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Recent Advances in Diagnostic Techniques for Dental Caries in Dentistry

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Abstract
Tooth decay is one of the most common health problems that many people suffer from around the world. Therefore, the process of diagnosing tooth decay must be completed in the early stages to stop the decay process and maintain the aesthetic and functional aspects of the teeth. Many techniques and methods have been developed to detect tooth decay lesions that traditional methods fail to detect early. This review will provide an overview of the most important modern methods and techniques used in detecting tooth decay. Finally, modern methods such as laser fluorescence, quantum light-induced fluorescence (QLF) and Ultrasound Caries Detector help in the early detection of tooth decay lesions.
Keywords: dentistry, caries detection, X-rays, DiFOTI, QLF, ECM, EIS, Laser Fluorescence, Electronic Conductance Measurements.

Introduction:

Dental caries is one of the most important health problems faced by many people worldwide. Dental caries is known to be a complex multifactorial disease that arises due to the formation of bioacids in the mouth and exposure to fermentable carbohydrates leading to demineralization of dental hard tissues such as enamel, dentin and cementum [1].

Bacterial biofilms (plaque), fermentable carbohydrates, hard dental tissues, and time are among the most important factors that contribute to dental caries [2]. In addition, personal and oral environmental factors influence disease. Owing to the tremendous medical advancements in our present era, especially in the field of dentistry, the rates of dental caries have gradually started declining due to the use of fluoride, oral health awareness and newer techniques for early diagnosis [2,3]. Overall, the modern methods used in caries diagnosis are effectively contributing to identifying patients with higher or lower risk of caries, and getting better, cost-effective and reliable treatment [4,5].

In general, diagnosis is referred to as the art of recognizing a disease through symptoms. Thus, caries diagnosis is the science of integrating the information obtained from clinical dental examination, diagnostic tools and direct communication with the patient [4,6]. The main objective of using dental caries diagnostic methods is to detect and classify the lesions and determine the causes, which contributes to effective medical intervention for treatment and achieving comfort for the patient [7].

Routine dental examinations of patients at risk of caries are required, as well as visual inspection of the risk of dental caries. Radiography is preferred to increase the accuracy and effectiveness of treatment, and microbiological examinations to check for lactobacilli and streptococci mutations [7,8]. For modern dental examinations against cavities, the electrocardiogram has also emerged as a valuable treatment in practice. The heterogeneous results of caries risk management indicate differences with misinterpretation of the risk of clinical values of caries management [9,10].

This review aims to identify the latest methods used in diagnosing dental caries, and thus develop effective treatment and preventive plans for managing dental caries.

Diagnosis and detection of dental caries:

There are many methods used to detect tooth decay, but they all aim to stop the decay process and develop treatment plans that aim to restore the tooth in terms of aesthetics and function. In general, traditional diagnostic methods fail in some cases to detect tooth decay, such as visual examination and the use of the explorer tip or what is known as tactile sensation. Therefore, it is necessary to develop specialized and advanced systems to detect tooth decay, especially with the information revolution that dentistry is witnessing and the development of many methods and materials used in dentistry [11]. Studies indicate that there are gaps and discrepancies in the diagnosis of dental caries. These discrepancies are attributed to the differences in methods of diagnosing dental caries among dentists and the lack of sensitive and specific methods for detecting and measuring caries lesions [9,12]. Modern methods of detecting dental caries avoid over- or under-treatment, and the placement of unnecessary restorations. In general, the process of diagnosing dental caries affects the oral health status of patients and the cost of care in the short and long term [7].

Radiographic or X-rays Diagnosis

In the world of modern dentistry, X-rays have become an integral part of the diagnosis and treatment process. This technology allows doctors to see what the naked eye cannot see, which contributes to providing better and more accurate health care for patients [13]. Traditional methods rely on visual examination to evaluate the surface of the teeth and detect caries, but they are not sufficient for accurate detection and evaluation of the condition. In contrast, X-rays provide accurate information about the clinical condition of tooth decay. The mechanism of X-ray work depends on the characteristics of hard tissues and bones in the teeth that appear opaque due to their calcified structure that does not allow X-rays to pass through them, unlike soft tissues that are not calcified like bones or teeth and will allow X-rays to penetrate them, making the structure appear transparent to X-rays. This contributes to the diagnosis of caries and gum disease by seeing the bones surrounding the teeth, thus determining the extent of the disease and taking the necessary measures for treatment [14,15].

Carious lesions appear on radiographs as low-density areas indicating demineralization of hard tissues. Proximal caries begins at the point of contact and spread along the dentin-enamel junction, while occlusal caries appears as radiolucent spots in pits and fissures. Root and cementum caries appear as radiolucent areas above the bone height and below the cementum-enamel junction. Recurrent caries, occurring near fillings, also appear as low-density areas of demineralization, necessitating careful differentiation from lining materials [7].

Common radiographic techniques for detecting caries include posterior bite-wing, periapical, and panoramic images. Bite-wing images are the preferred method for identifying proximal caries, while periapical images help detect caries in anterior teeth and periodontal problems [16]. Panoramic images provide a broad overview but lack the detail for early detection of caries. It is important to note that radiography alone cannot differentiate between cavitated and non-cavitated lesions or active and inactive caries [15].

Visible Light - Enhanced Visual Techniques

This technique relies on improving vision through the phenomenon of light scattering. It is usually done through three techniques [17]:

- Fiber Optic Illumination (FOTI)
- Quantum Light-Induced Fluorescence (QLF)
- Fiber Optic Illumination for Digital Imaging (DiFOTI)

Fiber Optic Illumination FOTI is expected to be at least as effective as visual inspection. It is expected that FOTI will improve the discrimination of occlusal lesions (especially dentin lesions), as well as better detect proximal lesions (in the absence of X-rays). As a technique, FOTI is an obvious choice for translation into general practice; the equipment is economical, the learning curve is short, and the procedure does not take long. In fact, some work has been done to trial the use of FOTI in practice with encouraging results. However, the simplicity of

the FOTI system comes with limitations; the system is subjective rather than objective, there is no continuous data output, and it is not possible to record what is seen in the form of an image. Therefore, longitudinal monitoring is a complex issue. To address some of these concerns, an imaging version of FOTI has been developed – DiFOTI [18].

Modern caries diagnostic techniques rely on various light sources, such as high-intensity light, which faces several challenges including light reflection on the tooth surface, shadows of the underlying dentin, and refraction of the saliva layer. Fiber optic illumination is an effective technique for diagnosing proximal caries, as light photons can cause enamel rupture and break optical connections, by penetrating densely packed hydroxyapatite crystals. In addition, the fluorescence phenomenon, which involves exciting the body with a specific wavelength of light and emitting fluorescent light with a longer wavelength, is one of the innovative methods in this field. Quantitative Light-induced Fluorescence (QLF) is increasingly used to detect a range of lesions and is considered one of the most promising techniques in caries diagnosis, as it has shown a close correlation with changes in mineral content. Studies have also shown that enhanced white light provides high clinical efficacy in the early detection of caries lesions [19].

Detection systems based on electrical current measurement

Each material has its own electrical signature; that is, when a current is passed through the material, the properties of the material dictate the degree to which that current is conducted. The state in which the material is stored or physical changes in the structure of the material will affect this conductivity. Dental caries results in increased porosity of tissues, whether enamel or dentin. This increased porosity results in a higher fluid content than healthy tissue, and this difference can be detected electrically by a decrease in electrical resistance or impedance [20].

Detection systems based on measuring electric current are divided into:

1. **Electronic Caries Monitor (ECM):** A device uses a constant frequency alternating current to measure the “total resistance” of tooth tissue. The system typically includes a “probe” through which the current is passed, a “substrate” which is usually the tooth, and a “reverse electrode” which is often a metal strip held by the patient. The probe is applied directly to the target site, such as a fissure, to measure the electrical resistance. During the five-second measurement cycle, compressed air is expelled from the tip of the probe, providing information useful for characterizing the lesions. The increased porosity associated with tooth decay is thought to be responsible for the mechanism of action of the ECM device. However, physical factors such as tooth temperature, tissue thickness, hydration of the material, and surface area also affect the device’s results [21]. Clinical trials have shown that ECM may be particularly suitable for the diagnosis of root caries. A study of the effects of a toothpaste containing 5,000 ppm fluoride versus 1,100 ppm fluoride on patients with root caries showed that the group using the high-concentration fluoride toothpaste showed better remineralization. These results suggest that ECM could be an effective tool for long-term caries monitoring, and that it may help clinicians monitor remineralization attempts and potentially halt the progression of root caries in patients [22,23].
2. **Electrical Impedance Spectroscopy (EIS):** Unlike ECM, which uses a fixed frequency (23 Hz), EIS scans a range of electrical frequencies, providing information on capacitance and resistance. This process allows for a more detailed analysis of tooth structure, including detection of the presence and extent of caries. A simplified commercial system known as Carie Scan has been developed and is currently available on the market. This technology enhances the ability of clinicians to accurately assess the condition of teeth, contributing to improved diagnostic and treatment strategies for dental caries [21].

Ultrasound Caries Detector

Ultrasound caries detection (UCD) was first proposed over 30 years ago, but development of the method has been slow. The basic idea of the technique is to collect tissue images using reflected sound waves. The waves pass through gases, liquids and solids, allowing images of

tissue to be created by collecting the reflected waves. To reach the teeth, the sound waves must first pass through a binding mechanism, and several materials have been proposed for this purpose, such as water and glycerol. Studies have shown that ultrasound technology is able to differentiate between caustic and non-caustic caries lesions in the interdental areas (proximal lesions) [24]. ultrasound measurements at 70 proximal sites in the laboratory showed a sensitivity of 1.0 and a specificity of 0.92 compared to the histological gold standard. A study in the clinics also showed that UCD outperformed X-rays in diagnosing caries at 253 proximal sites. Despite these promising results, research in this area is ongoing, and UCD has been shown to reduce patients' exposure to ionizing radiation and improve the accuracy of caries detection [25]. However, the ultimate responsibility for diagnosing the presence, progression, and activity of caries remains with the dentist, and these technologies enhance the diagnostic skills of dentists, not replace them.

Laser fluorescence

DIAGNOdent (DD) uses ultrasound to detect caries by measuring fluorescence with a 655nm laser. This technology is based on detecting fluorescence produced by teeth, with the device displaying numerical values rather than producing an image of the tooth. DD has the advantage of being able to detect non-caustic caries in fissures and smooth surfaces, improving diagnostic accuracy in the early stages. Studies show that DD can differentiate between caries lesions that are not visible clinically or radiographically and have shown better accuracy in detecting approximate lesions than conventional X-rays [26].

Despite its effectiveness, DD requires teeth to be clean and dry, as the presence of stains, tartar or plaque has been shown to negatively impact readings. studies have also shown that DD performs well in detecting dentin caries, but there is considerable variability in results due to the different designs of the studies [27]. Although recent studies suggest that fluorescence-based devices do not significantly improve early detection, these tools can be used as adjuncts to the International Caries Detection and Assessment System (ICDAS) [28]. The primary role in caries diagnosis remains with the dentist, and these devices are used to enhance diagnostic skills rather than replace them.

Conclusion:

Dentistry is witnessing modern techniques and methods for detecting dental caries, as the methods discussed in this review are considered part of the process of diagnosing dental caries and detecting and evaluating caries lesions. Despite the importance of these methods, visual examination is still a basic method for detecting caries and should be followed with all patients initially, in addition to using modern methods and techniques that provide accurate clinical information about the status of dental caries and other matters related to oral and dental health. In addition, the International Caries Detection and Assessment Standards (ICDAS) should be used, which work to increase the accuracy and reliability of these modern techniques and methods for detecting dental caries.

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