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Review Article

A Complete Review on Dental Carious Lesion Detection Methods and its Challenges

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Abstract

Dental caries is a common bacterial oral disease of teeth. Our mouth gets unhygienic due to the presence of carbohydrates, acid and bacteria. These destroy the enamel, dentine layer of the tooth. Streptococcus mutants are responsible for dental caries. As per World Health Organization report worldwide, 60–90% of school children and almost 100% of adults have dental caries. Dental caries and periodontal disease for long days without treatment causes tooth losses. Near future it will be an epidemic. It is a chronic disease that can affect us at any period of age. Recent research has indicated that there are possible links between oral infections and diabetes, heart, lung disease, stroke, and premature births. Hence early detection of dental caries in enamel would be very essential. Dentists generally use radiographs to detect dental caries. Frequently taken x-ray is harmful to human body. Unfortunately there is not a single method to detect caries in its early stage. Therefore, the purpose of this review paper is to identify the existing caries detection methods and find out its loopholes.

Keywords: Dental Caries; Teeth; X-Ray

Introduction

Dental caries is most common oral infectious disease. It is painful and caused by Streptococcus mutants, acid and carbohydrates [1]. If dental caries remain untreated then it affects the root of the teeth and finally uprooted the teeth. Hence, if caries detected at its early stage then surgical interventions could be avoided. World Health organization (WHO) report reveals that 98% adult people and (60-90)% [2] of school children are suffering from dental caries. It is an infectious and chronic disease that can affect us at any age. Near future it will be an epidemic. Hence early caries detection is very essential. The reason behind dental caries is unhealthy oral condition and negligence of teeth caring like brushing at least twice in a day, wash full mouth after smoking etc. There are some general symptoms of dental caries like tooth pain, sensitivity due to hot and cold, bleeding from gums, pain during chewing the food etc [3,4]. Multiple factors are responsible to increase the growth rate of dental caries. These are teeth condition, saliva, plaque, time and food habits. Dental caries are mainly two types;

- **Enamel caries:** This type of caries firstly affect the enamel layer and if it remains untreated then it spread into dentine layer and touches root of the teeth. Figure 1(a) shows enamel caries. Figure 2(a-d) shows different types of dental caries at its different stages.
- **Inter-proximal Caries:** Here dental caries occur intermediate position of two teeth. Figure 1(b) shows interproximal caries.

Figure 1: Shows Different types of dental caries.

Figure 2: Types of Caries: (a) Occlusal Caries, (b) Interproximal Caries, (c) Enamel Caries, (d) Root Caries.

Figure 3 shows the worldwide caries affected rate at the middle age. This graph is prepared according to the WHO report [2]. According to this report, 11% of the total populations are highly effected (that means the risk factors) in dental caries, 12% people of the total population are suffering moderately that means they have pain, they were going through the filling. 9% people of the total population have caries at its early stages, other 7% people have very low risk dental caries and remaining 61% data are not found.

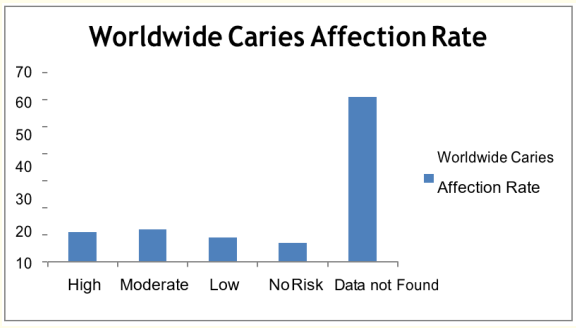

Figure 3: Worldwide Dental Caries Severity Regions.

The major risk behind dental caries is that, it increases the probability of some chronic disease like pneumonia, birth of premature babies, complications in diabetes etc [5]. Early caries detection and diagnosis not only reduces the risk factors of dental caries but also reduces the time of patients and doctor along with treatment cost. Dental caries detection methods are broadly categorized into four methods. These are instrument based, radiography, software techniques and image processing techniques. In the "point method", light absorption and secondary emission technique is used to determine the mineral concentration in the tooth. This mineral concentration is different for caries and healthy teeth region. This method is suitable for early caries lesion detection. "Based on visible property of light" is a kind of imaging technique that determines the caries lesion according to the visible light scattered or absorption quantity. It is capable to distinguish different phase of dental caries evolution. "Radiographs" is also used an imaging technique to detect caries lesion. In this technique, very high frequency light is used for imaging. "Software tools" are kind of hybrid approach which include sound data, visual change data, localized enamel breakdown change data etc to decide the caries lesion. It is a kind of automation of the techniques that are used by the experienced dentists to detect the caries lesion. Instrument based method is quite expensive where as software based techniques is not fully reliable. Till date dentists uses radiograph to detect not only the affected caries lesion but also other oral disease.

Short Description of Different Caries Detection Methods in Short [6-20]

There are many caries detection methods exists that are used by dentists. These are

1. Point methods like diagnodent, ECM
2. Based on light peoperty method like FOTI, DiFOTI
3. Radiographs
4. Light emitting devices like QLF, LED etc
5. Software based methods like Logicon
6. Image processing based methods.

Point methods

Point detection method is very complex. Here measurements are taken at different time period during investigation. This method is of two types. These are Diagnodent and Electronic Caries

Monitor (ECM). DIAGNOdent device utilizes LASER Fluorescence Measurement method with a 655 nm diode laser. This laser is capable of detecting occlusal pit-and-fissure caries, non-cavitated and smooth surface caries at the earliest stage. DIAGNOdent has high sensitivity and low specificity for permanent teeth. That means that the tool is suitable for caries detection however it should have low specificity that is higher rate of false positive. On the other hand, electronic caries monitoring method consists of probes and substrates. Probes means from which the current will flow and substrate means contra electrode region. Here measurements are taken either from enamel or exposed dentine surfaces. In this method, the result comes as a number between 1 and 13; higher numbers refers to deeper lesion. ECM method monitors the suspected carious lesion due to its electrical resistance behaviour. It also computes the bulk resistance of tooth tissue. Sound enamel is a poor conductor of electricity and its pore size is not large [6-8].

Based on light property method

This method is performing on the basic principle of light spreading. It is categorized into two subcategories. FOTI and DIFOTI. It uses 780 nm wavelength near infrared radiation instead of white light source. FOTI is a useful technique for diagnosing proximal caries. In this technique, decay of enamel can identify by penetrating photons of light through densely packed hydroxyl-apatite crystals. Red and green colour is used for a object to excite by particular wavelength of light and fluorescent light is of a larger wavelength. On the other hand, DIFOTI utilizes many light sources, high intensity along with visible lights. These have many limitations like reflection of light over the tooth surface, refraction due to presence of saliva and shade of dentine layer [9-11].

Radiographs

Radiographs are the most used and popular caries detection method. Dental practitioners use radiographs to identify mature caries and advanced caries. Radiographic caries detection is mostly accurate for cavitated proximal lesions. It is suitable to detect dentin caries lesions. In detecting initial lesions more sensitive methods radiographs produces high caries risk and prevalence. However, be careful while taking dental radiographs. Because digital radiographs need radiographic dose that may harmful to our body. One advantage is that these radiographic images are that it is easily stored for monitoring purpose [12-14].

Light emitting devices

Quantitative light-induced fluorescence (QLF) is a new method for oral health assessment. QLF also provides the additional visual information about caries and bacterial activities in it. QLF uses the principle of fluorescence for visual enhancement of caries detection and bacterial activity. This method depends on contrast differences between sound and demineralized dentin by fluorescence. The basic principle of QLF is similar with the principles of fluorescence that are used to visually contrast sound, affected enamel layer and affected dentin layer. The observed natural fluorescence of a tooth is decreased due to increased scattering when a carious lesion is present. QLF is an ideal tool for more sensitive advanced stage of caries [15,16].

Software based methods

The International Caries Detection and Assessment System (ICDAS) is a clinical scoring system. It was developed for clinical research, clinical practice and to solve the epidemiological aims. This method allows to detect and assessment of caries activity. There were inconsistencies among the research criteria for caries measuring systems. It is required a uniform system that allows comparison of collected data from different researches. The ICDAS detection codes for caries range from 0 to 6 depending on the severity of the lesion. Table 1 shows the details [17,18].

Code	Description
0	Sound
1	First Visual Change in Enamel
2	Distinct Visual Change in Enamel
3	Localized Enamel Breakdown
4	Underlying Dark Shadow from Dentin
5	Distinct Cavity with Visible Dentin
6	Extensive Distinct Cavity with Visible Dentin

Table 1: Code meaning are given as follows.

Image processing based methods

Many researchers contributed their valuable insights in the fields of dental caries detection using image processing techniques. The researchers have worked upon different types of images like RGB, gray scale etc. Here we focused on the methods that worked upon RGB images and gray scale images i.e. the radiography methods.a

RGB based methods

In this method images are taken from intra oral camera. For early detection and accurate representation of dental conditions, an intraoral camera is essential to delivering optimum quality of care. This camera is light weight and fully manual. It can only detect the enamel caries. This method fails to detect inter-proximal or complex caries lesions. Koutsouri., *et al.* [19] proposed a method to detect occusal caries lesion from colour images. This method contains three steps. The steps are a) detection of decalcification area, b) ROI segmentation and c) fusion of the result. Olsen., *et al.* [20] reported a method used for research purpose; the students of dentistry department. Here Directed Active Shape Model (DASM) algorithm is used to find the accurate boundary of the lesion. This research also includes the design and testing of a posture-monitoring component for a portable educational system. Maintaining proper position is critical for dental practitioners, because poor position can affect not only the dental practitioner's health, but also the quality of the practitioner's work. The algorithms and techniques designed for use in the dental education support system could also be applied in the design of computer-aided educational systems for the development of procedural skills in many other fields, and in the design of systems to support practicing dentists. Datta., *et al* [21] proposed a method that able to find out teeth wise exact carious lesion size. At the early stage of caries, the enamel colour is being started to changed, this method also capable to identify whether a teeth is affected in caries. Proposed method also finds the teeth wise carious lesions features like, volume, height, width, aspect ratio. They used guided filter, colour based segmentation techniques, morphological operations along with tangent curvature properties.

Techniques based on X-ray gray scale images

Most of the diagnosis is made with the dental radiographs and they are efficient in exhibiting the dental caries that takes place between the teeth. Further the hidden caries are complex to estimate, because they are invisible at the surface. These hidden caries are due to the bacterial action that penetrates the enamel in order to reach the inner surface of the teeth. This type of hidden caries is not detected using x-ray image. However inter-proximal caries are easily detected using x-ray images. Rad., *et al.* [22] formulated a novel segmentation technique based on level set. Here the main algorithm works on two phases. In the first phase, the initial contour is generated using morphological operation and in the second phase, back propagation neural network is used to segment the teeth region. The outcomes procedure is much accurate than the other method. The integral projection technique was employed with an intention of isolating the caries tooth from the other good tooth. Problem is that it can't handle the noisy teeth x-ray image. If any artifacts present during taking of x-ray then it is treated as a part of that teeth. Choi., *et al.* [23] formulated automatic detection of caries lesion in its early stage. In the proposed method, four modules are used to do specific tasks. These are

- Horizontal alignment of teeth
- Probability map generation
- Crown extraction if any and
- Refinement

Authors first align the pictured teeth horizontally as a pre-process to minimize performance degradation due to rotation. Next, a fully convolutional network is used to produce a caries probability map while crown regions are extracted based on optimization schemes and an edge-based level set method. In the refinement module, the caries probability map is refined by the distance probability modelled by crown regions since caries are located near tooth surfaces. Patil., *et al.* [24] proposed a caries detection method based on adaptive dragonfly method and neural network classifier. Once the features are extracted, they are multiplied with a weighting factors. Further non linear programming optimization technique is used with an intention of maximizing the distance between the resulting feature output. The NN classifier is trained using an adaptive DA algorithm. Datta., *et al.* [25] proposed a method based on isophote concepts. This method is very fast and offers good accuracy. Table 2 shows the comparative study between above mentioned dental caries methods. Table 2 shows the merits and demerits among instrument based method, radio-graph and software techniques shortly.

Challenges of the existing methods

Most of the caries detection methods are primarily based on visual examination, subject surface textures, position, touching consciousness etc. These methods show the carious lesion area on the tooth. In real life, it is more critical to determine the carious affected area in between two teeth i.e., inter-proximal caries. The methods described at previous section confirm good resolution towards detection of dental caries [17,26]. But there are some known drawbacks as mentioned in table 2 in details. The main challenges are listed as follows

Category	Sub-method	Typical Feature	Advantage	Limitation
Point methods for accessing dental caries	Diagnodent method	It is a chair side, battery- powered, quantitative, diode laser-based fluorescent device Diagnodent is better than visual method in the diagnosis of secondary caries of dentin compared to visual method	Flexible and mobile operated. It provides simple, fast and pain less test. Offers accuracy as compared with other conventional methods for detection of enamel caries.	Even though Diagnodent has excellent sensitivity and specificity, in some cases it has over scored the teeth. The laser device Diagnodent is not able to detect the amount of demineralization. Adequate learning and experience is required for precise use before considering it as a reliable diagnostic method. Diagnodent is a suitable device for detection of caries in complement of other methods and its use alone is not enough to provide treatment plan.
	Electrical Caries Monitor (ECM)	It is single fixed frequency alternating current. It is being used experimentally to detect occlusal caries.	ECM is capable to help dentist for monitoring, demineralization, root caries lesion for their patients. It helps for more detail analysis of the structure of the tooth to be developed.	ECM performance depends on certain criteria: Temperature of the tooth Thickness of the tissue Hydration of the material and surface area. It has higher sensitivity.
Based on light property method	FOTI	Fiber optic trans illumination (FOTI) is a simple, easily repeatable, non-invasive, painless procedure that can be used repeatedly with no risk to the patient.	FOTI devices are small, compact, and battery- powered Used for evaluation of cusp fractures and cracked teeth Gives good result to detect early carious lesion.	Its sensitivity and specificity are around 85% and 99% respectively Can detect occlusal caries on premolars and molars teeth only.
	DIFOTI	It is a dental diagnostic imaging instrument. It can also discover marginal caries. Used to monitor incipient carious lesions, fractures. It provides real-time imaging during caries excavation.	No ionizing radiation, No film, Real-time diagnosis, and higher sensitivity in detecting early lesions It's able to monitor selected lesions over a period of time	DIFOTI is not able to provide quantitative monitoring. Due to the heavy size of DIFOTI camera it is quite difficult to fit it into younger's mouth.

Light emitting devices	QLF (Quantitative Light Induced Fluorescence)	QLF uses light with wavelengths around 405 nm to excite yellow Fluorescence QLF offers a potential tool to reduce the time needed for clinical research.	Reliable method for quantifying mineral loss from enamel and subsequent monitoring of this loss User friendly Well suited to children because it can easily be fitted into their mouths Suitable for quantitative assessment of early enamel lesions in visually accessible surface	Lesion fluorescence decreases with dehydration, thereby influencing the result of the measurement in clinical application There is difficulty in repositioning the optical monitor probe at the same measuring points at different times when used longitudinally. There are also problems with sterilization of the instrument and limitations for the size of the bulky laser equipment presently used as light source QLF device is unable to accurately identify inter-proximal lesions.
Radio graphs	Digital Radiographs - (intraoral) and (extra oral)	Intraoral X-rays, provide great detail and are used to detect cavities, check the status of developing teeth, monitoring of teeth and bone health Extra oral X-rays do not provide the details of intraoral X-rays and are not used to identify individual tooth problems. They are used to detect impacted teeth, and identify potential problems between teeth, jaws or other facial bones.	In real time it's possible to make images darker, lighter, enlarge and superimpose texture on demand. It's very fast method save time and money	Due to use of ionizing radiation, it is very harmful for human being The limitations for the use of dental film Some direct systems sensors are thicker and bulkier than dental films that cause patient discomfort. Thickness and rigidity of the sensors.

Table 2: Comparative Study between Different types of Caries Detection Methods [4-17].

- Infrastructural implementation is much harder in some methods like ECM.
- Infrastructural investment is much expensive like QLF.
- QLF has high level specificity, but low sensitivity and reproducibility.
- There is not a single method exists that can able to measure lesions growth rate.
- Interproximal caries lesion is not identified properly with these methods.
- The lesion's depth is not identified.
- Radiographs are harmful for our health

Conclusion

Dental caries is not only associate with tooth ache but also irritates in the mouth, it is one of the heralds of other life-threatening diseases to adult and as well as children. So, proper care and treatment from the early stage of caries region are essential. The care and treatment procedure of caries region has changed with the evolution of technology. Some of the methods are highly expensive or cost-effective or injurious to health or fails to detect caries in its early stage or partially invasive in nature. In this review work, we discuss the merits and demerits of some caries detection techniques which are well-known. Detection and

treatment of caries affected lesion are not confined into only the boundary of normal disease detection, treatment methods; it also includes the essence of beauty or overall face look satisfaction and capability to effort money with less painful treatment. We expect that this review article will give a brief idea regarding different caries detection techniques.

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