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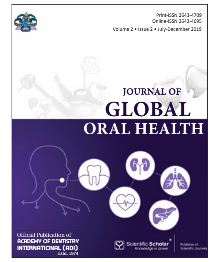

Systematic Reviews and Meta-analysis

Advanced diagnostic aids in dental caries – A review

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ABSTRACT

Dental caries is a result of shift in the balance of mineral loss and gain, leading to more changes in the tooth structure, which cannot be accepted as healthy but should be considered as pathological. This change of dental caries from a physiological process to pathology is continuous and affected by numerous variables and also there is a lack of a definite boundary line between health and disease. The progression of non cavitated lesions seems to be slower, allowing preventive strategies to be implemented when the lesions have the greatest opportunity to arrest. Thus, early and accurate detection and diagnosis of dental caries are an important component of the overall management of dental patient. Advanced diagnostic modalities available to clinicians today expand greatly on the foundation of a comprehensive visual assessment, which has been and will be the cornerstone of the diagnostic process.

Keywords: Diagnosis, Radiography, Sensitivity, Specificity, Dental caries

INTRODUCTION

Dental caries is a complex disease, defined as a progressive, irreversible, microbial disease affecting the hard parts of the tooth exposed to the oral environment, characterized by demineralization of inorganic constituents and destruction of the organic constituents thereby leading to a cavity formation.[1] As long as the dynamic equilibrium between the mineral content of the tooth-oral fluid and the microbial content of the biofilm are maintained, the entire sequence remains within the boundary of a physiological process, where loss and gain are equalized.[2] However, if the factor disturbing this homeostasis is strong, intense, and long lasting, then the demineralization persists and prevails. The mineral loss is now more than the gain, which becomes evident as structural changes in the tooth structure. Along a timeline, this shift in the balance leads to more changes in the tooth structure, which cannot be accepted as healthy, but should be considered as pathological. Thus, the physiological dental caries process becomes a pathological dental caries disease.[3]

The change of dental caries from a physiological process to pathology is a continuous process and is affected by numerous variables and also there is a lack of a specific boundary line between health and disease. The progression of non cavitated lesions seems to be slower, allowing preventive strategies to be implemented when the lesions have the greatest opportunity to arrest.[4] Thus, early and accurate detection and diagnosis of dental caries are an important component of the overall management of dental patient. It is imperative that the diagnostic methods with suitable level of sensitivity and specificity are used in conjunction to obtain a valid diagnosis. This paper aims to review some of the advanced caries diagnostic methods available.

ILLUMINATION METHODS

1. Fiber-optic transillumination (FOTI)
2. Wavelength dependent FOTI
3. Digital imaging FOTI (DIFOTI).

FOTI

In recent years, because of concerns over the cumulative effects of ionizing radiation, a simple technique called FOTI that utilizes a light emitting diode was developed for caries detection, which uses a narrow beam of white light to transilluminate the tooth. FOTI, as a caries detector technique, is based on the fact that carious enamel has a lower index of light transmission than sound enamel. As the demineralization process disrupts the crystalline structure of enamel and dentin, more light is absorbed due to changes in the light scattering and absorption of light photons. In essence this gives that area a more darkened appearance.[5]

FOTI was initially designed by Friedman and Marcus in 1970 for the detection of proximal caries**.** Posterior approximal caries is diagnosed by placing the light probe on the gingiva below the cervical margin of the tooth, whereby light passes through the tooth structures and approximal decay appears as dark shadow on the occlusal surface. The FOTI has higher sensitivity for dentin lesions than for enamel lesions.

Meta-analysis by Ie and Verdonschot[6] showed that FOTI performed superiorly in diagnosing occlusal caries in comparison to visual inspection and xeroradiography and a study by Ismail[7] observed that FOTI is the most valid method for caries detection of precavitated caries in dentin followed by radiographic examination and visual examination. Peers *et al.*[8] carried out an *in vitro* comparison of the performance of radiography and FOTI using histologic examination as the gold standard. They found no significant differences in the Sn values of radiography (0.59) and FOTI (0.67) with regard to approximal caries detection. FOTI is widely accepted by clinicians as a valid method for detection of approximal caries in anterior teeth as well as dentin-involved caries in posterior teeth.

In reference to occlusal caries, Wenzel *et al.*[9] consider transillumination to offer better performance than conventional X-rays in detecting early-stage dentin caries. Côrtes *et al.*,[10] in an *in vitro* study, reported greater sensitivity than specificity for FOTI and superior performance with respect to X-rays both for enamel and dentinal lesions and had a better correlation with histology.

However, the fact that FOTI is not routinely used by dental professionals and is not recommended as a technique of choice, due to a large proportion of false-negative results. The main advantage of FOTI is its optimum positive predictive value performance, which means that any positive reading is almost certainly indicative of an existing lesion, no exposure to radiation, gives instant images simple, non time consuming, and comfortable to patients.

Wavelength dependent FOTI

In incipient white-spot lesions, mineral loss is accompanied by an increase in light scattering. In older, discolored lesions, light absorption is also enhanced. The induced effect at the occlusal surface is caused by a combination of material properties and the distance light propagates through tooth material from the light source to the detector. This combination will be called "effective decadic optical thickness" and is dependent on the light wavelength. It is assumed that, in the case of small lesions, the effective decadic optical thickness increases linearly with mineral loss.[11,12]

Vaarkamp *et al.*[13] observed that wavelength-dependent light propagation through carious tissues can be utilized for quantitative diagnosis of approximal caries lesions. Furthermore, comparisons regarding the diagnostic performance of optical technique, bitewing radiography and dyes was performed on 33 extracted premolar teeth and it was concluded that the optical technique performed as well as bitewing radiography in diagnosing small approximal caries lesions.[14]

It has certain advantages like; it gives quantitative information about the depth of the lesion and there is no radiation hazard. However, it is not applicable in all locations of carious lesions and has considerable intra and inter-examiner variations. Based on the research, quantitative diagnosis of approximal caries lesions is feasible when wavelength-dependent light propagation through carious tissues is utilized.

DIFOTI

This technique was introduced to overcome the limitations of FOTI by combining FOTI and a digital charge-coupled device (CCD) camera. DIFOTI is the only dental diagnostic imaging instrument of its kind to be approved for the detection of incipient, frank, and recurrent caries.[15] It can also be used to detect fractures, cracks, and secondary caries around restorations.

It is based on the principle that carious tooth tissue absorbs more light than surrounding healthy tissue and appears as darker area. DIFOTI system consists of two handpieces (one for occlusal surface and one for smooth surface and interproximal areas), a disposable mouthpiece, a foot pedal for selecting the image of interest and a computer system to capture and store the resulting image.

Schneiderman *et al.*[16] found that DIFOTI technique has superior sensitivity over conventional radiographic methods for the detection of approximal, occlusal, and smooth surface caries. Hae-Woong *et al.*[17] observed that the DIFOTI diagnostic system is the most accurate means of detecting occlusal, buccal, and lingual surface carious lesions, while mesial and distal proximal carious lesions were most accurately assessed using bitewing radiography.

Kazuhiro[18] examined the clinical usefulness of DIFOTI, to detect dental caries and cracks. Image data of the tooth obtained by visible-light fiber-optic transillumination were acquired with a digital CCD camera and sent to a computer for image analysis. Then, the incorporated data are immediately projected on the monitor as an image of the tooth. As a result, DIFOTI was shown to be effective in detecting initial caries and cracks on the surface of a tooth.

Bin-Shuwaish *et al.*[19] evaluated the correlation between DIFOTI and clinical and radiographic images in estimating the true clinical axial extension of Class II carious lesions. It was observed that DIFOTI images correlated well with clinical depth, especially for smaller lesion. It also improved the estimation of lesion size when used in conjunction with the digital sensor and D-speed images. As reported by Astvaldottir,[20] though the potential for detecting lesions in dentin by DIFOTI, Film and digital radiography is similar, the diagnostic accuracy of DIFOTI in detecting early approximal enamel lesions was greater 20.

Although it has certain advantages like gives instant images that can be stored for future references, there are several limitations of DIFOTI. The method does not measure lesion depth, and a difficulty in discriminating deep fissures, stain, and actual dentin lesions. Furthermore, overdiagnosis can occur due to lower specificity when compared with conventional radiographs. Dark areas on the images can be attributed to scatter and the absorption of light as it passes through demineralized enamel and dentin or near the surface; consequently, white spots can be mistaken for cavitations.[21]

MIDWEST CARIES ID™ (MID)

MID is a small, battery-operated technology that emits a soft LED light for detecting and quantifying caries. A specific fiber optic signature captures the resulting reflection and refraction of the light in the tooth and is converted to electrical signals that run through a computer-based algorithm for analyzing the presence of caries.

Patel *et al.*[22] reported the sensitivity and specificity for this detection device as 0.56 and 0.84, respectively. Krause *et al.*[23] reported sensitivity of 100%, which was calculated by comparing the Midwest to radiographic findings. However, Rodrigues *et al.*[24] assessed the performance of two LED (MID and Vista Proof-VP) and two laser fluorescence (LF)-based devices (DIAGNOdent 2095-LF and DIAGNOdent pen 2190-LF pen) in detecting occlusal caries *in vitro* on 97 permanent molars. Both LF devices seem to be useful as supplementary tools to conventional methods, presenting good reproducibility and better accuracy. Furthermore, MID could not differentiate sound surfaces from enamel caries and VP still needs perfection on the cutoff limits for its use.

Aktan *et al.*[25] compared laser-based (DIAGNOdent) and LED-based (MID) in the detection of occlusal caries and concluded that MID device more regularly revealed the presence of occlusal caries in comparison to DIAGNOdent pen. Van Hilsen and Jones[26] evaluated and compared MID, visual photographic examination (CAM) and cross-polarization optical coherence tomography (CP-OCT) observed that MID and CP-OCT were useful in detecting the presence of demineralization, but cannot be utilized to adequately assess the depth of the demineralization.

ENDOSCOPY

Endoscopy includes:

- Endoscopically viewed filtered fluorescence
- White light fluorescence
- Videoscope.

Endoscopically viewed filtered fluorescence

This technique utilizes the fluorescence of enamel that occurs when it is illuminated with blue light in wavelength range 499–500 nm. When the tooth is viewed from a specific gelatine green filter number 58, attached to the eyepiece, white spot lesions appear darker than sound enamel.

Pitts and Longbottom[27] explored the use of EFF for the clinical diagnosis of carious lesions and compared results with conventional alternatives on occlusal and approximal sites. The EFF method has been shown to be highly sensitive for occlusal enamel caries and high specificity for approximal lesions at both thresholds. This work developed to include the use of an intraoral video system for caries detection, the prototype "videoscope."

Longbottom and Pitts[28] compared the diagnostic performance of visual endoscopic caries diagnosis (with and without the benefit of differential fluorescence) with that of conventional visual diagnosis, bitewing radiography, and conventional transillumination. The study concluded that endoscopic methods detected a greater number of carious lesions than do conventional visual, radiographic, or FOTI methods.

One of the main advantages is that it gives a magnified view of carious lesions and provides large range of viewing angles, and the areas, which are difficult to view by conventional means, are easily accessible. However, it has few limitations like being time consuming and technique sensitive. Thus meticulous drying and isolation are necessary for accurate results.

White light fluorescence

A white light source is connected to the endoscope by a fiber-optic cable and teeth are viewed without a filter. It has certain limitations like weight of fiber-optic cable tends to destabilize the machine and the increased distance between eyepiece and light source decreases illumination.

Videoscope

The integration of the camera and endoscope is called a videoscope. This is designed in such a way that the image of the surface of enamel can be viewed directly over a television screen. The videotapes are viewed by expert independent examiners who had also examined the teeth visually and by conventional methods.

It has certain advantages like providing a magnified image and being clinically feasible. However, it requires meticulous drying and isolation of teeth and is time consuming and very costly thus making it for limited use only.

INTRAORAL TELEVISION CAMERA (IOTV)

Intraoral cameras are based on the same idea as endoscopes, using a small visualization device to provide a better view of the oral cavity. The intraoral wand camera projects magnified digital images from a patient's mouth. Through the IOTV, the dentist can educate the patient and at the same time, can also improve their own diagnostic expertise as they see magnified oral conditions which are significantly better than direct vision.

Certain advantages such as increased vision, improved posture, and patient positioning, and increased magnification helps in diagnosis. Forgie *et al*.[29] concluded that IOVC can achieve very high level of sensitivity, but this is accompanied with drop in specificity and not suitable for large epidemiological surveys which require extensive human and economic resources.

Boye *et al*.[30] compared diagnostic performance for the detection of caries using photographs (taken with intra-oral camera) with an established visual examination method and histological sections as the reference standard and concluded that the photographic assessment method had higher sensitivity for caries detection than visual examination. The two methods had comparable specificities.

Paul *et al*.[31] described a laser-supported dental endoscope, which is a combination of a customary intraoral camera with a laser as an illumination source. The use of a laser beam at 530 nm for illumination enables a significant presentation of early caries on tooth enamel. The laser-supported dental endoscope, employing a laser beam of 337 nm, is also suitable to detect early caries on the basis of the autofluorescence of the tooth enamel.

ELECTRICAL CONDUCTANCE MEASUREMENT (ECM)

The idea of an electrical method for caries detection was proposed by Magitot in 1878, and is based on the theory that sound dental hard tissue, especially the enamel, shows very high electrical resistance or impedance. In the impedance measurement system a circuit of a very weak alternating current is closed through the patient. From the device, a fiber leads to a probe, which is placed on the site that is to be measured.[32]

Based on the differences in the electrical conductance of carious tissue and sound enamel, two instruments were developed and tested in 1980, i.e. Vanguard electronic caries detector and caries meter. In Vanguard electronic caries detector method, resistance measurements are made between a hand held connection and probe tip placed within the fissures of the teeth. Superficial saliva is removed to prevent surface conduction. Machine gives a reading on a scale of 0-9, which is directly proportional to the degree of demineralization. In caries meter method, the resistance measurement is made between the probe tip and clip attached to oral electrode, and colored light reflects the status of tooth.

The disadvantages are that the area of diagnosis is confined to the dimension of the probe, technique sensitivity as salivary or temperature changes can change measurements and the status of lesion is not known such as arrested or active. The advantages are small and handy systems, accurate diagnosis and no pain to the patient. Further, Sengun *et al*.[33] found that the ECM is very useful at the diagnosis of occlusal caries which are difficult to detect clinically and in this way minimizes the risk of unnecessary tissue loss. With this device, it can be possible to avoid unnecessary radiographs.

Various studies have shown that ECM has higher sensitivity values (0.90) compared with conventional methods for detecting occlusal dentin caries lesions. However, lower specificity values (around 0.80) have been observed.[34,35] In Ashley *et al*.[36] study, surface-specific electrical measurements were recorded every 6 months during the second 18-month period of a 3-year clinical trial comparing two products whose relative anti-caries effects were unknown. Over an 18-month period, ECM measurements demonstrated a significant difference in the mean distributed file system increment between the test and the control groups. In contrast, the conventional detection methods used in the trial were unable to discriminate between the products over three years.

Improved diagnoses at the dentinal level were obtained, when EC and LF were used at higher cutoff values as an adjunct to visual inspection, as the latter rely exclusively on fissure discoloration. In cases of discolored fissures, these methods help to overcome false-positive identification of dentinal caries. However, attainable reliabilities of diagnoses do not seem to exceed about 50–60%.[37]

Fennis-Ie *et al.*[38] compared the performance of visual inspection on FOTI, and electrical conductance measurements (ECMs) and concluded that ECM is a better predictor of occlusal caries than fissure discoloration and FOTI. A cost-effective analysis is envisaged to obtain insight into the practical value of ECMs in the prediction of occlusal caries and, thus, into the effectiveness of sealant application.

RADIOGRAPHY

Digital imaging radiography

Digital radiography is a form of radiography that uses X-ray - sensitive plates to capture data and then immediately transferring it to a computer system without the use of an intermediate cassette. This gives advantages of immediate image preview; elimination of film processing steps; less radiation; and a wider dynamic range, which reduces the chances of over- and under-exposure; as well as the ability to apply special image processing techniques that enhance overall display quality of the image.

No significant difference between digital and conventional radiographic modalities in the detection of non-cavitated interproximal caries was observed by Abesi *et al.*[39] and Abreu *et al.*,[40] and Syriopoulos *et al.*[41] concluded that the diagnostic accuracy of digital systems is comparable with that of dental films, and the main contributing factor for correct diagnosis depends on the ability of dentists, but not the imaging modality. Further Anbiaee *et al.*[42] did not find any significant difference between digital and conventional radiography in the diagnosis of recurrent caries.

El-Samarrai and Misbah[43] compared the diagnosis of an initial carious lesion by clinical and conventional radiographic methods in comparison to direct digital radiography. For both dentitions, the direct digital radiographs were more precise in the detection of decayed surfaces compared to both clinical and conventional radiographic examinations. Pontual *et al.*[44] showed that the performance of the three intraoral storage phosphor plate digital systems was similar to that of the conventional film for detection of approximal enamel caries, and the histological depth of enamel caries was not significantly correlated with radiographic measurements.

One important advance with digital radiology was the introduction of caries detection software, Logicon Caries Detector™ Software (Kodak Dental Systems, Atlanta, GA), for assisting in the diagnosis of interproximal caries. Logicon software extracts image features of the digital radiographic image and correlates them with a database of known and identified caries problems. This software has the ability to locate and classify proximal caries, indicating the depth of caries penetration. The Logicon program had an increased sensitivity, especially in lesions with caries extending into the dentin.[45]

Subtraction radiography

Subtraction radiography is a technique by which structured noise is reduced to increase the detectability of changes in the radiographic pattern. Subtraction images can be obtained from photographic, electronic, and digital methods. Other methods have disadvantages such as inability to produce correct projection geometry and improper density and contrast. Van der Stelt[46] reported that impregnation of occlusal surfaces with SnF_2, in combination with subtraction radiography, produces diagnostic images that give more true positive and less false-negative observations, thus improving the diagnosis of occlusal carious lesions.

Valizadeh *et al.*[47] showed that digital subtraction images have the potential to measure the depth of proximal caries; however, no significant difference was observed with histopathologic evaluation. Park *et al.*[48] also demonstrated that digital subtraction radiography from single radiographic image of artificial caries was highly efficient in the detection of dental caries compared to the data from simple digital radiograph. Furthermore, Paymani *et al.*[49] showed that DSR can be used as a specialized and precise method in the diagnosis of Class III caries.

Computed tomography (CT)

CT, invented by Hounsfield in 1973, is considered as a technical break-through, well-known medical technique for the non-destructive examination of internal structures and its introduction to dentistry has been innovative as it provides true three-dimensional (3D) imaging. Cone-beam CT (CBCT) is a new application of CT that generates 3D data at lower cost.

van Daatselaar *et al.*[50] carried out an *in vitro* observer study of the detection of interproximal caries by local CT, and it was observed that vertically reformatted CT slices obtained with local CT performed significantly better radiographs in visually detecting caries than conventional two-dimensional digital. Furthermore, Young *et al.*[51] observed that dentists were able to detect dentinal proximal-surface caries using 3DX high-resolution CBCT images compared with CCD images when compared to occlusal dentinal caries.

X-ray microtomography

X-ray microtomography is a shortened version of computerized axial tomography with a resolution of the order of micrometers. Microtomography (commonly known as Industrial CT scanning), like tomography, uses X-rays to create cross-sections of a 3D-object that later can be used to recreate a virtual model without destroying the original model. The term micro is used to indicate that the pixel sizes of the cross-sections are in the micrometer range.

Transverse microradiography (TMR)

TMR or contact-microradiography is the most practical and widely accepted method used to assess demineralization and remineralization of dental hard tissues. Hall *et al.*[52] aimed to demonstrate the quantitative nature of LF, by means of TMR and demonstrated that LF can detect mineral loss, and, with the refinement of the image analysis system, LF was capable of detecting re-mineralization. Lo *et al.*[53] compared the detection of changes before and after re-mineralization of artificial enamel and dentin caries and found that both micro-CT and microradiography are able to detect a change of similar magnitude in the artificial caries lesions after re-mineralization.

Tuned aperture CT (TACT)

TACT is a new imaging device which enhances the image by decreasing the superimposition of anatomical structures. It uses digital radiographic images and its software correlates these images into layers so that sliced sections can be viewed. A series of eight radiographs can be assimilated into one TACT image. Shi *et al.*[54] evaluated the use of TACT for the detection of primary occlusal caries and reported that TACT radiographs were significantly better than conventional radiographs for diagnosing all types of occlusal caries.

LASERS

Quantitative light-induced fluorescence (QLF)

QLF uses the natural fluorescence of the teeth and depends on the light absorption and scattering properties of the teeth, to discriminate between caries and surrounding sound enamel. The auto-fluorescence of tooth tissue 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. Stookey[55] reported that QLF can be used to assess the impact of preventive measures on the re-mineralization and reversal of the caries process as it is capable of monitoring and quantifying changes in the mineral content of white spot lesions.

Ando *et al.*[56] determined and compared the ability of QLF (laser) and QLF II (light) to quantify mineral loss from carious lesions in both deciduous and permanent teeth and concluded that the use of either QLF method to quantify mineral loss in early carious lesions in deciduous teeth is slightly more accurate in comparison to permanent teeth. Heinrich-Weltzien *et al.*[57] concluded that QLF seems to be a sensitive method that is suitable for the detection of visually undetected initial caries lesions on all maxillary and mandibular smooth surfaces in caries-risk adolescents

Higham *et al.*[58] concluded that "QLF has the potential to detect, diagnose, and longitudinally monitor occlusal caries and provides useful information to the clinician with regard to the severity of the lesion and likely treatment." Unlu *et al.*[59] compared LF device, electronic caries monitor (ECM), and caries detector dye and concluded that LF has significantly detected residual caries.

Gimenez *et al.*[60] performed a comprehensive systematic review and meta-analysis to evaluate the accuracy of fluorescence-based methods in detecting caries lesions. In general, the analysis demonstrated that the fluorescence-based method tends to have similar accuracy for detecting more advanced caries lesions on all types of teeth, dental surfaces, or settings.

Diagnodent

Diagnodent with a laser diode generates a pulsed 655 nm laser beam through a central fiber, which is transported to the tip of the device and into the tooth. When the incident light interacts with tooth substance, it stimulates fluorescent (or luminescent) light at longer wavelengths. The intensity of fluorescence depends on the degree of demineralization or bacterial concentration in the probed region.

Advantages include 90% success rate in diagnosing pit and fissure caries, higher sensitivity (0.92) than electronic caries monitor, high reproducibility and reliability, easy and quick to use, readily transportable, non-invasive and painless, does not suffer from operative bias, safe, and no X-ray exposure. However, it has certain limitations like false results with the presence of plaque and debris, cannot distinguish between hypomineralized and carious structure, readings do not relate to the amount of dentinal decay, and cannot be used for recurrent caries.

Shi *et al.*[61] carried out *in vitro* study and concluded that the diagnostic performance of the DIAGNOdent method was superior to that of radiography. Reis *et al.*[62] compared the DIAGNOdent readings on three different macroscopically sound and intact occlusal surfaces and compare with visual and radiographic inspection and concluded that in a low prevalence sample, the visual inspection provided the highest proportion of true disease and DIAGNOdent provided the highest proportion of non-disease identified correctly.

Goel *et al.*[63] concluded that DIAGNOdent showed higher sensitivity and accuracy as compared with other conventional methods (visual and tactile examination and bitewing radiographs) for detection of enamel caries, whereas for detection of dentinal caries, even though the sensitivity was high, accuracy of the DIAGNOdent device was similar to other conventional caries diagnostic methods. Pinheiro *et al.*[64] and Khalife *et al.*[65] reported that, although the laser device had acceptable performance, this equipment should be used as an adjunct method to visual inspection to avoid false-positive results.

OCT

The first OCT in the field of dentistry was performed by Colston *et al.* in 1998. It creates cross-sectional images of biological structures using, differences in reflection of light. Microstructural details are revealed by differentiating between scattered, transmitted, or reflected photons. Baumgartner *et al.*[66] showed that it can provide additional information related to the mineralization status and/or the scattering properties of the dental materials.

Amaechi *et al.*[67] investigated the correlation between fluorescence loss measured by QLF and the reflectivity loss measured by a OCT system in a demineralization process to produce artificial dental caries and concluded that the decrease in reflectivity of the enamel during demineralization, measured by OCT, could be related to the amount of mineral lost during the demineralization process.

Nguyen *et al.*[68] reported that the diagnostic capability of OCT (78–88% sensitivity and 71–84% specificity) was best in superficial, inter-proximal areas, and margins of restorations and was least effective in deep caries at locations exceeding 2 mm depth and concluded that OCT is a rapidly developing, promising modality for *in vivo* real-time imaging with excellent capability for non-invasive early caries detection and monitoring.

SPECIES SPECIFIC MONOCLONAL ANTIBODIES

This was given by Shi *et al.* in 1998, identified specific monoclonal antibodies that recognize the surface of cariogenic bacteria. They used three highly species-specific monoclonal immunoglobulin G (IgG) antibodies targeted against *Streptococcus mutans*. The probes are tagged with fluorescent molecules that measure quantitatively with spectrometer.

Advantages include that it can be used at chairside by dentist, quick results, and the overall risk assessment can be made in operatory itself. Shi *et al.*[69] developed three highly species-specific monoclonal IgG antibodies against *S. mutans* that quantitatively detect *S. mutans* in <1 min and is sensitive enough to detect a single bacterial cell and concluded that these methods could be widely used in basic and clinical studies related to *S. mutans* and in the clinical diagnosis and treatment of caries in humans. Gu *et al.*[70] study showed that MAb-based salivary *S. mutans* tests exhibit significantly higher specificity and sensitivity than the commonly used selective culture method and thus provides useful information and tools for analyzing the role of *S. mutans* in human dental caries.

CARIESCAN

This device is based on alternating current impedance spectroscopy and involves the passing of an insensitive level of electrical current through the tooth to identify the presence and location of the decay. It is the first dental diagnostic tool to use an impedance spectroscopy to quantify dental caries early enough to enhance preventative treatment. CarieScan is not affected by optical factors such as staining or discoloration of the tooth. It provides a qualitative value based on the disease state rather than the optical properties of the tooth.[71]

Bader *et al.*[72] carried out a systematic review comparing CarieScan with a clinical visual examination, bitewing radiograph, and DIAGNOdent reported CarieScan to have superior sensitivity and specificity both 92.5% over other methods.

CONCLUSION

Advanced diagnostic technologies are increasingly playing a more key role in this process, both in data collection and assessment capabilities and the utilization of the information obtained. Diagnostic modalities available to clinicians to expand greatly on the foundation of a comprehensive visual assessment, which has been and will be the cornerstone of the diagnostic process.

Declaration of patient consent

Patients consent not required as patients identity is not disclosed or compromised.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Shafer W. Textbook of Oral Pathology. 6th ed. New Delhi: Elsevier; 2009. p. 567.

2. Fejerskov O. Concepts of dental caries and their consequences for understanding the disease. Community Dent Oral Epidemiol 1997;25:5-12.
3. Carounanidy U, Sathyanarayanan R. Dental caries: A complete changeover (Part II)-changeover in the diagnosis and prognosis. J Conserv Dent 2009;12:87-100.
4. Gomez J. Detection and diagnosis of the early caries lesion. BMC Oral Health 2015;15 Suppl 1:S3.
5. Abogazalah N, Ando M. Alternative methods to visual and radiographic examinations for approximal caries detection. J Oral Sci 2017;59:315-22.
6. Ie YL, Verdonschot EH. Performance of diagnostic systems in occlusal caries detection compared. Community Dent Oral Epidemiol 1994;22:187-91.
7. Ismail AI. Clinical diagnosis of precavitated carious lesions. Community Dent Oral Epidemiol 1997;25:13-23.
8. Peers A, Hill FJ, Mitropoulos CM, Holloway PJ. Validity and reproducibility of clinical examination, fibre-optic transillumination, and bite-wing radiology for the diagnosis of small approximal carious lesions: An *in vitro* study. Caries Res 1993;27:307-11.
9. Wenzel A, Verdonschot EH, Truin GJ, König KG. Accuracy of visual inspection, fiber-optic transillumination, and various radiographic image modalities for the detection of occlusal caries in extracted non-cavitated teeth. J Dent Res 1992;71:1934-7.
10. Côrtes DF, Ellwood RP, Ekstrand KR. An *in vitro* comparison of a combined FOTI/visual examination of occlusal caries with other caries diagnostic methods and the effect of stain on their diagnostic performance. Caries Res 2003;37:8-16.
11. ten Bosch JJ, van der Mei HC, Borsboom PC. Optical monitor of *in vitro* caries. A comparison with chemical and microradiographic determination of mineral loss in early lesions. Caries Res 1984;18:540-7.
12. Brinkman J, ten Bosch JJ, Borsboom PC. Optical quantitation of natural caries in smooth surfaces of extracted teeth. Caries Res 1988;22:257-62.
13. Vaarkamp J, Ten Bosch JJ, Verdonschot EH, Tranaeus S. Quantitative diagnosis of small approximal caries lesions utilizing wavelength-dependent fiber-optic transillumination. J Dent Res 1997;76:875-82.
14. Vaarkamp J, ten Bosch J, Verdonschot EH, Huysmans MC. Wavelength-dependent fibre-optic transillumination of small approximal caries lesions: The use of a dye, and a comparison to bitewing radiography. Caries Res 1997;31:232-7.
15. Kidd EA. Essentials of Dental Caries. 3rd ed. US: Oxford University Press; 2005. p. 42-44.
16. Schneiderman A, Elbaum M, Shultz T, Keem S, Greenebaum M, Driller J, *et al.* Assessment of dental caries with digital imaging fiber-optic transillumination (DIFOTI): *In vitro* study. Caries Res 1997;31:103-10.
17. Hae-Woong Y, Seung-Hoon Y, Jong-Soo K. Early detection of initial dental caries using a DIFOTI. J Korean Acad Paediatr Dent 2004;31:587-97.
18. Kazuhiro U. Clinical evaluation of the DIFOTI digital imaging system. Jpn J Cons Dent 2001;44:750-4.
19. Bin-Shuwaish M, Yaman P, Dennison J, Neiva G. The correlation of DIFOTI to clinical and radiographic images in class II carious lesions. J Am Dent Assoc 2008;139:1374-81.
20. Astvaldottir A, Ahlund K, Holbrook WP, Verdier BD, Tranaeus S. Approximal caries detection by DIFOTI: *In vitro* comparison of diagnostic accuracy/efficacy with film and digital radiography. Int J Dent 2009;6:21-8.
21. Yang J, Dutra V. Utility of radiology, laser fluorescence, and transillumination. Dent Clin North Am 2005;49:739-52, 6.
22. Patel SA, Shepard WD, Barros JA, Streckfus CF, Quock RL. *In vitro* evaluation of Midwest caries ID: A novel light-emitting diode for caries detection. Oper Dent 2014;39:644-51.
23. Krause F, Melner DJ, Stawirej R, Jepsen S, Braun A. LED based occlusal and approximal caries detection *in vitro* (Abstract 0526). J Dent Res 2008;87:526.
24. Rodrigues JA, Hug I, Neuhaus KW, Lussi A. Light-emitting diode and laser fluorescence-based devices in detecting occlusal caries. J Biomed Opt 2011;16:107003.
25. Aktan AM, Cebe MA, Ciftçi ME, Sirin Karaarslan E. A novel LED-based device for occlusal caries detection. Lasers Med Sci 2012;27:1157-63.
26. Van Hilsen Z, Jones RS. Comparing potential early caries assessment methods for teledentistry. BMC Oral Health 2013;13:16.
27. Pitts NB, Longbottom C. The use of endoscopically viewed filtered fluorescence for the clinical diagnosis of caries lesions in dental enamel. Med Sci Res 1987;15:535-6.
28. Longbottom C, Pitts NB. Initial comparison between endoscopic and conventional methods of caries diagnosis. Quintessence Int 1990;21:531-40.
29. Forgie AH, Pine CM, Pitts NB. The assessment of an intra-oral video camera as an aid to occlusal caries detection. Int Dent J 2003;53:3-6.
30. Boye U, Walsh T, Pretty IA, Tickle M. Comparison of photographic and visual assessment of occlusal caries with histology as the reference standard. BMC Oral Health 2012;12:10.
31. Paul R, Strauss J, Finke CH, Fink F. Laser-supported dental endoscope (LSDE) for the detection of early carious lesions. Laser Phys 2003;13:773-80.
32. Pretty IA. Caries detection and diagnosis: Novel technologies. J Dent 2006;34:727-39.
33. Sengun A, Ozbay Y, Akdemir B, Ozturk B, Ozer F, Baglar S. Reliability of electronıcally detectıon of fıssure carıes (by usıng a prototype devıce): An alternative diagnostic electronic caries monitor device. J Restor Dent 2013;1:26-30.
34. Bader JD, Shugars DA, Bonito AJ. A systematic review of the performance of methods for identifying carious lesions. J Public Health Dent 2002;62:201-13.
35. Longbottom C, Huysmans MC. Electrical measurements for use in caries clinical trials. J Dent Res 2004;83 Spec No C: C76-9.
36. Ashley PF, Ellwood RP, Worthington HV, Davies RM. Predicting occlusal caries using the electronic caries monitor. Caries Res 2000;34:201-3.
37. Kordic A, Lussi A, Luder HU. Performance of visual inspection, electrical conductance and laser fluorescence in detecting occlusal caries *in vitro*. Schweiz Monatsschr Zahnmed 2003;113:852-9.
38. Fennis-Ie YL, Verdonschot EH, van't Hof MA. Performance

of some diagnostic systems in the prediction of occlusal caries in permanent molars in 6- and 11-year-old children. J Dent 1998;26:403-8.
39. Abesi F, Mirshekar A, Moudi E, Seyedmajidi M, Haghanifar S, Haghighat N, *et al.* Diagnostic accuracy of digital and conventional radiography in the detection of non-cavitated approximal dental caries. Iran J Radiol 2012;9:17-21.
40. Abreu M Jr., Mol A, Ludlow JB. Performance of RVGui sensor and kodak ektaspeed plus film for proximal caries detection. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2001;91:381-5.
41. Syriopoulos K, Sanderink GC, Velders XL, van der Stelt PF. Radiographic detection of approximal caries: A comparison of dental films and digital imaging systems. Dentomaxillofac Radiol 2000;29:312-8.
42. Anbiaee N, Mohassel AR, Imanimoghaddam M, Moazzami SM. A comparison of the accuracy of digital and conventional radiography in the diagnosis of recurrent caries. J Contemp Dent Pract 2010;11:E025-32.
43. El-Samarrai S, Misbah MM. Diagnosis of initial carious lesion by clinical and conventional radiographic methods in comparison to direct digital radiography. J Baghdad Coll Dent 2007;19:77-80.
44. Pontual AA, de Melo DP, de Almeida SM, Bóscolo FN, Haiter Neto F. Comparison of digital systems and conventional dental film for the detection of approximal enamel caries. Dentomaxillofac Radiol 2010;39:431-6.
45. Strassler HE, Sensi LG. Technology-enhanced caries detection and diagnosis. Compend Contin Educ Dent 2008;29:464-5, 468, 470.
46. Van der Stelt PF. Digital Radiography as a Diagnostic Tool in Dentistry. From the Summer 2004 AADMRT Newsletter. St. Louis: Mosby; 2004.
47. Valizadeh S, Ehsani S, Esmaeili F, Tavakoli MA. Accuracy of digital subtraction radiography in combination with a contrast media in assessment of proximal caries depth. J Dent Res Dent Clin Dent Prospects 2008;2:77-81.
48. Park JH, Choi YS, Hwang EH, Lee GJ, Choi S, Park YH, *et al.* Proximal caries detection using digital subtraction radiography in the artificial caries activity model. Korean J Oral Maxillofac Radiol 2009;39:35-9.
49. Paymani A, Talayeepour A, Anaraki SN, Mehralizadeh S, Delavar AS, Talebi S. Evaluation of the accuracy of digital subtraction radiography in the diagnosis of different depths of class III caries (An *in vitro* study). J Res Dent Sci 2011;8:120-9.
50. van Daatselaar AN, Dunn SM, Spoelder HJ, Germans DM, Renambot L, Bal HE, *et al.* Feasibility of local CT of dental tissues. Dentomaxillofac Radiol 2003;32:173-80.
51. Young SM, Lee JT, Hodges RJ, Chang TL, Elashoff DA, White SC, *et al.* A comparative study of high-resolution cone beam computed tomography and charge-coupled device sensors for detecting caries. Dentomaxillofac Radiol 2009;38:445-51.
52. Hall AF, DeSchepper E, Ando M, Stookey GK. *In vitro* studies of laser fluorescence for detection and quantification of mineral loss from dental caries. Adv Dent Res 1997;11:507-14.
53. Lo EC, Zhi QH, Itthagarun A. Comparing two quantitative methods for studying remineralization of artificial caries. J Dent 2010;38:352-9.
54. Shi XQ, Han P, Welander U, Angmar-Månsson B. Tuned-aperture computed tomography for detection of occlusal caries. Dentomaxillofac Radiol 2001;30:45-9.
55. Stookey GK. Quantitative light fluorescence: A technology for early monitoring of the caries process. Dent Clin North Am 2005;49:753-70, 6.
56. Ando M, van Der Veen MH, Schemehorn BR, Stookey GK. Comparative study to quantify demineralized enamel in deciduous and permanent teeth using laser-and light-induced fluorescence techniques. Caries Res 2001;35:464-70.
57. Heinrich-Weltzien R, Kühnisch J, Ifland S, Tranaeus S, Angmar-Månsson B, Stösser L, *et al.* Detection of initial caries lesions on smooth surfaces by quantitative light-induced fluorescence and visual examination: An *in vivo* comparison. Eur J Oral Sci 2005;113:494-8.
58. Higham SM, Smith PW, Pretty IA. Development of an occlusal caries index for quantitative light-induced fluorescence (QLF). In: Stookey GK, editor. Early Detection of Dental Caries III: Proceedings of the 6th Annual Indiana Conference. Indianapolis: Indiana University, School of Dentistry; 2003. p. 195-212.
59. Unlu N, Ermis RB, Sener S, Kucukyilmaz E, Cetin AR. An *in vitro* comparison of different diagnostic methods in detection of residual dentinal caries. Int J Dent 2010;2010:864935.
60. Gimenez T, Braga MM, Raggio DP, Deery C, Ricketts DN, Mendes FM, *et al.* Fluorescence-based methods for detecting caries lesions: Systematic review, meta-analysis and sources of heterogeneity. PLoS One 2013;8:e60421.
61. Shi XQ, Welander U, Angmar-Månsson B. Occlusal caries detection with kaVo DIAGNOdent and radiography: An *in vitro* comparison. Caries Res 2000;34:151-8.
62. Reis A, Zach VL Jr., de Lima AC, de Lima Navarro MF, Grande RH. Occlusal caries detection: A comparison of DIAGNOdent and two conventional diagnostic methods. J Clin Dent 2004;15:76-82.
63. Goel A, Chawla HS, Gauba K, Goyal A. Comparison of validity of DIAGNOdent with conventional methods for detection of occlusal caries in primary molars using the histological gold standard: An *in vivo* study. J Indian Soc Pedod Prev Dent 2009;27:227-34.
64. Pinheiro IV, Medeiros MC, Ferreira MA, Lima KC. Use of laser fluorescence (DIAGNOdent) for *in-vivo* diagnosis of occlusal caries: A systematic review. J Minimum Interv Dent 2008;1:45-51.
65. Khalife MA, Boynton JR, Dennison JB, Yaman P, Hamilton JC. *In vivo* evaluation of DIAGNOdent for the quantification of occlusal dental caries. Oper Dent 2009;34:136-41.
66. Baumgartner A, Dichtl S, Hitzenberger CK, Sattmann H, Robl B, Moritz A, *et al.* Polarization-sensitive optical coherence tomography of dental structures. Caries Res 2000;34:59-69.
67. Amaechi BT, Podoleanu A, Higham SM, Jackson DA. Correlation of quantitative light-induced fluorescence and optical coherence tomography applied for detection and quantification of early dental caries. J Biomed Opt 2003;8:642-7.
68. Nguyen VT, Truong M, Jequinto G, Sarkiss A, Le A, Zhang J, *et al.* Early detection of dental caries using optical coherence

tomography. Int Assoc Dent Res 2005;5:693.
69. Shi W, Jewett A, Hume WR. Rapid and quantitative detection of *Streptococcus mutans* with species-specific monoclonal antibodies. Hybridoma 1998;17:365-71.
70. Gu F, Lux R, Anderson MH, del Aguila MA, Wolinsky L, Hume WR, *et al.* Analyses of *Streptococcus mutans* in saliva with species-specific monoclonal antibodies. Hybrid Hybridomics 2002;21:225-32.
71. Amaechi BT. Emerging technologies for diagnosis of dental caries: The road so far. J Appl Phys 2009;105:102047-9.
72. Bader JD, Shugars DA, Bonito AJ. Systematic reviews of selected dental caries diagnostic and management methods. J Dent Educ 2001;65:960-8.

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