Design of a Fluorescence Camera for Detection of Dental Caries

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Abstract

The aim of this study was firstly to design a dental camera based on the fluorescence technique for detection of dental caries and secondly to apply this device in the analysis and diagnosis of different types of caries. Using light-emitting diodes operating in the near ultraviolet spectral regions (370–390 nm) for excitation, the obtained fluorescence images of carious teeth were different from of sound teeth due to the presence of bacteria Streptococcus mutans producing metabolites called porphyrins. The sound teeth showed the blue fluorescence while the carious regions illuminated the red light. Based on the fluorescence color, dental caries can be discovered even in the early stages. Besides, this tool have some advantages such as safety (non-ionizing radiation), rapid test time, mobility, archiving software (saving diagnostic result as image and video) and low cost.

Keywords

Dental caries • Diagnosis • Fluorescence camera

1 Introduction

Dental caries and dental disease are one of the prevalent chronic diseases of people around the world in general and in Vietnam in particular. According to the recent statistics of the Ministry of Health of Vietnam nearly 97% of Vietnam's population has dental disease, 44% the people visit dentist when they have been the detail hurt symptom, which have caused many difficulties in the process of treatment and rehabilitation.

The detection of carious lesions has been primarily a visual process, based principally on clinical-tactile inspection and radiographic examination. A major shortcoming of clinical-tactile inspection is very limited for detecting non-cavitated lesions in dentin or posterior proximal and occlusal surfaces, while X-ray based methods can cause damage to cells in the body, which in turn can increase the risk of developing cancer.

Researchers are developing tools that are sensitive and specific enough for the current presentation of caries. One of the newly developed diagnostic procedures employs fluorescence diagnostics. Quantitative light-induced fluorescence (QLF) is based on the autofluorescence of teeth. When teeth are illuminated with high intensity blue light, they will start to emit light in the green part of the spectrum. The fluorescence of the dental material has a direct relation with the mineral content of the enamel [1]. It is important to emphasize that QLF can be influenced by some factors, such as stains, dental plaque, dental fluorosis or hypomineralization. Another fluorescence technique—laser-induced fluorescence is based on the quantification of emitted fluorescence from organic components of dental tissues when excited by a 655 nm laser diode located on the red range from the visible spectrum. The laser is able to excite either the hard dental tissue, resulting in the tissue autofluorescence, or fluorophores present in the caries lesions. This device has shown good results in the detection

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of occlusal caries, however, it might not be used as the only method for treatment decision-making process [2]. The other investigators have shown that under UVA light (near ultraviolet) sound teeth emit blue-green color, while caries teeth emit the red fluorescence [3–9]. Based on the difference in the color of the teeth fluorescence caries lesions can be detected.

In this paper the fluorescence technique was applied to design and create a device model for detecting the appearance of bacteria causing caries and this device was examined in analysis and diagnosis of different types of caries.

2 Materials and Methods

2.1 LEDs

The device for detection of dental caries is a system that consists of two LEDs: one white LED PLCC-6 Oval for the general examination, one SMD 380-nm LED with 1 W-power for exciting teeth fluorescence. The field of view of white LED must provide the full overview of the oral cavity in the inspection process. For that request, a white LED with three integrated diodes was used.

With 380-nm LED, the wavelength and power play a important role in stimulating fluorescence. According to the research results of the thesis of Duong Van Hung and Nguyen Van Tuan [6] the UVA or violet light (365, 380 and 405 nm) are suitable for exciting teeth fluorescence. The fluorescence images stimulated by 380 nm wavelength had high contrast between the blue and red fluorescence better than by 365 and 405 nm. With 1 W power LED the fluorescence intensity of all obtained images was available for the unaided eye observation. Therefore, the 380-nm LED with 1 W power was chosen in this study.

2.2 Source and Stable Voltage Circuit

Two LEDs are provided with 3–3.4 V DC power from batteries or USB port of the computer through a stable voltage circuit and source selector switch. The power of LEDs is controlled by hand in a flexible manner. The stable voltage circuit receives input from the battery or the computer and the output voltage is 3–3.4 V to match the performance parameters of the LEDs (Fig. 1).

2.3 Camera

The recorded image can be directly observed with the naked eye or through the camera. Due to the poorness of the light and space condition in the oral cavity the camera should

have a short focal length and high sensitive to appropriate to record fluorescence image of the teeth [10]. This camera is connected to computer with usb cable 2.0.

2.4 Filters

The light emitted from the 380-nm LED is not monochromatic with a spectrum from 370 to 390 nm. The edge of the LED spectrum in the visible region causes the overlap with the fluorescence spectrum of teeth. In this case, one UV bandpass filter (UG-1, Edmund Optics) was used for passing only wavelength shorter than 400 nm and eliminating unwanted visible light from the LED [11].

The 380-nm LED is arranged close to the camera so the LED light can scatter and decrease the quality of fluorescence images recorded by camera. Therefore, a JB490 filter was placed in front of the camera to block the scattered light from LED and pass the fluorescence signals from teeth [12].

2.5 Radiator for LEDs

The heat emitted in the working process of device is mainly due to the LEDs. The temperature does not affect the course of the survey and the quanlity of fluorescence images but shortens the life span of LEDs. A radiator base plate for LEDs was designed and placed at the back of the white and 380-nm LEDs.

3 Results and Discussion

3.1 Design-Build Process

The aim of this study was to design a portable fluorescence camera for observation in the oral cavity. Therefore, the device must be easy to use: the camera header is small for comfortable manipulation in the visual inspection, the body of device should be light and fit for hand, and the LED controller in a convenient location for controlling LED intensity. The device was modeled by SolidWorks software and built by 3D printing (Figs. 2 and 3).

3.2 Safety Equipment

In any electrical and radiation equipment, the most important requirement is safeness. By using low voltage (under 5 V), and plastic material for device casing, dental caries detection device is perfectly safe. Besides, the light-emitting diodes operating in the near ultraviolet (UVA), the lowest photon energy of the three ultraviolet wavebands, has virtually no
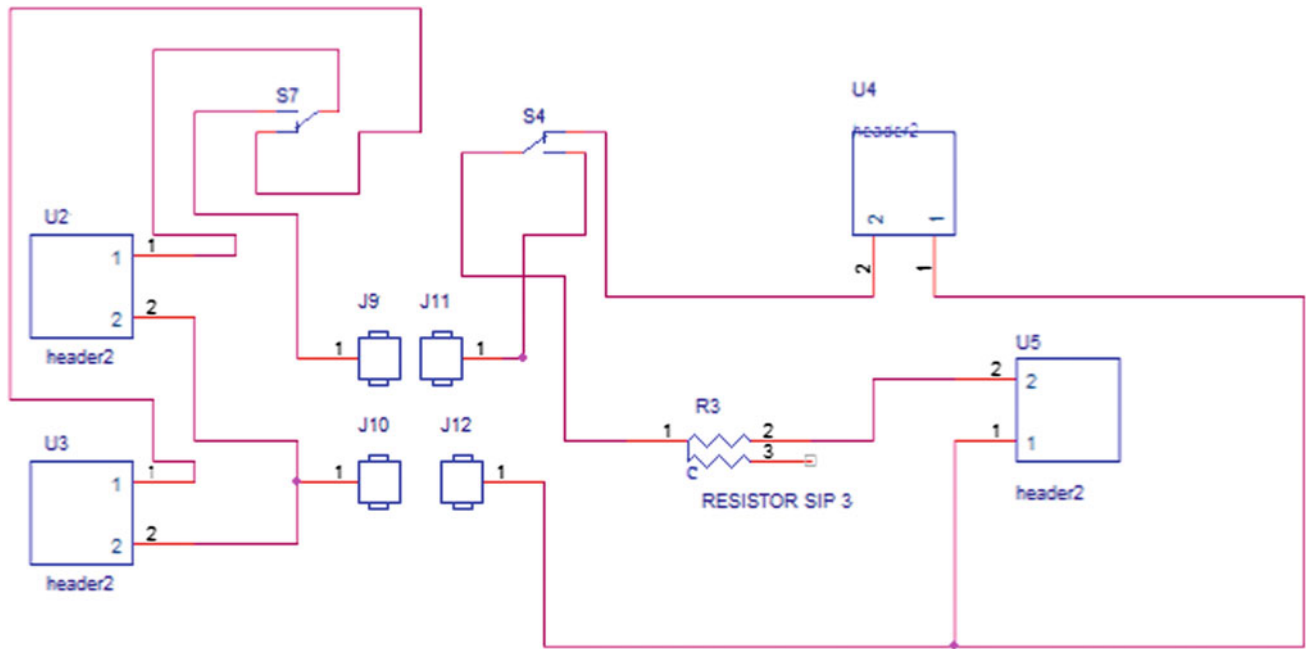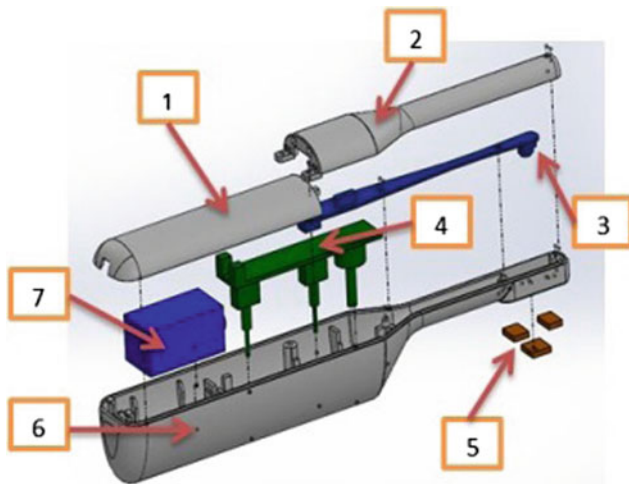
Fig. 1 Stable voltage ciruit

Fig. 2 Device structure: *1* Battery cover, *2* Upper body, *3* Camera, *4* Circuit, *5* Filters, *6* Lower body, *7* Battery

Fig. 3 Fluorescence camera

effect on human tissue with short-term exposures [13]. In this research, we had tested the power LEDs emitting 380-nm peak in exciting human tissue in 1 min and below.

3.3 Test of Device

3.3.1 Tooth Samples

The experiments were made on extracted teeth (in vitro) randomly collected from hospitals and dental office. All samples, without dental restorations to ensure the presence of questionable occlusal ca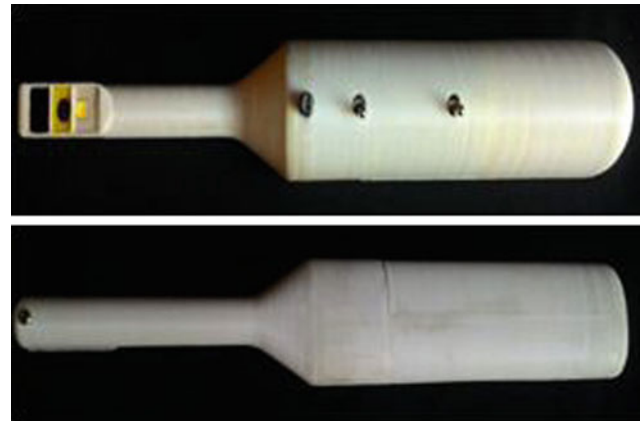ries, were classified according to the visual criteria of the International Caries Detection & Assessment System (ICDAS) [14].

3.3.2 The Results of Device Testing

All samples of the sound and lesion teeth were observed under white light and 380-nm LED of designed fluorescence camera.

Figure 4 shows a sound teeth specimen (sample 1). Under UVA excitation, as can be seen in Fig. 4b, this sample emitted the blue-green color on a white background. As known that the healthy teeth emits blue or green fluorescence when irradiated with near ultraviolet or violet-blue light, respectively [15, 16]. In this work the 380-nm LED emitting band from 370 to 390 nm was used
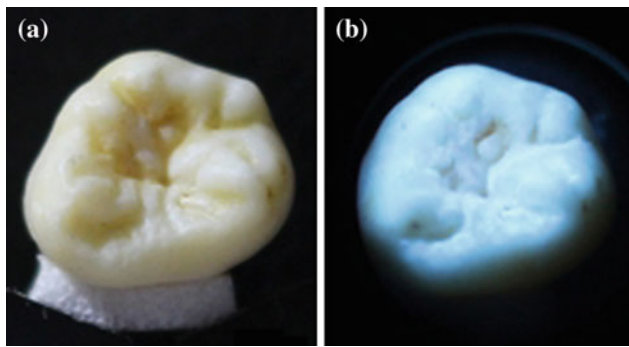
Fig. 4 Sample 1: white light image (a), fluorescence image (b)

that was capable of stimulating a broad emission band in the visible region with maximum located at blue-green wavelengths. For many years, researchers have studied the origin of natural fluorescence in dental hard tissue. While the chromophores of fluorescence at 350–400 nm (in UVA wavelength) with excitation wavelength shorter than 300–325 nm have been identified (traces of tryptophan and hydroxypyridinium [17], the other fluorescence colors in visible region remain unidentified. Thus, the determination of fluorophores emitting blue-green color in sound teeth requires further investigation.

Besides blue-green fluorescence observed in sound teeth, the red color appeared in the samples with different types of lesions. Sample 2 with dental calculus is presented in Fig. 5, where the calculus illuminated the strong red fluorescence. Calculus is a form of hardened dental plaque. It is caused by precipitation of minerals from saliva and gingival crevicular fluid in plaque on the teeth. There are about 1000 out of the 25,000 species of bacteria that are involved with the formation of dental plaque, but microorganisms that form the plaque are mainly Streptococcus mutans and anaerobes, with the composition varying by location in the mouth [5]. It has

long been recognized that the bacteria Streptococcus mutans produces special metabolites called porphyrins. Porphyrins are the native fluorophores that strongly emits red light under UVA excitation. This fluorescence is detected in some studies [6–8, 18, 19]. The denser the bacterial colonization, the more intense the red fluorescent signal will be.

The red fluorescence was also found in more advanced lesions (dentinal lesions) as can be seen in Fig. 6 (sample 3). The caries in of this sample was scored as International Caries Detection & Assessment System Code 6 (extensive distinct cavity with visible dentin). Dental caries, also known as tooth decay, cavities, or caries, is breakdown of teeth due to the activities of bacteria. The mouth contains a wide variety of oral bacteria, but only a few specific species of bacteria are believed to cause dental caries: Streptococcus mutans and Lactobacillus species among them. These organisms break down the hard tissues of the teeth (enamel, dentin and cementum) by making acid from food debris on the tooth surface [4]. As mentioned above, the bacteria Streptococcus mutans produces porphyrins, which have red fluorescence observed in Fig. 6.

However, the caries expression is not always cavitated as in the case of sample 3. The base of a pit or fissure, which is usually the most susceptible to acid attack, often exhibits caries without any visual occlusal evidence other than stain. For example, Fig. 7a presents sample 4 scored as International Caries Detection & Assessment System Code 0 (sound tooth). No mark of caries of this sample was found in lit room with normal white light illumination. However under UVA stimulation a small red spot, with careful attention, was caught. This spot was magnified 10 times for more detailed observation (Fig. 7d) by using a 10x-magnification multiple lens system. Doubting about the presence of a caries hiding under the enamel layer at an early stage, this area was ground from the surface to the dentin layer until the cavity was
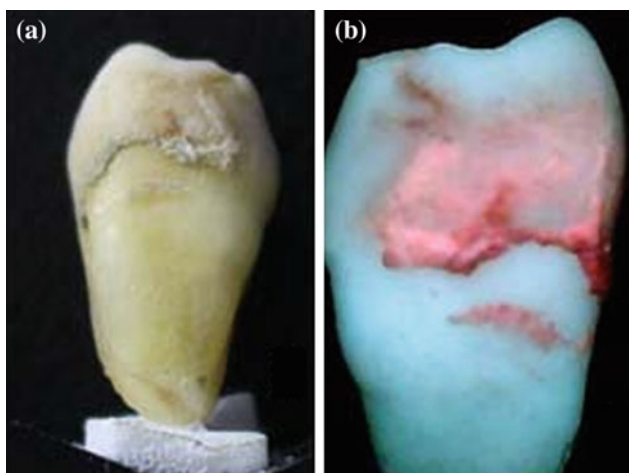

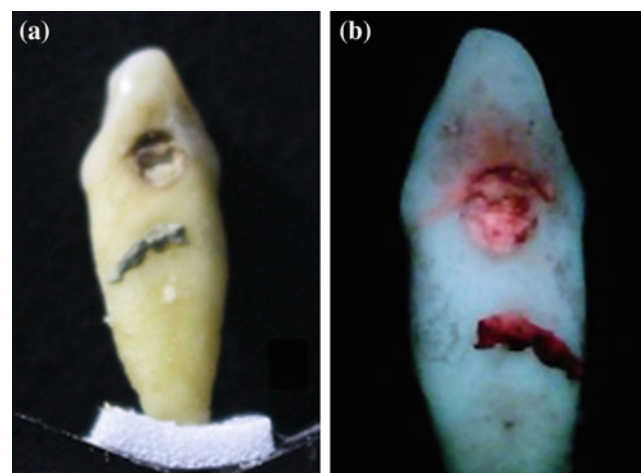Fig. 5 Sample 2: white light image (a), fluorescence image (b)

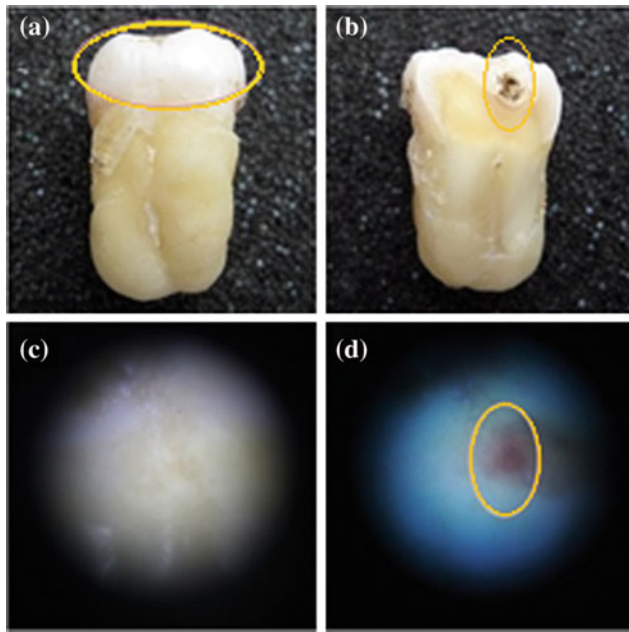Fig. 6 Sample 3: white light image (a), fluorescence image (b)

Fig. 7 Sample 4: white light image before and after grinding (**a**, **b**), magnified white light and fluorescence images before grinding (**c**, **d**)

Fig. 8 Sample 5: white light image (**a**), fluorescence image (**b**)

appeared (Fig. 7b). The result showed not an initial caries but a distinct cavity in the dentin layer.

The question is "Where is this caries cavity from"? Note that the enamel layer (thickness 1–3 mm) is a filtering membrane allowing the transit of substances from the exterior to the interior, and vice versa. These zones allow the flow of acids from bacterial plaque, giving rise to disintegration of the organic material and posteriorly conditioning demineralization of the inorganic component—thus supporting the proteolysis—chelation theory of dental caries. These enamel areas with disintegration of the organic material, and the large structural defects such as cracks, which are rich in organic material, can facilitate the penetration of bacteria into deep areas of the enamel, without the existence of superficial cavitation [20].

The next question is "How can the excited light penetrate into the dentin layerat the depth of about 1–2 mm, and on the other hand, the emission light escape from the tooth surface?". In the visible region, dentin and enamel weakly absorb light and light scattering plays an important role in determining the deposited energy distribution in the tissue [21]. From the tooth surface to the end of enamel layer, the photon density slowly decreases. The fluence at the end of enamel layer is over 95% of the value on the surface. The photons are almost completely absorbed at the depth of 3.7 mm. In the case of sample 4, the caries was found at the depth of 1–2 mm. At this depth, the excited light can completely penetrate into the carious area for stimulating, and vice versa, the emission light can escape to the surface for observing.
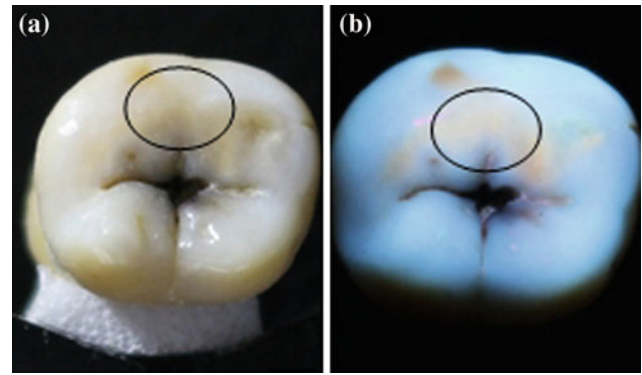
The other interesting tooth (sample 5), presented in Fig. 8, need to be attended. For this sample, in white lighting condition we can see the tooth surface without any damage or plaque, but there was a brownish-yellow area circled in Fig. 8a. When stimulated by 380 nm LED this area showed the reddish color. Brown spots on teeth could be stains, enamel demineralization or they could be a symptom of tooth decay at the early stage. The lesion itself may first become noticeable as a dark spot or blemish that grows in size over time (typically months to years), frequently involving obvious tooth destruction. In this case, reddish color of brown area under 380 nm demonstrates the presence of bacteria, so the symptom of early caries.

4 Conclusion

The aim of the present research was to design a portable device for early diagnosis of dental caries using fluorescence imaging techniques, with small size and can be easily used in oral cavity. This device was used to investigate the fluorescence property of sound and lesion teeth. The test results showed that fluorescence images can give interesting information about hidden caries and caries at the early stage. These results require further investigation, but they show the ability to apply fluorescence technique in the development of a dental diagnostic tool owning a number of advantages such as safety, mobility, low cost and rapid test time.

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6th International Conference on the Development of
Biomedical Engineering in Vietnam (BME6)
Vo, T.V.; Nguyen Le, T.A.; Nguyen Duc, T. (Eds.)
2018, XVII, 945 p. 668 illus., Softcover
ISBN: 978-981-10-4360-4