Review Article

Diagnostic Methods for Early Detection of Dental Caries – A Review

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Abstract

Management of dental caries demands early detection of carious lesions. This article provides an overview of the state of the art methodologies for the detection and assessment of early carious lesions. This review is based on PubMed for available literature on caries detection methodology and tools, using terms such as "early detection of caries," "caries detection methods or tools," "transillumination," "fluorescence," and "newer caries detection method," Conventional or the traditional methods for the detection of caries have failed to detect early incipient caries effectively. The advanced methods provide promising results in detection both early caries and also caries occurring on all surfaces of the tooth, which paves the way for a more preventive approach to caries management. Each caries detection tool has advantages and disadvantages; some perform better on certain surfaces than others. Newer diagnostic methods which are still under research may prove to be very effective for early detection of caries in the near future. The change in the paradigm to minimally invasive dentistry has ascertained the field of dentistry to a more preventive approach to caries management, which demands a proper caries risk assessment and an early detection of caries. Not all the methods accurately detect early lesions. Hence, the clinician must ascertain as to which method and diagnostic tool should be used for clinical assessment of early detection of caries.

Key words: Caries detection methods, early detection of caries, fluorescence, transillumination

Introduction

Diagnosis is an art and science, which results from the synthesis of scientific knowledge and clinical experiences in identifying the signs and symptoms of a disease process.

Dental caries is a complex disease, defined as the process of progressive demineralization of inorganic component of the tooth accompanied by disintegration of the organic portion.[1] It is a dynamic disease process, in which early lesions undergo many demineralization and remineralization cycles before being expressed clinically. Therefore, recognition of the initiation and early detection of caries should be the primary concern rather than the search for cavities.

Need for accurate diagnosis before cavitation would permit targeted preventive treatment such as fluorides and pit and fissure sealants, thereby significantly improving dental health and reducing the need for extensive drilling and filling.

Diagnostic methods become the science behind the creation of diagnosis. A clinician requires knowledge, ability, and skill to apply the right diagnostic method and to interpret them. Visual examination using mouth mirrors, probes, and conventional radiography were the diagnostic methods commonly used earlier. The results of several studies indicate that the use of probe has limited value in caries detection and is also known to disrupt remineralization.[2]

Modern dentistry emphasizes more on prevention, and hence the original maxim of "extension for prevention" has been eschewed for a minimal intervention approach.

An Ideal Diagnostic Tool

Tools to assess future caries risk and present caries activity are required, as diagnostic tasks are becoming more difficult and important from the standpoint of long-term oral health.

Ideally, a diagnostic tool should:
1. Detect dental caries at its earliest stage possible
2. Provide valid prospective caries risk assessments for different age groups

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3. Determine present caries activity and monitor lesions behavior over time.

Requisites of an ideal diagnostic tool

- Accuracy
- Reliable
- Precise/simple
- Easy to apply
- Useful for all surfaces of teeth
- Identifying caries adjacent to restorations
- Objectivity
- Sensitivity
- Specificity
- Reproducibility
- Validity
- Quantitative analysis.[2]

Qualitative versus quantitative methods

- Conventional or traditional tools are qualitative in nature
- They show a poor validity with low sensitivity and moderate specificity
- This implies that caries diagnosis, as normally performed in daily clinical practice, is an inexact procedure that results in both over- and under-diagnosis. This has paved way to search for quantitative detection methods
- Advanced diagnostic methods are all quantitative in nature.[3] They detect lesions at an earlier stage and are more reliable than the conventional methods.[4]

Advanced Methods of Caries Detection

The following are methods of advanced caries detection [Table 1].

Digital radiographic methods

- Digital image enhancement
- Digital subtraction radiography
- Tuned-aperture computed tomography (TACT).

Visible light

- Optical caries monitor
- Quantitative fiber-optic transillumination
- Digital Image fiber-optic transillumination
- Quantitative light/laser-induced fluorescence (QLF).

Laser light

- DIAGNOdent – Laser autofluorescence.

Electrical current

- Electrical conductance measurement
- Electrical impedance measurement.

Ultrasound

- Ultrasonic caries detector.

Digital Radiographic Methods

Digital imaging is an image formed and represented by a spatially distributed set of discrete sensors and pixels. There are two types:

- Direct – The direct image receptor that collects X-ray directly, for example, RVG [Figures 1 and 2]
- Indirect – For example, video camera is used for forming digital images of a radiograph.

Digital detectors

- Charged couple device (CCD)
- Complementary metal oxide semiconductor
- Photo Stimulable Phosphor plate (PSP).

Digital image enhancement

- Resolution of unenhanced digital image is lower than radiographs
- Range of gray shades is limited to 256, whereas in a radiographic film, over 1 million shades of gray appear
- Contrast can be digitally enhanced using a mathematical rule often decided by the algorithm/filter
- They are not practically used because they are very time-consuming.

Digital subtraction radiography

- A digital bitewing radiograph is taken and later a second radiograph of exactly the same region is produced with identical exposure time, tube current, and voltage
- By subtracting gray values for each coordinate of the first radiograph from equivalent coordinate of second, a subtraction image is obtained [Figure 3]
- If no changes have occurred, the result of subtraction is zero
- Nonzero result will be obtained in case of onset or progression of demineralization
- It is not yet routinely applied in clinical caries detection due to difficulty of image registration.

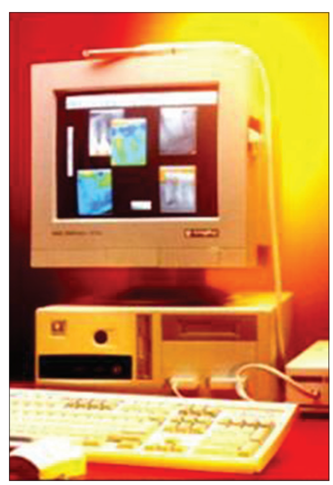

Figure 1: Schick system.

Table 1: Advantages and disadvantages of advanced diagnostic methods for early detection of caries

Diagnostic methods	Advantages	Disadvantages
Digital radiography	Instant and consistent image	High cost
	No dark room needed	Life expectancy of chip
	Eliminates hazards of film development	
	Radiation dose is decreased	
	Capable of teletransmission	
Digital image enhancement	Contrast can be digitally enhanced	Time-consuming
Digital subtraction radiography	Detects onset or progression of demineralization	Difficulty of image registration
Tuned-aperture computed tomography	Detect small primary and secondary carious lesions	Technique sensitive
Visible light		
Optical caries monitor	No hazards	Inter- and intra-observer variation
	Lesion not diagnosed by radiographs can be diagnosed	Low sensitivity[6]
Digital imaging fiber-optic transillumination	Detects initial areas of demineralization	Technique sensitive
	Inspects integrity of teeth	High cost
	Detects cracks, tooth fractures, and wear	
	No harmful radiation	
	Uses safe white light	
	Images all coronal surfaces including interproximal, occlusal, smooth surfaces	
	Determines depth of lesion accurately	
	Only dental diagnostic imaging instrument approved by the Food and Drug Administration for detection of incipient and recurrent caries	
	Magnification of up to ×16	
Quantitative light/ laser-induced fluorescence	Provide very early caries detection and quantification	Cannot detect incipient lesions effectively
	In vivo and *in vitro* quantitative assessment of caries, plaque, calculus, and staining	Can only discern enamel demineralization and cannot differentiate between decay, hyperplasia, or unusual anatomic features
	Helps to quantify mineral loss, lesion depth, size, and severity	Inability to detect or monitor interproximal lesions
	It has high sensitivity, precision, and repeatability	It is limited to measurements of enamel lesions at several hundred micrometers depth
	Image acquired can be stored and transmitted for referral purposes	High cost
	Images can be used as patient motivators in preventive practice	
Laser light		
DIAGNOdent	Early detection of caries	False results with plaque and debris
	High sensitivity and specificity[17]	Not useful for approximal caries detection
	Precise and extremely reliable method[18]	Cannot be used for the detection of recurrent caries
	Reproducible results permit checking, stabilization, and documentation	Readings do not relate to the amount of dentinal decay
	Even very small lesions missed out by conventional methods can be detected at the earliest stages	High cost
	Over 90% accurate to diagnose pit and fissure caries	
	Early detection of pathological changes that are undiagnosed by conventional methods[19]	
	Easy and quick to use	
	Safe and no radiation exposure[7]	
	Noninvasive and pain-free	
	Readily transportable with flexible unit which is battery operated	
DIAGNOdent Pen	Cordless – Can be used anywhere	High cost
	Handy – Always there when needed	
	Simple – Easy to use	
	Precise – Provides complete caries detection	
	Intraexaminer reliability is high	
Electric current		
Electrical conductance measurement	Early detection of fissure caries in recently erupted molar teeth	Moderate sensitivity and specificity
	Predicts probability that a sealant or a restoration will be required within 18–24 months	Detection of caries is limited only to occlusal surfaces of teeth
	Good reproducibility[20]	Cannot be used where amalgam filling is present
		Not a good predictor of invasive treatment needs
		Used only as supplementary aid

Contd...

Table 1: Contd...

Diagnostic methods	Advantages	Disadvantages
Electrical impedance measurement	Detection of occlusal and proximal carious surfaces	Technique sensitive
Ultrasound caries detector	Quick and reliable tool for the detection of caries in enamel Effective in detecting proximal caries that were missed out on radiographs	Not a quantitative method of caries detection

Figure 2: Digora system.

Figure 4: Tuned-aperture computed tomography.

Tuned-aperture computed tomography

This method constructs radiographic section through teeth. The slices can be viewed for the presence of radiolucency [Figure 4].

Mechanism of action

As exposure begins, the tube and film move in opposite directions simultaneously through a mechanical linkage. With this synchronous movement, images of objects in the focal plane remain in fixed positions on radiographic film and are clearly imaged.

On the other hand, images of objects located outside focal plane have continuously changing positions on the film. As a result, images of these objects are blurred beyond recognition

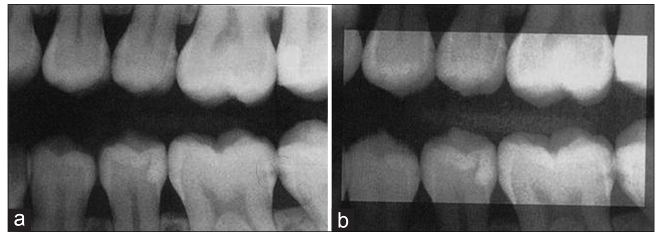

Figure 3: (a and b) Digital subtraction radiography.

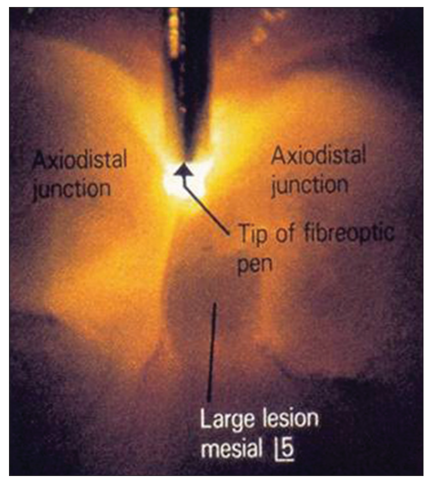

Figure 5: Optical caries monitor.

by motion unsharpness. Slices can be brought together in a three-dimensional computer model called pseudo-hologram. TACT slices and pseudo-hologram can adequately detect small primary and secondary carious lesions.[5]

Visible Light

Optical caries monitor

- Principle used is that in white spot carious lesion, scattering is stronger than in sound enamel surface
- Light is transported through a fiber bundle to the tip of handpiece. Tip is placed against the tooth surface and reflected light is collected by different fibers of the same tip [Figure 5].[6]

Digital imaging fiber-optic transillumination

Digital imaging fiber-optic transillumination (DIFOTI) was developed in an attempt to reduce the perceived shortcomings of FOTI, by combining FOTI with a digital CCD camera. DIFOTI has elevated traditional transillumination to more sophisticated diagnostic levels [Figure 6].

Mechanism of action

It uses a safe white light with which images taken from all the tooth surfaces can be digitally captured using a digital CCD and sent to a computer for analysis. Receptor with photocells converts photon energy to electrical energy – transmitted to a video processor and converted into color value and displayed on video monitor.

When the teeth are transilluminated, areas of demineralized enamel or dentin scatter light and incipient caries appear darker in the resultant image. Images taken during different examinations can be compared for clinical changes between several images of the same tooth over time.[7]

Quantitative light/laser-induced fluorescence

The use of fluorescence for the detection of caries dates back to 1929 first described by Benedict. Fluorescence results from change in the characteristics of light caused by a change in wavelength of incident light rays following reflection from the surface of material.

QLF is based on the principle of fluorescence. It enhances early detection of carious lesions, particularly progression or regression of white spots of smooth surface lesions. It provides a fluorescent image of a tooth surface within yellow-green spectrum of visible light that quantifies mineral loss and size of the lesion [Figure 7].

It is a suitable method for quantitative assessment of early enamel lesions in visually inaccessible areas. Most important parameters produced by QLF are lesion area, depth, and volume.[8]

Figure 6: Digital imaging fiber-optic transillumination.

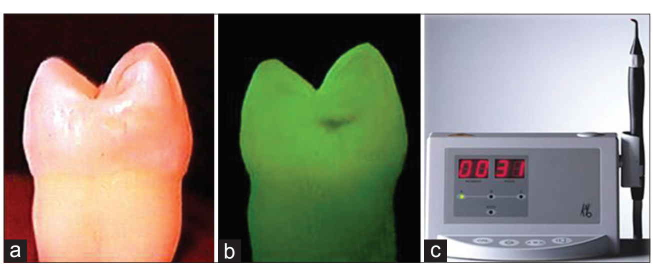

Figure 8: (a-c) Tooth is seen on the computer monitor as fluorescent green and dark areas indicate mineral loss.

Mechanism of action

System includes a measurement probe, control unit, and computer fitted with a frame grabber. The control unit consists of an illumination device and imaging electronics. Light source is a special arc lamp based on xenon technology. The light from this lamp is filtered by a blue-transmitting filter. A liquid light guide transports blue light to the teeth. Recording of florescent image is done with a yellow transmitting filter positioned in front of the color CCD sensor. Image is then digitized by the frame grabber and is available for quantitative analysis. Tooth is seen on a computer monitor as fluorescent green and dark areas indicate mineral loss or white spot lesions. Image can be saved and compared over time to track demineralization or remineralization [Figure 8].

At times, a red fluorescence appears that indicates leaking around restorations and sealants. It is emitted by porphyrins metabolized by bacteria in dental biofilm, calculus, or an infective carious lesion and usually indicates a high caries activity. Area of concern can be tracked over time to evaluate the success of remineralization.[9]

Laser Light

DIAGNOdent - laser autofluorescence

DIAGNOdent was first introduced in 1998 to aid the diagnosis of occlusal caries in adjunct to visual and radiographic

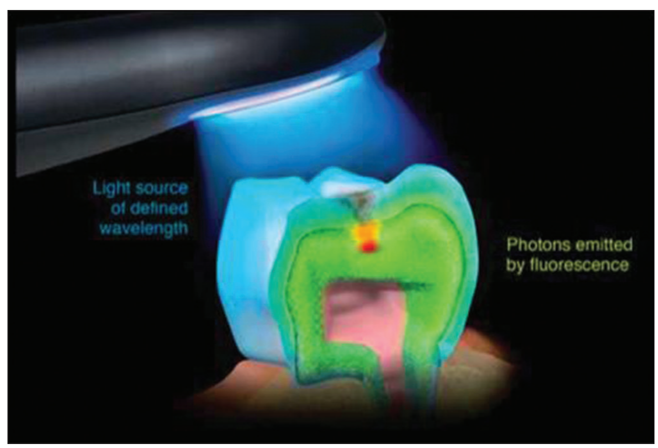

Figure 7: Quantitative light/laser-induced fluorescence.

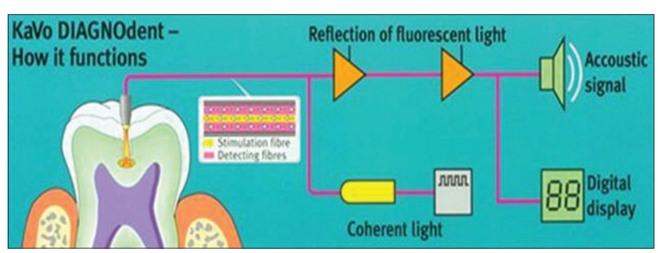

Figure 9: DIAGNOdent - laser autofluorescence.

examination. It is a variant of QLF system and was introduced based on research by Hibst and Gal.

DIAGNOdent system is a part of exciting new generation of dental equipment. It uses infrared laser fluorescence of 655 nm for the detection of occlusal and smooth surface caries [Figure 9].[10]

Mechanism of action

DIAGNOdent technology uses a simple laser diode to compare the reflection wavelength against a well-known healthy baseline to uncover decay.

At specific wavelength that the device operates, healthy tooth structure exhibits little or no fluorescence, resulting in very low scale readings on the display. Carious tooth structure exhibits fluorescence proportionate to the degree of caries, resulting in elevated scale readings on the display.[11]

The unit has a fiber-optic cable that transmits light source to a handpiece that contains a fiber-optic eye in the tip. First, the laser diode is aimed at the healthy enamel tooth structure to obtain a benchmark reading. After calibration, it is moved to inspect all the surfaces of the teeth, shining the laser at 2.5 mm into all suspected areas.

As the laser pulses into grooves, fissures, and cracks, it reflects fluorescent light with particular wavelength. This is because light is absorbed by the organic and inorganic components of the tooth which induce infrared fluorescence.

This fluorescence is collected at the top of handpiece and transmitted back to the DIAGNOdent unit. Light is measured by receptors, converted into an acoustic signal, and evaluated electronically to reveal values between 0 and 99 [Figure 10].[12]

DIAGNOdent pen

DIAGNOdent pen is an advancement made in the DIAGNOdent technology. DIAGNOdent pen 2190 is the perfect tool to detect fissure and smooth surface caries accurately [Figure 11].[13]

Electric Current

Electrical conductance measurement

Electrochemical machining (ECM) is based on the principle that a demineralized tooth has more pores filled with water or saliva, and this is more conductive than intact tooth surface.

It was first proposed by Magitot in 1878. Greater the amount of demineralization, higher is the electrical conductivity through enamel. Demineralized sites and sites with high pore volume and cavities can be detected by measuring the conductance.[4]

This technique has two methods of application.

Site-specific

Applies probe as electrode into fissures and the electrical conductance of that site is measured. To prevent current from leaking through superficial layer of moisture through the gingival, airflow is applied to dry the tooth surface around the probe. Disadvantage is that only small areas of occlusal surface can be measured at one time [Figure 12].

Surface-specific

This technique measures the entire occlusal surface, which is covered with an electrolyte-containing medium where the electrode is placed. ECM uses a fixed frequency of 23 Hz alternate current [Figure 13].[14]

Two instruments based on the difference in electrical conductance of carious and sound enamel were developed.

Vanguard electronic caries detector

It used a current of 25 Hz. Measured conductance was then converted to an ordinary scale of 0–9. Moisture and saliva were removed by a continuous stream of air to prevent surface conductance.

Caries meter

It used a current of 400 Hz. Measured conductance was then converted to four colored lights.

- Green: No caries
- Yellow: Enamel caries
- Orange: Dentin caries
- Red: Pulpal involvement.

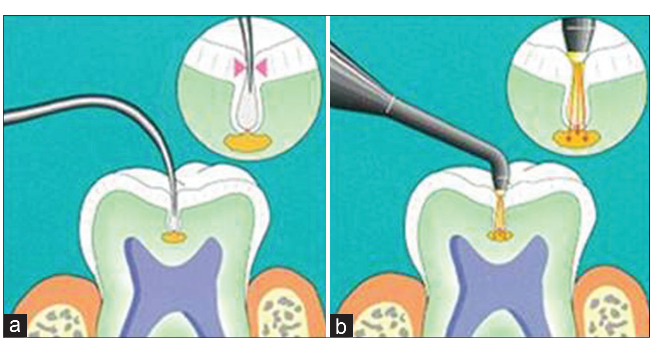

Figure 10: (a and b) DIAGNOdent mechanism.

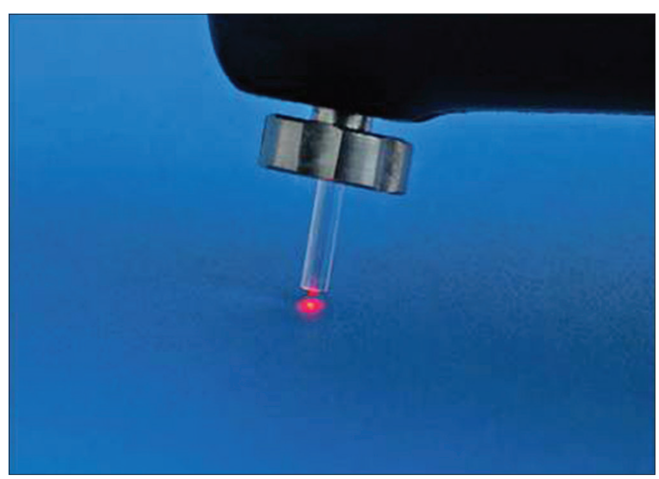

Figure 11: DIAGNOdent pen.

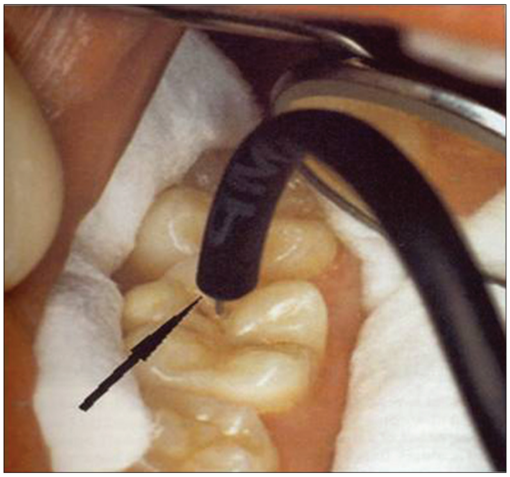

Figure 12: Site specific.

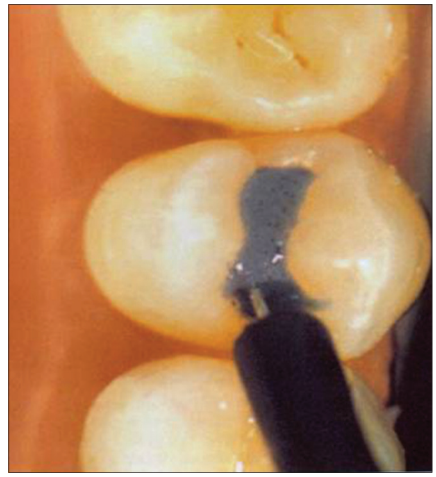

Figure 13: Surface specific.

This method requires pits and fissures to be moistened with saline.

Electrical impedance measurement

Electrical impedance measurement is a measure of degree at which an electric circuit resists electric current flow when a voltage is applied across two electrodes. Caries tissue has a lower impedance than sound tooth. It is also known as electronic caries monitor.[15]

Ultrasound Caries Detector

Use of ultrasound to detect dental caries has been proposed for the past 30 years, but the technique has received renewed interest particularly in the past 10 years. It was introduced for detecting early carious lesions on smooth surfaces.

Demineralization of natural enamel is assessed by ultrasound pulse-echo technique. It is observed that there is a definite correlation between the mineral content of the body of the lesion and the relative echo amplitude changes.[16]

Principle

Ultrasound makes the use of sound waves with frequency. They are longitudinal or pressure waves which travel through gasses, liquids, and solids. Ultrasound interacts differently with different tissues.

They have a frequency of >20,000 Hz and have all the properties of waves, in that they may be reflected, scattered, refracted, or absorbed. The relative ability of a medium to reflect sound depends on its mechanical properties such as elasticity, density, and wavelength of sound.

Amount of sound reflected provides information about the structure of reflecting interface, whereas the time taken for sound to be reflected provides information about the position of the reflecting interface. Sound waves produced as a result of minute changes in crystal dimension may be omitted continually, as burst of waves or as a single pulse.

Mechanism of action

For sound waves to reach the tooth, they have to travel through a coupling medium or an agent which has acoustic impedance. Various acoustic coupling agents have been used such as mercury, aluminum rods, water, and glycerin.

An ultrasonic probe is used which sends and receives longitudinal waves to and from the surface of the tooth. Initial white spot lesions produce no or weak surface echoes, whereas sites with visible cavitation produce echoes with substantially higher amplitude.

This method if improved can be a realistic alternative to radiographic diagnosis of caries on approximal surfaces. It is also more sensitive than visual-tactile method.

Newer Technologies in Store for the Future

Current and future technologies lay emphasis on the objective measurement of the properties of light waves, namely, scattering reflection, absorption, and fluorescence.[16]

Newer technologies include

1. Multiphoton imaging[12,21]
2. Infrared fluorescence[12,22]
3. Infrared thermography[23,24]
4. Terahertz imaging[25]
5. Optical coherence tomography[26]
6. Polarized Raman spectroscopy[26,27]
7. Modulated (frequency-domain) infrared photothermal radiometry.[28,29]

Mechanism of light in detection of dental caries

- The regular structure of teeth ensures good propagation of light through the crystalline enamel and tubules of dentin and disruption to structure of a tooth increases likelihood of scattering
- Uptake of fluid into pores created by demineralization in addition to the uptake of exogenous stain, bacterial

breakdown products, and other contaminants present as a result of caries process will change the normal interaction of light with tooth structure
- In addition to scattering, these changes will include absorption and fluorescence
- Many of the newer techniques use one or more of these interactions.[16]

Conclusion

The shift in treatment philosophy from "extension for prevention" to "minimally invasive dentistry" has afforded the dentist the opportunity to diagnosis and manage caries at an early stage.

An ideal caries detection method should capture the whole continuum of caries process, from the earliest to the cavitation stage. It should be accurate, precise, easy to apply, and useful for all surfaces of teeth, as well as for caries adjacent to restorations.

More technologically, advanced measures based on optical properties (fluorescence and transillumination) are the most potent methods for the detection of incipient carious lesions.

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Conflicts of interest

There are no conflicts of interest.

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