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Multispectral Near-Infrared Imaging of Composite Restorations in Extracted Teeth

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Abstract

One major advantage of composite restoration materials is that they can be color matched to the tooth. However, this presents a challenge when composites fail and they need to be replaced. Dentists typically spend more time repairing and replacing composites than placing new restorations. Previous studies have shown that near-infrared imaging can be used to distinguish between sound enamel and decay due to the differences in light scattering. The purpose of this study was to use a similar approach and exploit differences in light scattering to attain high contrast between composite and tooth structure. Extracted human teeth with composites (n=16) were imaged in occlusal transmission mode at wavelengths of 1300-nm, 1460-nm and 1550-nm using an InGaAs image sensor with a tungsten halogen light source with spectral filters. All samples were also imaged in the visible range using a high definition 3D digital microscope. Our results indicate that NIR wavelengths at 1460-nm and 1550-nm, coincident with higher water absorption yield the highest contrast between dental composites and tooth structure.

Keywords

Near-IR imaging; dental enamel; dentin; composite restoration; transillumination

1. INTRODUCTION

Dentists spend more time replacing existing restorations that fail due to microleakage and secondary decay than they do on placing new restorations. Composite restorations are often color matched to the tooth structure, which makes it difficult to differentiate between them. Being able to discriminate between sound enamel, demineralized enamel and composites will allow better discrimination of secondary caries lesions. Therefore there is a need for new imaging tools that are capable of monitoring decay around existing restorations. Light scattering in sound dental enamel decreases markedly in the near-infrared (NIR) region and studies have shown that enamel has the highest transparency near 1310-nm. At this wavelength, enamel is virtually transparent in the NIR, the attenuation coefficient is only 2 to 3 cm⁻¹, which is a factor of 20 to 30 times lower than in the visible region [1]. In addition to the high transparency of enamel in the NIR, there are other important advantages for

imaging dental caries. In NIR images of occlusal surfaces, stains are not visible since the organic molecules responsible for pigmentation absorb poorly in the NIR making it easier to identify areas of demineralization [2]. Dental composites also have unique spectral signatures in the NIR due to combination absorption bands that can be used for differentiation from tooth structure and other types of composites. Dental resins have absorption bands in the near-IR that arise from overtones and combinations of the fundamental mid-IR vibrational bands due to C-H, N-H, and O-H groups in both the resin and water and the most prominent bands lie at 1171, 1400, 1440, 1620 and 1700-nm [3], [4], [5]. Since dental composites contain less water than dental hard tissues and the absorption and scattering properties vary in the NIR, we suspected that the contrast would be greater at longer wavelengths.

At longer wavelengths, water absorption increases significantly and reduces the penetration of the NIR light [6]. Even though the light scattering for sound enamel is at a minimum in the NIR, the light scattering coefficient of enamel increases by 2-3 orders of magnitude upon demineralization due to the formation of pores on a similar size scale to the wavelength of the light that act as Mie scatterers [7]. Caries lesions have been imaged with optimal contrast in previous studies by directing the NIR light below the crown of the tooth while imaging the occlusal surface both *in vitro* and *in vivo* with high contrast. Our current study uses this same approach to investigate optimizing the contrast for composite restorations.

In summary, the objective of this study was to investigate the contrast at three NIR wavelengths 1300, 1460 and 1550-nm between the sound enamel and the composite restoration area and between dentin and the composite restoration area on the occlusal surfaces of molars and premolars. Chung et al. [8], [9] showed the first set of NIR images of composite restorations seen from the occlusal surface; however, this study will be the first to report that the contrast at wavelengths with higher water absorption yielded the highest contrast.

2. MATERIALS AND METHODS

2.1 Sample Preparation

Extracted molars and premolars that contained composite were collected (CHR approved) from oral surgeons in the San Francisco area (n=9) and sterilized with gamma radiation. Criteria for selection included size and visibility of composite, and amount of decay near the composite.

In addition to collecting extracted teeth with composite restorations, sound teeth were selected and placed together in mounting stone to simulate interproximal contacts. The selected teeth in groups of two (n=7) were arranged by position (upper or lower jaw, distal or mesial, left or right side) and orientation (lingual-buccal) and mounted together as they would be positioned in the mouth. Class II preparations were then drilled on one of the teeth for each set of two teeth using high-speed dental burs and filled with Z250 composite (3M, Minneapolis, MN). All samples were then stored in a moist environment of 0.1% thymol to maintain tissue hydration and prevent bacterial growth. In Figure 1, depth composition 2-D images taken with a Keyence VHX-1000 digital microscope are shown for two teeth with

composite restorations. The top image shown has stain in the pit and fissures but since histology was not performed for this study we cannot determine whether the tooth is carious.

2.2 NIR Transillumination Images

In Fig. 2, the imaging setup is shown for the NIR occlusal transillumination. A 150-W fiber-optic illuminator FOI-1 E Licht Company (Denver, CO) with a low profile fiber optic with dual line lights, Model P39-987 (Edmund Scientific, Barrington, NJ) was used with each light line directed at the cemento-enamel junction (CEJ) beneath the crown on the buccal and lingual sides of each tooth. Light leaving the occlusal surface was directed by a right angle prism and images were captured using a 320×240 element SU320-KTSX InGaAs camera equipped with a Navitar (Rochester, NY) SWIR-35 lens, a 75-mm plano-convex lens LA1608-C Thorlabs (Newton, NJ). The band-pass (BP) filters BP1300-90, BP1460-85 from Spectrogon (Parsippany, NJ) and FB1550-40 from Thorlabs were used in this study.

2.3 Digital Microscopy

In order to acquire visible light images, tooth occlusal surfaces were examined using a digital microscopy/3D surface profilometry system, the VHX-1000 from Keyence (Elmwood, NJ) with the VH-Z25 with a magnification from 25 to 175 $\times$. Images were acquired by scanning the image plane of the microscope and reconstructing a depth composition image with all points at optimum focus displayed in a 2D image.

2.4 Image Analysis

A region of interest (ROI), approximately 25×25 pixels were extracted from the NIR images on the occlusal surfaces of an area of sound enamel from the left side and right side of the composite and averaged to obtain an intensity for I_S . An ROI was also taken of the composite region which has a higher intensity and the image contrast was calculated using the equation $(I_C - I_S)/I_C$; where I_S is the mean intensity of the sound enamel, and I_C is the mean intensity of the composite. The image contrast varies from 0 to 1 with 1 being very high contrast and 0 having no contrast. The contrast was calculated for each wavelength. For teeth with composite that extended into the dentin, the same analysis was performed to calculate the image contrast between the sound dentin and the composite restoration. All image analysis was carried out using Igor pro software (Wavemetrics, Inc., Lake Oswego, OR). A one-way analysis of variance (ANOVA) followed by the Tukey–Kramer post hoc multiple comparison test was used to compare groups for each wavelength employing Prism software (GraphPad, San Diego, CA).

3. RESULTS AND DISCUSSION

Figure 3 shows occlusal transillumination images of three teeth taken at three different wavelengths along with the visible reflectance images. The composite is visible with markedly higher contrast at 1460 and 1550 nm. This is likely due to the reduced water content of the composite versus the peripheral enamel and dentin.

Visible images taken using the digital microscope are also shown in Fig. 3. Even after the teeth are air dried and imaged under 25 $\times$ magnification, it is still hard to identify the

composite restorations shown by the yellow arrows. In the occlusal transillumination imaging mode, the composite restoration appear lighter than the surrounding sound enamel. It is very hard to see where the margins of the restoration are in the NIR images acquired at 1300-nm. Staining and discoloration can interfere with imaging in the visible region, however the chromophores responsible for stains in the visible region, do not absorb NIR light and therefore do not interfere at NIR wavelengths. Some of the extracted teeth in the study had staining in the pits and fissure and around the margins of the restorations. Tooth 2 appears to have demineralization in the pit and fissures and tooth 3 has a hidden caries. Tooth 2 is an example of a tooth that has a composite restoration that extends into the dentin and contrast is quite high at 1460 and 1550-nm.

The contrast between tooth structure and composite in transillumination increased with wavelength as shown in Fig. 4 for enamel and Fig. 5 for dentin. In both graphs, the contrast was significantly higher for longer wavelengths 1460 and 1550-nm than for 1300-nm. It is interesting that the contrast between dentin and composite at 1300-nm was negative. The contrast at 1550-nm was higher than at 1460-nm even through the absorption of water is lower at 1550-nm however they were statistically similar.

The improved performance of wavelengths greater than 1400-nm vs. wavelengths for the 1300-nm region is likely due to differences in water absorption between composite and tooth structure. The occlusal surface topography is complex and the optimal illumination geometry for occlusal lesions has not been established. Light entering the tooth near the gum-line enters the dentin where it is highly scattered and can migrate up through the dentin to the crown providing high contrast or it can migrate around the dentin through the more transparent enamel through internal reflection. Increasing the fraction of light diffusing up through the dentin is likely to produce the highest contrast for occlusal lesions. Differences in the optical properties of both enamel and dentin in the NIR profoundly influence that fraction and the distribution of light exiting the crown. Increased absorption by water is expected to decrease the amount of light diffusing up through the dentin.

This study clearly demonstrates that a NIR imaging system has considerable potential for the imaging of composite restorations with high contrast on occlusal surfaces. The NIR wavelengths coincident with higher water absorption yielded significantly higher contrast than other methods. The high contrast between sound enamel and composites suggests that NIR imaging may be advantageous for screening for secondary caries. In addition to the high contrast in this study, another potential advantage NIR imaging has over visible imaging methods and fluorescence-based methods is the lack of interference from stains and discoloration, since stains are not visible in the NIR.

In summary, it appears that NIR wavelengths at 1460 and 1550-nm provided improved contrast performance for the transillumination of occlusal surfaces with composite restorations. In future experiments, both artificial and natural secondary caries lesions around restorations and under sealants will be investigated in reflectance and transmission modes at multiple NIR wavelengths.

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REFERENCES

1. Jones RS, Fried D. Attenuation of 1310-nm and 1550-nm Laser Light through Sound Dental Enamel. *SPIE Proceeding*. 2002; 4610:187–190.
2. Bühler CM, Ngaotheppitak P, Fried D. Imaging of occlusal dental caries (decay) with near-IR light at 1310-nm. *Optics Express*. 2005; 13(2):573–582. [PubMed: 19488387]
3. Li X, King TA. Microstructure and Optical Properties of PMMA/Gel Silica Glass Composites. *Journal of Sol-Gel Science and Technology*. 1995; 4:75–82. 4 75-82 (1995).
4. Venz S, Dickens B. NIR-spectroscopic investigation of water sorption characteristics of dental resins and composites. *Journal of Biomedical Materials Research*. 1991; 25:1231–1248. 25 1231-1248 (1991). [PubMed: 1812117]
5. Stansbury JW, Dickens SH. Determination of double bond conversion in dental resins by near infrared spectroscopy. *Lasers in Dentistry XIV*. 2001; 17:71–79.
6. Hale GM, Querry MR. Optical constants of water in the 200-nm to 200- μ m wavelength region. *Appl. Optics*. 1973; 12:555–563.
7. Darling CL, Huynh GD, Fried D. Light scattering properties of natural and artificially demineralized dental enamel at 1310 nm. *Journal of Biomedical Optics*. 2006; 11(3):34023. [PubMed: 16822072]
8. Chung S, Fried D, Staninec M, Darling CL. Near infrared imaging of teeth at wavelengths between 1200 and 1600 nm. *SPIE Proceeding*. 2011; 7884:78840X, 78841–78846.
9. Chung S, Fried D, Staninec M, Darling CL. Multispectral near-IR reflectance and transillumination imaging of teeth. *Biomed. Opt. Express*. 2011; 2(10):2804–2814. [PubMed: 22025986]

Fig. 1.
Depth composition 2-D images of teeth from the occlusal view using the Keyence VHX-1000E digital microscope (Itasca, IL).

Fig. 2. NIR occlusal transillumination schematic diagram consisting of a (A) SU320-KTSX InGaAs Camera from Sensors Unlimited (Princeton, NJ), (B) interchangeable bandpass filters for 1300, 1460 and 1550-nm, (C) prism, and (D) a tungsten-halogen light source.

Fig. 3.

Images of three teeth with composite restorations shown by yellow arrows. Tooth 1 and 2 have Z-250 composite and the composite used in tooth 3 is unknown. Occlusal transillumination images are shown for visible, 1300-nm, 1460-nm and 1550-nm.

Fig. 4. Mean contrast values between the sound enamel and composite restoration area for (n=16) teeth at 1300-nm, 1460-nm and 1550-nm wavelengths. Statistical groups containing the same color are statistically similar ($P>0.05$).

Fig. 5. Mean contrast values between the sound dentin and composite restoration area for (n =9) teeth at 1300-nm, 1460-nm and 1550-nm wavelengths. Statistical groups containing the same color are statistically similar ($P > 0.05$).