# Detection of Dental Secondary Caries Using Frequency-Domain Infrared Photothermal Radiometry (PTR) and Modulated Luminescence (LUM)

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## Backgrounds

### Dental Caries:
- Also known as tooth decay or cavity
- A bacterial infection that causes demineralization of hard dental tissues by producing acid by hydrolysis of the food debris accumulated on the tooth surface

### Dental Secondary Caries:
- **A form of dental caries; it occurs between the marginal interface of the tooth and the existing restoration [1-2]**

### Photothermal Radiometry (PTR):
- Based on modulated thermal infrared response of a medium
- Radiation absorption → non-radiative energy conversion → temperature rise [3]
- Sub-surface information about an opaque medium well beyond the range of optical imaging [3]

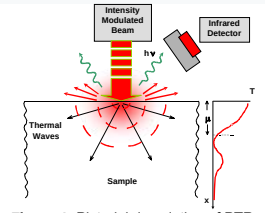

**Figure 1**. Pictorial description of PTR

### Modulated Luminescence (LUM):
- Based on optical-to-radiative energy conversion
- Absorption of optical energy → excitation of chromophores to a higher-energy state →de-excitation of chromophores to a lower energy state → emission of longer wavelength photons
- Complementary channel to PTR

## Research Motivation

### Conventional diagnosis techniques of secondary caries:
**Visual inspection, dental probing, and x-ray**
- Very crude tool with low sensitivity and specificity
- No quantitative evaluation is available
- Diagnosis of dental secondary caries is the principal cause of restoration failure/replacement [4]

➢ **Development of novel technologies for secondary caries detection is highly desirable**

## Research Objectives

- **To investigate the ability of PTR-LUM system to detect dental secondary caries at an early stage**

➢ Investigate the signal behaviour upon progressive demineralization / remineralization of the localized spot on the sectioned vertical tooth wall surface

## Methods

### Sample Preparation:
- Several extracted human teeth (free of cracks, stains, Brown/white spots) → Vertically sectioned and mounted on a LEGO block (Figure 2) → Stored in a humid container to prevent dehydration

**Figure 2**.

### Demineralization / Remineralization:

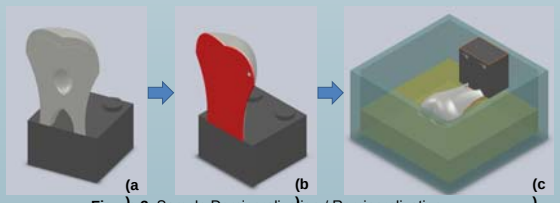
(a) (b) (c)

**Figure 3.** Sample Demineralization / Remineralization

- A mask (red UPVC tape in Figure 3b) with a hole-opening on the sectioned vertical tooth surface → Solution applied to the opened area of the surface (Figure 3c)

### Experimental Set-up:
- Infrared laser source: a semiconductor laser diode (λ = 660 nm; max. power = 130 mW)
- Software lock-in amplifier modulates the laser current
- PTR-LUM Signal is focused by two off-axis paraboloidal mirrors and collected at detectors

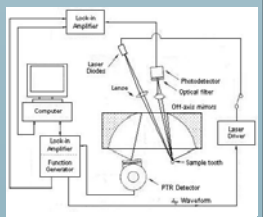

**Figure 4.** Schematics of the set-up.

### Measurement (PTR-LUM scan):
- **Line / frequency scans** were conducted at several stages of demineralization and remineralization (before demineralization → after 1, 2, 3, 5, 7, 10, and 14 days of demineralization → after 1, 2, 3, 4, and 6 weeks of remineralization)
- **Line-scan**: measures PTR-LUM signals along spatial coordinate at fixed frequencies (2Hz for PTR and 200Hz for LUM)
- **Frequency-scan**: measures frequency dependence of PTR-LUM signals at some fixed positions (at interfacial edge, 100 μm away from the edge, and 2 mm away from the edge)

## Results

### PTR-LUM signal behavior upon progressive de/remineralization:

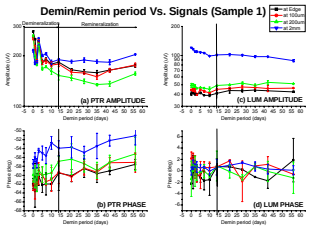

**Figure 5**. PTR-LUM scan at fixed positions after each de/remineralization period.

- **PTR Amplitude** (Figure 5a): Decreased upon demineralization; Delayed upward trend upon remineralization
- **PTR Phase** (Figure 5b): Slightly increased upon de/remineralization
- **LUM Amplitude** (Figure 5c): Slight downward trend upon de/remineralization

### Line Scans:

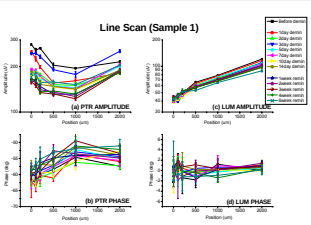

**Figure 6.** Line scan data obtained after each de/remineralization period

- **PTR Amplitude** (Figure 6a): Decreased upon demineralization; Increased upon remineralization
- **PTR Phase** (Figure 6b): Increased upon de/remineralization
- **LUM Amplitude** (Figure 5c): Decreasing trend upon de/remineralization

➢ Consistent results with Figure 5

### Frequency Scans:

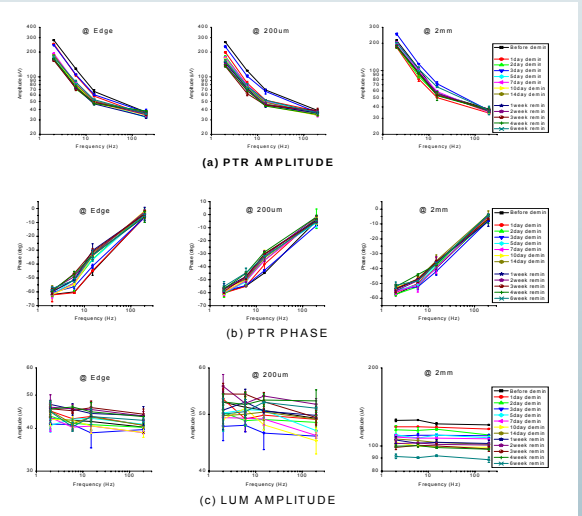

**Figure7.** Frequency scan data obtained after each de/remineralization period

- **PTR Amplitude / Phase** (Figure 7a and 7b):
  - Converge above 100 Hz, i..e. they become less sensitive or insensitive to the condition of the vertical wall above 100 Hz
- **LUM Amplitude** (Figure 7c):
  - Decreasing pattern at excitation/probe distances larger than 200 μm away from the edge upon de/remineralization
  - Slightly decrease upon demineralization and slightly increase during the subsequent remineralization in locations close to the edge (up to ~200 μm)

➢ Probing closer to the vertical surface undergoing localized de/remineralization enhances PTR and LUM sensitivity to these processes

## Conclusions

Progressive demineralization and remineralization resulted in changes in PTR-LUM signals in a certain pattern

➢ **It was demonstrated that PTR-LUM has the ability to sense localized spot demineralization and remineralization on a section of the vertical wall of teeth**

## References

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[4] Hickel R, Manhart J (2001). Longevity of restorations in posterior teeth and reasons for failure. *The journal of adhesive dentistry* 3(1):45-64