Interference-free Detection of Atherosclerotic Plaques by 3D Co-registration Imaging of Frequency-Domain Differential Photoacoustic and Ultrasound Endoscopic Radar

Sean Choi, Bahman Lashkari and Andreas Mandelis

Department of Mechanical & Industrial Engineering

UNIVERSITY OF TORONTO | Engineering

CADIPT

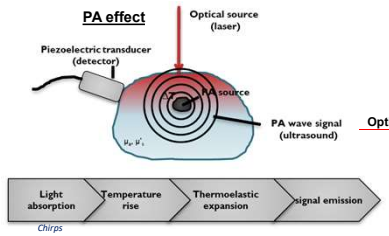
Introduction / Overview

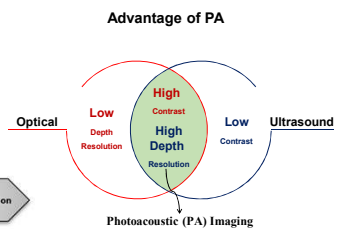
Photoacoustic (PA) radar

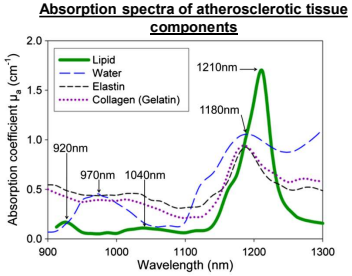
- PA Radar (PAR) is the depth resolved PA
- PAR imaging has higher contrast, higher depth resolution than conventional optical imaging and ultrasound imaging
- Amplitude: directly provides magnitude and depth information of the subsurface light-tissue interaction.
- P-ISDV: provides statistical information about the presence of the target at the corresponding depth.
- PFA: encodes statistical information of P-ISDV on amplitude to further enhance contrast and axial resolution of the signal.

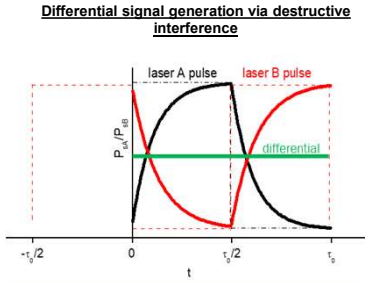
Principle of differential PAR

- λ_1 = 1210 nm and λ_2 = 980 nm are simultaneously modulated with identical chirp waveforms with ~ 180º phase difference (ΔP).
- Amplitude ratio (R) between the two resulting PA waves is adjusted to be ~ 1 against non-target sources.
- Noise and undesirable absorptions are highly suppressed to ~ zero baseline, resulting in high sensitivity, specificity and accuracy

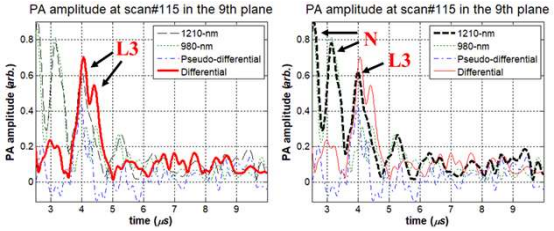




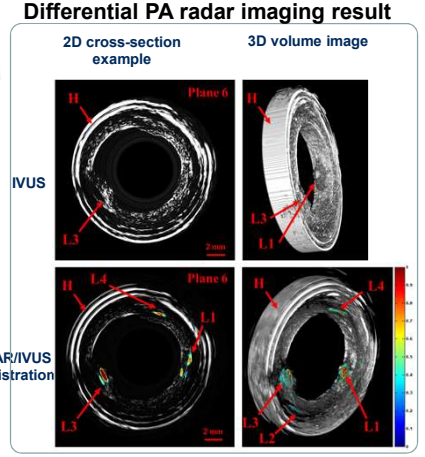




Major Outcomes/Results/Impact



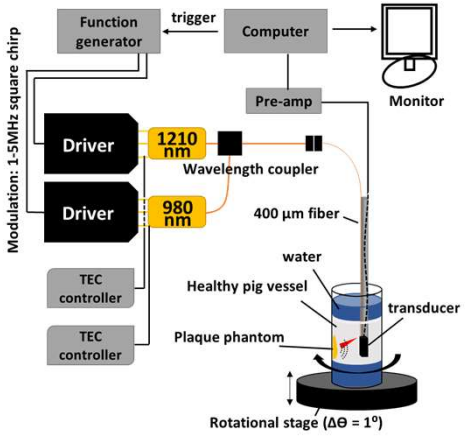
- At this measurement location, L3 is located adjacent to strong system RF noise (N).
- Differential PA mode (red) specifically detects front and back surfaces of L3.
- Single-ended PA mode (black) fails to detect all cholesterol peaks due to the presence of nearby noise and undesirable interference with it.



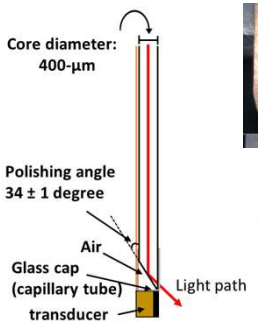
- IVUS sees H (sample holder), L1 and L3 by morphology, but fails to provide depth distribution of cholesterols.
- IV-DPAR mode (PFA channel) detects all plaque-mimicking lumps with great sensitivity and specificity regardless of cholesterol injection amount and depth.

Methods: Wavelength-modulated differential PAR (WM-DPAR)

Set-up



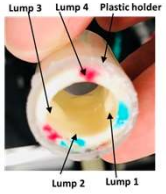
Catheter tip



Endoscopic transducer

- 1.5 X 1.5 mm element
- 4-MHz center frequency
- To be miniaturized further

Sample



- Porcine artery with four micro-injected cholesterol oleates
- Injection amount and depth vary
- L1 and L3 are large and visually differentiable
- L2 and L4 are small and appear to be flat.

The Future: Challenges & Opportunities

When co-registered with US imaging, WM-DPAR imaging provides a sensitive and specific endoscopic technology directed to the defined targets for very early stages of arterial disease due to background and stray signal subtraction.

Pulsed PA endoscopic imaging is more readily amenable to high-frequency (~ 40 MHz) signal acquisition and high radial resolution. State-of-the-art WM-DPAR operates in the 4 – 14 MHz range with potential for 30 – 40 MHz operation, limited by the laser diode driver / laser interface current impedance. Radial resolution improves greatly upon PFA operation.

Catheter miniaturization for minimally invasive coronary artery inspection can be achieved, limited by the size and transfer function of the US transducer and intra-catheter optics.

Acknowledgements

- CIHR/NSERC for a CHRP grant, NSERC Discovery grant and Canada Research Chairs Program to A. Mandelis
- NSERC CGS-D, QEII-GSST grants, Barbara and Frank Milligan Fellowship and William Dunbar Memorial Scholarship to SS. S. Choi
- Conavi Medical and Foster Lab at Sunnybrook research institutes Centre for tissue samples and clinical relevance input in the IV-DPARI catheter design.