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# Evolution in Diagnosis of Dental Caries: An Update.

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**ABSTRACT**

The process of caries diagnosis involves both risk assessment and the application of diagnostic criteria to determine the disease state.The primary objective of caries diagnosis are to I) Detect thepresence or absence of caries and II) Quantify the progress of the lesions,following which we can plan a minimal invasive or invasive and surgical treatment. Dental caries is considered to be the protagonist of maximum the dental problems. Therefore, continuous upgrading of the caries diagnostic aids for every dentist is necessary. This article stresses on the update on advances in caries diagnostic aids with a standardization. Diagnostic aids mentioned here can either be used individually or in combination for a more efficient diagnosis along with detection of caries.
**Keywords**: Caries diagnosis, Demineralisation, Laser fluorescence, Radiographs

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## INTRODUCTION

Detection of the dental caries in its earliest stages should be the primary objective of caries diagnosis. It should also be able to determine all pathologic changes attributable to the disease from early demineralization to cavitation. Regrettably, none of the currently accepted caries diagnostic methods have the ability to account for the dynamics of dental caries, including the possibility of reversal. Instead, clinicians are forced to measure a dynamic process as a dichotomous variable of either presence or absence of caries using subjective clinical criteria like color, softness and resistance to removal. Tools like sharp explorer and dental radiographs for tracing out caries are also of least use for now.

Till date no single method is presently developed thatallows detection of caries on all tooth surfaces, but have the potential of higher specificity and sensitivity in caries detection and quantification to facilitate the development of more effective preventive interventions. [1] Following are some of the useful diagnostic aids to clinician; (a) Visual inspection & tactile sensation, (b) Radiographic methods- Conventional radiographs, Xeroradiographs, Digital radiographs, Digital Subtraction Radiography, (c) Electrical conductance measurement (ECM), (d)Quantitative laser and light fluorescence (QLF), (e) Infra red laser fluorescence, (f)Diagnodent, (g) Fiber optic Trans Illumination (FOTI), (h) Three dimensional x-ray imaging, (i) X-ray microtomography, (j) Microradiography, (k) Longitudinal Micro Radiography (LMR), (l) Tuned Aperture Computed Tomography (TACT), (m) Terahertz Pulse Imaging (TPI)

## DISCUSSION

### VISUAL INSPECTION& TACTILE SENSATION

Visual inspection is performed in a visible light (preferably fiber-optic), clean, dry field, with the aid of magnification. Visual evidence of caries is a good indicator of the degree of caries penetration within tooth tissues. Sharp eyes with or without the aid of x2-4 loupes, in conjunction with good lighting and drying with a three-in-one syringe – detectition triangle. If there is any obvious cavitation then visual tactile sensation can be considered to determine any exposed dentin. [2]

### RADIOGRAPHIC METHOD

Radiographic examination has great significance in determining those carious lesions, which are not readily detected by clinical examinations. An examination for dental caries is inadequate without a properly conducted radiographic examination of the affected teeth.

When radiation passes through an object with differences in mass, it is subjected to differential absorption, due to variations in atomic composition, density and thickness of the tissues. A mineral loss within the dental hard tissues therefore creates the basis for its radiographic detection. The carious process leads to demineralization of the affected area of the tooth, this area appears radiolucent on the radiograph.

Factors contributingfor the commonly use of radiographic examination as an aid forthe caries diagnosis and subsequent treatment are: The depth of a lesion can be evaluated and thus the relation between the lesion and the pulp of the tooth, A high number of proximal lesions are usually found when radiograph is used as an adjunct to the clinical examination, Radiograph is a non-invasive method while probing may cause a break of the enamel covering a subsurface lesion. [3]

#### Limitations of Radiographs

1. For accurate reproducibility standardized geometric angulation, exposure time, processing procedures, and analyzing facilities are necessary.
2. Radiography does not disclose the earliest stage of lesion development.
3. It is a two dimensional image of three-dimensional object. Because of this, sometimes interpretation becomes difficult.
4. Radiographs under estimate the extent of demineralization, but over estimations may also occur, as a result of projection errors.

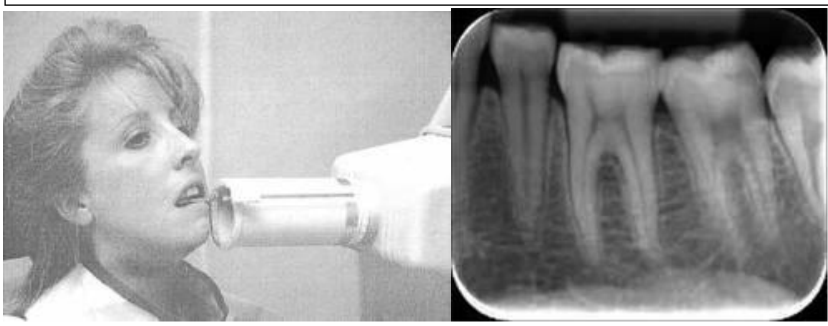
5. Radiolucency on radiograph cannot be judged whether this is because of caries or resorption or any other defect.
6. Approximal secondary caries on the more apical part of a restoration may not be detected.
7. Noncavitated carious lesions on the root are difficult to diagnose.
8. Overlapping of proximal contacts.

**Conventional Radiographs**

Conventionally, intra-oral periapical (IOPA) and bite wing radiographs are two types of popularly employed techniques. Others like occlusal and panoramic radiographs are though important but rarely employed in the caries detection. Occlusal and panoramic views are employed for detecting other pathological lesionsof the oral cavity and for educating the public through a broader view of the oral cavity.

Periapical radiographs are primarily useful for detecting changes about the roots and in between the teeth. However, if parelleling technique is used for obtaining periapical radiograph, the usefulness of this projection for detecting caries in both anterior and posterior teeth is increased. [3]

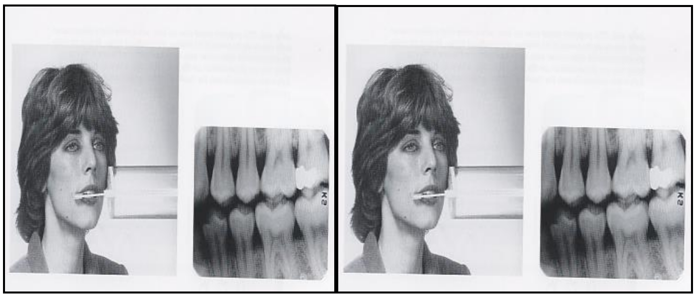
**FIG-1: PERIAPICAL RADIOGRAPH TECHNIQUE AND RADIOGRAPH**



The Bitewing view is the radiograph of choice for the detection of interproximal and occlusal caries in the early stages of development before being clinically apparent.

Because of the horizontal angle of projection, theyalso reveal secondary caries below restorations that may escape recognition in the periapical views.[4]

**FIG-2: BITEWING RADIOGRAPH TECHNIQUE AND RADIOGRAPH**



**Xeroradiography [37]**

Xeroradiography is a relatively new method for recording the images without a film, based on an electrostatic process similar to that used in some photocopying machine. Features like pronounced edge enhancement (differentiating areas of different densities especially at the margins or edges), a choice of positive and negative displays, good detail, and wide exposure latitude make xeroradiography attractive. [5]

The xeroradiography unit for dental is 110 system.The image receptor plates are the size number 1 and number 2 films made up of aluminium plate coated with a layer of selenium particles.The film fit conveniently into the oral cavity. When X-rays passthe film, it causes selective discharge of the particles.This forms the latent image and it is converted to a positive image by a process called development in the processor unit.

Xeroradiographs have greater ability to resolve fine structures than conventional radiographs.Significantly, it requires only about one-third the exposure of conventional D speed films. Caries withfine details of teeth and bone may be visualized well on xeroradiographs. Occasionally, excessive edge enhancement around metallic restorations stimulates recurrent caries. This situation may be over come by reducing the exposure or the contrast on the xeroradiographs. [6]

**Digital Radiograph**

A digital radiographshows an image formed and represented by a spatially distributed set of discrete sensors and pixels. Digital, filmless, techniques for intraoral radiography have been developed for several important reasons like: Conventional film absorbs only a few percent of the x-rays that reach it, utilizing very little of the radiation to which the patient has been exposed, Poor darkroom procedure can lead to both unnecessarily high doses of radiation and loss of diagnostic information, Development of films is time consuming and the developer and fixing solutions are hazardous to the environment.

There are two types of non-film receptors for recording digital images:

- The digital Image Receptor (DIR) which collects the X-rays directly (Direct digital imaging).
- Video camera for forming digital images of a radiograph (Indirect digital imaging).

Digital image Receptor works on a Charged Couple Device (CCD), connected, to a computer. CCD is a semiconductor made up of metal oxides such as silicon coated with x-ray sensitive phosphorous, that is sensitive to both x-rays and visible light. The intraoral DIR is placed in the mouth instead of the x-ray film. The image area is limited by the size of the CCD present in the digital image receptor. Once the image is captured by the CCD (like an image of silver halide crystals in an x-ray film) it can be stored in the computer memory for image processing and can be displayed for viewing. [7] Some of the digital radiography systems available commercially are: Radio-Visio - Graphy (RVG), Flash Dent and Sens-A-Ray

**FIG-3: CCD image receptor producing a digital image in RVG (RADIO VISIO GRAPHY )**

Digital radiographic system linked to the dental unit offers an attractive design, because the well adapted flat screen to the bracket table of the dental unit, right in front of the patient, facilitating discussion with the patient about the findings from the radiographs as well as from an intraoral camera.

**FIG-4: DIGITAL RADIOGRAPHIC SYSTEM ATTACHED TO DENTAL CHAIR**

Conventional film radiographs may provide insufficient density contrast in the area under suspicion for a carious lesion. Contrast can be enhanced by digital mode. It has been shown that by digital mode one can enhance density and contrast upto 70%. Digital method is found 50% more sensitive in detecting occlusal caries compared to conventional films. [8]

Advantages of digital radiography over conventional are: No requirement of darkroom, instant image viewing, consistent quality of image, highsignal to noise ratio, greater exposure latitude, elimination of the film development hazards, decreased radiation dose, capability of teletransmission. Limitations of digital radiography are: no fixed life expectancy of CCD and high cost of the system. [8-10]

**Computer Aided Radiograph**

Computer-aided radiographic methods exploit the measurement potential of computers in assessing and recording lesion size.

The variation between observers in the interpretation of radiographs is well known. Development of computers in the last few years have made it possible to use automated procedure which are able to overcome the shortcomings of human eye to quite a great extent. Software's have been developed for automated interpretation of digital radiographs in order to standardize image assessment. [11]

These programs are based on the "expert system" containing facts about the pathologic conditions. The clinician enters the patient's data and the programme compares the patient's data with the basic knowledge of the pathology. This programme tells us the possible diagnosis, and even tells the possibilities of other ailments. The system can suggest the need for additional tests to improve the reliability of the diagnostic outcome.

Advantages of this method are: Automated analysis providing sensitive and objective observation of smaller lesions which otherwise are not perceptible to naked eye, monitoring the lesion and quantification of small lesions. Its limitations are:a need for standardization of exposure geometry, higher sensitivity but lesser specificity, time consuming and high cost. [7, 11]

**Subtraction Radiography**

Subtraction radiography is a technique by which structured noise is reduced in order to increase the detectability of change in the radiographic pattern. The structurednoises are the images, which are not of diagnostic value and interfere in routine interpretation of radiographs. [12]

Subtraction images can be obtained from photographic, electronic and digital methods. Presently Digital Subtraction Radiography (DSR) is being used and popularized in every field of dentistry. Other methods have the disadvantages such as:Inability to produce correct projection geometry, improper density and contrast. The development of Digital subtraction radiography has overcome many of the limitations of photographic images. [13]

Digitization is achieved by taking a picture of the radiograph using high quality video camera. This is fed to a computer imaging device, termed as digitizer. Two standardized radiographs produced with identical exposure geometry are used. The first one is the “Reference Image” and the subsequent images are for comparison. The reference image is displayed on the screen. Then the subsequent images are superimposed. The difference between the original and the subsequent images will show as dark bright areas, which can be interpreted readily. One should remember that digitization does not increase the information available in the original radiograph. Only it turns the image into a form, which can be read by the computer. [12-14]

Subtraction radiography solution has also been demonstrated to be superior to conventional film radiography for detecting artificially produced recurrent caries by reducing the false positive diagnosis. It is also useful in detecting the progress of re-mineralization and de-mineralization patterns of dentinal caries. [14]

**MAGNIFICATION IN DETECTION OF CARIES**

Whitehead and Wilson in 1990’s, used a binocular magnification(x3) for detection of caries reporting the modification in restorative decision making with the use of magnification aids. With the use of magnification there may be an increase in both the number of restorations planed for replacement and no of surfaces to be restored. To date detection of caries in clinical practice does not tend to include use of magnification system. [2]

**FIG-5: MAGNIFYING LOUPS WITH BINOCULARS**

**ELECTRICAL CONDUCTANCE MEASUREMENT**

*Magitot*in 1878, first proposedthe idea of electrical method of caries detection.The theory behind the use of ECM is the observation that sound surfaces should possess limited or no conductivity, whereas carious or demineralized enamel should have a measurable conductivity that will increase with increasing demineralization.With decreasing thickness and increased porosity, the performance of electrical resistance has been reported to be as valid as or better than more traditional methods of diagnosing fissure caries. [1]

Ricketts et al. using ECM, showed that the amount of air flow used had a direct bearing on the level of sensitivity and specificity obtained in vitro. An air flow of only 5 liters/minute was found to be inadequate and led to a high number of false positive readings. Increasing the air flow to a minimum of 7.5 liters / minute increased the sensitivity to 92% and specificity to 82%. Air flow is vital in the use of ECM to remove superficial moisture and to reduce the possibility of gingival conductance.

Low specificity and sensitivity was a common finding in the early trials of diagnostic instruments using ECM, but by using a newly developed system (LODE Diagnostic, Groningen,TheNetherLands),researchers have demonstrated significant improvement in sensitivity (93%). [15]

Currently, ECM can be used in conjunction with other methods to improve diagnosis of occlusal caries. It is regarded as a supplement in identifying and monitoring sites in which non invasive intervention is indicated in caries control. [16]

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**FIG-6: ELECTRICAL CONDUCTANCE MEASUREMENT**


**QUANTITATIVE LIGHT INDUCED FLUORESCENCE (QLF)**

*Bjelkhagen and Sundstrom in 1980,*didasystematic investigation of fluorescence from visible light excitation of teeth and demonstrated an enhanced differentiation between carious and sound enamel. [17]

Fluorescence is a well known phenomenon in science and technology. In simple terms, light at one wavelength (excitation wavelength) is absorbed by the tissue and emitted at a second longer wavelength (emission wavelength).This phenomenon occurs only when there is specific substance that is excited by specific wavelength of light. Light scattering is a measure of the observed whiteness of a carious lesion that can be correlated with degree of mineral loss. [18] *Vaar Kamp et al*postulated that light scattering in enamel is primarily caused by hydroxyapatite crystals and that the dentinal tubules are responsible for scattering in dentin. No threshold for detection of white spot lesions using light scattering techniques has been determined but lesions with a depth of 25μm have been measured in vitro. [19, 20]

Groups of Netherlands and Sweden worked on QLF during the later 1980s and throughout 1990s in collaborationwith USA. Hardware and a software system was developed that collects images of lesions based on excitation at 488nm with an 'Argon laser'. This technique is useful for smooth surface lesions but as yet has not been proved successful for occlusal caries. [21]

The blue light is used to irradiate the tooth surface by a specifically constructed hand piece and the fluorescent image is captured by a computer. A filter is used to eliminate the excitation wavelengths from the emitted light so that only fluorescence is detected.

The lesions appear as shadowy images against the bright fluorescent background of sound enamel. The shadow may be primarily due to increased scattering in the lesion. The images can be stored, measured and quantified in terms of shape and area. Images at subsequent times can similarly be taken, and by subtraction, the clinician can decide on lesion reversal or progression

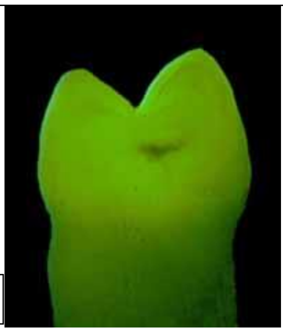
The use of Argon laser in the oral cavity is considered safe and when properly used, is not a potential health hazard to either patient or practitioner. *Vaarkamp et al* have also recommended the use of He Ne laser (λ-633nm) for early detection of dental caries. QLF has also been used for quantification of in situ Remineralization of incipient lesions where it was even possible to follow weekly changes in enamel mineralization. [22]

The restriction of light scattering for caries diagnosis to smooth surfaces constitutes a significant drawback to this technique, although research is continuing to develop a QLF system to detect occlusal caries. [17]

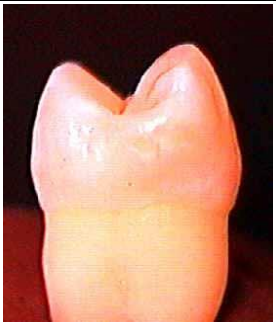
**FIG-7: QUANTITATIVE LIGHT INDUCED FLUOROSCENCE**

**FIG-8 (A): TOOTH WITHOUT (B) WITH QUANTITATIVE LIGHT INDUCED FLUOROSCENCE**

8A



8B



**DIAGNODENT**

Diagnodent is a commercial development device of laser fluorescence in the chair side, battery powered, and quantitative diode laser fluorescence.

Diagnodent system uses 680nm filter and detects caries by measuring changes in fluorescence intensity rather than analyzing spectral differences.

It is therefore fundamentally different from typical QLF methods and so the basic research for typical QLF technique cannot be extrapolated to Diagnodent device. [20]

The unit emits light at 655nm wavelength from a fibrotic bundle directed onto occlusal surface of the tooth. A second fiber optic bundle receives the reflectedfluorescent beam. Changes caused by demineralization are assigned a numeric value, which is displayed on the monitor. The system is calibrated to a provided standard and to reference (sound) enamel.

Instructions for this system specify that the occlusal area to be diagnosed be clean because plaque, tartar and discoloration may give false value. A laser probe is used to scan over the fissure area in a sweeping motion. Two values are displayed, a current value for the probe position (“Moment”) and a maximum value for the whole surface examined (“Peak”). [23]

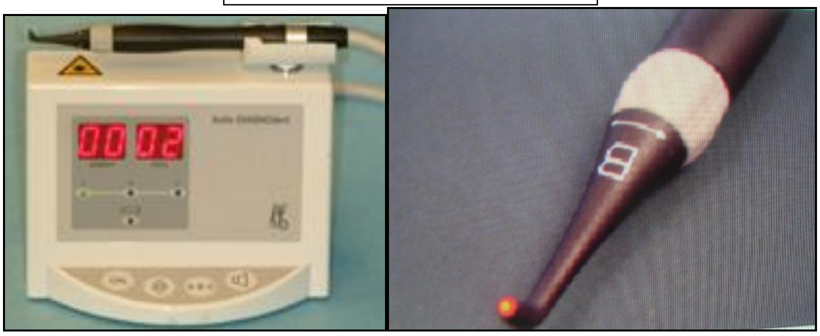
The instructions suggest that, in general, numeric data between 5 and 25 indicate initial lesions in the enamel and the values greater than this range indicate early dentinal caries.Advanced dental caries in dentin is said to yield values greater than 35. The scale ranges from 0 to 99.

Limited clinical and histological studies to date have shown that a low signal signifies sound tissue below with greater than 80% accuracy.Most importantly, as the signal increases, it indicates caries that needs chemical or physical intervention. The management of these occlusal lesions can be followed either non invasively with time to assess the success or other wise of intervention regimens such as antibacterial and fluoride therapy. [24]

Atypical QLF shows a strong correlation with degree of enamel demineralization only but no correlation with degree of dentinal decay. For the Diagnodent device, it has been postulated that the diode laser light does not reach deeper dentinal layers, which would explain the inability of the device to distinguish between superficial and deep dentinal decay. [25]

It has been reported that instrument is very sensitive to presence of stains, deposits and calculus, all of which lead to erroneous readings. Similarly, any changes in the physical structure of enamel, including disturbed tooth development or mineralization produce erroneous readings.As with any clinical tool, the results must be used in conjunction with other clinical observations. As yet there are limitations to the accuracy of the device but as a functional tool to be used with care, it shows a great promise. Clinical experience is a “fundamental pre-requisite” to using this device. [22]

**FIG-9: DIAGNODENT**



**FIBRE OPTIC TRANS ILLUMINATION (FOTI)**

FOTI is a practical method of imaging teeth. The use of light in caries diagnosis as opposed to more traditional means of caries detection has evolved because of growing concerns about the use of explorer or ionizing radiations which can be rather damaging. [26]

This method of caries detection uses a light source, preferably bright, to illuminate the tooth. This shows internal variation of color, shade and morphology which goes undetected when tooth is exposed to only low, mainly reflective light.

The light is absorbed more when the decay process disrupts the crystalline structure of enamel and dentin. This in essence gives that area a more darkened appearance.

The system makes the use of a fibre optic hand piece to illuminate the tooth from inside to outside the mouth. The resultant changes in light distribution as the light traverses the tooth are then recorded as an image for analysis. [27]

Digital Imaging Fibreoptic Trans Illumination (DIFOTI) is a relatively new methodology that has been developed by combing FOTI and digital CCD (Charged Couple Device) camera. Images captured by the camera are sent to a computer for analysis using algorithm.

A study by *Oggard and Ten Bosch* used an optical, light scattering method to measure changes in decalcified enamel. The base line readings were taken, presumably of healthy enamel and throughout demineralization process. The demineralization was induced and then the areas were left to either regress further or to remineralize. What was interesting was that the optical scattering measurements moved down as the areas demineralized and moved back up to the baseline readings as the remineralizing process reversed the lesion.

This could be a way to monitor white demineralized lesions to see if they will heal instead of restoring immediately. FOTI to find inter-proximal lesions in their initial stages, has also been studied. Peers et al, observed FOTI to be as accurate as bitewing radiograph and far superior to visual examination.

The use of DIFOTI allows instantaneous images to be made and projected, and images taken during different examinations can be compared for clinical changes between several images of same tooth overtime. The results of in-vitro comparison of DIFOTI to conventional radiographs indicated that DIFOTI was twice as sensitive in detecting proximal lesions and three times as sensitive in detection of occlusal caries.

One interesting study by *De Josselin, De Jonget et al,* used a CCD camera with a high pass filter to collect fluoroscence image of carious teeth. The teeth were illuminated intra-orally with a diffuse laser light. Incipient lesions showed a loss in fluoroscence. The images were saved on a computer and analyzed with a software program. They showed a direct correlation not only between loss in fluorescence and presence of caries and also a quantitative correlation of that loss and amount of caries present.

However there seems to be a limitation in the advanced lesion where Tran illumination is concerned. In a study by *Vaarkamp, TenBosch and Verdon Schot* using light absorbing and light scattering fluids, it was shown that the radiance change caused by a carious lesion is mainly determined by the enamel part of the lesion. This would preclude this method from detecting the extent of lesions where enamel destruction is minimal but dentin invasion is extensive. [28]

Yet, it has been concluded that DIFOTI provides clear signatures of different types of frank caries on all types of teeth and it can detect incipient or recurrent caries before they are visible on radiograph

**FIG-10: DIFOTI (DIGITAL IMAGING FIBREOPTIC TRANSILLUMINATION)**


**Three Dimensional X ray Imaging**

Since the discovery of the x-ray in 1895 and its application to dentistry, radiographic imaging of oral anatomy has consisted primarily of viewing 3-D structures collapsed onto a two-dimensional (2-D) plan. This form of imaging, known as transmission radiography, is characterized by a point source of radiation producing a beam which passes through the patient and strikes a relatively flat image receptor (usually a film).

This produces essentially an attenuation map of the structures through which the beam has been transmitted. While the dental profession has relied on this method for obtaining information about the hard tissues of the oral cavity, it inevitably superimposes anatomy and metallic restorations which confound the problem of identifying and/or localizing diseases or objects in three dimensions.

Moreover, studies have shown that intra-oral films produced in this way are not sensitive for the detection of caries, periodontal, and periapical diseases as it was previously thought. Increasing the diagnostic yield for caries may be possible with three-dimensional (3D) imaging methods.

However, general dentists currently use two-dimensional (2D) images, and although CT/MRI modalities exist for hospitals, there are no systems for general practitioner caries diagnosis. The choices for 3D imaging of dentoalveolar diagnostic tasks are currently limited to different forms of local CT including x-ray microtomography (XMT), tuned aperture computed tomography (TACT) and super-ortho-cubic CT. [29]

**X-ray Microtomography**

X-ray microtomography is a miniaturized version of computerized axial tomography with a resolution of the order of micrometres. In the biomedical field, it is particularly useful in the study of hard tissue because of its ability to accurately measure the linear attenuation coefficient. From this, the mineral concentration can be computed, which is one measure of bone quality. [29] Using microtomography we can form three-dimensional images of bone from which structural parameters can be derived which could not be measured using conventional histomorphometry. [30]

Daatselaar et al. described the development of a bench top local CT device which is able of producing spatial and contrast resolutions necessary for improved detection of interproximal caries as well as other dentoalveolar conditions. The authors concluded that 'local CT reconstruction are feasible' and 'the resolution of the local CT images produced from basis projections that were acquired using standard dental CCD sensor was diagnostically suitable. This makes local CT a potential technique for the diagnosis of interproximal caries. [31]

**Transverse Micro Radiography**

TMR or contact- microradiography is the most practical and widely accepted method used to assess de- and re- mineralization of dental hard tissues in studies. It is a highly sensitive method to measure the change in mineral content of enamel and dentine samples. In TMR, the tooth sample to be investigated is cut into thin slices (about 80 and 200 for dentine samples). A microradiographic image is made on high resolution film X-ray exposure of the sections together with a calibration step wedge.

The microradiogram is digitized by a video camera or photomultiplier. The mineral can be automatically calculated from the gray levels of the images of section and step wedge. Parameters of interest are mineral loss (Delta Z in Vol %.), lesion depth (Lesd in), ratio or average loss of mineral content in the lesion area (Delta Z/ Lesd in Vol %), the mineral Vol % and position of the subsurface layer and lesion body.The accuracy of TMR for enamel and dentine in lesion depth is about 200 Vol %. in deltea Z. With mineral details of approximately 2-3 µm can be detected. [29]

The time required for making 5 scans plus evaluation is 3-4 minutes (which is less than 1 minute for a scan). The time required for acquiring step wedge data is one minute or less depending on the number of step wedge steps. Statistical analysis of many scans is supported. [32]

**Longitudinal Micro Radiography (LMR)**

LMR is a method to determine mineral loss in tooth slice samples in vitro. In this method, a microradiogram of a slice of a tooth is prepared. Mineral content is then computed by performing measurements of the optical density of the microradiogram and by comparing these values with that of an aluminum step wedge. [31] LMR is based on the same principle as TMR. In contrast to TMR, where a transversal slice of the tooth is created, LMR is based on longitudinal slices. The LMR system is highly automated. Scanning the sample is performed using a XY scanning table and all calculations are performed automatically. [33, 34]

**Tuned Aperture Computed Tomography (TACT) [33]**

It has been shown in controlled in vitro studies that it can enhance the clinician's ability to detect and localize disease, anatomically significant structures and abnormalities. TACT promises to overcome some of the current limitations of conventional dental technologies and increases the 3-D information currently available in ways that can influence significantly the diagnosis and management of dentoalveolar diseases and abnormalities.

With TACT, the patient has to remain motionless only during each individual exposure. The time between exposures is determined by convenience, diagnostic task, economics or other factors, because delays have no impact on the accuracy of the reconstruction. [35]

This approach also permits the signal-to-noise ratio to be tuned interactively to the needs of the examination. [32]

Harse et al. performed a study to compare the difference in the accuracy of proximal caries detection by extraoral tuned aperture computed tomography (TACT), intraoral TACT, and film radiography. It was concluded that extraoral TACT was not statistically different from intraoral TACT or film radigraphs for proximal caries detection. This suggested that extraoral TACT may have some clinical utilities. [35]

**Terahertz Pulse Imaging (TPI) [33]**

Terahertz pulse imaging (TPI) is s relatively new imaging technique that has been demonstrated in both non-biological applications. Although, the TPI system is a new technique for imaging caries using non ionizing impulses of terahertz radiation, (an electromagnetic radiation) and its ability to detect early stages of caries lesions in various sections of teeth and a hope in future when this technique could indicate caries in all areas of teeth.

Terahertz systems are relatively expensive and do not offer the resolving power of radiographic examination. This system also needs more researches to make it possible to be inserted into the mouth for in vivo studies, while it is expected that technological developments will improve the systems to bring them within easy reach of dentists.

The coherent detection scheme of the TPI system uses only micro-watts of radiation of a type that is non-ionizing. Because the exposure levels from this system are orders of magnitude smaller than exposure levels that occur naturally, thissystem will be safer than those employing X-rays. Unlike radiography TPI also delivers a spectrum of different frequencies for each pixel measured. This offers the possibility of using that spectrum for diagnosis that goes beyond simply measuring mineralization levels. [36]

Pickwell et al. compared terahertz pulsed imaging (TPI) with transmission microradiography (TMR) for depth measurement of enamel demineralizations. It was concluded that TPI measured demineralization in the range of 47% of that of TMR depth plus an intercept of micron, whereas further calculations allowed the TMR depths to be determined to within 5% using TPI. [37]

## CONCLUSION

These are some caries diagnosis methods used today. In this era of evidence based dentistry, systematic reviews and validation studies of caries detection methods have been addressed in some studies but there is still need for more studies in the future to clearly determine the best and most accurate ways of caries diagnosis.

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