^{30,31}



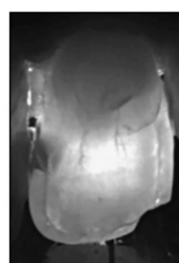
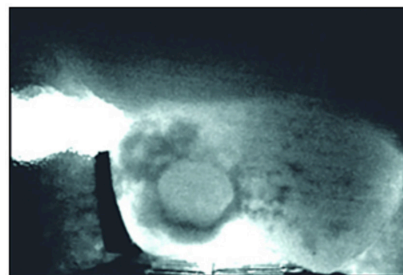
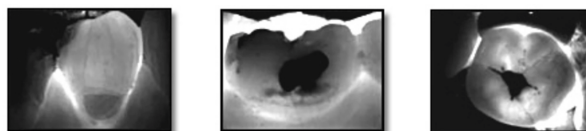
Click here to view additional information:
[KaVo clinical tutorial and background of the DIAGNOdent.](#)

Fiber-Optic Transillumination

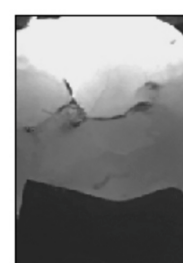
When the product originally launched, optical transillumination was taken to a new level with DIFOTI, an instrument designed for the early detection of demineralized enamel. Schneiderman et al.³² *in vitro* results showing more sensitivity than bitewing radiography for early caries detection using this technology. Keem and Elbaum,³³ also using *in vitro* data, concluded DIFOTI was superior to radiography, based on their position that, using DIFOTI, there is “no ionizing radiation, no film, real-time diagnosis, and higher sensitivity in detection of early lesions not apparent to X-ray.”



Clinical Images Taken with the DIFOTI



Interproximal Caries found using DIFOTI



Occlusal Caries found using DIFOTI

Young³⁴ reviewed both DIFOTI and DIAGNOdent with respect to their clinical uses and possibilities in early caries detection and management. Although each of these approaches showed early promise, they both suffered from limitations of the technologies used.

One of the newest trans-illumination methods is the DIAGNOcam³⁵ system. Information on the DIAGNOcam system can be found at www.kavo.com. This system is a transillumination device that works with infrared light and essentially sees right through the teeth. Although it is not a quantitative device, it does provide a unique perspective on the current state of overall tooth health. While not yet available in the United States, it is clear that tooth imaging technologies using optical trans-illumination continue to be at the forefront of dental hard tissue research.

Quantitative Light-induced Fluorescence (QLF™)

This caries detection system takes advantage of tooth fluorescence to record images that can be analyzed to obtain data on: lesion Area (Area in mm^2 , lesion depth expressed in percentile fluorescence loss (ΔF in %), and lesion volume (ΔQ in $\text{mm}^2\%$) and bacterial activity in terms of percentile increase of red fluorescence (ΔR).

The Inspektor™ Pro QLF camera system:



The Inspektor™ QLF-D Biluminator™ 2+ camera system:

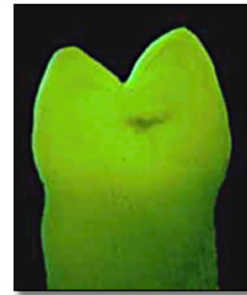


Both of these devices use blue light to illuminate the tooth. This causes the teeth to fluoresce in green (so-called auto-fluorescence). The resulting QLF images show a higher contrast between sound and demineralized tooth tissue as seen in the figures of the extracted premolar.

Besides the green auto-fluorescence, the blue light can also generate red fluorescence that can be seen in the picture below. This red fluorescence is believed to be caused by porphyrins that are the result of the metabolic

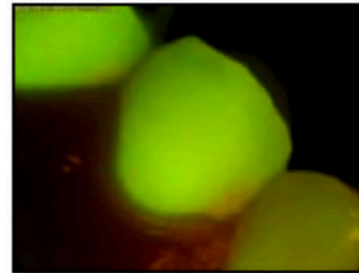


Extracted premolar with white spot as seen with white light.



The same premolar seen with QLF.

process of specific bacterial strains. The intensity of the red fluorescence has been shown to be related to the activity of those bacteria. In addition to caries related bacteria, some of the most recent studies using QLF have suggested the red fluorescence may also be related to other oral care issues, such as gingivitis and halitosis.



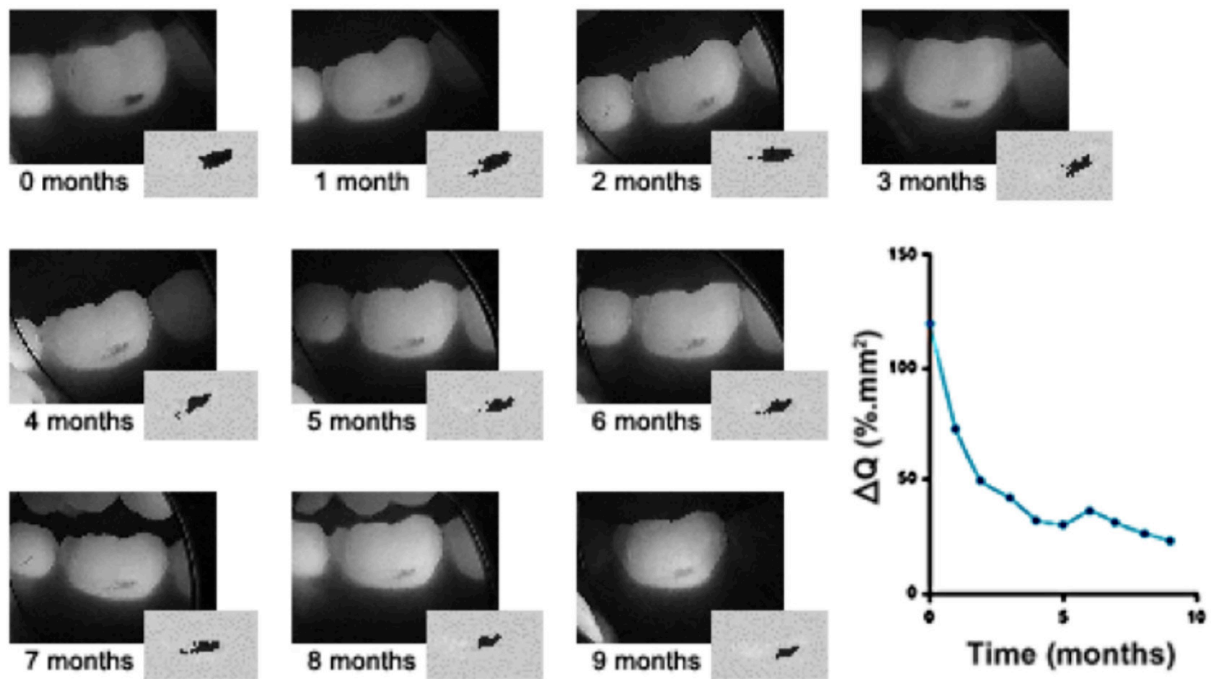
Clinical QLF showing green auto-fluorescence on the buccal surfaces and red fluorescence at the proximal areas.

A powerful feature of QLF is the ability to follow tooth surfaces over time (longitudinal monitoring). The software includes automatic video repositioning that enables the acquisition of comparable QLF images of the same surfaces at different time points.

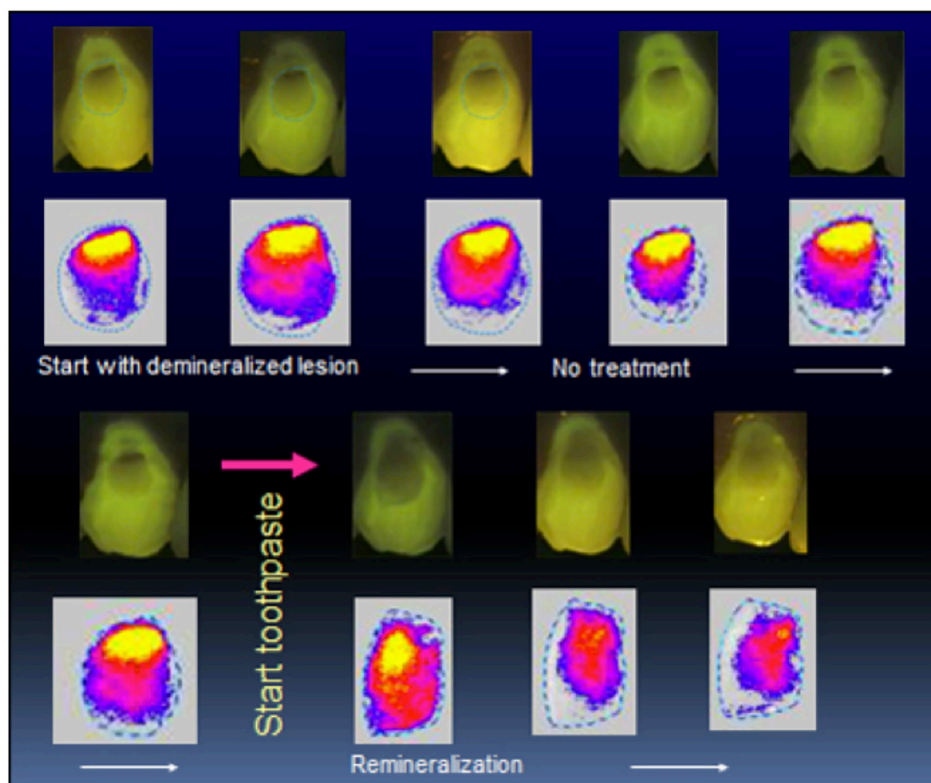
The software can also analyze recorded images and, thus, provide an objective assessment of areas of concern over time.

The photos shown below are research images showing remineralization of a white-spot lesion over a 9 month time period.

Remineralization of a white spot after debracketing:



Images and data courtesy of S. Al-Khateeb, Karolinska Institutet, Stockholm, Sweden



Inspektor Research System

Image source: Inspektor Research Systems BV, Amsterdam, The Netherlands

Another study (above) demonstrated that with no treatment, lesions present at the start of the study continued to progress; once fluoride dentifrice was incorporated into the test regimen, reversal of the lesions became quickly apparent.

Clinical Application

The Inspektor Pro QLF Camera system has been approved by the FDA and is available for dental professionals and research and educational institutes in several countries. The device was designed to be used in any clinical environment. The basic version brings QLF images and analysis to the dental practice. The research version supports the use of QLF for fundamental research and clinical trials.

QLF-D is a recent addition to the available QLF systems and is making the measurement of early caries even simpler. QLF-D works using the same principles as other QLF systems. However, the QLF-D system utilizes images taken using a high resolution camera, rather than the QLF handpiece used in the earlier Inspektor Pro system.

Some examples of the use of the handpiece to acquire images of the various surfaces:

Orientations of the QLF handpiece when taking an image of various surfaces:



Lower-left buccal



Lower-front buccal



Lower-right buccal

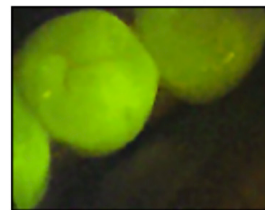


Lower-right occlusal

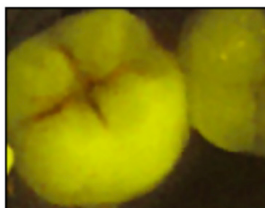
Some examples of QLF images:



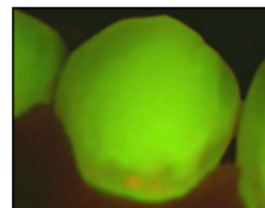
Occlusal view of the upper left 2nd molar with enamel breakdown in the central fossa.



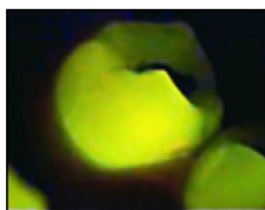
Sound fissures in the upper right 2nd bicuspid.



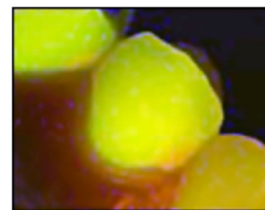
Fissures of the upper right 2nd molar are covered by matured plaque obstructing a clear view.



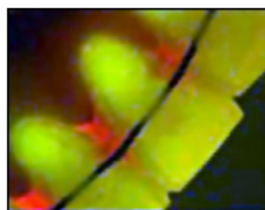
Red fluorescence inside a white spot lesion developed during orthodontic treatment (the QLF image was made after professional cleaning)



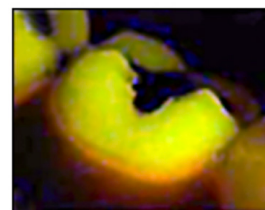
Calculus at the proximal area.



Matured plaque at the proximal area.



Retention wires are a good retention site for plaque.



Matured plaque along the gingival margin.

Validation

Scientific studies on QLF are accumulating in the literature. Technical validation of QLF has generally been favorable (see, for example the work done by the group of Angmar-Månsson in 1996³⁶) showing good correlation between mineral loss and deltaF. Its use for smooth surfaces and occlusal surfaces was reported by van der Veen and de Josselin de Jong,³⁷ and data was published on its use for demineralization and remineralization as a potential tooth for clinical assessment by Amaechi and Higham.³⁸ Its use for the detection and monitoring of secondary caries was published by Gonzalez-Cabezas et al.³⁹ Later, its use was coupled with fluorescent dye to effectively measure root surface demineralization/remineralization and shows promise as an *in vivo* method for root caries detection and classification.⁴⁰

QLF detection of red fluorescence is showing promise as a key method for determining the presence of caries activity. More and more studies are suggesting a strong correlation between active caries and red fluorescence. A study by Lee et al.⁴¹ demonstrated that the red fluorescence measured using QLF-D correlated with the cariogenic properties of dental microcosm biofilms *in vitro*. According to the authors, these data indicate “that this device can be used to detect the levels of cariogenicity of a dental biofilm.” Both of the QLF systems are broadly used in the dental research community, and the QLF-D system is quickly becoming established in dental practices outside the US. Future prospects of using this type of technology in the US for identifying and quantifying early caries, along with the ability to track progress over time, are exciting. The ability to take non-ionizing radiation measurements with QLF, recommending a treatment such as a fluoride toothpaste, and then monitoring remineralization at regular recalls, is an exciting prospect for all dental professionals.

Electrical Resistance

Electrical resistance has been used over the years in various forms in an attempt to detect caries. It basically uses a change in resistance to indicate mineral content. It has

been used for occlusal caries detection,⁴² as well as for an *in vitro* and *in vivo* assessment of remineralization of lesions with toothpaste. Some difficulties existed and statistical significance was not seen, but the conclusions indicated that with modifications, “...electrical resistance measurements may be a means of comparing the remineralization performance of toothpastes.” Even more recently, electrical resistance (using the Electric Caries Monitor – ECM) has been used *in vitro* in a comparison to transversal micro-radiography to measure remineralization (root lesion depth and mineral loss) with several fluoride treatment regimes. It appears ECM specificity is only 80%, which makes it inappropriate for clinical use at this time.⁴³ Although not ready for clinical application at present, it does indicate alternative possibilities for measuring remineralization/demineralization of difficult to detect root surface lesions in the future.

In a 2013 publication by Twetman and colleagues,⁴⁴ the authors reviewed the available literature regarding adjunct methods for caries detection. They concluded: “There was insufficient scientific evidence for diagnostic accuracy regarding fiber-optic methods and quantitative light-induced fluorescence (+OOO). The electrical methods and laser fluorescence could be useful adjuncts to visual-tactile and radiographic examinations, especially on occlusal surfaces in permanent and primary molars, but evidence was graded as limited (++)OO). No conclusions could be drawn regarding the cost-effectiveness of the methods. There is an obvious need to standardize study designs for *in vitro* and *in vivo* validation of the different methods.”

Clearly there is a need to increase the sensitivity of our methods of caries detection while maintaining the highest level of specificity. Our desire is to be able to detect caries activity even before it is clinically or radiographically visible so that we can institute effective methods for remineralization and stop the net demineralization. The caries process is a dynamic continuum, and current detection methods need more study and comparison to the “gold standard.”⁴⁵ With improved methods for caries detection,

Ekstrand⁴⁶ suggests the need for potential clinical trials using non-cavitated lesions. These early detection methods need evaluation but are suggested for clinical trials of therapies aimed at correcting the demineralization/remineralization imbalance in individuals at risk. Imrey and Kingman⁴⁷ reviewed this area and suggested data analysis will be needed that fully exploits ordinal or continuous-scale outcome measures. Hopefully, we will continue to see more clinical trial data with methods that measure early carious lesions in a quantitative manner. We will then be able to apply these methods for individual patient therapy involving remineralization approaches.

The Canary System

One final caries diagnostic system is one known as the Canary System.



According to the company [website](#):

"The Canary System is a precise, low-powered, laser-based instrument with an integrated intraoral camera that detects the presence of cracks and caries (tooth decay) before they are large enough to appear on dental X-rays. Intraoral camera images can be displayed for immediate chair side review with the patient. A patient report is generated containing an odontogram with Canary Numbers, which are color-coded for the examined teeth, along with the dentist's treatment recommendation. This report can also be examined by the patient on [The Canary Cloud](#)."

In describing how the system works, the following information is provided:
 "When placed on the tooth surface, a low-powered, pulsating laser light is shone on the

tooth during a 3 second scan. The pulses of laser light generate photothermal (PTR) and luminescence (LUM) responses. By using a laser pulse at a frequency of 2Hz, the laser light can penetrate below the tooth surface and permit detection of a carious lesion as small as 50 microns (20 times smaller than a millimeter) and as deep as 5 mm from the tooth surface."

An explanation of the Canary scale is also offered:

"A Canary Number is the output generated by The Canary System to inform the oral health care professional about the probable health status of a given tooth. Using a complex algorithm, The Canary System converts the unique PTR/LUM signatures into a Canary Number on a scale from 0 to 100 which appears on a monitor screen and is also audible. Lower numbers suggest healthy enamel and higher numbers suggest the presence of cracks and caries."

Finally, as noted by the company when describing the benefits of this particular system over others:

The Canary System is the only caries detection system that:

- Analyzes and measures the crystal structure of the tooth
- Measures up to a depth of 5 mm
- Detects decay on all tooth surfaces including:
 - Around and beneath the intact margins of restorations including amalgam, composites and crowns
 - Smooth surfaces,
 - Occlusal pits and fissures, including beneath stained areas
 - Around orthodontic brackets
 - Interproximal regions
 - Beneath opaque and transparent dental sealants

Evaluating the Caries Evidence with Respect to Fluorides - Scientific Support for Clinical Decisions

The world of dentistry has begun to change to require sound scientific evidence for clinical applications of both treatment and preventive approaches to dental caries. In a nutshell, Cariology is evolving as a part of evidence-

based dentistry. Evidence-based dentistry (EBD) is defined by the American Dental Association as "...an approach to oral health care that requires the judicious integration of systematic assessments of clinically relevant scientific evidence, relating to the patient's oral and medical condition and history, with the dentist's clinical expertise and the patient's treatment needs and preferences."⁴⁸

Duke University has a tutorial "[Welcome to the Introduction to Evidence-Based Practice](#)" in Evidence based-Medicine that helps in the understanding of this approach. Forrest and Miller⁴⁹ have provided an approach for evidence-based decision making in dentistry and demonstrate the process with clinical examples. The PICO approach – Population (P), Intervention (I), Comparison (C) and Outcome (O) system can easily be applied to remineralization/demineralization.

Ismail and Bader⁵⁰ provided a practical clinical approach to evidence-based dentistry, discussed various models for use and stated in their conclusions "In the evidence-based approach to clinical decision making, dentists incorporate the best scientific evidence—evidence that is critically appraised in systematic reviews—with clinical experience and their patients' preferences for treatment outcomes." Clinical practitioners have access to a large amount of scientific literature just as patients do via the Internet. A quick search using [PubMed](#) at the time of updating this course revealed 42,336 articles cited using the keywords tooth and demineralization. Two thousand and forty-four (2,044) citations were found when tooth remineralization was used and 1,544 discovered for enamel remineralization.

Jeyanthi⁵¹ indicates a number of useful databases to be used in evidence-based dentistry when performing searches that include:

- AMED ([Allied and Complementary Medicine Database](#))
- ProQuest ([Applied Social Sciences Index and Abstracts](#))
- CancerLit ([US National Cancer Institute](#))
- [ProQuest Dissertations & Theses Global™](#)
- DAIC ([Dissertation Abstracts International](#))

- EMbase ([Biomedical Database](#))
- ERIC ([Educational Resources Information Centre](#))
- [PsycINFO](#)
- HTA ([Health Technology Assessment Database](#))
- LILACS ([Latin American & Caribbean Health Sciences Literature](#))
- [Oxford Pain Database](#)

These will not normally be the object of many clinical practitioners' searches for evidence, but one should be aware that they exist and are used in analysis of clinical questions. Evaluation of the evidence is done using strict criteria by such groups as the [Cochrane database](#). When one looks at the current dental topics, the following reviews of fluorides are excellent examples:

Cochrane Review: Fluoride Toothpastes

The review included 96 studies published between 1955 and 2014 in this updated review.⁵² The authors concluded: "This Cochrane Review supports the benefits of using fluoride toothpaste in preventing caries when compared to non-fluoride toothpaste. Evidence for the effects of different fluoride concentrations is more limited, but a dose-response effect was observed for D(M) FS in children and adolescents. For many comparisons of different concentrations, the caries-preventive effects and our confidence in these effect estimates are uncertain and could be challenged by further research. The choice of fluoride toothpaste concentration for young children should be balanced against the risk of fluorosis." This is perhaps one of the most rigorous evaluations of the dental literature completed, and it strongly supports the use and recommendation that patients use fluoridated dentifrices for caries prevention.

It should be noted that most dose response studies, in which higher doses of fluoride have been found to provide greater anticaries benefits, are generally done using the same fluoride agent. One interesting clinical study, however, found that an 1100ppm F toothpaste (formulated with stabilized SnF₂), was similar in performance to a 2800ppm F NaF toothpaste,⁵³ suggesting that different sources of fluoride may provide different levels of efficacy.

A Second Cochrane Review: Fluorides in Orthodontic Patients

A Cochrane Review from 2004 evaluated fluoride for the prevention of demineralized white spot lesions (DWLs) during orthodontic treatment.⁵⁴ This review included 15 trials with 723 participants and had less strength to their conclusions which were, “There is some evidence that the use of topical fluoride or fluoride-containing bonding materials during orthodontic treatment reduces the occurrence and severity of white spot lesions, however there is little evidence as to which method or combination of methods to deliver the fluoride is the most effective. Based on current best practice in other areas of dentistry, for which there is evidence, we recommend that patients with fixed braces rinse daily with a 0.05% sodium fluoride mouthrinse. More high quality, clinical research is required into the different modes of delivering fluoride to the orthodontic patient.” An update to the 2004 review was published in 2019 10 studies, with data from nine studies and compared eight interventions, involving 1798 randomised participants (1580 analysed).⁵⁵ In the updated review, the authors “found a low level of certainty that 12,300 ppm F foam applied by a professional every 6 to 8 weeks throughout fixed orthodontic treatment, might be effective in reducing the proportion of orthodontic patients with new DLs. In addition, there is a low level of certainty that the patient use of a high fluoride toothpaste (5000 ppm F) throughout orthodontic treatment, might be more effective than a conventional fluoride toothpaste. These two comparisons were based on single studies. There was insufficient evidence of a difference regarding the professional application of fluoride varnish (7700 or 10,000 ppm F). Further adequately powered, randomised controlled trials are required to increase the certainty of these findings and to determine the best means of preventing DLs in patients undergoing fixed orthodontic treatment. The most accurate means of assessing adherence with the use of fluoride products by patients and any possible adverse effects also need to be considered. Future studies should follow up participants beyond the end of orthodontic treatment to determine the effect of DLs on patient satisfaction with treatment.”

The Next Relevant Cochrane Review: Fluoride Gels

This review was done to evaluate the effects of fluoride gels for caries prevention in children and adolescents.⁵⁶ Twenty-eight studies were analyzed which included over 9,000 children. Key results from this review “confirmed that fluoride gel can reduce tooth decay in children and adolescents. We combined the results of 25 trials and found that on average there is a 28% reduction in decayed, missing and filled tooth surfaces (21% reduction in trials that used a placebo gel in the control group and 38% reduction in trials where the control group received no treatment) in permanent teeth. From the three trials looking at the effect of fluoride gel on first or baby teeth, the evidence suggests that using fluoride gel results in a 20% reduction in decayed, missing and filled tooth surfaces. We found little information about unwanted or harmful effects or how well children and young people were able to cope with the application of the gel.” The authors concluded: “The application of fluoride gel results in a large reduction in tooth decay in both permanent and baby teeth. We found little information about potential unwanted or harmful effects from accidental swallowing of the gel during treatment. As children often swallow gel during application, more research is needed on these effects.” Clearly, fluoride gels have a caries preventive effect. They are office applied and should be selected based on individual patient situations and caries risk assessments when the decision is made to use them in practice.

The Final Cochrane Review: Fluoride Mouthrinses

This review “included 37 studies in which more than 15,000 children (aged six to 14 years) were treated with fluoride mouthrinse or placebo (a mouthrinse with no active ingredient) or received no treatment.”⁵⁷ Key results from the study “confirmed that supervised regular use of fluoride mouthrinse can reduce tooth decay in children and adolescents. Combined results of 35 trials showed that, on average, there is a 27% reduction in decayed, missing and filled tooth surfaces in permanent teeth with fluoride mouthrinse compared with placebo or no mouthrinse. This benefit is likely to be present

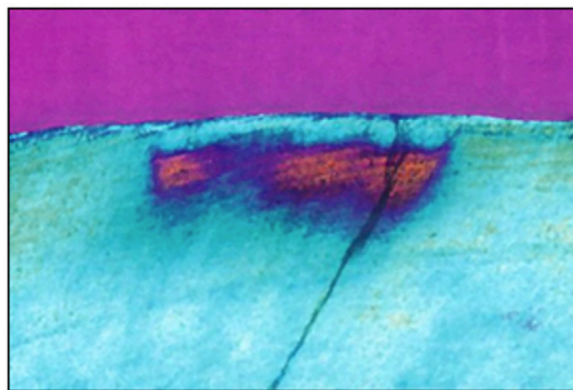
even if children use fluoride toothpaste or live in water-fluoridated areas. Combined results of 13 trials found an average 23% reduction in decayed, missing and filled teeth (rather than tooth surfaces) in permanent teeth with fluoride mouthrinse compared with placebo or no mouthrinse. No trials have looked at the effect of fluoride rinse on baby teeth. We found little information about unwanted side effects or about how well children were able to cope with the use of mouthrinses.” The reviewers concluded “Regular use of fluoride mouthrinse under supervision results in a large reduction in tooth decay in children’s permanent teeth. We found little information about potential adverse effects and acceptability.” Therefore, fluoride mouthrinses can be effective in caries prevention. In our best clinical judgment it may be that patients using fluoridated toothpastes who are at risk of caries may be candidates for the additional benefits of a fluoridated rinse.

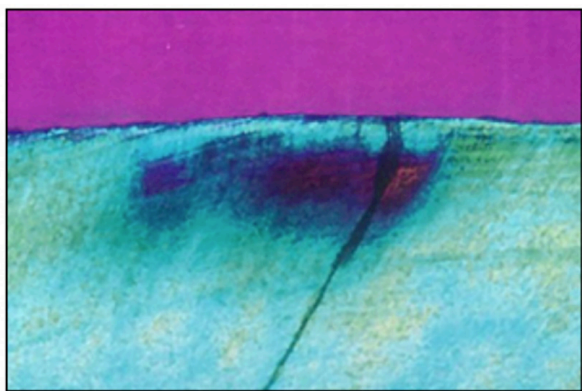
A shift toward a “medical model” in the treatment and prevention of dental caries as described by Anderson⁵⁸ has been suggested. Barber and Wilkins⁵⁹ discuss the application of an evidence-based approach to caries and indicate a caries risk level must be evaluated at each maintenance appointment. We have experienced a “paradigm shift” in the approach to caries from surgical to a medical model as described by Steinberg⁶⁰. The model includes bacterial control, reduction of risk levels for at-risk patients, reversal of active sites by remineralization, and follow-up and maintenance. It is hoped the shift in approach and addition of an evidence-based approach will lead many practitioners to a higher quality of care for their patients and much more sound approach in preventive care rather than a “drill and fill” surgical approach that was present in the past. To quote ten Cate in the 50th Anniversary ORCA Congress,⁶¹ “The caries-preventive effects of fluoride are beyond any reasonable doubt! Inclusion of fluoride use in caries prevention protocols has resulted in significant reduction in caries prevalence in the majority of the population.”

Over recent times, there have been a number of “models” in use that focus not only on lesion identification and severity, but also on

recommendations for appropriate intervention. The International Caries Detection System (ICDAS), the International Caries Classification and Management System (ICCMS), Caries Management by Risk Assessment (CAMBRA), Caries Management System (CMS) and the American Dental Association Caries Classification System are all systems that have been in use. A 2012 meeting held at Kornberg School of Dentistry in Philadelphia brought together a diverse group of experts from academia, research, industry and dental organizations to review all of the available models. One outcome of this meeting was the Caries Management Pathways (CaMPs) model that serves as an umbrella that incorporates all of the various classification systems. At this conference, a new mission for dentistry was defined; “that it is time for all oral health professionals to focus on the promotion of oral health and preservation of sound teeth rather than counting the number of surgical procedures provided.” There was overwhelming agreement that there is a need to preserve dental tissues, and to only perform restorative measures when needed. Focusing on the identification of lesions in the earliest stages enables dental health professionals to implement appropriate interventions, such as fluoride treatment, to remineralize these challenged areas.⁶²

At present, the ICDAS System, an integral aspect of the ICCMS™ approach, is the most favored model. While the ICCMS™ represents a new, enhanced approach to the diagnosis and management of caries, the ICDAS System provides a standardized method for assessing and tracking changes in caries activity.



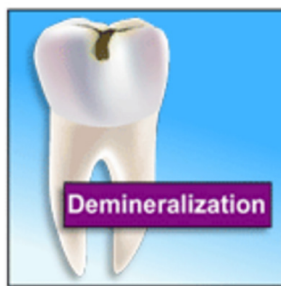


Images provided by Dr. James Wefel

Polarized-light micrographs (in water) of a single section enamel lesion used in an *in vivo* human model to observe the remineralization of a lesion through the use of fluoride therapy. The top micrograph is prior to placement in the appliance and the bottom micrograph is the same section after the experimental period in the patient's mouth while using a fluoride regime. Note the reversal in the size of the body of the lesion indicating remineralization.

At every given moment, when the pH drops below the critical threshold for caries, for every tooth surface, no matter the age or location of the surface, it will undergo an acid challenge...a tug of war.

Fluorides become an integral part in the prevention of dental decay for every tooth surface, no matter the age or location...and fluorides play a major role in our practices today.



Conclusion

To sum up the caries process on both enamel and root surface:

Coronal Caries:	Root Surface Caries:
88 vol. % mineral	45 vol. % mineral
plaque related	plaque and recession related
acid dissolves subsurface "white spot"	acid dissolves surface subsurface "sticky"
complete dissolution=cavitation	complete dissolution=surface contour changes
until cavitation occurs, remineralization is possible	with collagen in place, remineralization is possible once collagen is destroyed, no framework for remineralization to occur

Course Test Preview

To receive Continuing Education credit for this course, you must complete the online test. Please go to: www.dentalcare.ca/ca-us/professional-education/ce-courses/ce73/test

1. **Dental caries became a matter of national concern in the _____.**
 - A. 1930s
 - B. 1940s
 - C. 1950s
 - D. 1960s
2. **According to the most recent National Health and Nutritional Examination Survey (NHANES; 1999-2004), the following statement(s) is(are) correct.**
 - A. Caries has been essentially eliminated as a childhood disease
 - B. Overall, dental caries in deciduous (baby) teeth of children ages 2 to 11 declined from the early 1970s until the mid-1990s.
 - C. From the mid-1990s until the most recent survey, the trend has actually reversed: a small but significant increase in primary decay was found, with the trend being more severe in younger children.
 - D. B and C
3. **The earliest clinical evidence of an enamel lesion of dental caries is _____.**
 - A. a white spot lesion
 - B. a roughened surface
 - C. an explorer "stick"
 - D. a darkened appearance
4. **Radiographically, an early lesion of enamel caries appears as _____.**
 - A. a break in the outer layer of enamel
 - B. an opaque area
 - C. a demineralized zone beneath the intact surface layer
 - D. an area of increasing roughness
5. **Caries activity usually begins _____.**
 - A. at the outer-most surface of the enamel
 - B. along the rod margins below the outer tooth surface
 - C. mostly on smooth surfaces
 - D. within 1 to 2 microns of the outer tooth surface
6. **The elements that dissociate during demineralization are _____.**
 - A. fluorapatite
 - B. calcium hydroxide and phosphorous
 - C. calcium citrate and pyrophosphate
 - D. calcium and phosphate
7. **A remineralized area of enamel is actually stronger than it was prior to acid attack due to which of the following?**
 - A. The incorporation of fluoride into the teeth with calcium and phosphate makes enamel more resistant to acid demineralization than it was originally.
 - B. Remineralized enamel has fewer bacteria.
 - C. The pellicle is removed during remineralization.
 - D. Amalgam is acid resistant.

- 8. Which of the following statements regarding remineralization and demineralization processes is false?**
- A. The processes of remineralization and demineralization are similar on any tooth surface upon which they are occurring (enamel pits, fissures, smooth surfaces).
 - B. Some tooth surfaces tend to have higher incidence of lesion formation compared to others.
 - C. The reason for differences in caries incidence on different tooth surfaces is related to the hardness of the enamel on each surface.
 - D. Pit and fissure, along with interproximal sites, experience the highest rates of lesion formation.
- 9. Human dentin (root surface) is approximately ____% (by volume) of mineral.**
- A. 45
 - B. 55
 - C. 65
 - D. 76
- 10. Which of the following statements about enamel caries and root caries is true?**
- A. Coronal caries is related to acidic foods, while root caries is related to both acidic food and drinks.
 - B. During enamel caries, acids demineralize and create subsurface lesions, while in root caries, the surface can become sticky and change in contour.
 - C. Even with fluoride treatment, cavitation will eventually occur once the demin process has started.
 - D. Enamel caries is reversible, but root caries are not.
- 11. Saliva is important for caries protection because it_____.**
- A. neutralizes acids formed by plaque bacteria
 - B. contributes the needed calcium and phosphate for preventing caries and allowing remineralization to occur
 - C. naturally contains a high level of fluoride
 - D. A and B
- 12. The NIH Caries Consensus Conference in 2001 reached which of the following conclusions?**
- A. The research data on fluorides in water and dentifrice support their efficacy.
 - B. The use of pit and fissure sealants is supported by the data.
 - C. Research data showing the effectiveness of chlorhexidine is strong.
 - D. Calcium is highly effective as an anticaries agent when delivered from toothpaste.
 - E. A and B
- 13. Fluoride plays a key role in the remineralization process by _____.**
- A. speeding up the remineralization process
 - B. inhibiting demineralization at the crystal surfaces
 - C. slowing the crystal growth process
 - D. A and B

14. Duggal et al used a human intra-oral model to examine carbohydrate frequencies and the use of non-fluoride and fluoride toothpaste and found when a F-free toothpaste was used and carbohydrate frequency exceeded 3 times per day, significant demineralization occurred. When subjects used a fluoride-containing toothpaste, however, net demineralization was only seen when carbohydrate consumption exceeded _____.
A. 3 times per day
B. 5 times per day
C. 10 times per day
D. 15 times per day
E. more than 19 times per day
15. One published study on digital radiography reports:
A. A significantly improved accuracy of caries diagnosis while reducing observer variability.
B. Lower reliability for digital radiographs compared to conventional films.
C. There is a greater ease of storage for conventional films compared to digital images.
D. It takes more time to take digital images than conventional films.
16. The process of evidence-based dentistry includes:
A. Following a strict protocol written only for dental patients.
B. Consultation with an attorney.
C. Incorporate the best scientific evidence (evidence that is critically appraised in systematic reviews) with clinical experience and their patients' preferences for treatment outcomes.
D. A and B
17. The most recent "Cochrane Review" on fluoride toothpaste that indicated it is clearly efficacious in preventing caries included data from _____.
A. 120 studies published between 1960-2020
B. 96 studies published between 1955 and 2014
C. 3 studies published within the past 10 years
D. 15 studies considered to be high quality studies
18. Leake, in an evidence-based review on root caries, stated that "Severity reaches over one lesion by age fifty, two lesions by age seventy, and just over ____ lesions for those seventy-five and older."
A. Four
B. Five
C. Three
D. Six
19. The paradigm shift from a surgical model to a medical model for caries control as described by Steinberg includes:
A. Bacterial control
B. Reduction of risk levels for at-risk patients
C. Reversal of active sites by surgical repair
D. A and B

20. The “Cochrane Review” on Fluoride in Orthodontic Patients reported:

- A. There is little to no evidence that the use of topical fluoride or fluoride-containing bonding materials during orthodontic treatment reduces the occurrence and severity of white spot lesions.
- B. Based on current best practice in other areas of dentistry, for which there is evidence, the daily use of a 0.5% cetylpyridinium chloride (CPC) mouthrinse is recommended.
- C. We already have sufficient, high quality, clinical research available to make recommendations as to the best toothpaste and mouthrinse that orthodontic patients should use.
- D. Found a low level of certainty that 12,300 ppm F foam applied by a professional every 6 to 8 weeks throughout fixed orthodontic treatment, might be effective in reducing the proportion of orthodontic patients with new DLs.

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