Review / Derleme

Recent Methods for Diagnosis of Dental Caries in Dentistry

Diş Hekimliğinde Güncel Çürük Tanı Yöntemleri

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Abstract

In recent years, the early diagnosis of dental caries has gained importance as conservative dentistry is kept in the forefront. Especially in pediatric patients, the dentist should focus on the early detection of dental caries and minimally invasive treatment options. The conventional caries detection methods often fail to detect initial enamel lesions that have not progressed to cavitation. For this reason, various new techniques have been developed aiding early detection of caries. The aim of this review is to give general information about recent caries detection methods and to mention their benefits when used in conjunction with conventional methods.

Öz

Koruyucu diş hekimliğinin ön planda tutulduğu günümüzde, diş çürüklerinin erken tanısı oldukça önem kazanmıştır. Özellikle çocuk hastalarda diş çürüklerinin erken dönemde saptanıp minimal invaziv tekniklerle tedavi edilmeleri amaçlanmaktadır. Diş çürüklerinin tanısında sıklıkla kullanılan geleneksel yöntemler, henüz kavitasyona neden olmamış çürüklerin tanısında yetersiz kalmaktadır. Bu nedenle diş çürüklerinin tanısında geleneksel yöntemlere ilaveten yeni yöntemler geliştirilmiştir. Bu derlemenin amacı, çürük tanısında kullanılan güncel yöntemler hakkında genel bir bilgi vermek ve bu yöntemlerin geleneksel yöntemlerle birlikte kullanıldığındaki yararlarından söz etmektir.

Keywords
Dental caries, caries detection, early diagnosis

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Introduction

Early detection and diagnosis of dental caries reduces irreversible loss of tooth structure, the treatment costs and the time needed for restoration of the teeth. Dental caries often initiates at the fissures in the occlusal surface of the tooth. Conventional examination for caries detection is primarily done using visual inspection, tactile sensation and radiographs. While these methods give satisfactory results in detection of cavitated lesions, they are usually inadequate for the detection of initial lesions. Because of these deficiencies, new detection methods have been developed to aid better diagnosis. General criteria for an ideal caries detection method include following (1,2);

- Ideal caries detection method should capture the whole caries progress, from the earliest stage to the cavitation stage,
- It should be accurate,
- It should be precise,

• It should be easy to apply,

• It should be useful for all surfaces of the tooth including caries adjacent to restorations,

• It should assess the activity of the lesion,

• It should be sensitive, allowing lesions to be detected at early stages.

Conventional Methods Used in Diagnosis of Dental Caries

Visual Inspection

It is one of the most common diagnosis methods implemented by dentists. In order to make an accurate assessment, the teeth should be clean, dry and examined under a light source. In visual examination, changes in tooth structure such as; enamel dissolution, white spot lesions, discoloration, surface roughness and presence of cavitation are assessed. When illuminated, the carious tissues scatter the light and make enamel look whiter and opaque. This is due to increased porosity caused by demineralization. Similarly, when dentin undergoes demineralization, a shadow is observed under the intact enamel. When caries progress, the surface breaks down and a cavitation is formed (2).

In the International Consensus Workshop on Caries Clinical Trials, held in Scotland in 2002, the importance of the early detection of caries was emphasized and the idea of development of International Caries Detection and Assessment System (ICDAS) was proposed. In 2005, the ICDAS criteria was revised and published as ICDAS II (3).

According to studies, ICDAS gives reliable and accurate results in identification of early caries lesions and changes taking place in the long term (4).

The basic codes are given as follows;

0. Sound tooth surface,

1. First visual change in enamel,

2. Distinct visual change in enamel,

3. Localized enamel breakdown due to caries with no visible dentin,

4. Underlying dark shadow from dentin (with or without enamel breakdown),

5. Distinct cavity with visible dentin,

6. Extensive distinct cavity with visible dentin.

Tactile Sensation

The explorer and the dental floss are used for tactile examination but the use of an explorer is not preferred because (1,5);

1. Sharp tip of the explorer can produce traumatic defects on the enamel surface,

2. The cariogenic bacteria may be transferred from one tooth surface to another,

3. Probing may cause cavitation and fracture in the incipient lesions,

4. Explorers have low sensitivity resulting in undetected lesions.

If the explorer catches or resists removal when moderate pressure is applied, and when this is accompanied by one of the following;

• Softness at the base of the lesion,

• Opacity adjacent to the pit or fissure,

• The enamel is softened adjacent to the pit and fissure, we can conclude that the area is carious.

Pickard, proposed the use of dental floss for the detection of caries. When there is food packing between the teeth and the floss is frayed when passed through the contact area, this might be the indication of caries (6).

Radiography

Radiographic examination has great value in detecting caries lesions especially when they are not clinically visible. In low caries population, as a result of fluoride use, the surface of enamel does not break down, making the caries detection harder. In recent years, the incidence of such lesions has increased dramatically (7). According to studies, bitewing radiography has been proven to be an effective method in the detection of proximal caries and hidden caries (8).

Besides its advantages, radiographs also have some limitations too. For this reason, it is advisable to use clinical evaluation along with radiographic imaging. The disadvantages of radiography are as follows (2,9);

• Proximal contacts are overlapped,

• The lesion depth may appear to be increased due to angulation and this may lead to false diagnosis,

• Occlusal lesions may not be detected because of the superposition of the buccal and lingual cusps,

• The real cause of the radiolucency can't be determined whether it is due to caries, resorption or wear,

• The superficial demineralization of the buccal and lingual surfaces may seem like proximal caries,

• Active and arrested caries can't be distinguished in the radiographs,

• Radiographs may give false positive results due to a phenomenon called "Mach band effect". In this

perceptual phenomenon, the contrast between the dark and lighter areas has increased, resulting in a dark demarcation band. This effect causes formation of a radiolucent area in dentin enamel junction,

• Cervical burn out is another optical phenomenon where a wedge shaped radiolucent area is seen between the bone and the cemento-enamel junction. This effect is due to tissue density and the low penetration of X-rays at the cervical region.

Despite the disadvantages, radiographs are the most commonly used diagnosis tool and with the development of new techniques many of the problems are solved (10).

Caries Detecting Dyes

There are two layers of decalcification in carious dentin. The first one is the soft and infected layer which doesn't have the capacity of remineralization. The second one is hard, intermediately decalcified and has the ability of remineralization. Many studies were carried out to differentiate these layers. Although there are opinions stating the benefit of caries detection dyes, there are also opinions that dyes can lead to over-reduction in the dentin (6).

Most clinical investigations have concluded that, caries detection dyes don't stain bacteria but stain the less mineralized organic matrix. In a study of Demarco et al. (11) they suggested that dye remnants that remained on the walls of the cavity may cause a decrease in the shear bond strength between the composite restorations and the enamel.

Novel Methods for Caries Detection

Digital Imaging

Digital image is an image composed of a series of sensors and pixels distributed orderly (2).

The advantages of digital imaging over conventional radiography is as follows (2,6);

• The radiation dose is approximately 60-90% lower,

• The image receptor is often larger,

• The image is immediately available,

• The image can be electronically transferred,

• Magnification, contrast, brightness can be adjusted,

• There is no need for processing solutions, protecting the environment and lowering the costs.

In order to be seen in the radiographs, there must be 40% of demineralization in the lesions. This means that detection of deeper lesions is significantly harder compared with superficial lesions (12).

In an *in vitro* study comparing the capacity of conventional radiographic imaging with digital imaging systems in detection of proximal caries, it was concluded that these two systems provided similar results, showing no significant difference over another. It is highly recommended to use digital imaging as the radiation dose is significantly lower (13).

Fiber Optic Transillumination

The light transmission index of decayed and sound tooth are different (6). Sound enamel is formed of densely packed hydroxyapatite crystals. When this structure is disrupted, in the presence of demineralization, the photons of light are scattered resulting in an optical disruption (14). When we examine the carious tissues with fiber optic device, we observe dark shadows along the dentinal tubules as it has lower light transmission index compared with the sound tooth structure (6). The best utilization of the fiber optic transillumination (FOTI) device is for evaluating the depth of occlusal lesions (if the caries has reached to the dentin or not) and for the detection of the proximal lesions (15).

Digital Fiber Optic Transillumination Imaging

This method is the combination of the FOTI and a digital camera in order to reduce the shortcomings of FOTI. This system uses 780 nm wavelength near infrared radiation instead of white light source (16). This new detection method looks promising for identification of caries and measuring the severity of the lesions. According to studies, this method is non-invasive, doesn't use ionizing radiation and it is more sensitive than X-rays in detecting early demineralizations (17).

Also, the images obtained by this method can be saved and viewed later, the properties of the lesions can be examined by increasing the contrast of the image. This method is useful in detecting changes like fractures and fluorosis (18).

Xeroradiography

This technique uses the xeroradiographic copying process for recording images produced by X-rays (6).

Xeroradiography is twice as sensitive as D-Speed films. This technique offers the opportunity of

edge enhancement. Edge enhancement helps distinguishing the areas of different densities at the margins or edges (2).

For many years, xeroradiography was considered as a promising technique for caries detection but according to recent studies, it is regarded equivalent to E-Speed films used in conventional radiography (19).

Susbtraction Radiography

This technique is extensively used for detection of caries and assessment of bone loss in periodontology (14). Digitalization is done by taking a picture of the radiograph with a high-quality video camera. This image is transferred to a computer imaging device named as digitizer. Two standardized radiographs exposed to same amounts of beam are superimposed using a software. The difference between the two images looks as dark bright areas (2).

Mini-D

This device is based on the fiber optic principle, it is easy to use and requires no calibration. Mini-D uses LED and fiber optic technologies to detect occlusal and proximal caries lesions. This device emits 635-880 nm wavelength LED light, analyzes the light reflected from the surface of the tooth and converts it to electrical signals. The presence of caries is identified by two signals; sound and light (green light turns to red). It is also effective in wet environment but the plaque must be removed before the examination (20).

Fluorescence

Two methods have been developed based on the fluorescence of the organic components of teeth; they are quantitative light-induced fluorescence [QLF (QLF-clin, Inspector Research Systems BV, Amsterdam, Netherlands)] which uses an arc lamp with a wavelength of 290-450 nm and DIAGNOdent (KaVo Dental laser fluorescence pen, DIAGNOdent pen, Lake Zurich) which uses infrared light and has a 655 nm wavelength (1).

DIAGNOdent

This system has a range of 0 to 99. The value 0 indicates the healthiest state of the tooth. It is an effective method in detecting initial lesions without cavitation. It's also useful for measuring different decalcification values in different surfaces of the tooth. The fiber optic probe directed onto the occlusal surface of the tooth emits a light of wavelength 655 nm. The changes caused by demineralization are converted into numeric values and displayed on the screen. The surface to be examined must be clean because dental calculus, plaque and discoloration may cause false results (2).

According to studies carried on permanent teeth it is indicated that DIAGNOdent has high sensitivity and low specifity. Having a high sensitivity means that the tool is suitable for caries detection but having low specifity means a higher rate of false positive results are obtained. Therefore, it is recommended to use DIAGNOdent in combination with other techniques (21,22).

Recently, a device called DIAGNOcam was proposed to the market. This technology uses a laser diode of wavelength 780 nm for transillumination of teeth. Carious tissues absorb lighter than their surroundings and a digital camera is used for monitoring the images. The caries tissues appear as dark spots. According to a recent study, the results obtained by DIAGNOcam were better correlating with the clinical results when compared with DIAGNOdent (23).

Another new technology is DIAGNOdent pen (KaVo Dental, Biberach, Germany). This device works with the same principle as DIAGNOdent and it comes with two different sapphire fiber tips: A cylindrical tip and a conical tip. In a study comparing DIAGNOdent and DIAGNOdent pen in detecting occlusal caries it was found that this new device gives comparable results with DIAGNOdent (24).

Quantitative Light Induced Fluorescence

This technique is based on the principle that as the mineral content of the tooth changes the auto fluorescence of the tooth changes also. The light scatters much faster in carious tissues compared to sound dental tissues, shortening the pathway of the light in the lesion and decreasing the absorption and fluorescence in this area. This means that, the scattering of the light is used for evaluating the mineral loss related with the lesion (25). The QLF method can also be used in measuring the red fluorescence from microorganisms in plaque. The value of red fluorescence can be used in the evaluation of oral hygiene, assessment of the plaque on the dentures, detection of the infected dentin and detecting the leakage of a sealant or caries at the margin of a restoration (17).

The QLF method was suggested as an efficient technique not only for the detection early caries but also monitoring the progression of a lesion or remineralization process (25).

Carbon Dioxide Laser

The reason of the application of carbon dioxide laser as a diagnostic tool is because the subsurface of the carious lesion has more organic compounds than the adjacent sound tissues. When carbon dioxide laser is applied to an incipient lesion, the organic contents evaporate leaving a black carbonized residue behind whereas the inorganic substance of sound enamel containing minimum amount of water is less affected by the laser beam (10).

More clinical studies should be carried out in order to understand the efficacy of carbon dioxide laser.

Electrical Conductivity Measurements

Because of its high mineral content, sound enamel is a good electrical insulator. Demineralization process results in the formation of pores and saliva fills these pores forming a conductive pathway for electric current (10). The electrical conductance increases as the pores get larger meaning that demineralization is directly proportional with electrical conductance (6).

In an *in vivo* study carried out by Ashley, it was concluded that in detection of non-cavitated occlusal lesions of posterior teeth, electrical conductivity measurements were superior to visual examination, FOTI, conventional and digital bitewing radiographs (26).

Ultrasonics (Ultrasound Caries Detector)

Sound waves can be used for the detection of caries. Ultrasound can detect lesions easily because the travel time of ultrasonic pulses differ in sound and demineralized enamel tissues (27,28). This method is considered promising in detecting early enamel lesions because the white spot lesions confined to enamel produce no detectable or weak echoes whereas deeper lesions produce substantially higher amplitudes (6).

Endoscope/Videoscope

This technique works with the principle of observing the fluorescence that occurs when the tissues are illuminated with a blue light that has a wavelength of 400-500 nm. The changes in the fluoresced tooth structure is viewed through a specific gelatin filter; white spot lesions appear darker than sound enamel. Similarly, when a light source is connected to an endoscope by a cable, the teeth can be viewed without a filter. This technique is called white light endoscopy (10).

It has been demonstrated that this technique gives efficient results in the detection of early carious lesions (6).

Micro Air Abrasion

This method allows the examination of dark areas in the bottom of the pits and fissures. If a darkened area is considered as decay, the abrasion technology is used to deliver alumina particles to the suspicious area. If this darkened area is stain or organic plug, it will be cleaned by abrasion leaving the sound tissue behind (6). Usually after the bursting of the particles the underlying decay masked by the stain is revealed. This undetected caries may even be a deep lesion. Further application of abrasion can be used to remove the caries until the healthy tooth structure is revealed (29).

Tuned Aperture Computed Tomography

This technique was recently introduced and is still under development. The image produced with this technique is the three-dimensional image of the original object. Detection of demineralization and vertical root fractures is possible with this method (30).

Compared to present detection tools used, tuned aperture computed tomography (CT) has a promising future for the detection of recurrent caries. It is possible to slice the coronal anatomy into pieces and observe the interested region. The main advantage of this technique is that it offers the examination of individual projections of an area (6).

Cone Beam Computed Tomography

This technique is a new application of CT. The absorbed doses and the costs are significantly lower than CT. The information from the craniofacial region are obtained at higher resolutions at axial plane compared to CT systems (31). In dentistry, there are many studies showing that cone beam CT (CBCT) is widely used in the placement of implants, grafting, orthodontic treatment planning, evaluating the temporomandibular joint, detecting anatomic variations, evaluating trauma patients, caries detection (32).

In a study, the detection of carious lesions beneath three different ceramic restorations (zirconia, lithium disilicate, metal supported ceramic) with CBCT was investigated. It was found that the lesions of ICDAS grade 3 and above can be detected by CBCT (33).

Typically, the sensitivities were higher for the CBCT modalities but specificities were less, suggesting that CBCT imaging may result in an increase in the number of false-positives. Also, CBCT doses for caries detection are still higher for many types of intraoral examinations. The application of CBCT imaging to caries diagnosis is promising but more studies are needed, especially *in vivo* investigations. In addition, with current technology, it is assumed that teeth with metal or radiopaque restorations should not be considered for CBCT caries imaging. Another disadvantage of CBCT imaging is its high cost (34).

Optic Coherence Tomography

This technique uses a high penetration near infrared light at a wavelength of 780-1550 nm. No potential biological side effects had been reported of this system so far (2).

Optic coherence tomography (OCT) generates high-resolution cross-sectional images of the oral structures. OCT is found to be more sensitive in the detection of recurrent caries and evaluation of the marginal adaptation of the restorations compared to other tools. Like ultrasonics, OCT uses near infrared emissions to determine not only the presence of the caries lesions but also measures the depth of them. Another important advantage of this technique is that the patient is not exposed to X-rays (2).

Terahertz Imaging

This method uses waves in terahertz frequency (10^{12} Hz or a wavelength of 30 µm). This wavelength is short enough to provide reasonable resolution but long enough to prevent loss of signal due to scattering (2). Several advantages of this system are as follows (2);

- Human tissue is relatively transparent to terahertz rays,
- Low powers are used for imaging,
- Non-ionizing radiation is used,
- The electrical charge of the tissues examined remain unchanged,
- The images are clear but due to long wavelength of the source spatial resolution is low.

Studies concerning this method of imaging are limited but promising.

Multiphoton Imaging

Infrared light of 850 nm wavelength is used in this imaging technique. While conventional fluorescence imaging uses a single blue photon to excite fluorescence compound of the tooth, multi photon imaging uses two infrared photons (with half the energy of the blue photon) which are absorbed simultaneously (2).

With this technique, sound tooth structure shows strong fluorescence whereas carious tissues fluoresce weaker. The carious regions appear as dark areas in strongly fluorescing tooth (2).

Infrared Thermography

Thermal radiation energy travels in the form of waves. The changes in thermal energy can be measured when fluid is lost from a lesion by evaporation. The thermal energy emitted from sound tissues is compared to that of the carious structures. This technique has been described by Kaneko in 1999 and has been proposed as a method of determining lesion activity rather than its presence or absence(2).

The studies carried out using this technique revealed that the early carious lesions in enamel can be distinguished from the sound areas. This technique was considered efficient for *in vitro* studies. More studies must be carried out in order to investigate the efficacy of thermographic imaging *in vivo* (35).

Infrared Fluorescence

There are limited studies regarding this technique. In theory, the tooth is irradiated with 700-15000 nm wavelength light. Barrier filters are used to measure the resulting fluorescence. In an unpublished study carried out by Longbottom, it was concluded that this technique was able to discriminate between sound and carious enamel and dentin. Further studies need to be done for evaluating the efficacy of this technique (4).

Conclusion

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.

Ethics

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Authorship Contributions

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