AN OPTICAL SENSOR FOR CONTINUOUS HEMOLYSIS MEASUREMENT

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Introduction

Hemolysis induced by blood pumps is routinely evaluated by in-vitro testing according to the ASTM-F1841 standard [1]. This usually involves taking blood samples from a test bench once per hour and assessing hemolysis by determining plasma-free hemoglobin (pfHb). However, the manual sample processing is time-consuming, resource demanding, and prone to errors. Therefore, this work proposes an optical sensor to continuously measure hemolysis in whole blood without the need for blood sampling. Such a sensor could also be integrated into the graft of left ventricular assist devices (LVADs) to continuously monitor hemolysis and oxygen saturation (sO_2) in LVAD patients.

Methods

The optical hemolysis sensor (c. f. Figure 1) contains four LEDs (645 nm, 730 nm, 810 nm, and 940 nm) and two photodiodes, with barriers in between. The LEDs and photodiodes are soldered to circuit boards, that are connected to 3D-printed half-shells. The half-shells are clamped around a transparent plastic tube adapter for ½ inch tubes. The LEDs were switched on one after each other for 250 ms and the reflected light intensity was measured at the photodiode on the same side.

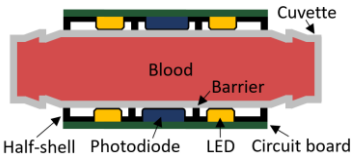

Figure 1: Structure of the optical hemolysis sensor.

The voltage change due to hemolysis $U_{hemolysis}$ of each LED was calculated by correcting the measured sensor voltage U_{sensor} for oxygen saturation:

$$U_{\text{hemolysis}} = U_{\text{sensor}} - f(sO_2) \qquad (1)$$

Thereby, $f(sO_2)$ is a third order polynomial for each LED describing the dependence between sO_2 and U_{sensor} as shown in Figure 2 (left).
The sO_2 was estimated from the sensor voltages at 810 nm (U_{810}) and 940 nm (U_{940}) (c. f. Figure 2 (right)):

$$sO_2 = 430.2 \cdot \left(\frac{U_{810}}{U_{940}}\right) - 244.7 \qquad (2)$$

The sensor was evaluated using a test bench according to the ASTM F1841 standard [1]. The test bench was extended by an oxygenator and a CDI 500 device to vary and measure the oxygen saturation. Porcine blood with a hematocrit of 35 % was circulated at a flow rate of 5 L/min for six hours using a Sputnik LVAD.

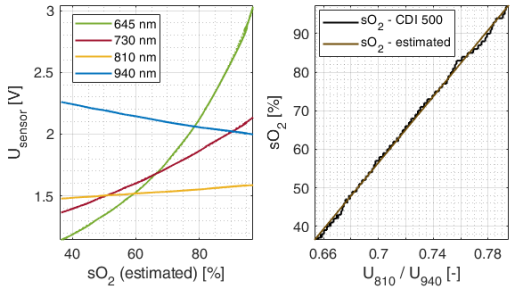

Figure 2: Dependence of the estimated sO_2 on U_{sensor} (left) and sO_2 estimation from sensor signals (right).

Results

During 6 hours, pfHb increased linearly from 116 mg/dL to 839 mg/dL (Figure 3), while $U_{\text{hemolysis}}$ decreased linearly for all wavelengths. The correlation coefficient between these was at least -0.96.

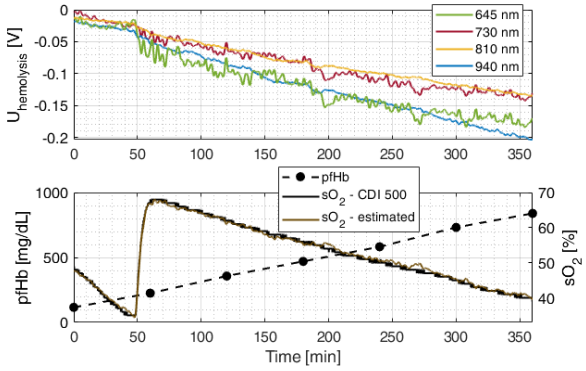

Figure 3: sO_2, pfHb, and $U_{\text{hemolysis}}$ during a 6-hour hemolysis trial. sO_2 was changed at t = 50 min.

Discussion

The strong negative correlation between pfHb and $U_{\text{hemolysis}}$ for all wavelength could be explained by the increase of the scattering coefficient of blood due to hemolysis [2]. The findings are also in accordance with Neudel et al. [3], which aimed for the determination of sO_2 and hematocrit, but regarded hemolysis as a disturbance. However, further trials have to be conducted to assess the reproducibility and accuracy of the developed hemolysis sensor.

References

1. ASTM International, ASTM F1841 – 19, 2019.
2. V. Tuchin et al, Opt Express, 12:2966-71, 2004
3. F. Neudel et al, Med. Eng. & Physics, 24:301–307, 2002

Acknowledgements

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