Long-wave and mid-wave photothermal coherence tomography imaging of human teeth

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Enhanced truncated-correlation photothermal coherence tomography (eTC-PCT) using mid-wave infrared (MWIR) cameras (spectral range 3-5 μm) has recently been shown to offer tomographic visualization of early dental caries. However, it has been theorized that long-wave infrared (LWIR) eTC-PCT systems may offer better tomographic performance by taking advantage of the intrinsic attenuation of direct radiative emission by dental enamel in the LWIR spectral range (8- 14 μm), enabling more effective delayed conductive thermal contributions from subsurface caries. In this study, we compare the performance of LWIR and MWIR eTC-PCT systems for detecting natural caries, bacterial caries, and artificially demineralized enamel surfaces. The comparative results show that the LWIR eTC-PCT system provides 3D visualization of early caries and internal micro-cracks similar to those obtained from the MWIR-based eTC-PCT system, albeit with ~1.3 dB lower signal-to-noise ratio.

Background – The infrared transmission spectrum of human enamel shows that the enamel is significantly more opaque in the long-wave infrared band (8-14 μm) compared to the mid-wave infrared band (3-5 μm). Therefore, direct radiative transfer competes with conductive heat transfer in MWIR while the conductive heat transfer is more dominant in LWIR. For tomographic imaging, direct radiative emissions are unwanted as they are instantaneous/in-phase, possibly dominating the delayed and depth-dependent conductive thermal contributions of defects. 3D tomographic visualizations of dental caries using a MWIR camera and an eTC-PCT system have been frequently reported; however, tomographic imaging using a LWIR eTC-PCT system has not yet been explored. Therefore, the purpose of this study is to assess the performance of LWIR eTC-PCT in detecting dental caries and compare this modality to conventional MWIR eTC-PCT.

Methods – We adopted the same experimental setup and eTC-PCT data processing software as thosereported in [1]. LWIR and MWIR eTC-PCT systems featured similar configurations and components but were equipped with a LWIR and a MWIR camera each, as the goal was to study the eTC-PCT image characteristics in the mid-wave and long-wave IR spectral emission regions corresponding to the spectral responses of the two cameras. Three dental samples: one with natural caries and an internal crack, one with bacterial caries, and one with an artificially demineralized enamel surface were tested. 2D slice-by-slice images were extracted from the amplitude and phase channels and compiled to yield 3D images of the samples. Then, the 3D images obtained from both LWIR and MWIR systems were compared.

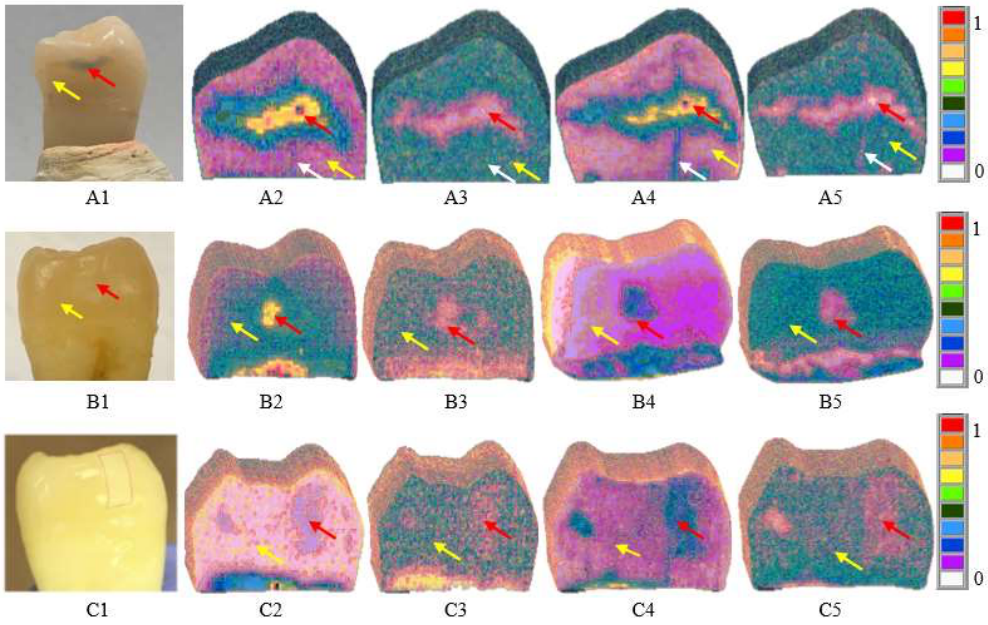

Fig. 1. Panel 1 shows photographs of dental samples with natural caries (A1), bacterial caries (B1), and an artificially demineralized surface (C1). Panels 2 and 3 show the 3D visualization of these samples with the LWIR eTC-PCT imager in the amplitude and phase channels, respectively. Similarly, Panels 4 and 5 correspond to the 3D visualization with the MWIR eTC-PCT imager.

Results – The 3D reconstructed images of the dental samples are shown in Fig. 1. The defective regions, such as natural caries, bacterial caries, and artificially demineralized surface (shown by red arrows in Panel 1), are clearly distinguishable from the corresponding intact areas (yellow arrows in Panel 1) in both 3D reconstructed images, amplitude (Panel 2) and phase channels (Panel 3) of the LWIR eTC-PCT imager; and amplitude (Panel 4) and phase (Panel 5) channels of the MWIR eTC-PCT imager, respectively. The carious regions are visible in both 3D amplitude and phase images. However, the amplitude channel reveals higher contrast compared to the phase channel. The hidden crack (white arrow in natural caries in Panel A) is shown in both the LWIR and MWIR systems; however, the MWIR system exhibits clearly higher contrast and "crisper" features compared to those obtained with the LWIR system.

Conclusions – The LWIR eTC-PCT imager provides 3D visualization of early caries and micro-cracks similar to those obtained from (the more expensive) MWIR eTC-PCT imager at the cost of lower SNR and spatial resolution of small size flaws and lesions. The carious sites are more prominently revealed in the 3D images compared to visual inspection. A hidden crack invisible under visual inspection was made visible in the 3D reconstructed images. While MWIR eTC-PCT imagers provide optimal imaging quality, contrast and resolution of dental lesions with superposed radiative and conductive photothermal image capability, LWIR eTC-PCT imagers can serve as a lower-cost purely conductive imaging alternative for the slice-by-slice detection of dental caries at different depths and 3D visualization of caries.

References

[1] S. Roointan et. al. 3D dental subsurface imaging using enhanced truncated correlation-photothermal coherence, Nature Sci. Rep. 9:16788 (2019) 1-12.