Functional monitoring of lung tissue using a hybrid hyperspectral Time-Resolved GASMAS system: a systematic study on ex vivo sample.

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Abstract: A portable hybrid system of three optical techniques GASMAS (Gas in scattering media absorption spectroscopy), TR-NIRS (time-resolved near-infrared spectroscopy) and CWBS (continuous wave broadband spectroscopy) have been proposed to monitor optical properties and gas concentration during the gas exchange in an *ex vivo* bovine lung. Increasing levels of lung inflation at different pressures showed significant changes in optical properties and gas dynamics, providing valuable insights for non-invasive monitoring of lung function.

1. Introduction

Diffuse optical techniques have been widely used for non-invasive characterization and monitoring of tissue optical properties (absorption, scattering). GASMAS is a non-invasive technique proven to monitor *in vivo* oxygen gas concentration in tissues [1]. Though the GASMAS can monitor gas concentration in non-accessible cavities it can't provide information about tissue constituents and absolute optical properties. A combination of a few wavelength time domain and broadband continuous-wave NIRS systems with GASMAS can provide gas concentration and absolute broadband optical properties. In this work, we propose a hybrid TD-NIRS to calibrate and extract broadband optical properties in combination with a CW technique that provides complementary information to the gas concentration measured by GASMAS. The combined multi-modal system was exploited on *ex vivo* lung tissue to monitor gas absorption imprint and optical propertyes at various inflation levels.

2. Material and Methods

The hybrid system is a combination of three techniques (GASMAS, CWBS, TD-NIRS), and measurements were time-multiplexed to prevent crosstalk between different optical signals. The portable TR-NIRS system[2,3] have been developed at Politecnico di Milano. This system exploits two pulsed laser diodes (670nm and 830nm) and a SiPM detector to estimate a few wavelengths absolute optical properties (absorption and reduced scattering coefficients) of the tissue under study. A broadband spectrometer (QE-Pro, Ocean Optics, Edinburgh, United Kingdom) has been coupled to a broadband light source (HL-2000, Ocean Optics, Edinburgh, United Kingdom) for hyperspectral (600- 1100 nm) information retrieval [4]. The hybrid CW and TR-NIRS system was tested and validated on a well-characterized matrix phantom kit [5]. And the GASMAS system (MicroLab) was manufactured by GASPOROX. A custom-designed probe was 3D printed to host the TD-NIRS and CWBS fiber in transmission geometry. The probe was optimized to probe a similar sample area by all three techniques to reduce the distortion of signal due to heterogeneity of lung sample.

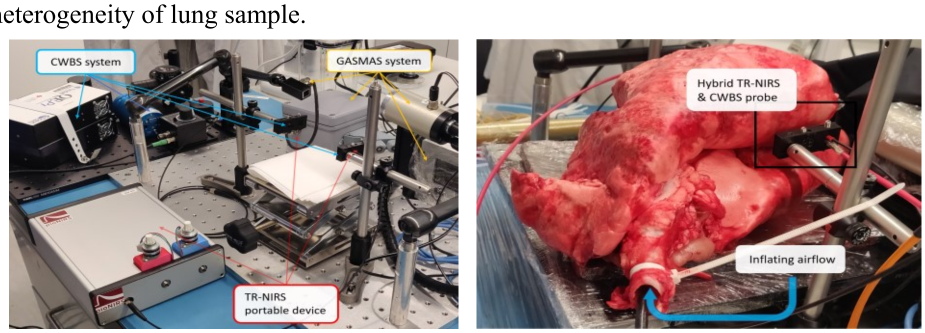

Fig.1 a) Instrumentation and b) measurement setup

The sample under study was an *ex vivo* lamb lung with easy access to the trachea. The lung was inflated through a gas tube inserted in the trachea. A variable flux of compressed air, 20% oxygen concetration, at different pressure was delivered. Four different inflation levels at a steady-state constant pressure were considered for the measurements. At each inflation level, the superficial oxygen concentration has been measured using an optical probe (Pyroscience) and the temperature of the lung has been monitored over time. The two probes have been placed in the lower part of the right lung lobe and the same tissue area has been measured in transmittance geometry for all four inflations.

3. Results

The analyzed data retrieved from the hybrid instrumentation at four inflation levels of the lung are shown in Fig 2.

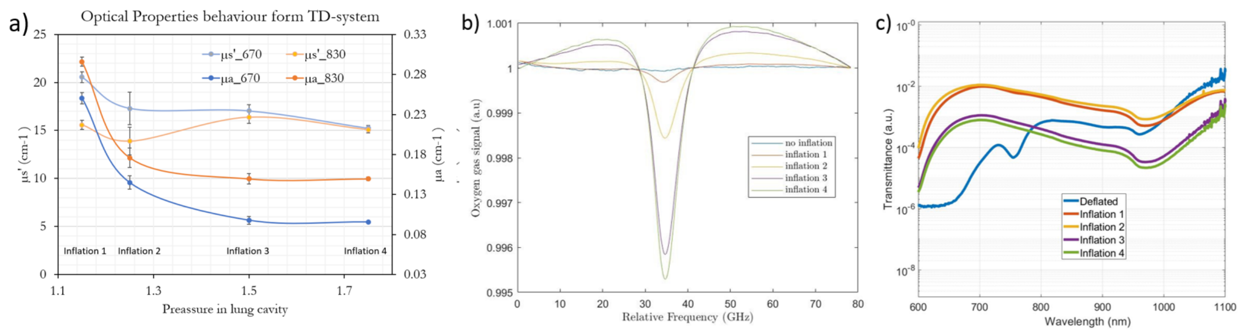

Fig.2 Results from crossed data analysis from the tree instrumentations: a) TD system, b) GASMAS, c) CW system.

Both absorption and scattering coefficients for wavelengths 670 nm and 830 nm show a trend with the increasing inflation pressure Fig 2a. Absorption coefficients tend to reduce for both wavelengths while the lung is expanding and a maximum relative variation of approximately 60% was seen over a change in inflation of 1.15bar to 1.75 bar maximum inflation condition. Scattering coefficients seem to suggest nearly constant behavior at 830 nm and a slight decrease, approximately 25% from inflation level 1 to inflation level 4 at 670 nm wavelength. From Fig 3b, the oxygen gas signal is increasing with an increasing inflation which is expected as the concentration of the gas increases with increasing pressure and volume of the lung. Fig 3c shows the CWBS transmittance spectrum which could be exploited to retrieve broadband optical properties using few wavelength absolute optical properties estimated by the TR-NIRS device.

4. Conclusions

To the best of our knowledge for the first time, a realistic inflated *ex vivo* lung tissue dynamics has been measured using a hybrid combination of three techniques. Broadband optical properties of the tissue were retrieved by a combined TD-NIRS and CW broadband spectrometer. Oxygen, and water vapor concentration have been measured in the same location by exploiting the GASMAS technique. Combined measurements from a hybrid such as the one depicted in this manuscript can give the possibility to simultaneously retrieve tissue composition, hemodynamics and gas concentration inside the lung cavities. It also thereby drastically reduces any error involved in separate measurements, for which signals will depend on several properties. This work could be extended to many *in vivo* applications in which the gaseous concentration of tissue cavities and tissue optical properties are of main interest.

References

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