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Diagnosing Dental Caries: An Insight

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Abstract: *Dental caries is one of the most common dental diseases till date and its detection at right time plays a very important role in arresting its progress and also to save the tooth from potential damage. Various techniques for detecting dental caries are available presently. This article briefly covers the various methods available right from old techniques to the newer advances in dental caries detection. Basic aim is to highlight the importance of caries detection and to understand the application of better and easier methods with greater sensitivity and specificity.*

Keywords: *caries, techniques, detection*

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I. Introduction

One of the most important basic diagnostic skill in oral health care profession is caries diagnosis. It is still considered a difficult skill to master by dental professionals. The management of caries depends entirely on accurate diagnosis since the lesion needs to be assessed as to whether the caries is limited to enamel or if it has progressed to dentin[1,2]. The activity of lesion needs to be determined as the therapeutic or operative management options for the lesion needs to be considered based on these findings[3]. The development of new technologies for early detection and quantitative monitoring of dental decay at initial stage could provide considerable health and economic benefits. The use of technologies as adjunct to clinical visual examination for diagnosis of dental caries will facilitate preventive care in dentistry thereby reducing the cost of treatment and also reduce the cost and time for testing potential anticaries agents[4].

Initial carious lesions in approximal surfaces can be diagnosed by radiographic examination. However, radiographic evaluation of occlusal surfaces has been found of minimal diagnostic value for detecting enamel caries and superficial dentin caries as it is surrounded by large amount of sound enamel. As x-ray is two dimensional picture of 3 dimensional structure, superimposition can occur. Later, the development of digitally enhanced radiography and use of computer technology helped in improving rate of diagnosis of early caries. But the main disadvantage is the high rate of false positive results when used for occlusal caries detection. Also, there is a risk of exposure to ionizing radiation.

In the past few decades, lot of research on dental caries detection is done leading to improved oral health. Studies were carried out to evaluate the natural history of dental caries using a standardized, visually based system, the International Caries Detection and Assessment System (ICDAS)[5-8]. It is known that not all caries lesions progress to cavitation, but little is known regarding the progression pattern of caries lesions.

II. Classification of Caries

The International Caries Detection and Assessment System (ICDAS) is the leading International system for caries diagnosis[9,10]. It offers a six stage, visual - based system for detection and assessment of coronal caries. It is found to be reliable and predictable as it combines features from several previously existing systems and does not rely on surface cavitation before caries can be diagnosed.

ICDAS Caries Classification

ICDAS Code	Description
0	Sound Tooth Surface
1	First visual change in enamel
2	Distinct Visual Change in enamel
3	Localized enamel breakdown due to caries with no visible dentin
4	Underlying dark shadow from dentin (with or without enamel breakdown)
5	Distinct cavity with visible dentin
6	Extensive distinct cavity with visible dentin

Diagnostic Tools. The detection of dental caries can be carried out by following diagnostic modalities :-

1. Visual
2. Tactile
3. Radiographic
a. Conventional
i. Intraoral periapical
ii. Bitewing
b. Xeroradiography
c. Modified radiographic techniques
i. Digital enhancement
ii. Computer Image
iii. Subtraction Radiography
iv. CBCT
4. Electric resistance (Electrical conductance and Impedance)
5. Optical detection
a. Optical caries monitor
b. Fibreoptic transillumination (FOTI)
c. Digital imaging fibreoptic transillumination
d. Ultraviolet illumination
e. Transillumination with near infrared light
f. Laser induced fluorescence
g. Quantitative laser fluorescence (QLF)
h. DIAGNOdent
i. Infrared Fluorscence
6. Endoscopy/Videoscopy
7. Dyes
8. Newer Techniques
a. CO_2 Lasers
b. Tera Hertz imaging
c. Multiphoton Imaging
d. Optical Coherence Tomography
e. Infrared Thermography
f. LED Technology (Midwest Cariess ID)
g. Alternating Current Impedance Spectroscopy (Caries Scan)
h. Frequency Domain Infrared Photothermal Radiometry and Modulated Luminescence
i. Magnetic Resonance Imaging (MRI)
j. Ultrasonic Imaging

1. **Radiographic Modalities**

a. The use of bitewing radiography as an adjunct to clinical examination allowed more sensitive detection of proximal and occlusal caries lesions in dentin. Also, it lead to better estimation of the lesion depth than the visual inspection alone.

b. Digital radiography has offered the potential to increase the diagnostic yield of dental radiographs. But the sensitivity and specificity of digital radiographs being significantly lower than those of regular radiographs while assessing small proximal lesions. Advantage of digital radiographs is that it offers a potential of image enhancement by applying a range of algorithms and also the radiographic dose is less.

c. Digital subtraction radiography is a more advanced image analysis tool. It can be used in the assessment of the progression, arrest or regression of carious lesions. The basic principle of subtraction radiography is that two radiographs of the same object can be compared using their pixel values. The value of the pixels from the first object is subtracted from the second object.

d. Computer Image analysis : In this, the computer does the evaluation of the diagnostic material i.e. radiographs and reaches the final diagnosis with no human input. In computer aided diagnosis, both the medical practitioner and a computer evaluate the radiograph and reach a diagnosis separately[11]. Example of CAD (Computer aided Diagnosis) is ‘Logicon’ system[12], which has a software containing a database of teeth with matching clinical images, radiographs and histologically known patterns of caries. A tooth after being radiographed, is evaluated by the software in graphic format giving the dental professional a tooth density chart and calculate a probability displayed on a scale of 0 to 1.0 that the area in question is a sound tooth, decalcified or carious and whether a restoration is required.

e. **CBCT (Cone Beam Computed Tomography)** : The cone beam computed tomography is a new application of CT that generates 3D data at lower cost and absorbed doses than conventional ‘fan beam’ CT. However, whether CBCT is superior to conventional modalities in diagnosis of dental caries is controversial. Also, routine use of CBCT instead of conventional radiography cannot be accepted.

2. **Electric resistance (Electrical conductance and Impedance)** : Basic principle behind Electrical caries monitor (ECM) is based on the electrical conductivity differences between sound and carious dental tissues. Electrical conductivity is a function of porosity. Due to enamel demineralization, there is increased porosity of enamel tissue and saliva fills the pores and forms conductive pathways for electrical transmission. The conductivity increases with demineralization as saliva is a better electrical conductor than enamel tissue. ECM measures the electrical resistance on the tooth during controlled drying. Higher measurements suggest that the tissue is well mineralized whereas lower values indicate demineralized tissue. One of the example of this device is a lode electronic caries monitor. Conductivity is measured from the probe tip in the fissure through the dental pulp to a hand held earth lead with the patient forming part of the circuit. ECM provides objective readings which can help in monitoring lesion progression, arrest or remineralization. The ECM readings can be seen on a screen in front of the device, which may vary in a range of about -1.00 to 13.00, representing increasing electrical conductance. Higher reading means more decay. Studies have reported high sensitivity and specificity of this machine[13]. Only disadvantage of using this monitor is that it is time consuming.

Electrical impedance tomography (EIT) is based on the principle of electrical impedance. Unlike caries meter, which uses fixed frequency, EIT uses range of frequencies and provide information on capacitance and impedance.

3. **Optical Caries Monitor** : Presently two methods are available

a. A method based on scattering of light by enamel crystals in relation to their surrounding environment.

b. A method that uses visible laser light within the blue green region as the light source to excite the auto fluorescence of enamel.

Dental caries involves structural changes to the dental hard tissue. Demineralized part of the tooth is filled mainly by bacteria and water. The porosity of this area is greater than that of the surrounding structure. Due to this structural changes, there is increased scattering of incident light, which is visible as white spot. Therefore, optical changes occurring in carious tooth can be measured and quantified with advanced detection methods based on light that shines on and interacts with the tooth[14].

4. **Fiber-optic Transillumination (FOTI)** : It is based on the differential transmission of light through healthy tooth structure as compared to carious tooth structure. A sound enamel is comprised of modified hydroxyapatite crystals that are densely packed produced a near transparent structure. As the carious tooth structure has a lower index of light transmission than sound tooth structure, an area of decay shows up as a darkened shadow that follows the spread of decay along the path of dentinal tubules. FOTI involves use of high intensity white light transmitted through small aperture in the form of a dental handpiece. The tip is 0.5mm and the light source is by 150 watt halogen lamp set at maximum intensity. The probe is applied perpendicular to the buccal and lingual surface and its position and angulation is manipulated to obtain maximum light scattering through the lesion. Advantage of FOTI is that it is simple, noninvasive, painless and can be used repeatedly as there is no risk to patient. It is particularly useful in detection of proximal lesions although it can detect caries on all surfaces. Disadvantage is that the system is subjective rather than objective and cannot record any data.

5. **DIFOTI** : One of the more accurate and noninvasive methods to reliably detect early lesions is Digital Imaging Fiber Optic Transillumination. Like its predecessor FOTI, DIFOTI is also based on transillumination of teeth with intense fiber optic light. However, DIFOTI system was designed to overcome the limitations of FOTI by providing digital image capture by electronic CCD camera[15]. The images can be stored and can be used to compare previously acquired images. Schneiderman et al in 1997 reported that DIFOTI had greater sensitivity for detection of approximal, occlusal and smooth surface caries lesions compared to conventional film radiographs. This system can use digital image processing methods to enhance contrast between sound and carious tissues and to quantify features of incipient, frank and secondary carious lesions. Also, it can be used to detect changes in coronal tooth anatomy such as tooth fractures and fluorosis. Advantage is that it is noninvasive, painless and can be repeated with no risk. Disadvantage is that it is unable to quantify lesion progression even if the images are compared over a period of time.

6. **Quantitative light induced fluorescence (QLF)** : QLF was introduced in 1995 and was used to monitor carious lesions over time. QLF uses the natural fluorescence of the teeth, which is determined by the light absorption and scattering properties of the teeth to discriminate between caries and surrounding sound enamel. The auto fluorescence of tooth decreases with demineralization and QLF measures the percentage fluorescence change in demineralized enamel with respect to surrounding sound enamel and relates it to the amount of mineral lost during demineralization. A demineralized tissue limits the penetration of light due to excessive scattering of photons entering the lesion with consequent limitation to the chance of photon being absorbed and fluorescence remitted. Based on this principle, the carious lesions appears dark when viewed with QLF. In case of QLF, the visible light has a wavelength of 370nm which is in the blue region of the spectrum. The changes in the enamel fluorescence can be detected and measured when the tooth is illuminated by violet-blue light (wavelength 290-450nm, avg 380nm) from a camera hand piece, following image capturing using camera fitted with a yellow 520nm high pass filter[16]. The QLF equipment comprises of a light box containing a xenon bulb and a hand piece similar in appearance to an intraoral camera. Live images can be displayed via a computer and accompanying software enables patient's details to be entered and individual images of the teeth of interest to be captured and stored. After this, lesions can be analyzed and a quantitative assessment of the demineralization status of tooth can be made.

Advantages : a) Increased contrast between carious and sound enamel makes earlier and faster detection of lesions possible; b) the examination presents no danger to patient or operator, since the excitation light is white light and is of relatively low intensity.

Disadvantage is that it cannot distinguish between caries stains on tooth surface and white spot due to developmental anomalies such as fluorosis.

7. **DIAGNOdent** : This is a laser fluorescence system capable of detecting changes in the tooth structure due to demineralization. It contains a laser diode (655nm) as the excitation light source and a photo diode combined with a long pass filter as the detector[17]. The excitation light is transmitted by an optical fiber to the tip of the device and into the tooth. The interaction of the incident light with tooth substance stimulates fluorescent light at longer wavelengths. The light passes through mature enamel without being deflected, but gets diffracted and dispersed in affected enamel. This generated fluorescent light travels through additional light fibers that are concentrically arranged around the central fiber into a microprocessor which analyses and translates the signal into an acoustic signal and a digital display of numerical figures which shows both a real time and a maximum value, ranging from 0-333, which can be used for diagnostic protocol. Advantage of this system is that it gives quantitative readings which can be used as guideline to intervene. Also, decay in patient can be followed longitudinally to monitor the extent of the decay at every recall. However, the presence of bacterial plaques, dental prophylactic pastes, fissure sealants and composite resin materials may give false positive readings with DIAGNOdent.

8. **Dyes** : Caries indicator dyes are nonspecific protein dyes which stains the organic matrix of less mineralized dentin, including normal circumpulpal dentin and sound dentin in the area of the amelo-dentinal junction. It is used as diagnostic aid for detecting occlusal caries. It is a technique which is time consuming involving multiple dye application and also needs a slow speed bur.

9. **CO2 lasers** : It is a gas active medium laser that incorporates a sealed tube containing a gaseous mixture with CO2 molecules pumped via electrical discharge current. The light energy, whose wavelength is 10600nm, is placed at the end of the mid infrared invisible non ionizing portion of the spectrum and it is delivered through a hollow tube like waveguide. Detection of carious lesion by laser light depends on fluorescence naturally from the tooth material or from bacterial by products.

10. **Terahertz imaging** : Terahertz band lies between the microwave and infrared regions of the electromagnetic spectrum. As the photon energy in this spectrum is very low, it does not pose any ionization hazard for biological tissues. It is strongly attenuated by water and is very sensitive to water content. Unique absorption spectra due to intermolecular vibrations in this region found in different biological materials makes terahertz imaging a promising asset for medical applications. It provides complimentary information to existing imaging techniques. It gives a better contrast for soft tissues than x rays. Terahertz used to investigate teeth can be pulsed or continuous wave (CW) system.

Terahertz pulse is sensitive to structural changes on the surface and inside the tooth within a region of depth less than 2mm. The high average power utilized in the continuous wave imaging system allowed for detection of structural changes below the surface of the bone/tooth structure. THZ imaging methods are highly sensitive to structural changes in teeth and have the potential to diagnose such changes which is an important factor to detect and monitor dental caries[18].

11. **Multiphoton Imaging** : Multiphoton excitation can be used to image normal and carious dental tissues noninvasively. The collagen in the dentin shows a strong second harmonic response. Both enamel and dentin emit strong autofluorescence that reveals in detail morphological features like dentinal tubules and enamel rods. Significantly reduced autofluorescence lifetime is exhibited by carious dental tissue[19]. This is consistent with

degree of demineralization determined by micro computed tomography.Therefore, two photon excited fluorescence lifetime imaging may be a promising tool for diagnosis and monitoring dental caries.

12. **Optical Coherence Tomography** : OCT can be used in oral tissue images, caries, periodontal disease and oral cancer. It was first reported by Fujimoto et al in 1991[20]. It is a noninvasive, nonradiative optical diagnostic tool based on interferometers. Low coherence broadband near infrared light source can be used to obtain excellent spatial resolution and real time images. OCT can produce an image of tissue microstructure of the carious lesion to show the changes within. It provides high spatial resolution (~10-20µm) and real time, two dimentional depth visualization. The principle of OCT is similar to B mode ultrasound imaging, except that OCT uses near infrared (NIR) light instead of sound. It is based on confocal microscopy and low coherence interferometry, through which it selectively removes the component of back scattered signal resulting in very high resolution images. OCT has the ability to quantitatively and qualitatively detect and monitor incipient enamel and root caries as early as 24 hrs in its development. It can provide 'optical biopsy' without the need for excision and processing of specimens as in conventional biopsy and histopathology.

13. **Infrared Thermography** : It is a non contact method of temperature measurement where the detector is kept remotely at a single spot. It consists of an infrared detector, amplifier-digitizer, a microcomputer and a video display[21]. Infrared detectors include single element infrared detector, linear array infrared detectors and two dimensional array detectors. The single element detector focuses the infrared flux emitted by the sub areas of the field of interest onto the mirrors as they are transparent to infrared light and have high refractive index. As the infrared radiation emitted by the face enters the germanium lens, it passes through the mirrors that are placed perpendicular to each other. The rotation of these set of mirrors is rapid and on a vertical and horizontal axis simultaneously. Therefore, every point on the field of view is scanned and reflected onto the detector where it is converted into electrical signals. Subsequently, an amplifier converts these electrical signals into digital values which are fed into computer where a digitized thermal image is reconstructed.

An infrared camera with a linear array of detectors requires just one mirror. The mirror generally rotates around a vertical axis, to scan the field of view and hence its vertical resolution is limited. Focal plane arrays (FPA) includes a germanium lens and a plate of miniature detectors. The advantages of the FPA cameras are that they have free performance since no moving part is required. Only disadvantage is limited special resolution.

14. **Midwest Caries ID** : The Midwest Caries ID is one of the newer tools to detect dental caries[22]. It detects difference of optical behavior inside the tooth related to change in the tooth structure. Therefore, it is not sensitive to bacterial content. It uses infrared and red light emitting diodes (LEDs) and a fiber optic to distribute light to the observed area present at the probe tip. A second fiber optic collects light from the observed area to a photodetector that measures returned collected light. This photodetector then transmits the signal to a microprocessor that compares signal levels with defined parameters. A positive result is indicated by deactivation of the third green LED by the processor. Negative result is indicated by the dominant green LED (i.e. healthy tooth area) resulting in a green illumination when healthy structure is detected and red illumination when caries are detected. Also, the intensity of demineralization is indicated by a beeping buzzer of different frequencies.

The Midwest caries ID can be used for approximal caries detection during the examination by slightly angling and moving the probe along the marginal ridge just over the vulnerable approximal area. It enables minimal dilution of the light signal from all surrounding structures by sending and capturing the light signal in a direct line toward the vulnerable regions inside the enamel. Studies found the sensitivity and specificity of Midwest Caries ID higher than that of DIAGNOdent. However, this device can give false positive signals in cases of teeth with growth malformations in the enamel or the dentin, teeth with thick dark staining, hypermineralization, hypocalcification, dental fluorosis and atypically shaped teeth due to alteration in the translucency of enamel caused by these conditions.

15. **Alternating Current Impedance Spectroscopy CarieScan** : It is based on alternating current impedance spectroscopy and involves the passing of an insensitive level of electric current through the tooth to identify the presence and location of decay[23]. The frequency domain is based on a sinusoidal signal applied to a sample at known amplitude and frequency. The response waveform is then measured and the impedance calculated by a transfer function relationship of the applied voltage perturbation and acquired response current. It is the first dental diagnostic tool to use AC impedance spectroscopy to quantify dental caries early enough to enhance preventative treatment. It is not affected by optical factors such as staining or discolouration of the tooth. It provides a qualitative value based on the disease state rather than the optical properties of the tooth. CarieScan is indicated for detection, diagnosis and monitoring of primary coronal dental caries (occlusal and accessible smooth surfaces) which are not clearly visible to human eye. This device uses disposable tufted sensors for single use and a nondisposable test sensor which is used to test the device and confirm if the system is operating correctly. During measurements a green colour display indicates sound tooth tissue whereas a red colour indicates deep caries requiring operative intervention. A yellow colour with a range of numerical figures

from 1-99 suggests varying severity of caries requiring only preventive care. Studies have suggested that sensitivity and specificity of CarieScan is superior to clinical visual examination, bitewing radiograph and DIAGNOdent.

16. **Frequency Domain Infrared Photothermal Radiometry and modulated luminescence** : It is the most recent technology in the field of caries detection and it combines frequency - domain laser induced infrared photothermal radiometry and modulated luminescence (PTR/LUM). PTR technique is based on the modulated thermal infrared response of a medium, resulting from optical radiation absorption from a low intensity laser beam and optical to thermal energy conversion followed by modulated temperature rise usually less than 1^0 C in magnitude. The generated signals from PTR/LUM instrument carry subsurface information in the form of a spatially damped temperature depth integral. Therefore, PTR can penetrate and yield information about an opaque or highly scattering medium well beyond the range of optical imaging. The PTR signal consists of both surface and subsurface responses of dental tissue and as such it is expected that it can distinguish between caries, stains on tooth surface and developmental white spots, unlike the fluorescence device such as QLF.

The advantage of PTR/LUM is that it is a depth profilometric technique unlike DIAGNOdent and all other photonics based technologies. It is sensitive to changes in both optical and thermal properties of the sample with zero PTR signal baseline unless there is optical absorption on the surface or in the bulk of the solid PTR and LUM techniques have the highest signal dynamic range in detecting very early demineralization and thus predictably yield the best diagnostic results in caries diagnosis[24]. The sensitivity and specificity of PTR and LUM has been found to be better than DIAGNOdent, radiographic and visual methodologies.

17. **USG** : Ultrasonographic images are acquired by collecting the reflected sound waves. In order for sound waves to reach the tooth they must pass first through a coupling mechanism usually water and glycerine. The pulse echo ultrasonic waves mean that any impulse generated in the transducer is transmitted into a medium (tooth) and then reflected back to the transducer if it strikes at any discontinuity. The ultrasonic system is composed of a transducer (probe) and an ultrasonic precision thickness guage. The contact transducer is of the right angle type with a 1.5mm tip contact diameter, 11 mHZ nominal center frequency with removable plexiglass delay tip. The delay line tip of the contact transducer is at a right angle so that it could be inserted or used in restricted height areas. These high frequency focused delay line transducers are compatible with any ultrasonic instrument capable of displaying a return echo at depths as minute as 0.010 inches. The useful range is from 0.010 to 0.25 inches approximately.

III. Conclusion

With the advancement of diagnostic tools, it is now possible to detect early carious lesions on tooth surface at an early stage. Some of the new advances like DIAGNOdent and CBCT are used routinely but these facilities are not available at all centres. So use of visual and tactile methods cannot be ruled out. Further, no single test can accurately diagnose carious lesion. A combination of methods is recommended to detect dental caries with 100% success rate. The use of these methods should be tailor-made as per the available resources with the treating dental surgeon which will enable in detecting caries at an early stage and thus help in avoiding potential damage to the tooth structure.

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