Development of Noninvasive Optical Method for Detection of Circulating Microbubbles in Blood with High Resolution

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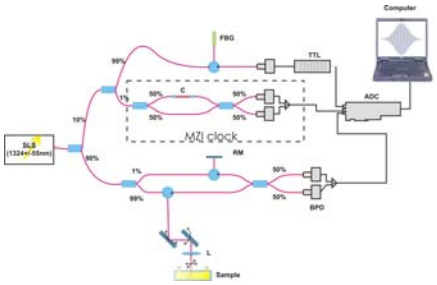
Introduction

Microbubbles in the body are formed whenever the body is subjected to a sudden pressure variations: for example deep sea divers, pilots, space researchers. These microbubbles travel into the body and could block the blood flow in skin micro-vessels leading to diseases associated with decompression sickness (DCS), venous gas emboli, barotrauma etc. These diseases can be diagnosed well before the symptoms appear by detecting and quantifying the microbubbles produced in the body. We are developing a novel diagnostic tool, phase stabilized swept source optical coherence tomography (PhS-SSOCT), for imaging, detecting and quantifying of gas microbubbles in blood and tissues.

Experimental 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-OC single acquisition
- Phase-stabilization by triggering the data acquisition using fiber bragg grating reflection

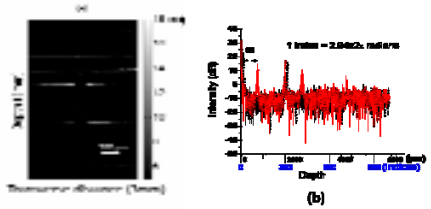


Parameters:

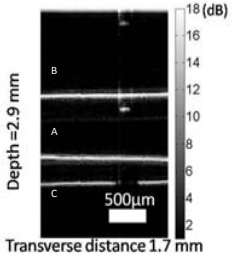
- λ = 1260+/-55nm ➔ axial resolution around 10 µm.
- coherence length of 13 mm ➔ maximum imaging depth of 6 mm.
- speed of laser source = 20 kHz ➔ A-line scan speed = 20 kHz
- transverse resolution = 25 µm.

Methods:

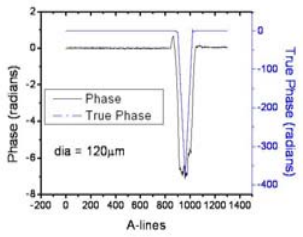
- change in refractive index is reflected in the temporal phase response at the self-interference peak
- The bubbles are quantified using $\frac{dn}{dC} = \frac{1}{l}\frac{\lambda}{4\pi}\frac{d\varphi}{dC}$



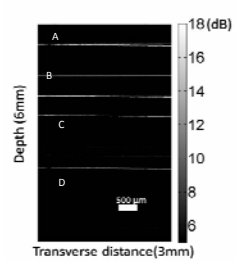
Results



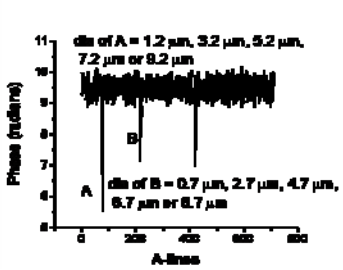
120 µm bubble in water



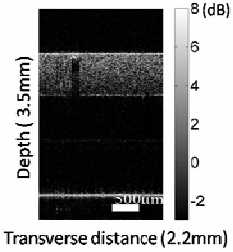
Temporal phase response



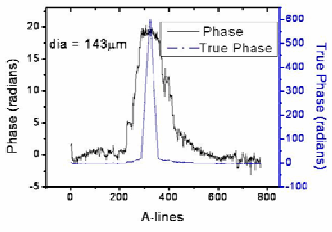
Bubbles of diameters beyond the imaging capability



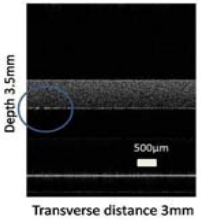
Temporal phase response indicating the presence of bubbles



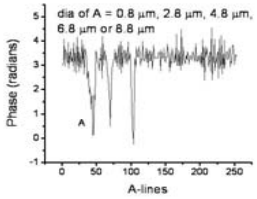
143 µm bubble in scattering media



Temporal phase response

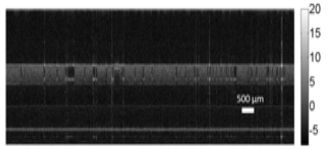


Bubbles not seen from the image



Phase response showing the presence of bubbles

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.



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

Conclusion

In this study, PhS-SSOCT was developed for real time monitoring, imaging and quantifying of microbubbles in clear and tissue simulated media. 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 development of the effective phase unwrapping algorithm that will quantify the fast moving microbubbles in both clear and blood simulated media.

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