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Interproximal dental caries detection using Photothermal Radiometry (PTR) and Modulated Luminescence (LUM)

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Abstract. Frequency-domain photothermal radiometry (FD-PTR or PTR) has been used to detect mechanical holes and demineralized enamel in the interproximal contact area of extracted human teeth. Thirty four teeth were used in a series of experiments. Preliminary tests to detect mechanical holes created by dental burs and 37% phosphoric acid etching for 20 s on the interproximal contact points showed distinct differences in the signal. Interproximal contact areas were demineralized by using a partially saturated acidic buffer system. Each sample pair was examined with PTR before and after micro-machining or treating at sequential treatment periods spanning 6 hours to 30 days. Dental bitewing radio graphs showed no sign of demineralized lesion even for samples treated for 30 days. μ-CT, TMR and SEM analyses were performed. Although μ-CT and TMR measured mineral losses and lesion depths, only SEM surface images showed visible signs of treatment because of the minimal extent of the demineralization. However, the PTR amplitude increased by more than 300% after 80 hours of treatment. Therefore, PTR has been shown to have sufficient contrast for the detection of very early interproximal demineralized lesions. The technique further exhibited excellent signal reproducibility and consistent signal changes in the presence of interproximal demineralized lesions, attributes which render PTR a reliable probe to detect early interproximal demineralization lesions. Modulated luminescence was also measured simultaneously, but it showed a lower ability to detect these interproximal demineralized lesions than PTR.

1 Introduction

The diagnosis and or detection of dental caries or tooth decay in the early stage of its formation is quite a difficult and often inaccurate science. There are very few quantitative and valid methods to determine the health and integrity of tooth structure underneath the enamel surface especially in inaccessible interproximal surfaces. Although the rate of progression of carious lesions is on the decline in fluoridated communities, this reduction in smooth surface caries has resulted in a relative increase in the incidence of small lesions in the pits and fissures and interproximal areas of teeth [1] as well as in the incidence of interproximal caries. The detection of early demineralization or carious lesions in interproximal regions or occlusal surfaces is more difficult than readily visible smooth enamel surfaces [2]. The aims of this study were (1) to evaluate the capability of PTR and LUM, which showed highly reliable sensitivity for both

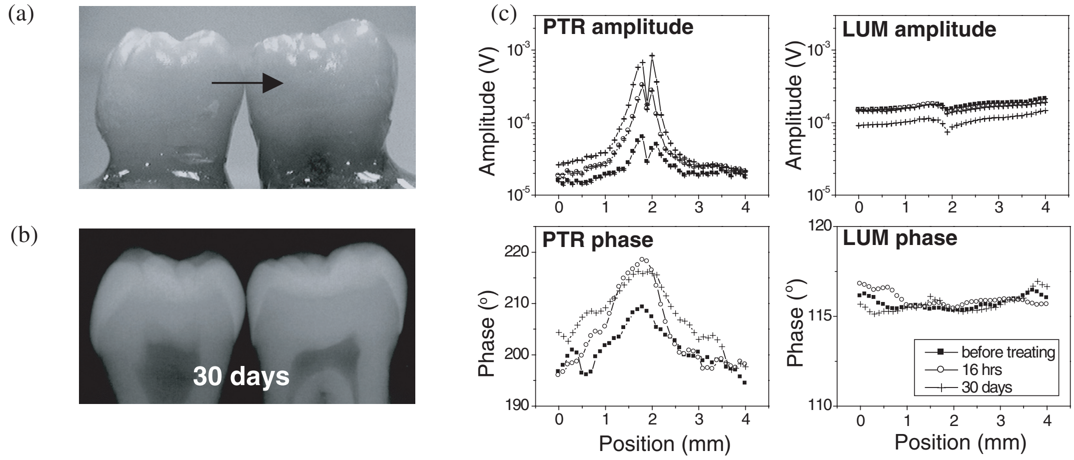

Fig. 1. An interproximal sample with artificial caries created by the buffer solution. (a) Side view of the tooth pair; (b) A radiograph of the tooth pair after 30-days treatment; (c) Interproximal scan results on the buccal surfaces at 30 Hz.

smooth surface and biting surface [3,4], to detect interproximal lesions represented by either mechanically created ∼250 μm-size holes, etched surfaces, or artificial demineralized lesions created by a saturated acidic buffer solution, in the interproximal contact region between two teeth, and (2) to compare the detection capabilities of PTR and LUM with established *in vitro* caries measurement and/or imaging techniques such as micro computed tomography (μ-CT), transverse micro-radiography (TMR) and scanning electron microscopy (SEM).

2 Experimental methods

Seventeen pairs of extracted human teeth were used. Each pair was carefully cleaned with a tooth brush and polishing paste (Temrex), mounted on LEGO blocks (15.8 mm (W) ×15.8 mm (D) × 9.5 mm(H)). Mounting teeth on LEGO blocks allowed the teeth to be separated and remounted into the exact position during repeated measurements.

Two semiconductor lasers with wavelengths 670 nm (450 mW) and 659 nm (80 mW) were used as the sources of both PTR and LUM signals. The modulated infrared PTR signal from the tooth was collected and focused by two off-axis paraboloidal mirrors onto a Mercury Cadmium Telluride detector. For monitoring the modulated luminescence, a photodetector of spectral bandwidth 300 nm ∼1.1 μm was used. Two lock-in amplifiers to measure PTR and LUM signals were connected to, and controlled by, the computer via RS-232 ports.

Preliminary tests to assess the ability of PTR to detect mechanical holes generated by 1/4-round carbide dental burs and 37% phosphoric acid etching for 20 s on the interproximal contact spots were performed. Interproximal caries was simulated by using a partially saturated acidic buffer system consisting of 2.2 mM potassium phosphate, monobasic (KH_2PO_4), 50 mM acetic acid (NaOAc), 2.2 mM of 1M calcium chloride ($CaCl_2$), 0.5 ppm fluoride (F^-), and potassium hydroxide (KOH) for balancing the pH at 4.5. The treated area was approximately 2∼3 mm in diameter and located at the contact point with the adjacent tooth. Each sample pair was examined with PTR before and after micro-machining or treating at sequential treatment periods spanning 6 hours to 30 days.

Three kinds of experiments were performed with each sample: 1) an interproximal scan in which the laser beam scanned samples as approximal pairs at a grazing angle, crossing the contact region on either buccal or occlusal surface; 2) a line scan in which the laser scanned across the treated area of a single tooth under normal incidence; and 3) a frequency scan, which measured the PTR and LUM signals at the center of the treated area by varying the frequency from 1 Hz to 1 kHz. The frequency range was segmented into 40 equal intervals on a logarithmic scale by a data acquisition computer program and the frequency was automatically incremented to the next value after each measurement. There was a 15 s time delay between measurements at successive frequencies to allow for thermalization of the tooth surface, the latter being necessary for stabilizing the signals. Regarding reproducibility, we measured a sample pair once, removed it from the stage, put it back on the stage and measured again. The four signals (PTR amplitude and phase, LUM amplitude and phase) showed 99.92∼100% of reproducibility.

After completing all the experiments, μ-CT, TMR and SEM analyses were performed to compare and correlate the PTR signals to depth of lesions and density changes.

3 Results and discussions

Mechanical holes and phosphoric acid etched enamel surfaces in the interproximal region, which are too small to appear in dental radiographs, exhibited clear differences in PTR signals. Modulated luminescence was also measured simultaneously, but it exhibited a lower degree of contrast to these interproximal lesions and stronger dependency than PTR on factors affecting wider enamel regions than the treated interproximal spots, possibly factors such as the hydration state of the surface. The demineralized interproximal lesions created by a saturated acidic buffer after continuous exposure from 6 hours to 30 days were examined by PTR and LUM. The PTR amplitude increased more than 300% after treatment with the acidic buffer for 80 hours and the PTR phase also changed 5∼13 degrees at 30 Hz as shown in Fig. 1. Dental bitewing radiographs were also taken to determine whether X-rays could identify these demineralized lesions as well, but they showed no sign of lesion even for samples treated for 30 days. After completing all the experiments, μ-CT, TMR and SEM analyses were performed to compare and potentially correlate the PTR signals to depths of lesions and density changes. Only SEM images of the treated surface showed slight changes, while cross sectional images showed no visible lesions. The mineral losses computed by TMR and the measured TMR lesion depths did not show clear correlation with total treatment time. PTR results yielded good correlation with independent μ-CT mineral loss measurements (correlation coefficient: 0.71).

4 Conclusions

Frequency Domain Photothermal Radiometry (FD-PTR) has been assessed to be capable of detecting artificial interproximal mechanical defects and demineralized lesions in human teeth. PTR has been shown to have the potential to be a reliable non-invasive tool for the detection of early interproximal demineralized lesions, which cannot be detected by conventional dental X-rays. Modulated luminescence was also measured simultaneously, but it showed a lower ability to detect these interproximal demineralized lesions than PTR.

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