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Chapter
Caries Management Aided by Fluorescence-Based Devices

Atena Galuscan, Daniela Jumanca and Aurora Doris Fratila

Abstract

Fluorescence-based intraoral cameras are increasingly gaining more interest in the modern dental practice, as an aid for the early detection of carious lesions. Such devices can have different operating systems, such as infrared lasers, quantitative light fluorescence (QLF), or LED lights, but they all rely on the fluorescent properties of tooth structures. Healthy enamel and enamel affected by demineralization have different light-scattering properties, a fact that allows for distinction under excitation with light of a known wavelength. The central problem in the treatment of dental decay is that operational care is still considered the predominant management plan for caries control in the general practice. Devices that use fluorescence have the potential to improve the detection and management of carious lesions significantly. Currently, there are several intraoral devices that employ fluorescence on the market, but more validation studies would be required to uphold the interest of the newly developed devices and to justify their reliability in clinical practice. Dental professionals cannot yet solely rely on one single-fluorescence device for incipient caries diagnosis, but they already present themselves as useful adjunctive tools to traditional examination methods.

Keywords: caries, fluorescence, intraoral scanners, oral health, diagnosis, prevention, noninvasive

1. Introduction

The clinical diagnosis of caries, which uses visual inspection and radiographs, is an imperfect process, making the development of dental plaque more likely to occur [1]. Previous studies have shown that the traditional examination for caries has limited performance, especially in detecting dental caries in the early stages. Appropriate treatment of carious lesions demands detection at an early stage and minimally invasive cavity preparation in order to preserve the maximum natural tooth structure; nevertheless, dental caries is one of the most afflictions worldwide [2–4].

For the visual-tactile examination for caries detection, the International Caries Detection and Assessment System (ICDAS-II) is usually used. The system provides proper data collection and guarantees standardization; however, visual evaluation is always dependent on the evaluator. Therefore, providing an additional diagnostic tool in the dental practice allows for objective assessment of enamel demineralization beginning from its early stages.
In the last years, the interest in optical devices which use nonionizing radiation, allowing them to detect and monitor caries, has been growing. Among these, cutting-edge technologies are intraoral cameras that combine fluorescence detection systems [5].

2. Fluorescent properties of teeth

Fluorescence occurs when a material emits light of different wavelengths, after absorbing light of higher energy. Because of this difference in energy, the color of the emitted fluorescence light is always different than that of the excitation light (produced by a source of defined parameters), having a longer wavelength and lower photon energy, as a result of the absorption of energy by the examined material [6, 7]. Hence, violet or blue excitation light will cause emissions that are green, orange, or red (depending on the examined material), all of which are longer wavelengths of visible light. Similarly, red excitation will cause emissions in the near-infrared region. This occurrence is known as the Stokes’ shift.

One of the most common bacteria associated with carious lesions is lactobacilli, which strongly emit visible red fluorescence; even stronger than the mutans streptococci. It has been generally acknowledged that red-light emission caused by violet light excitation is well suited for the detection of caries-associated pathogens, such as streptococci and lactobacilli. Because of this feature, a range of devices for caries detection started using 405 nm violet light-emitting diodes, including intraoral cameras [8, 9].

Another notable feature is the suitability of porphyrin molecules (such as protoporphyrin IX and coproporphyrin) as markers for identifying carious lesions, considering the fact that porphyrin derivates do not occur within healthy tooth surfaces. These molecules are, too, fluorophores with maximum excitation at around 405 nm. As soon as the initial stage of a carious lesion forms, red fluorescence is emitted by porphyrins. According to the literature, porphyrins emitted light over 570 nm with double peaks, which are characteristic of these molecules [10].

The number of fluorophores present in the examined area is linearly proportional to the emission intensity, the fluorescent property is thus a very useful tool for quantification [11].

Additionally, the Maillard reaction products are currently the best-known dental caries products. They manifest themselves through browning discoloration, being a nonenzymatic reaction between reducing sugars (carbohydrate) and amino acids (protein). The Maillard reaction has been thoroughly studied in the field of food chemistry, where it has been found to be responsible for characteristic changes, such as the browning of bread during baking. The exact molecular structure of the brown pigment is still unknown. The Maillard reaction in human tissues is often associated with the complications of diabetes and old age, which include vascular stiffening, atherosclerosis, and renal insufficiency [12].

The organic components of sound tooth structure are responsible for the even green fluorescence when under illumination with violet–blue light, and certain fluorophores, for instance, tryptophan, account for the regular fluorescence of healthy dentin.

Also, worth mentioning is the fact that dentin hard tissue presents a relatively higher number of chromophores, resulting in a much brighter fluorescence compared to enamel. A high concentration of the fluorophores that emit green light can further be found at the dentinoenamel junction [13].

The process in which the development of dental caries affects fluorescence has been studied and characterized by researchers of the Karolinska Institute in Sweden.
as early as the 1980s. They found that the reduction in green fluorescence during
caries development is caused by the reduction of mineral contents and simultaneously
rising water content in the enamel. As a result, this leads to changes in light-scattering
properties. Hence, when the green fluorescence fades, white spot lesions for instance,
which are usually below the diagnostic threshold, become detectable [14, 15].

As mentioned above, fluorescence can serve as a very useful tool for quantifica-
tion. Areas with a decrease in fluorescence over 5% are considered lesions [16]. This
property helps quantify images with loss of fluorescence concerning the adjoining
healthy tissue. For instance, fluorescence images of enamel areas that present white
spot lesions can be digitalized and the ratio between those areas and the healthy
surface on the same tooth can then be quantified efficiently [17].

3. Importance of adjunctive methods

A growing body of literature has studied and evaluated the importance of early
caries diagnosis in the past years. According to the World Health Organization
(WHO), untreated tooth decay impacts almost half of the worldwide population
(44%) as of 2020, making it the most common condition included in the Global
Burden of Disease Study. Carious lesions were shown to be five times more common
than asthma and seven times more likely than hay fever in children [18].

Unfortunately, there is still considerable uncertainty and even drawback, exhibited
by professionals regarding preventive strategies, which have yet to be utilized efficiently.
There could be several reasons for this, but the central problem is that operational care
is still considered the predominant management plan for caries control in the general
practice. This is negatively impacting aspects, such as caries epidemiology, patients’
quality of life, and long-term preservation of healthy tooth structure among others [19].

An increasing number of research highlight the need for innovative and reliable
detection methods in the early (pre-cavitated) stages of caries, pointing out that
visual examination has been found to be effective in more “pronounced” stages.
Because of this, more sensitive and accurate devices and technologies are being devel-
oped, for practitioners to detect initial carious lesions as efficiently as possible [20].

It has been suggested by Makhija in 2014 that around 96% of carious lesions
in early stages could be efficiently treated with noninvasive interventions. These
findings seem to be well-founded, taking into consideration the trend of modern
dentistry, which strives toward minimally invasive therapy, early diagnosis, and treat-
ment of caries being a top priority goal [21]. One of the major drawbacks to reaching
this goal is the fact that caries treatment often occurs in more advanced stages, being
based mainly on symptoms and clinical signs – thus making it inadequate for a non-
invasive treatment plan [22]. Uncertainties in detecting early lesions can arise even
in the ranks of experienced practitioners, an assumption that is very plausible and
natural [23, 24]. Accordingly, using digital methods like fluorescence-based devices,
can improve the early caries detection [25, 26].

4. Fluorescence-based devices

Fundamental considerations when using fluorescence-based systems are the differ-
ences between the fluorescent properties of healthy and carious tooth structure, the used
light wavelengths, as well as the approach used in examining the emitted fluorescence.
4.1 Infrared lasers

The DIAGNOdent Pen (KaVo, Biberach, Germany) is made up of a handpiece, which uses a red laser diode emitting light of 655 nm wavelength. Both the red light of the diode and the consequent fluorescence are transported through optical fibers (Figure 1). The emitted fluorescence is filtered and quantified to display the mineralization level of the examined surface/structure ranging on a scale from 0 to 99, which is then displayed by the device on a screen, showing a numerical value only (Table 1).

According to research conducted on the diagnostic validity of the DIAGNOdent Pen, it showed a higher sensitivity than visual or radiographic examination methods, but at the same time, lower sensitivity values of detecting dentin compared with enamel lesions. Some care is required in the use of the DIAGNOdent Pen camera when conducting clinical studies, due to difficulties with stain- and plaque- confounding assessments, and perhaps further work is needed before it can be routinely used in clinical studies [27].

A more recent study in which 628 occlusal fissures were analyzed, revealed a wide intra- and inter-investigator variability (reproducibility) for the DIAGNOdent Pen, findings which remain controversial [28].

According to multiple studies, what we know now, is that the DIAGNOdent Pen is insufficiently correlated with caries depth and ineffective for monitoring lesions over time. Because there is still some ambiguity regarding the performance and accuracy of the DIAGNOdent Pen, dental professionals should not rely on this device alone, overall having a poor clinical relevance in modern practice [29–33].

It is confirmed by systematic reviews of the DIAGNOdent Pen that further scientific research and insight into the clinical use of the device are necessary [34–36].

<table>
<thead>
<tr>
<th>Score</th>
<th>Meaning</th>
</tr>
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<tbody>
<tr>
<td>0–12</td>
<td>Healthy tissue</td>
</tr>
<tr>
<td>13–24</td>
<td>Demineralized enamel</td>
</tr>
<tr>
<td>&gt;25</td>
<td>Dentine involved</td>
</tr>
<tr>
<td>0–7</td>
<td>Healthy tissue</td>
</tr>
<tr>
<td>8–15</td>
<td>Demineralized enamel</td>
</tr>
<tr>
<td>&gt;16</td>
<td>Dentine involved</td>
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</tbody>
</table>

Table 1.
Score scale of the DIAGNOdent pen according to the manufacturer.
4.2 Quantitative light fluorescence (QLF)

QLF consists of an intraoral camera with CCD (charge-coupled device) technology, which is a highly sensitive photon detector, connected to a light source emitting blue–green light. This technology targets the quantification of the mineral content of enamel, depending on changes in the fluorescence of sound versus carious enamel, after excitation at 405 nm. The fluorescence of the teeth is displayed on a screen, healthy enamel appearing green. The bacterial activity of porphyrin reaction where caries forms, results in surface changes, and thus, in light scattering, where carious lesions become visible. It is considered that a surface with demineralization over 5% can be called affected [37, 38]. QLF can measure fluorescence radiance loss in percent, as well as lesion size (mm²) to describe lesion severity, making it, according to a significant number of authors, suitable for prospective monitoring of tissue de- and remineralization.

Therefore, QLF has a great potential in being a supportive tool for monitoring the effects of preventive care on dental patients. Moreover, combining QLF with visual examination can significantly increase the sensitivity of detecting initial lesions [39, 40].

Several devices using QLF technology have been developed [41], which are as follows:

- Inspektor Pro (Inspektor Research Systems BV, Amsterdam, the Netherlands) (1st generation)
- Digital Biluminator 2+ device (QLF-D, Inspektor Research Systems BV) (2nd generation)
- Qraycam (AIOBIO, Seoul, Republic of Korea) (3rd generation)

4.3 LED cameras

A more recently developed caries detection system aided by fluorescence is the LED technology of certain intraoral cameras. This system illuminates the examined area of the tooth, records the emitted fluorescence, and intensifies the resulted image with the help of dedicated software. These devices include among others the intraoral camera VistaCam iX (Dürr Dental, Bietigheim-Bissingen, Germany), which operates using the software DBSWIN. The “Proof” interchangeable head displays carious lesions and plaque using fluorescence.

Similar to QLF systems, healthy enamel can be identified by its green fluorescence. The teeth are illuminated with violet light of 405 nm wavelength and the reflected fluorescent light is then filtered for light below 495 nm. The filtered light consists of the green color of healthy enamel with a peak at 510 nm, as well as the characteristic red fluorescence of cariogenic oral bacteria with a peak at 680 nm [42] (Tables 2 and 3).

A study carried out by Jablonski-Momeni et al. in which an experienced and a novice professional examined occlusal caries using the VistaProof, found that the fluorescence-based device showed high reproducibility and good diagnostic performance. Both examiners were able to use this system efficiently as a supportive means for caried monitoring, as well as diagnosis. Moreover, it also provided insightful visual and quantitative feedback to patients [43].

Rodrigues et al. presented similar results regarding the performance of the VistaCam iX, as well as the VistaProof [44].
But one very recent study by Achilleos et al. (2021) has found that the use of neither the VistaProof device nor the DIAGNOdent Pen contributed to the incipient occlusal caries detection when compared to visual diagnosis criteria [13].

Another fluorescence-based device with an LED system is the SoproLife (Sopro-Acteon group, La Ciotat, France) intraoral camera. The practitioner can choose between two fluorescence modes of operating the camera:

- a diagnostic mode, in which the fluorescent colors are limited to those observed on the tooth
- a processing mode, in which the red of carious tissues is amplified, in order to guide the practitioner in eliminating the lesion
Additionally, there is a day-light mode, for intraoral photographs and videos. The emitted blue light in fluorescence-mode is of 450 nm wavelength, thus healthy enamel appears green and carious lesions appear light to very dark red, similar to the VistaCam iX. The image software enhances the emitted fluorescence of the examined surface (the tooth), allowing the practitioner to improve their visual inspection and decision-making [45].

The SoproLife camera allows observation of any variations in the optical properties to refine the caries diagnosis. It also provides more than a 50× magnification of the occlusal groove anatomy, to grant additional data on the carious potential of the examined tooth surface [46]. Although several authors consider the SoproLife camera a helpful tool in detecting and monitoring caries [47–50], others found no additional benefits in using this intraoral camera for detecting carious lesions in clinical practice [51].

More research is required, in order to facilitate the further development of these new systems and technologies, which should lead to improvements and better applicability in the modern and minimally invasive focused practice. Since there is currently a limited number of clinical research regarding the performance of fluorescence-based devices for caries diagnosis, especially for incipient carious lesions, values should be interpreted prudently until more clinically validated data is gathered through scientific studies.

5. Discussions

As modern dentistry is slowly shifting its focus on minimally invasive treatments and prevention is gaining more and more important in the day-to-day practice, there is no doubt that the constant development and innovation of new technologies is an essential step in this advance. This is also the reason we have chosen to review this particular topic, in order for recent graduates, young professionals, teachers, and even experienced practitioners to be up to date with research conducted on the accuracy and reliability of the currently available systems. Another reason would be to further raise awareness of the benefits and potential of new technologies for improving and easing the treatment quality. As observed in the present chapter, for all mentioned fluorescence-based devices, there are currently divided opinions and conclusions regarding their clinical relevance and benefit.

It is worth mentioning, that during the information gathering process for this chapter, a certain shortage of clinically relevant research conducted in the field of intraoral fluorescence cameras, in general, (but more striking, in the past years) has been noticed. It has occurred to us, that more validation studies are required to uphold the interest of the newly developed devices. Future studies should target the areas which require improvement for each device separately, after an extended period of clinical use, in order for companies to be able to improve said devices where necessary.

Fluorescence-based systems have a big potential in becoming an essential adjunctive tool for minimally intervention dentistry, enabling better detection of initial lesions and thereupon their remineralization. Nevertheless, it is of utter importance, for these, investigations to be continued and further parameters evaluated, for enhancement in their sensitivity, specificity, and reproducibility to aid the trustworthy and objective diagnosis of carious lesions.
6. Conclusions

We are confident that the fluorescence-based systems and devices used in dentistry will be further developed and improved, and they eventually will become meaningful tools in helping minimize the percentage of the population affected by dental caries significantly. Reducing operative care and increasing preventive care will have long-term benefits at levels for entire populations. Such devices even have the potential of becoming at-home monitoring tools for the dental plaque for patients, which then could lead to improved oral health.

The trend of minimally invasive and preventive dentistry has become remarkable in the past few years and this technology is truly revolutionary for modern oral health care.

Currently, we cannot solely rely only on one of the mentioned fluorescence devices, but they already present themselves as useful adjunctive tools for visual examination and radiography.

Conflict of interest

The authors declare no conflict of interest.

Author details

Atena Galuscan1,2, Daniela Jumanca1,2 and Aurora Doris Fratila3*

1 “Victor Babeș” University of Medicine and Pharmacy, Faculty of Dental Medicine, Timisoara, Romania

2 Translational and Experimental Clinical Research Center in Oral Health (TEXC-OH), Timisoara, Romania

3 Ludwig-Maximilian-University Munich, Faculty of Dental Medicine, München, Germany

*Address all correspondence to: a.fratila@campus.lmu.de
References


treatment of initial occlusal caries.


