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Research Article

NEWER TECHNOLOGIES IN DIAGNOSIS OF DENTAL CARIES: THE ROAD SO FAR

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A B S T R A C T

Introduction: It is now universally recognized that the development of new technologies for early detection and quantitative monitoring of dental decay at an early stage of formation could provide health and economic benefits ranging from timely preventive interventions to reduction in the time required for clinical trials of anticaries agents.
Material and Methods: This article describes the various technologies available to aid the dental practitioners in detecting dental caries at the earliest stage of its formation, assessing the activities of the detected carious lesion, and quantitatively or qualitatively monitoring of the lesion over time.
Results: The data discussed are primarily based on published scientific studies and reviews from case reports, clinical trials, and in vitro and in vivo studies. References have been traced manually by MEDLINE® or through manufacturer's websites. While some of the devices are fully developed and commercially available, others are still under development. The devices vary in their modes of action as well as their capability as caries diagnostic aids.
Conclusion: It is clear that the differences in caries presentations and behavior in different anatomical sites make it unlikely that any one diagnostic modality will have adequate sensitivity and specificity of detection of carious lesions for all sites; a combination of diagnostic tools will help us diagnose lesions earlier and detect failing restorations sooner, all to avoid more costly, destructive dental procedures and truly take dentistry into the preventive rather than the reactive mode

INTRODUCTION

Dental caries by definition "is an infectious microbiologic disease of the teeth that results in localized dissolution and destruction of the calcified tissues". The decline of dental caries in industrialized countries has been ascribed to several factors including improved oral hygiene, a more sensible approach to sugar consumption, effective use of fluorides, and school-based preventive programs. Establishing diagnostic methods that allow a previous screening of dental caries is a good strategy to set priorities and minimize spending for transporting inmate population. Tele dentistry can be an alternative to solve this problem, as it has been considered a practical and potentially cost-effective method of providing dental healthcare, increasing the possibility of early diagnosis and preventive treatment that can significantly reduce the frequency and severity of oral disease; however, it is important to know the validity of this diagnostic tool.

Diagnostic Tools

According to Pitts (1997), the ideal method or tool for diagnosis of carious lesions would be non-invasive and provide simple, reliable, valid, sensitive, specific, and activity, be based on biologic processes directly related to the carious process. It should also be affordable, acceptable to dentists and patients, and allow early implementation in both clinical practice and research settings. Its use should promote informed and appropriate preventive treatment decisions, enhancing long-term oral health. Unfortunately, there is at present no single, all-embracing method that fulfils these requirements. However, the last 10 years have seen a considerable increase in the assortment of diagnostic tools based on new technology. Prachi Mital *et al* in 2014 presented an article that described the various technologies available to aid the dental practitioners in detecting and diagnosis of dental caries at the earliest stage of its formation, assessing the activities of the detected carious lesion, and quantitatively or qualitatively monitoring of the lesion over time.[3]

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Newer Technologies

A variety of innovative technologies have been developed and introduced in the last few years to aid clinicians not only in early caries detection but make a firm diagnosis and to treat cases conservatively.

Terahertz

Terahertz (THz, 1 THz = 1012 Hz) radiation, also known as THz waves, THz light, or T-rays, is situated in the frequency regime between optical and electronic techniques. THz technology is introduced and some emerging applications in biology and medicine including molecular spectroscopy, tissue characterization and skin imaging are presented.[6]

The aim of this article is to review the potential of THz pulsed imaging and spectroscopy as a promising diagnostic method. Several unique features make THz very suitable for medical applications.. THz radiation has very low photon energy, which is insufficient to cause chemical damage to molecules, or knock particles out of atoms. Thus, it will not cause harmful ionization in biological tissues; this makes it very attractive for medical applications; THz radiation is very sensitive to polar substances, such as water and hydration state. For this reason, THz waves can provide a better contrast for soft tissues than X-rays; THz-TDS techniques use coherent detection to record the THz wave's temporal electric fields, which means both the amplitude and phase of the THz wave can be obtained simultaneously. The temporal waveforms can be further Fourier transformed to give the spectra. This allows precise measurements of the refractive index and absorption coefficient of samples without resorting to the Kramers-Kronig relations; and the energy of rotational and vibrational transitions of molecules lies in the THz region and intermolecular vibrations such as hydrogen bonds exhibit different spectral characteristics in the THz range. These unique spectral features can be used to distinguish between different materials or even isomers.

Principles of THz Pulsed Imaging and Spectroscopy

THz systems

Over the past two decades, technology for generating and detecting THz radiation has advanced considerably. Several commercialized systems are now available and THz systems have been set up by many groups all over the world. According to the laser source used, THz systems can be divided into two general classes: continuous wave (CW) and pulsed.

A typical CW system can produce a single fixed frequency or several discrete frequency outputs. Some of them can be unable. Generation of CW THz radiation can be achieved by approaches such as photo mixing, free-electron lasers and quantum cascade lasers.

A CW THz system has photomixes two CW lasers in a photoconductor. The mixing of two above-band gap (visible or near-infrared)wavelengths produces beating, which can modulate the conductance of a photoconductive switch at the THz difference frequency. The photomixing device is labelled "emitter". Since the source spectrum of the CW system is narrow and sometimes only the intensity information is of interest, the data structures and post processing are relatively simple. It is possible now to drive a whole CW system by laser diodes and thus it can be made compact and inexpensive. However, due to the limited information that CW systems provide, they are sometimes confined to those applications where only features at some specific frequencies are of interest.

Unlike CWTHz imaging system, coherent detection in pulsed THz imaging techniques can record THz waves in the time domain, including both the intensity and phase information, which can be further used to obtain more details of the target such as spectral and depth information. This key advantage lends coherent THz imaging to a wider range of applications.

Molecular interactions in the THz regime

THz spectra contain information about intermolecular modes as well as intra-molecular bonds and thus usually carry more structural information than vibrations in the mid-infrared spectral region which tend to be dominated by intra-molecular vibrations.

Unique advantages and challenges for biomedical applications

The energy level of 1 THz is only about 4.14 meV (which is much less than the energy of X-rays 0.12 to 120 keV),it therefore does not pose an ionization hazard as in X-ray radiation. The energy levels of THz light are very low, therefore damage to cells or tissue should be limited to generalized thermal effects, i.e. strong resonant absorption seems unlikely. However, the same high absorption coefficient that limits penetration in tissue also promotes extreme contrast between substances with lesser or higher degrees of water content which can help to show distinctive contrast in medical imaging.

Imaging Vs Spectroscopy

THz pulsed imaging

Early applications of THz technology were confined mostly to space science and molecular spectroscopy, but interest in biomedical applications has been increasing since the first introduction of THz pulsed imaging (TPI)in 1995 by Hu and Nuss. Their THz images of porcine tissue demonstrated a contrast between muscle and fats. This initial study promoted later research on the application of THz imaging to other biological samples. THz pulsed imaging actually can be viewed as an extension of the THz-TDS method. In addition to providing valuable spectral information, 2D images can be obtained with THz-TDS by spatial scanning of either the THz beam or the object itself.

In this way, geometrical images of the sample can be produced to reveal its inner structures. Thus, it is possible to obtain three-dimensional views of a layered structure. When a THz pulse is incident on such a target, a train of pulses will be reflected back from the various interfaces .For each individual pulse in the detected signal, the amplitude and timing are different and can be measured precisely. With advances in interactive publishing, Wallace *et al* highlighted the ability of 3-D THz imaging in a number of niche applications. For example they were able to resolve two layers of drugs beneath the protective coating of a pharmaceutical tablet.

THz spectroscopy

THz spectroscopy is typically done with a single point measurement (with transmission geometry in most cases)of a homogenous sample and the resulting THz electric field can be recorded as a function of time. This spectroscopic technique is primarily used to probe material properties and it is helpful to see where it lies in the electromagnetic spectrum in relation to atomic and molecular transitions.

THz spectroscopy is complementary to THz imaging and is primarily used to determine optical properties in the frequency domain.It is now possible to make time resolved far-infrared studies with sub-picosecond temporal resolution. Furthermore, another advantage of THz spectroscopy is that it is able to non-destructively detect differences because it uses radiation of sufficiently long wavelength and low energy that does not induce any phase changes or pho to chemical reactions to living organisms. Indeed THz spectroscopy can distinguish between two types of artificial RNA strands when measured in dehydrated form. Furthermore, Fischer *et al* demonstrated that even when the molecular structure differs only in the orientation of a single hydroxyl group with respect to the ring plane, a pronounced difference in the THz spectra is observed.

The dielectric spectrum has been widely used to describe the interaction between protein and its solvent molecule in THz frequency. A dielectric orientational relaxation time τ can then be defined as the time required for $1/e$ of the field-oriented water molecules to become randomly reoriented on removing the applied field. Measurements may be analyzed in terms of the complex dielectric constant $\varepsilon(\omega)$ (where ω denotes angular frequency) or the complex refractive index $n(\omega)$.

If dielectric measurements are made on protein solutions, then orientational relaxations of the protein molecule itself will also be observed. By investigating the concentration dependence of the spectra it is also possible to obtain an estimate of the hydration shell thickness around the protein molecules.

Skin cancer, breast tumors and dental caries

One potential application of THz imaging in diagnosis of skin cancer. Work by Woodward *et al* has demonstrated the potential to use THz imaging to determine regions of skin cancer non-invasively using a reflection geometry imaging system. Optical coherence tomography, ultrasound, near-IR, and Raman spectroscopy, MRI, positron emission tomography, *in situ* confocal microscopy, and X-ray techniques have all received much more attention and currently offer enhanced resolution, greater penetration, higher acquisition speeds, and specifically targeted contrast mechanisms. The sensitivity of THz signals to skin moisture, which is often a key indicator, is very high, and competing techniques such as high-resolution MRI are less convenient and more costly.

The high sensitivity of THz radiation to fluid composition and the variable conductivity in tissue is likely to lead to statistically significant differences between nominally identical samples taken at different locations in the body at different times or from different subjects. This may ultimately prove advantageous; however, in the short term, it will tend to mask sought for differences that are indicative of diseases[5].

Multiphoton Imaging

Infra red light of 850 nm has been used for multiphoton imaging of teeth. In conventional fluorescence imaging (QLF), a single blue photon is used to excite a fluorescent compound in the tooth. In the multiphoton technique two infrared photons (with half the energy of blue photon) are absorbed simultaneously. Caries will appear as a dark form with in a brightly fluorescing tooth. To highlight the diseased tissue, the image may be displayed in its negative form so that caries appear bright with in dark tooth[7]. MPM images were recorded using a custom-built multiphoton microscope based on a Zeiss Imager Z1upright microscope.1.3oil-immersion microscope objective (Zeiss). Images were created by scanning the sample using an x/yscanningpiezost age (P-542-2CD, Physik Instrumente). Two-photon fluorescence was epi-collected through the microscope objective. Fluorescence signal was discriminated from backscattered laser excitation and SHG signal using a short pass dichroicmirror (670 dcspxruv-3p, Chroma Technology Corp)and a combination of long pass, short pass and color glass filters (NT64-625, NT49-822 Edmund Optics and CG BG39 1.0 CVI Melles Griot respectively).This filters combination result in 475–700 nm bandpass for the fluorescence detection channel. Second harmonic signal was dia-collected through a large aperture oil immersion condenser and was discriminated from transmitted laser excitation an fluorescence signal using band pass (417–477 nm) and colored glass filters (NT48-074 Edmund Optics and CG BG39 2.0 CVI Melles Griot respectively).

Image analysis

SHG and 2PEF images were viewed using Image J(NIH, Bethesda, MD, USA, http://rsb.info.nih.gov/ij/).Lookup tables (LUT) were applied on 2PEF and SHG images, respectively the Green LUT and the16-colors LUT. Intensity profile plots perpendicular to the dentine-enamel junction were calculated with the same software. SHG image were overlaid on2PEF images using the co-localization finder plugin of Image[8].

Optical Coherance Tomography

OCT machinery used for caries detection

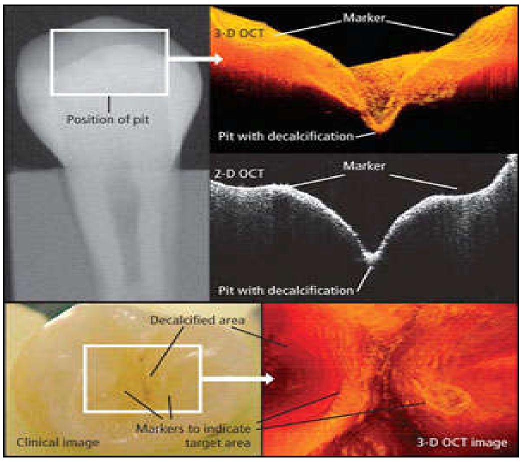
Optical coherence tomography (OCT)-which is similar in operation to ultrasound imaging, but uses light waves rather than sound waves-has been used in dentistry for decades[9]. OCT can be defined as optical inferometric technique to create cross-sectional images of scattering media. There are various functional techniques developed in OCT. They are

1. Polarisation sensitive Optical coherence tomography (PSOCT)
2. Doppler OCT
3. Wave length dependent OCT

OCT technology is an imaging modality that provides a tool for noninvasive evaluation of tissue microstructure by providing high spatial resolution (10–20 _m) and real-time, two dimensional depth visualization. The principle of OCT is similar to B-mode ultrasound imaging, except that OCT uses near infrared _NIR_ light instead of sound.

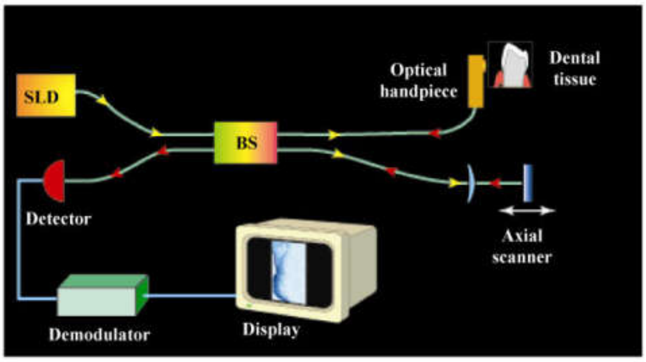
OCT uses low coherence interferometry to selectively remove the component of backscattered signal that has been multiply scattered, resulting in very high resolution images[10].

Following the modification of the system to produce polarization-sensitive OCT _PS-OCT_, the application of OCT in dentistry has widened covering *in vitro* images of dental caries. However, most reports refer to longitudinal OCT imaging only. This was especially useful for the *in vivo* application of the system. Using this system, they demonstrated the ability of OCT to quantitatively and qualitatively detect and monitor incipient enamel and root caries as early as 24 h in its development[11].



Diagramatic representation of a3D OCT imaging

OCT could possibly be used to quantitatively monitor the mineral changes in a caries lesion. Birefringence detected by PS-OCT, however, has been shown to be useful as a contrast agent indicating precarious or carious lesions in both enamel and dentin. Baumgartner *et al* showed that PS-OCT can provide additional information related to the mineralization status and/or the scattering properties of the dental materials.[12]



Pathway showing result accusation after OCT scanning

The studies demonstrated that PS-OCT is well suited for the imaging of interproximal and occlusal caries, early root caries, and for imaging decay under composite fillings. Longitudinal measurements of the reflected light intensity in the orthogonal polarization state from the area of simulated caries lesions linearly correlated with the square root of time of demineralization indicating that PS-OCT is well suited for monitoring changes in enamel mineralization over time.[13]

OCT provides high resolution morphological depth imaging of incipient caries. With OCT, early lesions can be readily identified as regions of high light backscattering with depth into the enamel as compared to healthy sound enamel. OCT is being combined with Polarized Raman Spectroscopy (PRS) since regions of high light backscattering not related to caries development can lead to false-positive results. PRS provides biochemical specificity along with molecular structural/ orientational information. In combination, OCT and PRS have potential for detecting and monitoring early lesions with high sensitivity and high specificity[7].

Donovan J. *et al* in 2013 conducted a study to assess whether Cone-Beam Computed Tomography is an essential diagnostic tool for endodontic practice the study proved that for now, cone beam computed tomography cannot be deemed an essential diagnostic tool for endodontic practice.

Midwest Caries I.D

The Midwest Caries I.D. detects differences of optical behavior inside the tooth related to change in the tooth structure and it is therefore not sensitive to bacterial content. The Midwest Caries I.D. can be used for approximal caries detection during the examination by slightly angling and moving the probe along the marginal ridge just over the vulnerable approximal area. This approach seems much more convenient than the DIAGNOdent® approach since it enables minimal dilution of the light signal from all surrounding structures which is the case for transillumination by sending and capturing the light signal in a direct line toward the vulnerable regions inside the enamel.

However, this device can give false positive signals in cases of teeth with growth malformations in the enamel or the dentin, teeth with thick, dark stains, hyper mineralization, hypo calcification, dental fluorosis, and atypically shaped teeth due to alteration in the translucency of enamel caused by these conditions If the probe is tipped at too much of an angle when checking for approximal caries, total surface light reflection can occur giving a false positive. Opaque artifacts (plaque, calculus, and organic plug) can cause false positives.[11]

Infrared Thermography

Thermal radiation energy travels in the form of waves. It is possible to measure changes in thermal energy when fluid is lost from a lesion by evaporation. The thermal energy emitted by sound tooth structure is compared with that emitted by carious tooth structure. The technique has been described by Kaneko *et al* (1999) and has been proposed as a method of determining lesion activity rather than a method of determining the presence or absence of a lesion.[15]

Although, a study described by Matsuyama *et al* (1998) found a reasonable correlation (0.67-0.79) between temperature changes and mineral loss and lesion depth, there is no evidence that the rate, or pattern, of fluid loss from a lesion is directly related to the subsequent reactivity of a lesion. It is not merely semantics, but paradigm shift, to consider dental caries as a 'complex disease caused by an imbalance in physiologic equilibrium between tooth mineral and biofilm fluid' [Fejerskov and Nyvad, 2003].

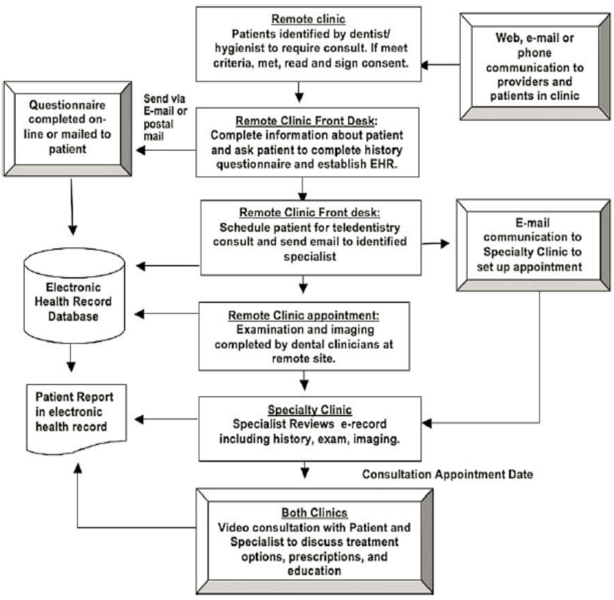
In concert with innumerable other factors (several of which we do not even know about yet), the oral and biofilm fluids will determine the likelihood for a net loss of mineral and the rate at which this occurs at any given site. A study was conducted by Stephen C. Berg *et al* which compared the effectiveness of detecting proximal carious lesions utilizing a new near-infrared transillumination (NIRTI) system (CariVu, Dexis) to traditional digital bitewing radiography (BWXR). Hence it was concluded that the the new NIRTI system (CariVu) may serve as an adjunct to BWXR in the diagnosis of proximal caries.[17]

Teledentistry

Teledentistry is an exciting new area of dentistry that uses electronic health records, telecommunications technology, digital imaging, and the Internet to link health care providers in rural or remote communities to enhance communication, the exchange of health information, and access to care for underserved patients.[16]

What is teledentistry and how does it work?

Teleconsultation can take on two forms. Real-time consultation uses direct on-line computer video telecommunication between a dentist, hygienist, or patient in a remote community and a dentist or specialist in a larger community who provides support or supervision. In the ''store and forward'' method, electronic health records and videos store data that can be retrieved and reviewed by the specialist who renders an opinion[19] .



Procedures followed in the recruiting patients in the dental office and obtaining consultation, illustrating the process for communicating between the remote site and the specialist clinic site.

Imara de Almeida *et al* in 2013, conducted a study to evaluate the Performance of Distant Diagnosis of Dental Caries by Teledentistry in Juvenile Offenders in Brazil. it was concluded that adolescent inmates could benefit from oral health screening using digital photography. Teledentistry appears to be a reliable alternative to the traditional oral examination for dental caries assessment.[2]

Yöntemleri DH. *et al* in 2018 presented a study, the aim of which was to give general information about recent caries detection methods and to mention their benefits when used in conjunction with conventional methods. They concluded that the caries detection tools aim the early detection of caries and prevent the progression of caries from demineralization to cavitation. None of the mentioned techniques alone are sufficient for diagnosis of dental caries. In the future, with the development of the diagnostic tools, small changes in the tooth structure will be detected and the dental structures will be protected by implementing preventive treatments.[18]

CONCLUSION

The two scientific revolutions (paradigm shifts) in cariology which are described in this paper necessitate a substantial rethinking of the design of future research projects in terms of data analysis and interpretation, and in advancement of new prevention and treatment strategies for dental caries. Kiberstis and Roberts [2002], stated that? of the greatest challenges facing biomedical researchers today is to sort out how these contributing factors interact in a way that translates into effective strategies for disease diagnosis, prevention and therapy.

Let us keep in mind that dental caries is ubiquitous in all populations [Fejerskov and Baelum, 1998], but the incidence rate varies greatly within and between populations. Diagnosis should be performed at non-cavitated stages because the dynamic nature of lesion progression allows for arrest of further mineral loss by restoring physiological equilibrium between tooth mineral and oral fluids. They just become ineffective because the caries incidence rate has changed as the environment has changed. At the individual patient level we have successfully 'controlled' the physiologic balance of the intra-oral environment with topical fluorides, dietary monitoring, plaque control', etc., but the well-trained clinician knows that some patients require much more and 'closer' monitoring than others to avoid new lesions. The consequence of the paradigms is to appreciate that the risk of developing new lesions is never zero. Therefore dental caries can never be 100% preventable at the individual and much less at the societal level because of its complex nature.

Dental caries is as old as mankind. Whatever directions caries research should take from here it will require a multidisciplinary approach to solving complex problems. History has shown that European caries research has an intellectual flexibility and scientific creativity which allows for ongoing stimulating debates. Let ORCA benefit from this by encouraging more in-depth scientific debates in conjunction with its meetings in the future. Let us bear Charles Darwin's dictum in mind: 'All observations must be for or against some view to be of any service'. Let the discussion in ORCA be fearless in conceptual daring, but humble in its respect for observation and facts.

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