A MD-NIRS sensor for the detection of the venous oxygen saturation

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Introduction
The oxygenation of the venous blood in the cerebral efferent vessels is a key factor for the estimation of the metabolism, perfusion and oxygenation of the brain, segmented in both hemispheres. The commercial available non-invasive systems detect only the local tissue saturation beneath the sensor at the forehead [1,2]. To extract the physiological information of the one hemisphere a system which measures the oxygen saturation of the venous blood in the cerebral efferent vessels is strongly required.

Objective
• Development of a reflective multi-distance (MD) NIRS sensor to detect these oxygenation changes.
• Evaluation of the sensor in a former developed model setup simulating the human head.

Material and methods
A former developed liquid phantom model setup based on [3] (Layer 1: Scalp; Layer 2: Skull; Layer 3: Blood inside of the target vessel, Layer 4: Brain), connected to a hemodynamic perfusion circuit to provide different oxygenation levels inside of the venous target vessel, was equipped.

A triple-wavelength (770; 808; 850 nm) multi-distance near-infrared spectroscopy (MD-NIRS) sensor (6 photodiodes (PDx), linearly arranged, separated 6 mm each) was equipped to detect these optical property variations. The photodiodes PDx recorded the reflective signals continuously separated for the different wavelengths (Fig. 1).

The SO2 and Hb levels (IL 682 Co-Oximeter) and the physiological blood parameters pO2, pH, pCO2, Glu (IL GEM 3000) served as a reference for the sensor data. Additionally a reference unit, consisting of a white light source (SSL, Stellarnet Inc.) and a detector 400-1100 nm (EPP200, Stellarnet Inc.), recording the spectrum of the blood, was attached.

Every experiment (M10x) contained three consecutively passed saturation plateaux PL1-PL3 (PL1: 55 %; PL2:100 %; PL3: 55 % of SO2, steady state at each plateau for approx. 1-3 min) which were adjusted by the variation of the gas supply. From the continuously recorded signals, the quotient 770nm / 850 nm for PD1, PD2 was calculated and the values at the constant plateaux (PL1-PL3) were identified for each PD. The difference between the plateau values was calculated according to the following equation:

\[ PDx = \frac{PDx_{\text{max}} - PDx_{\text{min}}}{(PDx_{\text{max}} + PDx_{\text{min}})/2}, x = 1-3 \]  

(1)

Results
The results prove the capability of the developed sensor system to detect the optical property variation of hemoglobin due to oxygenation and deoxygenation processes reproducible in a specific vessel. The recorded and smoothed sensor signals for PD1, 770 nm (M10x) are visualized in Fig. 2.

Fig. 2: Sensor signal 770 nm

The curve shapes of the ref. unit (Fig. 3) and the sensor were similar during the oxygenation and deoxygenation processes, which indicates that the oxygenation changes in the target vessel could be detected reproducibly. Tab. 1 visualizes the averaged oxygenation changes of the model and the corresponding sensor signals according to equation (1).

Tab. 1: Sensor and blood gas analysis data for M10, Changes of oxygen saturation (SO2) for the three plateaux (Pl1 - Pl3), Pco2 and the calculated sensor data (equation (1))

<table>
<thead>
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<th>SO2 [%]</th>
<th>SO2 [%]</th>
<th>SO2 [%]</th>
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<td>99.9</td>
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Conclusion
Based on the results the implementation of an algorithm to calculate adequate values for the venous oxygen saturation based on the source-detector separations of PDx is planned. The capability of the sensor system to detect changes in a saturation range beneath 50 % is under current investigation.

Bibliography

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