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Dental depth profilometric diagnosis of pit & fissure caries using frequency-domain infrared photothermal radiometry and modulated laser luminescence

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Abstract. Non-intrusive, non-contacting frequency-domain photothermal radiometry (FD-PTR or PTR) and frequency-domain luminescence (FD-LUM or LUM) have been used with 659- nm and 830-nm laser sources to detect artificial and natural sub-surface defects in human teeth. Fifty-two human teeth were examined with simultaneous measurements of PTR and LUM and compared to conventional diagnostic methods including continuous (dc) luminescence (DIAGNOdent), visual inspection and radiographs by calculating sensitivities and specificities. With the combined criteria of four PTR and LUM signals (two amplitudes and two phases), it was found that the sensitivity of this method was much higher than any of the other methods used in this study, whereas the specificity was comparable to that of dc luminescence diagnostics. Therefore, PTR and LUM, used together as a combined technique, have the potential to be a reliable tool to diagnose early pit and fissure caries and could provide detailed information about deep lesions with its depth profilometric character. Also, from experiments with natural or artificial defects, some depth profilometric characteristics were confirmed.

1. INTRODUCTION

Over the last few decades with the widespread use of fluoride, the prevalence of caries, particularly smooth surface caries has been considerably reduced and this has resulted in an increase in the proportion of small lesions in the pits and fissures of teeth[1]. The development of a non-invasive, non-contacting technique or instrument which can detect early demineralization on or beneath the enamel surface is essential for the clinical management of this problem. The use of lasers for dental diagnostics is considered to be promising, mainly through the phenomenon of laser-induced fluorescence in the enamel or fluorescence caused by porphyrins present in carious tissue[2-4]. The first attempt to apply the depth profilometric capability of frequency-domain laser infrared photothermal radiometry (FD-PTR) toward the inspection of dental defects was reported by Mandelis et al.[5] and Nicolaides et al.[6] and was recently reviewed by Mandelis[7]. In this study, fifty two human teeth were examined to evaluate the diagnostic capabilities of FD-PTR and FD-LUM and compared to DIAGNOdent as well as to visual inspection and radiographs. After the measurements were completed, the teeth were sectioned and histological findings were used as the gold standard to calculate and compare the sensitivity and the specificity of all the diagnostic methodologies used in this study. Also, various natural defects have been examined with this technique. In order to investigate whether an artificially drilled hole can influence either the PTR or the LUM signals, spatial scans on a side surface of a tooth were performed with a 659-nm laser at 5 Hz after gradual drilling of a hole from the opposite side.

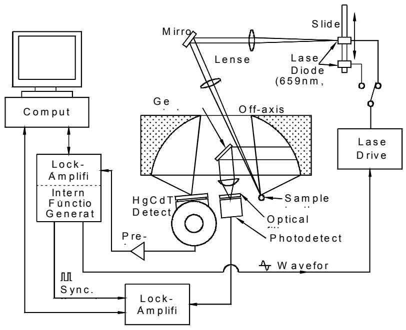

Figure 1. PTR and LUM experimental set-up for dental depth-profilometric diagnostic inspection.

2. EXPERIMENTAL METHOD

Fifty two extracted human teeth were evaluated. The total measurement sample finally consisted of 332 points, including 104 healthy points, 176 fissures on the occlusal surface, and 52 healthy points on the smooth surfaces of the teeth. The experimental set-up is shown in Fig. 1. In order to compare our experimental results to other clinical methods, 5 dentists examined and ranked the set of teeth by visual inspection and radiographs. DIAGNOdent (KAVO) measurements were also obtained from the occlusal surfaces of the teeth. Two semiconductor lasers with wavelengths 659 nm and 830-nm were used as the sources of PTR signals and LUM signals (830-nm laser only). 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. To build up signal statistics, at each measurement point, a frequency scan was performed measuring the PTR and the LUM signals by varying the frequency from 1 Hz to 1 kHz while the depth profilometric experiments were performed by moving a sample along any axis at a fixed frequency. All signals were maximized by rotating the surface of the tooth exposed to laser light so that the incidence was nearly normal to the surface. After all the measurements were finished, the teeth in our sample were sectioned and photographed with the CCD camera directed perpendicular to the surface at each measurement point. The photographs of the sectioned teeth were examined and ranked.

3. RESULTS

3.1 Statistical approach

In order to assess PTR and LUM as caries diagnostic techniques and compare them (combined and separately) to other conventional probes, sensitivities and specificities were calculated at two different thresholds (D_2: enamel caries) and (D_3: dentin caries) for all the diagnostic methods. To create suitable criteria for assessing the carious state via PTR and LUM, the general characteristics of the respective signals and their converting equations were used. Those characteristics were established from the experimental results of the frequency scans with carious and healthy tooth samples. The results of the statistical analysis are given in Table 1.

3.2 Depth profilometric experiments

In order to examine whether an artificially drilled hole can influence either the PTR or the LUM signals, or both, spatial scans on a side surface of a mandibular molar were performed with the 659-nm laser at 5 Hz after gradual drilling of a hole from the opposite side. The PTR amplitude and phase changed greatly when the first hole was made. The distance from the scanned surface to the bottom of

Table 1. Sensitivities and specificities at the caries level of enamel (D_2) and the caries level of dentin (D_3) for various examination methods.

Examination method	Sensitivity threshold (D_2/D_3)	Specificity threshold (D_2/D_3)	Size of sample (# of points)
PTR and LUM combined	0.81 / 0.79	0.87 / 0.72	280
PTR only	0.69 / 0.52	0.86 / 0.72	280
LUM only	0.61 / 0.58	0.81 / 0.77	280
Visual Inspection	0.51 / 0.36	1.00 / 1.00	52
Radiograph	0.29 / 0.36	1.00 / 0.85	52
DIAGNOdent	0.60 / 0.76	0.78 / 0.85	131

the drilled hole after the first drilling was approximately 5 mm. it was very likely caused by drilling out a large dark area (dentin very close to the pulp chamber) in the middle of the tooth. The LUM amplitude and phase also showed substantial differences after the first drilling, consistent with the removal of a luminescent source, albeit with less contrast than the PTR signals. With these results, it was concluded that PTR and LUM are able to detect sub-surface defects or changes in mineralization with sharp boundaries at depths greater than 5 mm, with PTR exhibiting superior sensitivity and contrast to both the presence of, and changes in, the sharp boundaries, as well as changes in mineral content of the tooth. Some natural defects such as a deep sub-surface carious lesion in dentin and a crack have been shown to be detected by this technology. Also more penetrating laser radiation at 830 nm exhibits better PTR resolution and contrast of scanned sub-surface carious features than 659-nm radiation at some expense of signal magnitude and signal-to-noise ratio at high frequencies. The imaging potential of the same features using LUM was shown to be less promising.

4. CONCLUSIONS

The combined information from four PTR and LUM signals (two amplitudes and two phases), including the availability of detailed frequency response curve shapes over a wide range of modulation frequencies, was used to examine a large number of spots (280) representing fifty two teeth. This yielded a statistical sensitivity higher than any of the other methods used in this study, and a specificity comparable to that of dc luminescence diagnostics. PTR depth profilometric capability within depths at least 5 mm below the enamel surface was demonstrated by means of artificial sub-surface hole drilling.

It is concluded that combined PTR and LUM have excellent potential to become a sensitive, non-intrusive, depth-profilometric dental probe for the diagnosis of near-surface or deep sub-surface carious lesions.

Acknowledgments

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