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Quantification of dental caries: a review of recent advances in optical methods

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Abstract

Detection of incipient carious lesions forms the foundation for minimal intervention dentistry as it provides the opportunity for reversal and elimination of the process, or at the very least, for the postponement of surgical interventions. The devices used for detection of caries should ideally detect the caries as soon as the initial stage sets in, where the organic matrix is yet unaffected, as well as the more advanced and latest stages of demineralized lesion. Remineralization of carious lesions and intervention before the operative protocol can only be done with the help of a curative agent, and/or in combination with improved oral hygiene; but for these methods to be effective, caries detection must be done at an early stage. Determining the success of such prophylactic measures can only be done using methods that detect the mineral content changes over time which is quantifiable in caries lesion. Since time immemorial, various methods have been developed, and newer methods keep emerging from time to time. This review article summarizes a number of caries detection devices, each with its own expertise in a particular area of interest.

Keywords: Caries; OCT, Children, Laser Fluorescence

Introduction

Dental caries is one of the most prevailing, widespread, and persistent diseases. Treatment for this has changed drastically in recent years, with present management involving wide varieties of procedures such as partial removal of carious lesions, and other non-invasive techniques[1]. If detection of incipient caries is done at an early stage, mineral loss can be reversed using a therapeutic agent, improved oral hygiene, or a combination of both. Determining the success of such prophylactic measures can only be done using methods that detect mineral content changes over time, which is quantifiable in caries lesion[2]. Wreckage repair of dental decay is costly in terms of oral health, time, and resources[3]. Early detection enables the dentist to improve the reversal of demineralization, and in addition, allows for a conservative approach instead of the rehabilitation of dentition by using effective preventive measures[5]. The significance of speedy detection and precautionary interruption before the commencement of irreversible damage is now generally accepted. Adequate methods which allow for incipient caries quantification will be instrumental for the entire society, oral health care schemes, and epidemiological trials[5].

In clinical practice, caries can be recognized by visuo-tactile examination. However, the clinical detection of caries which are present at difficult regions to visualize, for example proximal lesions ("hidden caries"), needs further support of bitewing radiographs. Even so, by the time the radiographic diagnosis becomes evident, the caries have already infiltrated layers of dentin. The detection of the originating events of demineralization remains a taxing task in dentistry[6]. Overall, decline in the prevalence of caries, and improved perception of the basic pathophysiology of the demineralization process have led to a change in the remedial approach[7].

For numerous years, radiography has been the mainstay for detection of caries and restorative decision making[4]. It is the most frequently employed inspection method with a 50 µm resolution, which is lower in comparison to that of OCT. The initial detection of dental caries is often difficult using these methods. Quantitative caries analysis can also be done by micro radiography, but clinical application is difficult. Other traditional methods such as dental explorer, visual inspection, and infrared (IR) imaging are not able to procure enhanced and accurate cross-sectional images[9]. Apart from exposing patients to ionizing rays, radiographic methods are not highly sensitive nor quantitative enough for detecting incipient lesions[4]. Due to ionizing exposure, radiography is not recommendable for monitoring the short-term advancement of lesions. Alternative strategies using non-radiative sources such as optical coherence tomography (OCT), fluorescence-based methods, and near-infrared (NIR) imaging for early caries detection, have been explored in several studies[6]. Non-destructive techniques for quantifying progression/regression of carious enamel lesions can be very handy in doing research on caries because they provide possibilities for detecting changes over time, after application of preventive efforts. Prompt identification and quantification of lesions provide various benefits which include opportunities for shortening the time of research trials[5]. Several research groups have used a method involving histologic analysis called Transversal Micro Radiography (TMR). It determines the loss of minerals, and the depth of caries. However, as it requires a sectioning procedure which is very thin, its dental applications have been meagre. In addition, detection of decay is possible only at a comparatively advanced stage when reversal is no longer an option. Furthermore, the incompetence of acquiring exact quantifiable measurements makes it difficult to stop the advancement of carious lesions[10].

The various **optical methods of quantifying and diagnosing enamel caries** are**:**

1. DIFOTI (Digital fibre optic transillumination)
2. Optical Coherence Tomography (OCT)

3. Polarization Sensitive Optical Coherence tomography
4. Laser Fluorescence (LF)
5. Quantitative Light Induced Fluorescence (QLF)
6. Infrared Fluorescence (IR Fluorescence)
7. Raman Spectroscopy (RS) / Polarized Raman Spectroscopy
8. Hyper-spectral Imaging
9. DIAGNODENT
10. Swept Source Optical Coherence Tomography (SS-OCT) 3D
11. Optical Frequency Domain Imaging Model
12. Transillumination with Near Infrared Light (TI – NIR)
13. Near Infrared Reflectance Imaging (NIR Reflectance Imaging)
14. Terahertz Pulse Imaging
15. Multiphoton Imaging
16. Time – Correlated Single Photon Counting Fluorescence Lifetime Imaging
17. Multispectral Near Infrared reflectance
18. Reflectance Confocal Microscopy
19. Fluorescence enamel imaging technique (Professional Caries Detection System PCDS)
20. Fluorescence Imaging With Reflectance Enhancement (FIRE)

Digital Imaging Fiber Optic Transillumination (DIFOTI)

DIFOTI is the modified version of its forerunner, Fiber Optic Transillumination (FOTI), both being based on the same principle requiring teeth to be transilluminated with intense fiber optic light. A carious lesion differs in comparison to adjacent healthy tooth structures in its optical properties, and these methods amplify great differences in absorption as well as scattering of photons. DIFOTI was invented to prevail over drawbacks offered by FOTI: it has the ability to yield digital images which can be captured, stored, and compared with previous ones. **A.A´ stvaldsdo´ ttir et al**. **(2012)** demonstrates the clinical applicability and diagnostic accuracy of DIFOTI in comparison to film and digital radiographic methods in detecting proximal lesions. Significantly higher sensitivity and diagnostic accuracy at D1 threshold (enamel & dentin caries) was shown by DIFOTI. At diagnostic threshold D3 (dentin caries), it showed lower specificity. Thus, its diagnostic precision in identification of incipient proximal caries in enamel can be claimed as superior compared to film & digital radiography at D1 diagnostic threshold (enamel & dentin caries)[7].

Optical Coherence tomography (OCT)

OCT allows us to obtain tissue sections in a noncontact/noninvasive manner. It measures the delay in time and light intensity which is scattered/reflected back from tissues – all of these allow their internal architecture to be viewed via tomographic imaging. The resolution of tissue scanning ranges from 1-15 µm; enabling real time tissue imaging in its original place eliminated any histological procedures, or x-ray imaging. Clinical applications involve evaluation and observation of advancement by incipient lesions on occlusal surfaces (non-cavitated), even those beneath preventive sealants. **Jennifer S. Holtzman et al. (2014)** stated that the OCT based assessments for caries severity of sealed teeth showed high sensitivity, specificity, and excellent predictive values (positive and negative)[8]. **Cynthia Soares de Azevedo et al. (2011)** showed that OCT was an effective technique which was not invasive, and can be used to determine lesional extent due to mineral loss[1]. **Ruchire Eranga Wijesinghe et al.(2016)** used a 1.3 µm spectral domain OCT system (SD-OCT) to study cross sections of images from an ex vivo tooth, and obtained some threshold parameters which were efficient for the initial detection of demineralization[9].

Laser Fluorescence (LF)

The property of absorbing lower wavelength radiation {ultraviolet (1-401 nm)}, and emitting higher wavelengths {visible light (430-451nm)} by any medium is called fluorescence. Decayed tissues fluoresce more compared to sound tissues when stimulated by infrared irradiation or red laser. This results from a combination of demineralization processes and bacterial byproducts present in decayed tissue[18]. Fluorescence variation between healthy and diseased structures is the core entity which led to the emergence of instruments that were able to quantify such differences. Fluorescence based techniques are divided into two parts: one using a visible spectrum (e.g. QLF), and the other using laser rays (e.g. Diagnodent). **Maria Rosa et al.** (2016) conducted a systematic review and meta-analysis for verification of the precision of LF for diagnosing decay, and found that in vitro, it has the ability to detect decay on occlusal aspects of permanent dentition, and enamel & dentin decay[12].

Quantitative Light-Induced Fluorescence (QLF)

It estimates the fluorescent percent change of decayed in comparison to adjacent healthy enamel, and relates directly to the net loss of minerals. **Amaechi, Bennett T et al. (2002)** monitored the development and remineralization of caries-like lesions, and showed that the fluorescent percent change (delta-Q) increases in line with the time taken for mineral loss, and decreases when the time taken for mineral gain increases. A bleaching agent was used to whiten stained teeth, after which, the intensity change in stains (delta-E) was measured. Based on results, the intensity of stains decreased in line as the tooth started regaining its natural hue and color. Thus, it can be said that QLF can detect, diagnose, and observe the advancement or reversal of early decay. However, detection of lesions is restricted by the existing salivary plaque or can even be amplified due to stains. Also, the shade variation of the teeth which were discolored – brought about by bleaching agents – can be quantified[3]. **Ana Marly Araújo Maia et al. 2016** compared through fluorescence loss (by QLF), and the changes of attenuation in light coefficient (by OCT). Based on the image results obtained by light attenuation, improved alterations in the optical properties of a tooth greater than fluorescence was measured through QLF[11].

Infrared Fluorescence (IR Fluorescence)

A wavelength of 650–950 nanometer range constitutes Near-Infrared Fluorescence (NIR), and is usually favoured as useful in fluorescence imaging in-vivo because it is superior to visible range. A greater penetration of tissues is accomplished because of the reduced absorption by hemoglobin/water, and less autofluorescence from the surrounding tissues (low background). These properties, along with good signal-to-background ratio, make it a desirable feature for in-vivo imaging. **Marinova-Takorova et al. (2016)** evaluated the efficacy of near-infrared transillumination in diagnosis for both occlusal and proximal incipient lesions via. visual, radiographic, and near-infrared transillumination. The study also suggested that it is an effective method for the diagnosis of lesions limited to enamel, including those extending to dentin. It could eventually eliminate the use of bitewing radiographs – especially in pregnant women and children – due to the absence of radiation, and its efficiency as a diagnostic tool[20].

Diagnodent

It is a diagnostic device with a probe capable of emitting a light which can be directed onto the mineralized surface under examination. Surfaces with structural differences will fluoresce, and are then captured back, with the device exhibiting a value which ranges from 0 to 99[17]. **Hanieh Nokhbatolfoghahaie et al. (2013)** provided a review of the DIAGNODENT efficiency in comparison to visual and radiographic techniques in diagnosing the occlusal surfaces of teeth, and evaluated its accuracy in the detection of primary and secondary caries. Although DIAGNODENT was considered an important device for diagnosing demineralization, concerns remained regarding its efficacy and accuracy. He concluded that DIAGNODENT was an effective treatment modality for the detection of caries as a complementary method besides other methods. Its primary use in the treatment plan was simply not enough.

Raman Spectroscopy (RS)

The spectroscopic method is based on optical light scattering by matter that is inelastic in nature (called Raman scattering—RS). A molecular vibration which changes the molecular polarizability that interacts with incident light, forms the basis for RS. Thus, vibrational technique, and Raman spectra provide specific molecular fingerprint data[21]. **R. Ramakrishnaiah et al. (2015)** reviewed the use of RS in predicting the early activity of the carious process. He described its use for tooth structure analysis, as well as its comparison with synthetic apatites for dental use. Spectral peaks provided important inputs in interpreting the chemical/structural properties of enamel/dentin. Both consisted of two primary components: an inorganic phase, and a mineral phase which are similar to hydroxyapatite. The Dentinal Raman Spectrum confirmed the existence of minerals based on crystalline phosphate. These spectroscopic techniques are based on a vibrational phenomenon; for example, Raman and Fourier Transform Infrared (FTIR) spectroscopy for biological tissue analysis are surfacing as alternatives to long-established diagnostic methods. These are complementary to each other. In FTIR, a change in the molecular diploe moment is assessed; in RS, a change in molecular polarization is observed. Of late, RS is being employed for biomedical application, including dental and oral health. Its use has also been increasing significantly due to progress in the instrument, and advancement of fiber optical probes. Its applications have been expanding in structural chemistry, biomaterials, and surface analysis. Furthermore, RS was found to have multiple applications in dentistry[13].

Polarized Raman Spectroscopy (PRS)

It can be used to determine the crystallographic architecture of isotropic two dimensional materials within plane strain, or of anisotropic two dimensional materials. **Ko et al. (2004)** demonstrated recognition of incipient lesions using PRS in which healthy enamel appeared strong, while incipient lesions typically demonstrated a weakened degree of Raman polarization anisotropy. The raman peak, especially that of sound enamel which arises from the symmetric ν1 vibration of PO4 3- at 959 cm^{-1}, showed strong polarization. Carious surfaces, however, demonstrated weak dependence of polarization under the same conditions. This allowed for differential between incipient caries and healthy enamel.[14]

Hyper-Spectral Imaging (HSI)

This technique scrutinizes a wider spectra of light rather than just allocating primary colors (blue, red, green) to individual pixels. The light which strikes individual pixels is further fragmented into various bands of spectra to procure more data. The image processing methodologies, and the algorithms with HSI are upshots of military research which were used in target identification, and other objects amidst background clutter[22]. **Christian Zakian et al.(2009)** compared the use of Near-Infrared (NIR) and visible light imaging, and concluded that NIR is preferable for the detection of caries as it exhibited lower absorption upon contact with stains, and a deeper penetration into teeth. Reflectance spectra analysis shows that dissipation of light by permeable enamel, and adsorption by water present in dentin, are useful for the quantification of lesional severity by obtaining an NIR score for caries. This technique offers several advantages like mapping lesion distribution instead of pin point estimates; it is insensitive to stains, not invasive, and not contacting. All findings suggest spectral imaging to be an effective technique for diagnosing caries quantitatively, clinically. It can also detect the presence of occlusal enamel/dentin lesions[15].

Conclusion

The effectiveness of Optical Methods for Diagnosis of carious lesions show potential significance in clinical practice, but should be reinforced with good clinical judgement that minimizes the subjective effects of diagnosis. These methods obtain images which can be digitally stored, and viewed later. Thus, it can be ascertained that quantitative assessment of dental caries is slowly forming the basis for evidence based dentistry in the near future.

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