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Diagnostic Modalities Of Early Caries Detection

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Abstract
Dental Caries is a complex dynamic process involving demineralization and remineralization. If detected at an early stage of progression, the surgical intervention could be avoided to achieve maximum conservation of tooth structure. The disease remain hidden until obvious cavitation occurs, emphasizing their early detection. In the past few decades, various technologies have emerged for the monitoring of these initial carious lesions improving the ability to maximum conserve demineralized non-cavitated enamel and dentine. Clinical diagnosis, which has advanced from visual-tactile method to radiography to the use of lasers, has been reviewed in this article.

Key Words
caries, early detection, visual-tactile method, radiographs, lasers.

INTRODUCTION

Dental caries has a multifactorial etiology and as extensive advances have been made in understanding the relationship between oral environment and caries, it is now clear that the early stages of caries which involve demineralization can be reversed/arrested or its progression be delayed. This has shifted the concept of treatment from "prophylactic odontomy" to minimally invasive dentistry or "microdentistry". Modifications in the methods for identification of these lesions, as early as possible, have greatly aided this transition. The traditional methods of caries detection have included direct visual-tactile inspection followed by radiographs. With the new paradigm shift in the prevention and treatment of dental caries need for newer diagnostic equipments and techniques have emerged. At the same time it must be remembered that caries activity cannot be determined at one time but it require continuous monitoring over a period of time. Hence, accurate, reliable, reproducible quantitative methods to detect and monitor early carious lesions are of utmost desire.

Dental caries detection methods:

Visual-tactile examination: The basic first step in caries detection is visual inspection (VI) of teeth aided by the use of compressed air. A new system gaining attention is ICDAS (International Caries Detection and Assessment System). It was developed as evidence based system to assess severity stages of dental caries. It consists of 7 categories (0-6) to assess every plaque-free tooth surface, under wet and dry conditions. ICDAS codes are

- 0: no or slight change in enamel translucency after prolonged air drying(5s)
- 1: first visual change in enamel(seen only after prolonged drying or restricted to within the confines of a pit/ fissure)
- 2: distinct visual changes in enamel
- 3: localized enamel breakdown in opaque/ discolored enamel(without visual signs of dentinal involvement)
- 4: underlying dark shadow from dentine
- 5: distinct cavity with visible dentine
- 6: extensive distinct cavity with visible dentine(involving more than half of the surface)

In the VI the dental practitioner should be looking for: White chalky lesions, changes in colour and translucency of enamel, any discoloration (gray/black), and break in the continuity in the enamel surface. This is usually followed by exploring the surface of teeth with an explorer. This tactile examination is no longer recommended as its scratching tends to prevent any chances of remineralization of any early lesion. If it has to be done either a slightly blunt probe should be used, that to with very little pressure.

Radiographic examination: Although radiographs still play an important role in caries detection their ability to identify earlier or hidden caries is questionable. At least 40-60% of tooth demineralization is required before it appears in the radiograph. Intraoral radiographs are better than extraoral radiographs due to their high resolution and greater image details. Bitewing radiographs are most suited for detection of proximal caries. They show lower sensitivity and specificity values for enamel caries than for dentinal lesions indicating intraoral radiographs are better for the detection of dentinal caries and have less value for detecting enamel lesions. Inability to detect incipient caries, the actual size/ depth of lesion, whether the lesion is active or arrested along with radiation exposure to the patient are few of the drawbacks of using radiographs as a diagnostic tool.

Digital radiographs: The turning point from film based to digital radiography dates back to 1972 when G.N.Hounsfield introduced his new invention called *computerized transverse axial scanning.* The advantages of digital imaging over conventional radiographs are lower radiation doses, shorter working time, and absence of darkroom processing, digital enhancement and image processing, easy imaging storage, digital subtraction ability. All these improve the quality and diagnostic accuracy of caries detection, especially for incipient and hidden carious lesions. Dental digital images are acquired by several means including: *indirect imaging* from conventional radiographs using a flatbed scanner; semi direct imaging using a PSP detector; *direct imaging* based on solid state electric detector, such as charge couple device-based sensor,(CCD), complementary metal oxide semiconductors (CMOS), and photo-stimulable phosphor plates (PSP). Sensitivity to caries detection was higher in digitized film images than either in xeroradiography/ film radiographs.

Electrical Conductance Measurements (EC): The concept was given first by Magitot in 1878. The electrical conductivity of a tooth changes with demineralization, even when the surface remains apparently intact, due to decreased electrical resistance in these areas of microporosities. Electrical conductance measurements make use of increased conductivity of carious enamel in pits and fissures. The entire occlusal surface is first covered with a conducting medium. Conductivity from the occlusal surface to a ground electrode is then measured with a probe. An increase in conductivity is due to the development of microscopic demineralized cavities within enamel, which are filled with saliva. Generally high sensitivity (.90) and low (.80) specificity have been reported for EC techniques.

Optical transillumination: In high-intensity fiber optic-based transillumination (FOTI) system, by Friedman and Marcus 1970, the detection of a carious lesion occurs because of the changes in the scattering and absorption of light photons resulting from a local decrease of transillumination, owing to the characteristics of the carious lesion. When a tooth is illuminated by a light, the carious tissue, because of porosity, scatters light more strongly and the enamel shows as a whiter opaque area. In case dentine is carious, a shadow is observed in the underlying dentine. When it is used for the detection of interproximal caries, a high-intensity light is placed on the buccal surface, and the interproximal surface is observed by transillumination through the occlusal surface. Enamel lesions appear as gray shadows, and dentinal lesions appear as orange-brown or bluish shadows. This method was not quantitative and relied upon the dentist interpretation, hence, low reliability value.

DIFOTI (Digital Fiber Optic Transillumination) was developed combining FOTI with a charge-coupled device digital intraoral camera. With this system, the images are captured, stored and displayed on a computer screen, which can be compared with the clinical presentation; however, as with FOTI, the detection is based on a subjective interpretation of the appearance of the lesion. It has high specificity but low sensitivity for both occlusal and proximal surfaces.

Fluorescence: Benedict first described enamel fluorescence and it was proposed to detect dental caries. Fluorescence results from change in the characteristics of light caused by a change in the wavelength of the incident light rays following reflection from the surface of a material. The intensity of the emitted fluorescent can be measured by using a filter system through which only the fluorescent rays pass. The inherent fluorescence of a material is often referred to as autofluorescence. Wavelength of the incident light affects the fluorescence: near ultraviolet light emits blue fluorescence, blue and green emits yellow and orange fluorescence, red and infrared light emits red fluorescence. It is suggested that fluorescence is caused by the presence of chromophores/ endogenous fluorophores within enamel and the differences in the fluorescence between sound and carious enamel, when illuminated with UV or near visible light are due to the loss of chromophores in the lesion. While others are of the view that this could be explained by the altered amounts of light scattering in the lesion which is much greater than in sound enamel, and the resultant absorption per unit volume is less in a lesion with less observed fluorescence. As in the lesion, the path length is short and an exciting photon has only a small chance of being absorbed.

QLF (Quantitative Light Fluorescence): The changes in enamel fluorescence can be detected and measured when the tooth is illuminated by violet-blue light (wavelengths 290-450 nm, average 380 nm), followed by image capturing using a camera fitted with a yellow 520 nm high pass filter. The image is captured, saved, and processed: it is first converted to black-and-white so that thereafter the lesion site can be reconstructed by interpolating the grey level values in the sound enamel around the lesion. The difference between measured and reconstructed values gives three quantities: ?F (average change in fluorescence, %), lesion area (mm2), and ?Q (area ×?F), which gives a measure of the extent and severity of the lesion. The QLF method also includes image analysis software which measures the difference in fluorescence between sound and demineralized enamel. Changes in fluorescent radiance and lesion area can be followed over time, to measure lesion development. For smooth surfaces, the mean sensitivity and specificity of QLF is 0.7 and 0.85. For occlusal surfaces, the values are 0.61 and 0.59.

DIAGNOdent: DIAGNOdent™ uses IR light of 655-nm wavelength to excite porphyrin fluorescence from bacteria byproducts trapped in the pores of demineralized tissue for the detection of "hidden" occlusal caries lesions. Although, this must be considered a major step towards better caries detection in occlusal surfaces, the principal limitation of this device is that it detects lesions in the later stage of development after which the decay has penetrated into the dentin and accumulated a considerable amount of bacterial byproducts and has a poor sensitivity (~0.4) for early lesions confined to enamel.

DIAGNOdent pen: it uses a probe with a tip that is designed specifically to fit the interproximal space between posterior teeth. The probe tip is a wedge-shaped, solid, single sapphire fiber with a prismatic shape which can be rotated along its long axis.

Multi-photon technique: In multi-photon imaging, two infrared photons (with half the energy of the blue photon) are absorbed simultaneously. The probability of this happening is normally low, but by exposing the tooth to many more photons, it is possible to increase greatly the chances of two-photon absorption. With this technique, sound tooth tissue fluoresces strongly, whereas carious tooth tissue fluoresces to a much lesser extent. Caries will appear as a dark form within a brightly fluorescing tooth. Multi-photon imaging is able to collect information from caries lesions up to 500 microns in depth. Currently, the technique has been performed only on extracted teeth, and the large and complex laser equipment required to produce such an image will require many years to develop into a clinically usable form. Its advantage lies in the non-invasive method of acquisition of a quantifiable measurement of mineral loss, as function of fluorescence loss, from a caries lesion in three dimensions. The low average level of laser power used means that there is low risk of phototoxicity to the pulp, and the longer incident wavelength results in enhanced depth penetration.

Photon Undulatory Non-linear Conversion (PNC): The fluorescence emission spectroscopy system tested (helium-neon [He-Ne], lambda = 633 nm) has a fiber optic device that delivers radiation to the tooth and a spectrophotometer device that detects bacterial porphyrins fluorescence, allowing detection of caries, fillings, and calculus by simultaneous measurement of backscattering and fluorescence intensity. It exceeds x-rays in sensitivity, without any ionizing radiation.

Optical Coherence Tomography: It was first developed in medicine for use in ophthalmology by Huang et al (1991). OCT is a noninvasive technique to produce morphologic depth images of near-surface tissue structures with a resolution that is an order of magnitude greater than ultrasound imaging. It is based on measurement of back-scattered near infrared light. OCT shows that sound enamel causes high-intensity back-scattering at the tooth surface that decreases rapidly with depth. In contrast, incipient lesions cause higher light back-scattering at the tooth surface and subsurface scattering indicative of porosity caused by demineralization. The scatter region within the enamel correlates well with the classical triangular shape of subsurface lesions observed in histologic sections. OCT imaging not only allows identification of incipient lesions, but also provides information on surface integrity and lesion depth.

Polarization-Sensitive OCT (PS-OCT) is a variation of conventional OCT that uses polarized incident light to create images and quantify caries. It provides additional contrast between sound and demineralized tissues.

Near Infrared Transillumination: Methods that use longer wavelengths, such as in the NIR spectra (780 to 1550 nm), can penetrate the tissue more deeply. This deeper penetration is crucial for the transillumination (TI) method. Enamel is highly transparent in the NIR range (750 nm to 1500 nm) due to the weak scattering and absorption in dental hard tissue at these wavelengths. Therefore, this region of the electromagnetic spectrum is ideally suited to the development of new optical diagnostic tools based on TI. The NIR light diffuses through the highly scattering dentin providing uniform back illumination of the enamel of the crowns allowing imaging of the occlusal surfaces. These images show high contrast between sound and demineralized areas. This method, exploits the high transparency of dental enamel and the strong scattering and weak absorption of the underlying dentin to deliver a uniform distribution of diffuse NIR light underneath the transparent enamel of the crowns to facilitate high contrast NIR imaging of the occlusal decay and detect hidden lesions beneath the surface. Demineralization (decay) can be easily differentiated from stains, pigmentation, and hypo mineralization (fluorosis) which leads to decreased number of false positive results. Moreover, the high transparency of the enamel enables imaging at greater depth for the detection of subsurface decay hidden under the enamel. NIR light at 1310-nm can be used to acquire images of early occlusal caries lesions which constitute the majority of newly developing lesions. This NIR technology can be used to acquire images of dental decay that is not detectable by conventional means either radiographically or by visual/tactile examination.

Infrared Thermography: Thermal radiation energy travels in the form of waves. It is possible to measure changes in thermal energy when fluid is lost from a lesion by evaporation. The thermal energy emitted by sound tooth structure is compared with that emitted by carious tooth structure. The technique has been described by Kaneko et al (1999) and has been proposed as a method of determining lesion activity rather than a method of determining the presence or absence of a lesion. Although, a study described by Matsuyama et al (1998) found a reasonable correlation (0.67-0.79) between temperature changes and mineral loss and lesion depth, there is no evidence that the rate, or pattern, of fluid loss from a lesion is directly related to the subsequent reactivity of a lesion.

Endoscope: It is based upon observation of the fluorescence that occurs when tooth is illuminated with blue light in the wavelength range of 400-500 nm. When this fluoresced tooth is seen through a specific broadband gelatin filter, white spot lesions appear darker than enamel. A white light can be connected to an endoscope by a fiberoptic cable so that the teeth can be viewed without a filter. This technique, referred to as endoscopy provides a magnified image.

Polarized Raman Spectroscopy (PRS): It is a form of vibrational spectroscopy that furnishes biochemical information about the tooth's composition, mineral content and crystallinity. Polarized Raman spectra of caries lesions exhibited a lower degree of Raman polarization anisotropy than those of sound enamel. The depolarization ratio derived from the dominant phosphate peak of hydroxyapatite in sound teeth is consistently lower than that from incipient caries. This difference is attributed to the structural changes in enamel crystallite morphology or orientation that occurs with acid demineralization and/or increased photon scattering resulting from the larger pores within the caries lesions. Based on the detected differences in the Raman polarization anisotropy between sound and carious enamel, ex vivo caries lesions were detected with 97% sensitivity and 100% specificity. Thus, PRS when used as an adjunct can rule out false-positive signals from non-carious anomalies.

Confocal microscopy: Until recently, the in vivo microscopic investigation of intraoral tissues at high resolution has been virtually impossible. Confocal microscopy enables high-resolution imaging to be achieved below semitransparent surfaces in intact living specimens. It uses a tandem scanning microscope, with images recorded via a SIT video camera. It can be used to collect light from different depths but only within the outer 100 microns of the tooth. Using this system internal tooth structure (e.g. enamel prisms/adhesive restoration interfaces) and the lining cells of the gingival crevice through to the junctional epithelium may be examined. Access is limited to the anterior regions as far back as the premolar teeth. Applications could include caries research, soft and hard tissue responses to biomaterials (e.g. implants), wound healing and monitoring the effect of periodontal treatment regimens. This new technique offers opportunities for the microscopic investigation of many clinical operative procedures in vivo, allowing the response of the tissues to be non-destructively monitored, over time, at high resolution.

Ultrasound: Ultrasound waves have a frequency of > 20,000 Hz. Ultrasound imaging was introduced by Ng et al. (1998) as a method for detecting early caries in smooth surfaces. They showed that artificial enamel lesions with less than 57% of the sound enamel mineral content in the body of the lesion could be differentiated acoustically from intact enamel on the basis of amplitude changes of the enamel surface echo and the amelodentinal junction echo. Thus, it can measure the mineral loss from a lesion body. The use of longitudinal waves to measure demineralization in relation to the ADJ is very useful, as is the potential for surface sound waves to detect cavitations. Ultrasound may be a quick and reliable tool for the detection of dental caries in enamel.

Terahertz pulse imaging (TPI): This method of imaging uses waves with terahertz frequency (= 1012 Hz or a wavelength of approximately 30 ?m). For an image to be obtained by terahertz irradiation the object is placed in the path of the terahertz beam or the terahertz beam can be scanned over the surface of an object. It is also possible to record terahertz images using a CCD detector. Higher attenuation of terahertz radiation was observed in carious enamel as compared with healthy enamel. Studies have demonstrated increased terahertz absorption by early occlusal caries and, intriguingly, an apparent ability to discriminate dental caries from idiopathic enamel hypomineralization. The advantages of TPI include: the relative transparency of human tissue to terahertz rays, low powers used for imaging (~ 1 ?W), the use of non-ionizing radiation, and no alteration of electrical charge of the tissues examined.

Photothermal Radiometry / Luminescence (PTR/LUM): Nonintrusive, noncontacting Frequency-Domain Photothermal Radiometry (FD-PTR or PTR) and Frequency-Domain Luminescence (FD-LUM or LUM) have been used with laser sources (650-850 nm) to detect artificial and natural subsurface defects in human teeth. Longer wavelength has shown better ability to detect deep subsurface lesions as compared to shorter wavelength. FD-PTR may also be used as a dynamic quantitative dental inspection tool complementary to modulated luminescence (LUM) to quantify sound enamel or dentin. PTR is sensitive to very deep (>5 mm) defects at low modulation frequencies (5 Hz). It is sensitive to various defects such as a deep carious lesion, a demineralized area, an edge, a crack, and a surface stain, while LUM exhibits low sensitivity and spatial resolution. PTR frequency scans over the surface of a fissure into demineralized enamel and dentin show higher amplitude than those for healthy teeth, as well as a pronounced curvature in both the amplitude and phase signal channels. These can be excellent markers for the diagnosis of subsurface carious lesions. PTR amplitude frequency scans over the surface of enamels of variable thickness exhibit strong thickness dependence, thus establishing depth profilometric sensitivity to subsurface interfaces such as the dentin/enamel junction.

Future management of dental caries requires early detection and risk assessment to defer operative intervention as long as possible. A diagnostic method for dental caries should aim at detection of earlier pathological changes so as to ascertain the stage up to which the disease can be reversed. Current caries detection rates suggest that there may be scope for improvement and dentistry needs new diagnostic tools and treatment methods to support improved patient care. The improvement in the detection of caries offers the possibility for dramatic improvement in dental healthcare.

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