NONINVASIVE IMAGING OF CIRCULATING MICROBUBBLES IN BLOOD WITH OPTICAL COHERENCE TOMOGRAPHY: IN VITRO STUDIES

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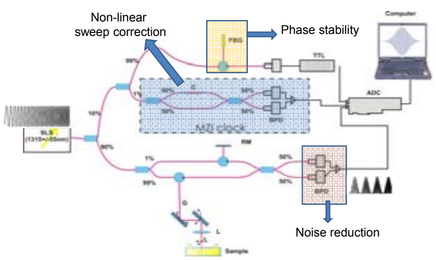
Introduction

Microbubbles formed/introduced in blood and tissues are one of the root causes for diseases such as Decompression Sickness, arterial or venous gas embroils, and barotrauma. A high in-depth, speed and sensitive device is required for the imaging, monitoring and quantification of these microbubbles in epithelial tissues for effective therapy. Here we present results on development of Optical Coherence Tomography (OCT)-based sensor capable of real-time, sensitive, accurate, and noninvasive imaging, monitoring, and quantification of microbubbles in whole blood.

System Setup

PhS-SSOCT:

- Phase stabilized swept source optical coherence tomography
- Interferometer, calibration optics and trigger and data acquisition constitutes the system
- Calibration optics contains MZI-based Optical Clock
- Phase-stabilization is achieved by triggering the data acquisition using fiber Bragg grating reflection



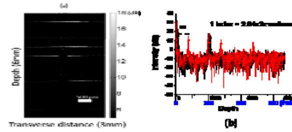
Parameters:

- λ = 1310+/-55nm ➔ axial resolution around 10 µm.
- coherence length of 13 mm ➔ maximum imaging depth of 6 mm.
- speed of laser source = 20 kHz ➔ A-line scan speed = 20 kHz
- transverse resolution = 25 µm.

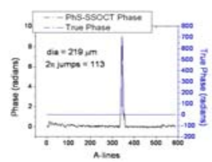
Procedure

Methods:

- change in refractive index is reflected in the temporal phase response at the self-interference peak
- The bubbles are quantified using:



$$d = \frac{1}{(n_{tissue} - n_{bubble})} \frac{\lambda}{4\pi} \delta\varphi$$

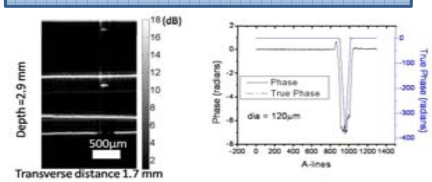


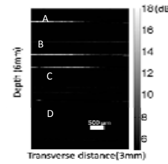
(c)

True phase = PhS-SSOCT phase + 2π*no. of jumps

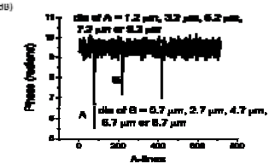
- no. of 2π jumps is calculated from the structural image
- One 2π jump corresponds to 2 µm path difference

Results

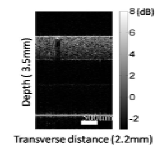




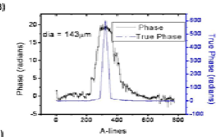
Bubbles of diameters beyond the imaging capability



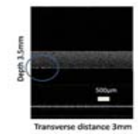
Temporal phase response indicating the presence of bubbles



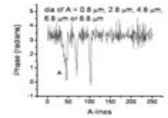
143 µm bubble in scattering media



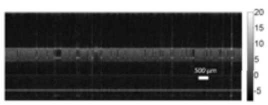
Temporal phase response



Bubbles not seen from the image

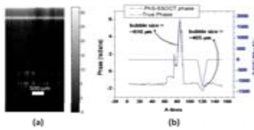


Phase response showing the presence of bubbles

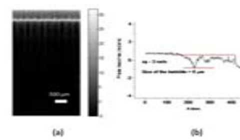


Very fast moving bubbles (> 3 mm/s) in scattering media

The microbubbles of diameters greater than 10 µm is detected in the structural image whereas the microbubbles of diameters less than 10 µm are detected and quantified in the temporal phase response. The Phase noise obtained is 0.03 radians that transforms to a bubble size of 0.01 µm can be theoretically detectable. Very fast moving bubbles (> 3 mm/s) are detected in the structural image.



(a) (b)



(a) (b)

Conclusion

In this study, PhS-SSOCT was developed for real time monitoring, imaging and quantifying of microbubbles in clear and tissue simulated media and blood. The results suggest that small microbubbles with diameter beyond imaging capabilities of the system can be detected and quantified using the PhS-SSOCT. Potentially, micro bubbles of diameters as small as 0.01 µm (that introduce a phase shift of 0.03 radians) can be detected and quantified with this method. Our future studies will focus on the detection and quantification of the fast moving microbubbles in animals.

Acknowledgements

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