# Multispectral pulse truncated-correlation photothermal coherence tomography with applications to dental imaging

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**Background** – Enhanced Truncated-Correlation Photothermal Coherence Tomography (eTC-PCT) is a dynamic frequency-domain imaging modality which is a promising technique for non-invasive biomedical imaging and for non-destructive testing of industrial materials. Various implementations of eTC-PCT method are possible. For example, an original embodiment of eTC-PCT [1] uses an 808-nm diode laser as excitation source. To obtain molecular specificity in biological samples we introduced multispectral (MS) TC-PCT that employs a Nd:YAG pulsed laser which pumps an optical parametric oscillator (OPO) for wavelength tunability. This work investigates the detection of early stage caries in photothermal images of teeth using MS TC-PCT. Our results have shown that near-surface and deep subsurface features can be imaged, thereby making MS TC-PCT a promising modality for further applications to hard tissue imaging.

Thermophotonic imaging takes advantage of the optical-to-thermal IR photon energy conversion and detection from samples, captured by a mid-infrared (MIR) camera. Detection of depth-integrated distributions of energy is a characteristic of the parabolic nature of diffusion-wave fields which results in poor axial resolution [2]. The eTC-PCT technique [1] overcomes the depth-integrated nature of thermophotonic technologies by using chirped or single pulse excitation with an 808-nm CW diode laser and cross-correlating the photothermal transient signals captured by the MIR camera with the in-phase and quadrature reference signals. The resulting cross-correlation is then truncated based on a time gating filter. eTC-PCT analysis provides two main output channels: amplitude and phase. MS TC-PCT is an extension of eTC-PCT whereby choosing the wavelength of the incident optical pulses, spectroscopic amplitude and phase images can be obtained at different wavelengths, generating molecularly specific thermophotonic diagnostics.

**Methods** – MS TC-PCT uses a Q-switched Nd:YAG laser (Surelite OPO Plus SLIII-10, Continuum, San Jose, United States) which generates 5-ns laser pulses at 10 Hz repetition rate which is the frequency of its flashlamp discharge. The laser output is frequency doubled to 532 nm, which then pumps an OPO tunable from 675 to 1000 nm. A MIR camera (A6700sc, FLIR, USA, 3–5 μm spectral response) records the thermal evolution of the sample following the laser irradiation. A function generator (Agilent 33220A, USA) captures the electrical pulse from the laser and records it using a high-speed data acquisition module (NI PCI-6281) for synthesizing the reference signal. The details of image reconstruction technique can be found elsewhere [1]. Briefly, the resulting eTC-PCT cross-correlation is truncated using a time gating filter which is calculated based on a user defined slice width and

millisecond delay incrementation. eTC-PCT software reconstructs the depth distribution of photothermal parameters from its main output channels.

**Results** – Figure 1(a) shows a human tooth with early caries. Figs. 1(b)-(c) show the MS TC-PCT amplitude and phase reconstructions of the tooth at single repetition frequency of 0.5 Hz, and at OPO wavelengths 532 nm, 675 nm, 700 nm, 750 nm, 808 nm, 850 nm, and 900 nm. In the amplitude images, the shorter wavelengths such as 675 nm and 700 nm show the demineralized area with finer details as compared to longer wavelengths (e.g. 808-900 nm) as they capture shallow features such as caries due to the shorter thermal diffusion lengths. Regarding the 532-nm images, the caries appears noisier and this can be due to the highly scattered incident photons at that wavelength which tend to also highlight other built-in near-surface natural tooth inhomogeneities. In the phase images, it can be seen that features such as the borders of the of the tooth are much less pronounced which is due to the phase channel containing almost purely thermal information subject to lateral diffusion. The phase images at 675 nm, and 700 nm show a highly detailed reconstruction of the anatomy of the caries.

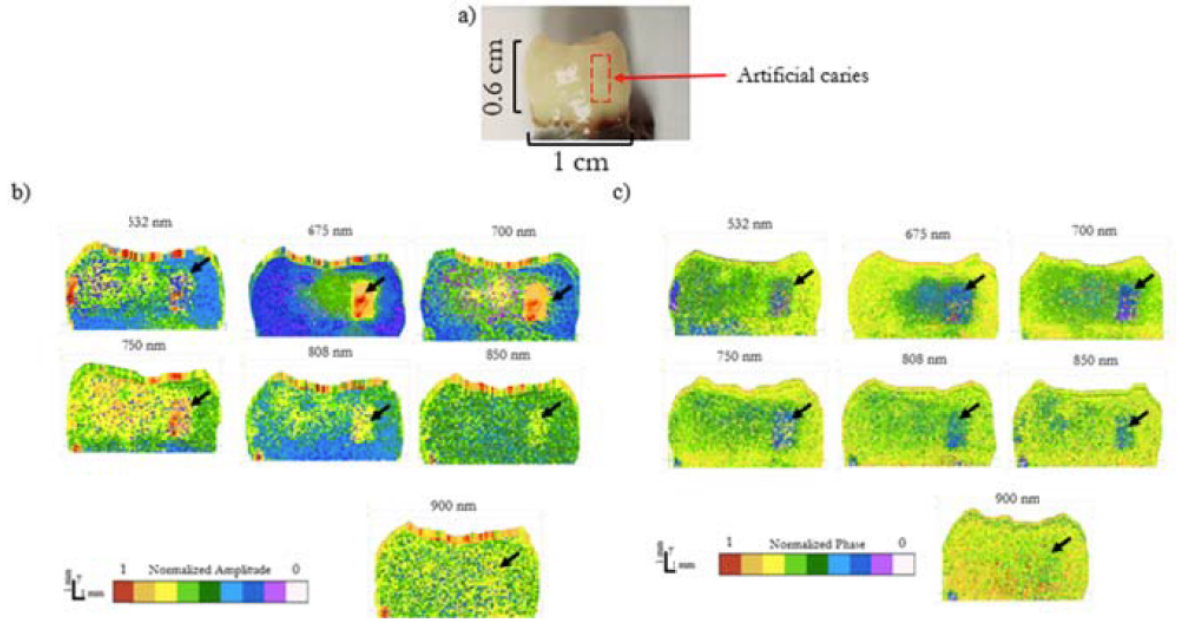


**Fig. 1. (a)** Tooth sample with caries, **(b)** 3D eTC-PCT amplitude and **(c)** phase reconstruction of a carious lesion in a tooth sample taken at 0.2 Hz at pulsed Nd:YAG laser OPO wavelengths 532 nm, 675 nm, 700 nm, 750 nm, 808 nm, 850 nm, and 900nm. The carious lesion is shown by a black arrow in each reconstruction.

**Conclusions** – This research reported on the implementation of a MS TC-PCT imaging modality and explored its application to dental caries diagnosis. MS TC-PCT allows one to choose the excitation and detection wavelengths with optimal contrast and resolution based on the tissue-light scattering phenomena in biological samples.

## References

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