

Application of Near—Infrared Technique in Studying Dental Lesions

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Abstract

NIR technique depends on scattering and absorption of sound enamel, dentin and damaged tissues in NIR wavelengths. Several researches have indicated that the optical properties of sound and demineralized enamel-dentin in NIR wavelengths are so different. In this study, two optical systems consisting of the transillumination and scattering methods were built to observe the approximal and occlusal of teeth in that order by 850 nm. The NIR images detected from these systems have high contrast. The areas suspected to be the demineralized enamel are distinctly distinguished from the stain and pigmentation because the demineralization areas are a lot darker than the surrounding areas in NIR images. In the clinical examination by using visible light, the early tooth lesions will be difficult to detect if they do not appear on the surface of the tooth. But under NIR illumination, the early tooth lesions are observed clearly in NIR images.

Keywords

Demineralization • Dental • Near-infrared

1 Introduction

Dental lesions are one of the most popular diseases affecting all ages on over the world, especially for children. Dental lesions are formed from a shift in the ecology and metabolic activity of the biofilm, whereby causes an ecological

imbalance in the physiological equilibrium between tooth minerals and oral microbial biofilms by increasing acid concentration ($\text{pH} < 5$) [1]. Some dental lesions like lesions on occlusal surfaces (proximal, buccal and lingual surfaces; cavitation) [2]. Nowadays, the diagnosis for damaged structure of tooth in general and early dental caries in particular are still a challenge for dentistry. Failure to detect dental lesions may leave the clinician with no option but restorative treatment rather than the application of non-invasive measures to reverse or arrest the lesion. Some diagnostic methods of dental lesions including X-rays, clinical visual inspection, caries indicator dyes, fluorescent methods, electrical conductance measurements (ECM), etc., are available.

The visual method is based on the combination of light, mirror, and the probe for detailed examination of every tooth surface, is by far the most commonly applied method in general practice worldwide [3]. With low sensitivity and high specificity, it may be possible to detect noncavitated enamel lesions on the free smooth surfaces (buccal and lingual), most anterior proximal surfaces, and the opening of some fissures [3]. However, this method is not sensitive enough, especially for early lesions and those affecting the proximal tooth surfaces [4].

X-rays is one of the most common diagnostic tool in dentistry. When X-rays pass through the oral cavity, much of the X-rays are absorbed by hard tissues like teeth and bones [3]. The absorbed X-rays will pass through the film or a digital sensor, creation a radiographic image of the tooth. This method makes to observe structure of hard tissue and surrounding soft tissues that cannot be observed by clinical examination methods, for example proximal tooth surfaces. However, this method also produces many adverse effects especially for children and pregnant women by the use of ionizing radiation.

Today, near-infrared method is new research, that is being investigated for the detection of early damages without using of ionizing radiation [5, 6]. NIR method shows tooth structure image detected by NIR camera. The created images

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are based on the optical properties of the tooth due to the transmission, absorption and scattering of dental tissues in NIR wavelength. For enamel, the absorption coefficients are very small in visible light and near [7, 8], while scattering is strong in visible light and weak in NIR [9]. Scattering in enamel decreases, this value is only $2\text{--}3\text{ cm}^{-1}$ at wavelengths 1310 and 1550 nm [8, 9]. It is 20–30 times lower than in visible light [9]. For dentin, the absorption is independent on wavelength in between wavelengths 400 and 700 nm [8]. Dentin strongly absorbs the 543–1060 nm wavelengths [8]. This translates to a mean free path of 3.2 mm for 1310 nm photons, indicating that enamel is transparent in the near infrared [10]. Therefore, near infrared method can observe the tooth structure lesions without the use of ionizing radiation (X-rays).

The damaged tooth structure is mostly demineralized enamel in which mineral density is reduced. Demineralization creates gaps scattering strongly in near infrared at the wall of gaps [10]. For demineralization, the scattering coefficient of demineralized enamel increases by 1–2 orders of magnitude at wavelength 1300 nm [11]. Because of the optical properties difference of sound enamel and demineralized enamel, the contrast between sound enamel and demineralized enamel in the near infrared image is high. In X-rays method, the contrast between sound enamel and demineralized enamel isn't clear [6, 10].

The purpose of this study was to build the optical system observing tooth structure in wavelength 850 nm. Many researches have indicated that wavelength 1300 nm is more effective than 850 nm, it's extinction and absorption of water is nearly 0 cm^{-1} but performance is so hard because of the limited equipment (LED and camera). Therefore, the system used wavelength 850 nm whose extinction is lower than 40 cm^{-1} in enamel and absorption of water is negligible [10]. 850-nm LED and NIR camera are available to get with affordable cost. In this study, the transillumination and the scattering NIR optical systems were designed to record the approximal and occlusal images of teeth.

2 Materials and Methods

2.1 The Transillumination System

The transillumination system shown in Fig. 1 consists of a light source, tooth sample and NIR camera. Approximal image of tooth was observed clearly by this system. transillumination method suits for thin teeth such as incisor and canine. Samples were illuminated at visible light and 850 nm wavelength, operated with an illumination source. In the NIR region, the wavelength and power play an important role in providing image quality. In this study, the 850 nm LED with 3 W power was chosen. An oral camera

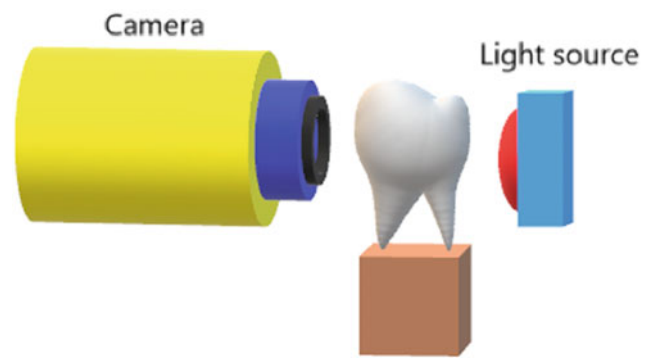


Fig. 1 Schematic diagram of the transillumination system

was used for image acquisition. The camera was connected to computer with USB cable 2.0. The illuminating light intensity and source-to-sample distance ($\sim 1\text{--}1.5\text{ cm}$) were adjusted for each sample to obtain the maximum contrast of images.

2.2 The Scattering System

The optical scattering system is shown schematically in Fig. 2. It consists of light source, specimen and NIR camera. System used two symmetrical light sources on two opposite sides of the sample. Scattering system was used for observing occlusal surface. This method is an effective way to observe molar tooth because of their thickness. Camera was put above the tooth and perpendicularly to the light path. Samples were illuminated in visible and NIR light respectively. The distance between the camera and sample was adjusted to suit each sample. Quality of tooth structure image depends on position of camera, light sources and tooth. Distance between sample and camera is $1\text{--}1.5\text{ cm}$ and light sources was located below the gum line of tooth. Power of light sources are also an important factor. If LED power is too high, the recorded images will be overwhelmed by light and no detail of teeth can be seen. For this system, the power of each LEDs was 1.5 W.

3 Results and Discussion

3.1 Tooth Discoloration

Figure 3 shows the result of a caries tooth specimen with dental discoloration (sample 1) taken by the designed systems. Figure 3a–c show a stained defect that is visible over a large portion of the tooth crown. In contrast, the transillumination image at wavelength 850 nm shows the lesion localized in the red circle (Fig. 1b). The appearance of discoloration on the tooth is caused by many factors such as

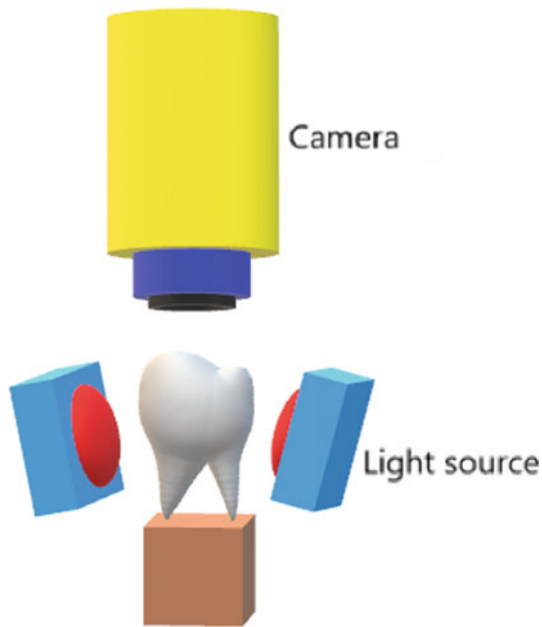


Fig. 2 Schematic diagram of the scattering system

smoking, fluorosis, etc., or demineralization. Smoking or fluorosis origins of stained teeth do not make change in crystal structure of tooth, but demineralization do. Demineralization is the process of removing minerals, in the form of mineral ions, from dental enamel.

As above mentioned, scattering of enamel is strong in visible wavelength region and weak in NIR, thereby increasing the transparency under NIR illuminating. Upon demineralization the scattering coefficient of enamel increases to yield high contrast between sound and demineralized teeth. The more demineralization is, the more scattering is, so the higher contrast between sound and

demineralized teeth is [5]. The images recorded by this method allow differentiating between the various degrees of tooth demineralization because and the contrast in NIR images increases according to the disease evolution.

The similar result of the discolored specimen on the surface is shown in Fig. 4 (sample 2). Inside the enamel, there is a small area showing sign of demineralization. In the clinical visual inspection, the signs of the discolored specimen on the surface are often difficult to be determined due to exogenous factor (cafein, smoking, etc.) or endogenous factors (tetracycline, fluor, demineralization, etc.). This result shows that the NIR method is able to determine exactly the demineralized locations and the early treatment is more effective. The researches show that staining and pigmentation do not interfere with observation in the NIR images, so the demineralization is easily discriminated between stains as well as between pigmentation [6].

3.2 Occlusal Lesions

Figure 5 shows a molar tooth (sample 3) with the occlusal lesion. In the molar tooth, the central and the distal fossae usually are sites that typically accumulate plaque and hence are also sites where caries most often occurs. In general terms, the initiation of occlusal lesion takes place in locations where bacterial accumulations are best protected against functional wear.

In the white light image, it is difficult to locate the position of the demineralization due to the similar color between the sound enamel and the graduation of pigmentation. Under white light (Fig. 5a–c) there is not sign of demineralization. But under NIR, as the red circle in Fig. 5d, a dark area appeared with high contrast that is suspected of the

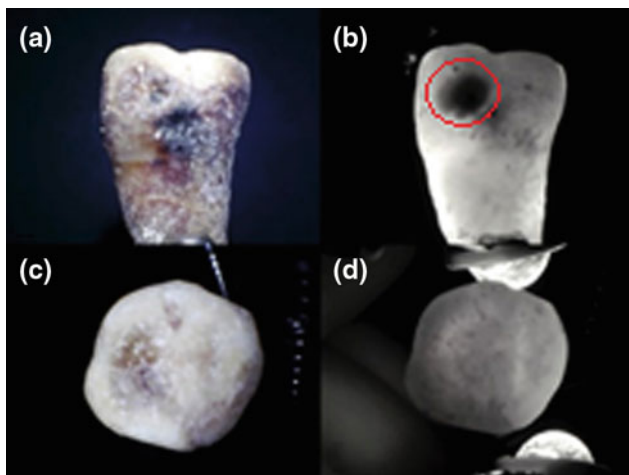


Fig. 3 Sample 1 taken by transillumination system (a–b) and scattering system (c–d) under white (left) and NIR (right) light

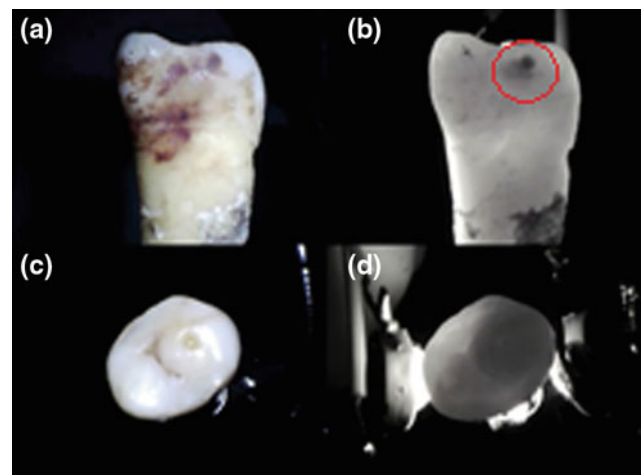


Fig. 4 Sample 2 taken by transillumination system (a–b) and scattering system (c–d) under white (left) and NIR (right) light

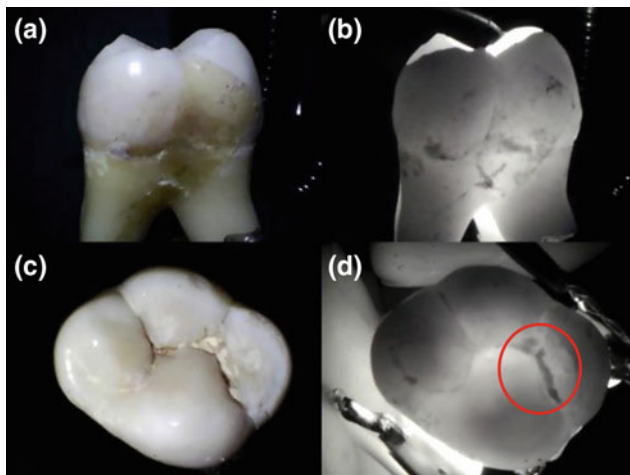


Fig. 5 Sample 3 taken by transillumination system (a–b) and scattering system (c–d) under white (left) and NIR (right) light

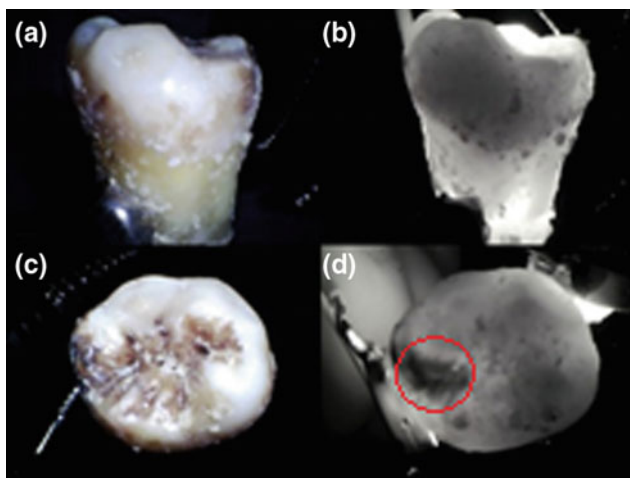


Fig. 6 Sample 4 taken by transillumination system (a–b) and scattering system (c–d) under white (left) and NIR (right) light

demineralization. Demineralization begins at the atomic level at the crystal surface inside the enamel or dentine and can continue unless halted with the end-point being cavitation. There are many possibilities to intervene in this continuing process to arrest or reverse the progress of the lesion. The similar result of the discolored specimen on the surface is shown in Fig. 6 (sample 4).

The radiograph of the tooth is difficult to determine the dental lesions because of the overlapping images of dental tissues in X-rays method [6]. Because enamel is transparent in the near infrared, the occlusal lesions inside the enamel are easily detected without the use of ionizing radiation. NIR method is an effective way to observe entire tooth in general and occlusal surface in particular.

4 Conclusions

This study has designed and built two optical systems with transillumination and scattering techniques using 850 nm LED. These systems were used to observe the approximal and occlusal of teeth and they had the ability to discriminate between the demineralized and discolored tooth. The result shows the possibility to apply NIR technique in the development of a specificity and sensitivity dental screening tool without the use of ionizing radiation. This dental device can support clinician to detect the early dental lesions. In the future, a photo processing software will be built to increase the image quality.

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Conflict of Interest Statement The authors declare that they have no conflict of interest.

References

1. Fejerskov, O., Kidd, E.: *Dental Caries: The Disease and Its Clinical Management*. Blackwell Munksgaard, Oxford (2008)
2. Ferreira, Z.A., Santiago, E., et al.: The natural history of dental caries lesions: a 4-year observational study. *J. Dent. Res.* 841–846 (2012)
3. Booshehry, Z.: Dental caries diagnostic methods. *DJH* 2(1), 1–12 (2010)
4. Marinova-Takorova, M., et al.: Effectiveness of near-infrared transillumination in early caries diagnosis. *Biotechnol. Biotechnol. Equip.* 30, 1207–1211 (2016)
5. Bussaneli, D.G., et al.: Assessment of a new infrared laser transillumination technology (808 nm) for the detection of occlusal caries—an in vitro study. *Lasers Med. Sci.* 30, 1873–1879 (2015)
6. Bühler, C.M.: Imaging of occlusal dental caries (decay) with near-IR light at 1310-nm. *Opt. Express* 13(2), 573–582 (2005)
7. Spitzer, D., et al.: The absorption and scattering of light in bovine and human dental enamel. *Calcif. Tissue Res.* 17, 129–137 (1975)
8. Daniel, F., et al.: Nature of light scattering in dental enamel and dentin at visible and near-infrared wavelengths. *Appl. Opt.* 34(7) 1278–1285 (1995)
9. Jones, R.S., Fried, D.: Attenuation of 1310 and 1550-nm laser light through dental enamel. *Lasers Dent.* VIII, 187–190 (2002)
10. Robert, S.J., et al.: Near-infrared transillumination at 1310-nm for the imaging of early dental decay. *Opt. Express* 11(18), 2258–2265 (2003)
11. Jacob, C.S., et al.: Near-IR transillumination and reflectance imaging at 1300 and 1500–1700 nm for in vivo caries detection. *Lasers Surg. Med.* 48, 828–836 (2016)