RESEARCH

Evaluation of two imaging techniques: near-infrared transillumination and dental radiographs for the detection of early approximal enamel caries

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Objectives: The aim of this paper was to evaluate a transillumination (TI) system using near-infrared (NIR) light and bitewing radiographs for the detection of early approximal enamel caries lesions.

Methods: Mesiodistal sections of teeth ($n = 14$) were cut with various thicknesses from 1.5 mm to 4.75 mm. Both sides of each section were included, 17 approximal surfaces with natural enamel caries and 11 surfaces considered intact. The approximal surfaces were illuminated by NIR light and X-ray. Captured images were analysed by two calibrated specialists in radiology, and re-analysed after 6 months using stereomicroscope images as a gold standard.

Results: The interexaminer reliability (Kappa test statistic) for the NIR TI technique showed moderate agreement on first (0.55) and second (0.48) evaluation, and low agreement for bitewing radiographs on first (0.26) and second (0.32) evaluation. In terms of accuracy, the sensitivity for the NIR TI system was 0.88 and the specificity was 0.72. For the bitewing radiographs the sensitivity ranged from 0.35 to 0.53 and the specificity ranged from 0.50 to 0.72.

Conclusion: In the same samples and conditions tested, NIR TI images showed reliability and the enamel caries surfaces were better identified than on dental radiographs.

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Introduction

Traditionally, dental professionals rely mostly on subjective interpretation of visual examination with tactile sensation, aided by dental radiography for caries detection.¹ Studies based on these methods often show low sensitivity, meaning that a large number of lesions may be missed.² Sensitivity and specificity are widely used measures to describe and quantify the diagnostic ability of a method.³ Bitewing radiograph for the detection of approximal caries in dentine has high specificity (correctly identified sound surfaces), but the sensitivity (correctly identified surfaces damaged by caries) is highly dependent on the extent of caries damage to the

dentine.^{2,4,5} This is an expected feature, since the greater the mineral loss, the more obvious the contrast on the radiograph between sound and caries tissue. For approximal enamel caries, the sensitivity is low and the lesion size and depth is often underestimated or can even be undetected radiographically.⁶ Furthermore, failure to detect early caries activity may leave the clinician with no option but restorative treatment rather than the application of non-invasive measures to reverse or arrest the lesion.⁴ In low-prevalence populations, only a few per cent of approximal enamel lesions are cavitated. In fact, such screening procedures may do more harm than good, since the predictive value of the positive test decreases significantly with decreasing disease prevalence, leading to overdiagnosis.⁷ Beside the possible hazardous effects of ionising radiation and the unsuitable exposure of radiation for patient groups such as children and pregnant

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women, the subjective judgement of this method is neither quantitative nor sensitive enough to detect early enamel caries lesions.^{8,9}

In the search for more accurate diagnostic approaches, investigators have developed non-invasive methods for early caries detection based on dental tissue optics.^{9–12} Transillumination (TI) of dental enamel with near-infrared (NIR) light is a novel and promising optical imaging technique for detecting the presence of early dental caries lesion and measuring its severity.^{9,13–16} The method is non-destructive, uses non-ionizing radiation and is said to be more sensitive to early demineralization than dental radiography.¹³ Jones *et al*¹⁶ compared NIR (1310 nm) images with radiographic images. Simulated approximal lesions in tooth sections of varying thickness were seen with poor contrast radiographically. However, a clearly demarcated boundary between the simulated lesion and the surrounding healthy enamel was shown with high contrast when illuminated with NIR light. It is easier to detect clear boundaries between an intact and carious tooth using a simulated caries lesion than an irregular object like a natural caries lesion. The aim of this study was therefore to compare the outcome of NIR TI and bitewing radiographs examination when analysing teeth with natural early enamel caries.

Material and methods

Ethics

The study was approved by the ethics committee at the Universidade Federal of Pernambuco, Brazil (268/2007). Premolar and molar teeth ($n = 14$) with natural enamel caries on one or both approximal surfaces were collected at the human teeth bank of the Department of Prosthesis and Dental-Facial Surgery of the Universidade Federal of Pernambuco. The teeth were stored in 0.9% physiological saline to preserve tissue hydration under refrigeration before and during the experiment.

Samples

14 teeth with early natural caries were used in the study. Three of these had caries both near the mesial and distal surfaces. Each tooth had the vestibular and lingual faces cut off with a Low Speed Diamond Wheel Saw (Model 650, South Bay Technology, San Clemente, CA) and discarded. Each tooth was then further thinned down to 1 of the following 14 thicknesses: 1.1 mm; 1.35 mm; 1.6 mm; 1.75 mm; 2.1 mm; 2.6 mm; 2.8 mm; 3.7 mm; 3.75 mm; 4.0 mm; 4.1 mm; 4.3 mm; 4.45 mm; or 4.75 mm. Subsequently, each sample was cut transversely so that the mesial and the distal surface of each tooth could be studied. This resulted in 28 samples (17 with caries and 11 without) distributed in pairs with similar anatomies and thickness dimensions. During the cutting procedure, mechanical measurements with a digital caliper (model

CD – 6 inch PS, Mitutoyo Corporation, Kawasaki, Japan) were performed to ensure that the enamel lesion was located centrally on the approximal surface.

Experimental set up

Based on the methodology described by Jones *et al*,¹⁶ a similar TI system was built at the Optoelectronics and Photonics Laboratory of the Universidade Federal of Pernambuco. The basic experimental scheme is illustrated in Figure 1. The laser light from fibre optics used as an illumination source operated with a 1.28 μm wavelength (super luminescent diode, SLD-571, SUPERLUM, Moscow, Russia) with a maximum output power of 5 mW and a bandwidth of 64.6 nm. Two crossed infrared polarizers were placed to experimentally block out the ambient and other undesirable scattered light from saturating the detector, a charge-couple device (CCD) camera with spectral response characteristic 0.4 μm to 2 μm (MicronViewer 7290A, Electrophysics, Fairfield, NJ). The 32-bit digital images were captured using the software program Spiricon Laser Beam Diagnostics (LBA-PC, Version 2.5, Logan, UT) and analysed with a downloadable image processing program, ImageJ (National Institutes of Health, Bethesda, MD).

The TI image was acquired from both approximal sides of the tooth section using uniform illumination positioned perpendicular to the section. The same procedure was performed by analogue radiography. The film (Ultra Ektaspeed Plus, Kodak, Rochester, NY) was positioned at an angle and distance of about 8 cm that would simulate a clinical bitewing. The radiograph Spectro II (Model 784782m Dabi Atlante, Sao Paulo, Brazil) was adjusted at 15 mA and 5 impulses. The exposed radiographic films were developed using fresh solutions (Revelator and Fixer, Kodak) and after drying positioned on a uniform Negatoscope radiographic film viewer (Tundra, China) and then digitalized with a digital camera (NIKON Coolpix 4500, 4.1 Mp, Japan).

Analysis

Two calibrated specialists in radiology evaluated the NIR images and the radiographs using a qualitative criterion to determine the presence of caries, in which code (1) meant probably no caries, (2) questionable and (3) probably caries. They also tried to analyse the caries lesions depth, according to a criterion in which code (0) meant sound tissue, (1) enamel caries, (2) caries reaching but not crossing the enamel–dentine junction and code (3) caries into dentine. Each approximal face was shown alone to avoid the psychological effect of the neighbouring surface in the moment of assessment. Half of the images were randomly selected and re-examined by the same specialists 6 months later. The samples were then filed down by a diamond saw mounted in a Micro Electrical Motor (Beltec, LB 100 Model, São Paulo, Brazil). The 500 μm sections were analysed using a stereomicroscope (Stemi 2000-C, Carl Zeiss, Göttingen, Germany) and magnification of 150 $\times$ as gold standard.

Figure 1 Near-infrared transillumination set up illuminating a tooth section (C) with a broadband light source (A), crossed linear polarizers (B) and (E), lenses (D) and (F), and Micron Viewer Infrared camera (G). CCD, charge-coupled device

Statistics

The reproducibility was assessed using unweighted Kappa statistics to quantify the level of agreement between the two specialists in radiology. The diagnostic accuracy of the imaging methods was calculated in terms of sensitivity and specificity according to the additional examiner.

Results

Examples of approximal lesions were viewed using the three imaging modalities: (a) NIR TI system, (b) dental radiograph and (c) stereomicroscope (Figures 2 and 3). Figure 2 is an example with enamel caries lesion and Figure 3 shows a sound enamel surface. A clearly demarcated boundary between the lesion and the surrounding healthy enamel was shown in images using the NIR TI in contrast with radiographs, where no lesion was seen.

Both specialists classified the presence of enamel caries as questionable in 32% of the observations of the radiographs. As a comparison, the examiners determined the presence of enamel caries as questionable in 8.9% of the observation when NIR TI images were evaluated.

Table 1 demonstrates unweighted Kappa values and confidence intervals for interexaminer reproducibility, based on caries lesion depth observations. The Kappa statistical test showed moderate agreement in the first evaluation (Ev1) for NIR TI technique and low agreement for radiographs. The second evaluation (Ev2), performed after 6 months, demonstrated similar inter-examiner reliability values. And the intraexaminer reliability also showed similar values for both techniques, with discretely better results in favour of the NIR TI method, presented in the right of Table 1.

The diagnostic ability in terms of sensitivity and specificity of the NIR TI method and dental radiograph is presented in Table 2.

Discussion

The results from this study showed better interexaminer reliability when evaluating NIR TI images compared with dental radiographs for the detection of early enamel caries. The specificity was good, without false-positive answers, even though the observers had no previous experience in analysing images captured with the TI technique. The observers, two specialists in

Figure 2 Natural enamel approximal lesion in a 2 mm section evaluated with: (a) near infra-red transillumination system, (b) dental radiograph and (c) stereomicroscope. The arrow indicates the position of the enamel lesion

Figure 3 Images of intact approximal surface captured with: (a) near infra-red transillumination system, (b) dental radiograph and (c) stereomicroscope

radiology, demonstrated low interexaminer reliability (0.26–0.32) as well as low sensitivity (0.35–0.53) when evaluating radiographic images. This is in agreement with numerous studies where the subjective judgement of this method is reported as being neither quantitative nor sensitive enough to detect early enamel caries lesion.^{15,17–21}

Our results showed better performance for the NIR TI method with a sensitivity value of 0.88 and a specificity of 0.72, which means that the presence of disease is greatly detected. Evaluation based on the radiographs showed unacceptable sensitivity and specificity. The systematic review by Bader and Shugars² rated the strength of the evidence for radiographic method as poor for all types of lesions on posterior approximal and occlusal surfaces. Corroborated with our results for approximal enamel and dentine caries, the radiographs had a mean sensitivity of 0.41 and 0.38, respectively, and a mean specificity of 0.78 and 0.95, respectively. This means a guess would provide the same result when we want to correctly identify an approximal enamel or dentine caries lesion. These findings are also supported by a recent review⁴ where it was concluded that bitewing radiographic diagnoses of approximal enamel and dentine caries show low value of sensitivity (<0.60), while value of specificity for the detection of dentine

caries on approximal surfaces is high (>0.95). This was probably owing to the fact that detection of early enamel caries is poorly shown on radiographic images as a result of the small variation of density in these lesions. Because of low attenuation of radiation in the demineralized zone, the typical radiographic appearance of caries is a radiolucent area; however, 40–60% of tooth decalcification is required to produce the radiographic image.²¹ By the time a lesion is radiolucent, it has often progressed well into dentine, at which point operative restorative dentistry might be needed.

Our results showed that useful images can be obtained when illuminating teeth sections as thick as 4.75 mm. This is in agreement with Jones *et al*¹⁶ who compared NIR (1310 nm) images with those of radiographic images. A clearly demarcated boundary between the lesion and the surrounding healthy enamel was shown with high contrast when illuminated with NIR light, instead of the poor contrast radiographically obtained from the same samples. The authors demonstrated that the NIR TI method was clinically feasible in resolving caries lesions through 5 mm of enamel in the interproximal area. The approximal contact site between teeth is difficult to monitor and the area is also vulnerable to the caries disease.

To study the potential of NIR laser in the diagnosis of early occlusal caries lesions, Bühler *et al*⁹ conducted an

Table 1 Unweighted Kappa values and confidence intervals for interexaminer reliability, and after second evaluation the intraexaminer reproducibility, for each diagnostic methods

	<i>NIR TI Ev1</i>	<i>Radiography Ev1</i>	<i>NIR TI Ev2</i>	<i>Radiography Ev2</i>	<i>NIR TI Ev1/Ev2</i>	<i>Radiography Ev1/Ev2</i>
Kappa	0.55	0.26	0.48	0.32	0.44/0.33	0.11/0.21
<i>P</i> value	<0.001	0.06	0.008	0.04	0.08/0.17	0.63/0.40
95% confidence interval	Upper: 0.81 Lower: 0.28	Upper: 0.55 Lower: −0.01	Upper: 0.69 Lower: 0.04	Upper: 0.52 Lower: −0.14	Upper: 0.94/0.81 Lower: −0.05/−0.14	Upper: 0.60/0.71 Lower: −0.36/−0.28

NIR TI, near-infrared transillumination; Ev1, evaluation 1; Ev2, evaluation 2

Table 2 Performance of the near-infrared transillumination (NIR TI) and dental radiograph systems, in terms of sensitivity and specificity

Detection methods/ imaging methods	Sensitivity		Specificity	
	Ev1	Ev2	Ev1	Ev2
NIR TI	0.88	0.88	0.72	0.72
Radiography	0.35	0.53	0.50	0.72

Ev1, evaluation 1; Ev2, evaluation 2

investigation where imaging reflecting occlusal caries lesions was compared with radiographic imaging. As in the previously mentioned study, the NIR images were found to be superior to those obtained by radiography.

TI of enamel with NIR light is a promising technique for the detection and imaging of occlusal and approximal lesions,^{9,17} *i.e.* surfaces most susceptible to caries.^{22,23} Application of repeatable, non-ionizing radiation of the tooth allows the TI method to be used without restriction to monitor the caries process. The method overcomes some of the limitations of dental radiography such as overlapping. A further advantage is that the method allows the use of miniature or

fibre-coupled light sources and imaging cameras. The TI method uses a range of wavelengths where low-cost light sources are available and the transmitted image can be detected by an ordinary CCD camera, similar to the one in mobile phones. Moreover, the method has the potential to indicate the relative position of an approximal lesion by calculating the ratio of contrast values obtained by illuminating tooth from the lingual or buccal surface, respectively.

Conclusions

This study clearly corroborated that the NIR TI system has considerable potential for imaging early approximal enamel lesions, as already reported in the literature.^{16,18,24} In this study, we demonstrated that the sensitivity and specificity of the NIR TI technique, when compared with radiography, provided very good results. The technique can be useful for early caries diagnosis and patient follow-up, and can improve routine monitoring of enamel lesions during preventive intervention.

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