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Title	Investigation of lung volume measurements in neonates using gas in scattering media absorption spectroscopy
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Publication date	2022-04-01
Original Citation	Pacheco, A., Jayet, B., Grygoryev, K., Messina, W., Dehghani, H., Svanberg, E.K., Dempsey, E. and Andersson-Engels, S. (2022) 'Investigation of lung volume measurements in neonates using gas in scattering media absorption spectroscopy', in Biophotonics Congress: Biomedical Optics 2022 (Translational, Microscopy, OCT, OTS, BRAIN), Fort Lauderdale, Florida, 24-27 April, Optica Publishing Group, TW1B.4. (2 pp). https://doi.org/10.1364/TRANSLATIONAL.2022.TW1B.4.
Type of publication	Conference item
Link to publisher's version	https://doi.org/10.1364/TRANSLATIONAL.2022.TW1B.4 - 10.1364/TRANSLATIONAL.2022.TW1B.4
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Download date	2026-10-31 15:49:49
Item downloaded from	https://hdl.handle.net/10468/13746

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Investigation of Lung Volume Measurements in Neonates Using Gas in Scattering Media Absorption Spectroscopy

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Abstract: We perform phantom and numerical studies of the changes in molecular oxygen and water vapor spectroscopic signals, showing the potential of measuring pulmonary volume changes with GASMAS technique in neonates. © 2022 The Author(s)

1. Introduction

Gas in scattering media absorption spectroscopy (GASMAS) is emerging as a potential clinical surveillance tool for lung function in neonates [1]. It is a non-invasive method used to measure absolute lung oxygen concentration. In a typical GASMAS measurement targeting to sense oxygen content in the lungs of a neonate, a dual wavelength diffuse laser source illuminates the walls of the chest. Photons scattered from the inflated alveoli, reach a photodetector and the attenuated signal from the gas is identified. One of the lasers scans an absorption line of molecular oxygen (~760 nm) and the second scans an absorption line of water vapor (~820 nm). The wavelengths are spectrally close, and the path length within the tissue is assumed to be approximately the same. The vapor concentration is calculated using the ideal gas law and the Arden Buck equation, for known relative humidity and temperature (100 % and ~37 ºC, respectively). The absorption signal at 820 nm is used to estimate the absorption path length by means of the Beer-Lambert law, which states that the absorption path length (l) can be calculated from the absorbance (logarithm of the ratio between light intensity at the source (I_0) and at the detector (I)), when the molar absorption (ε) and the concentration of the gas (c) are known:

$$I = I_0 e^{-\varepsilon c l} \tag{1}$$

Consequently, the calculated value of path length is input in equation (1) to estimate the oxygen concentration, using the absorption signal of light at 760 nm. This can be done because of the sharp and specific gas absorption lines, which enables sensitive measurements of gas concentrations even if they are surrounded by highly diffusive media (with much broader absorption features) such as biological tissue [4]. Previous studies have mentioned the potential to use this technique to assess pulmonary volume [2, 3]. Biophotonics@Tyndall aims to contribute in the clinical translation of GASMAS and in this work, we present results from bench–top and numerical studies which prove the feasibility of measuring gas volume changes during respiration.

2. Methods

2.1 Lung Phantom Mimicking Alveolar Composition and Pulmonary Temperature and Relative Humidity.

Phantom models are necessary to understand technical challenges and potential applications of GASMAS technique. We have created a simplified model that recreates the alveolar anatomy. The lung tissue phantom consisted of a capillary structure with air-filled spaces mimicking inflated alveoli, surrounded by capillaries filled with pulmonary optical properties (μ_a=0.5 cm^{-1} and μ_s'=5.4 cm^{-1}). The capillary array was placed inside a chamber maintained at pulmonary temperature (T=37 ºC) and relative humidity (RH~100 %). The chamber was designed for the placement of the laser and detector probes of the MicroLab Dual O_2/H_2O GASMAS bench-top system used to perform the measurements of this study, as shown in Fig 1.

Two measurement sets with 10 different gas volume configurations, were prepared to increase/decrease progressively the air volume inside the alveoli-like capillaries, and the GASMAS signals were acquired for both measurement sets.

2.2 Numerical model of respiratory volumes

We created a computational model of a neonatal thorax with nine major components (skin, fat, muscle, bone, cartilage, heart, artery, trachea and lung). The anatomical geometry of the thorax was recovered from a CT scan and μ_a and μ_s' values were assigned to each tissue type. The lung was segmented in three different volumes as a simplified model of inflation between inspiration and expiration. A three-dimensional (3D) mesh of the thorax was created to simulate the light propagation at 760 nm and 820 nm executing the forward model in NIRFAST for two configurations, one with the source placed in the trachea and the second one with the source under the right armpit. In both configurations a set of detectors were placed in a mesh array around the torso (Figure 2). The forward modeled provided information about the light fluence rate at each nodal point of the mesh, and with these values the variations in the detected light intensity associated with changes in the pulmonary volume were evaluated.

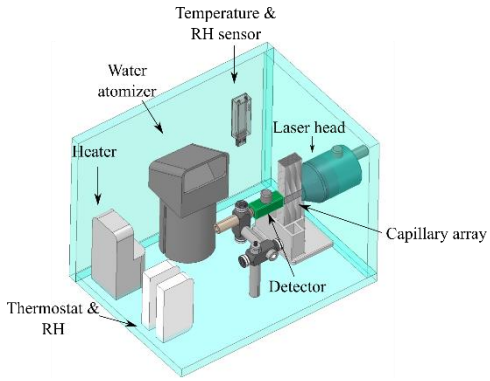


Fig.1. Experimental set up used to study the variations in GASMAS signal for different gas volumes.

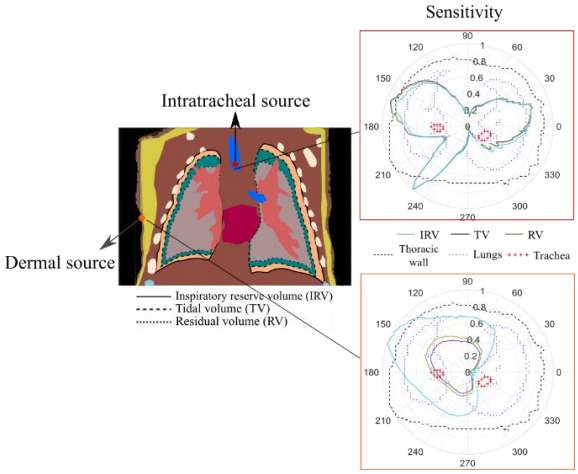


Fig.2. Computational model of the thorax of a neonate and sensitivity polar maps for intratracheal and dermal sources.

3. Results

We have designed a lung tissue phantom mimicking pulmonary optical properties, relative humidity, and temperature and a computational model of the thorax of a neonate, to explore the possibility of using GASMAS to measure changes in pulmonary volume during respiration. This represents an advantage compared to current methods such as radiography (associated with high), gas dilution (which requires the infant to remain quiet for at least 10 minutes) and plethysmography (not suitable for bedside measurements).

Acknowledgments: This research is supported by a research grant from the Science Foundation Ireland (SFI) under Grant Number SFI/15/RP/2828.

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