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Tissue oximetry in presence of pathologically thick fat and adipose tissue layers

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We successfully characterized our novel Near-Infrared Spectroscopy (NIRS) oximeter for thick layers of adipose tissue (ATT). At ATT=16mm the oximeter was still sensitive to oxygenation changes in the deeply buried tissue, simulated by an in-vitro set-up. We furthermore present a calibration method which can substantially reduce the measurement errors at high ATT.

Introduction

Obesity is an increasingly widespread phenomenon world-wide which is linked with many severe diseases in the long term. We intend to employ NIRS oximetry to assess energy expenditure. However, it is currently unknown if NIRS oximeters can be applied in case of thicker adipose tissue thickness (ATT). A previous study reported that superficial layers up to 6 mm have negligible influence on measurements of absorption and scattering coefficients [1]. Unfortunately, the influence of ATT on tissue oxygen saturation (StO_2) has so far not been investigated. We built an in-vitro set-up to assess up to which ATT measurements of StO_2 are possible with our novel NIRS oximeter.

Method

- Liquid phantom to resemble the properties of muscle tissue
- Differently thick windows to resemble different ATT
- Visible light oximeter directly immersed into the phantom as reference for comparison (independent of ATT)
- Steepness of curves defined as sensitivity
- Sensitivity normalized by ATT = 2.5mm (only marginally influenced)
- In vivo measurements at the lower arm of a subject (BMI=29.6)

Results

- Linear relationships in the range of interest ($16<StO_2<80\%$)
- Decreased sensitivity for increased ATT
- All lines cross approximately the same point (p_{cal})
- Relative sensitivity follows sigmoid curve (eq.1)
- Relative sensitivity (RS) and one value on thick ATT (p_{cal}) for calibration (eq.2)
- In-vitro the RMS error could be reduced by 43-53%
- Calibrated in-vivo results are more reasonable than uncalibrated

Conclusion

- Our NIRS oximeter still shows sensitivity at ATT=16mm
- Succesful characterization of the device for several ATT
- Calibration with just one point possible when ATT is known
  - Corrects for loss of sensitivity for bigger ATT
  - Substantially reduces the RMS error of measurements

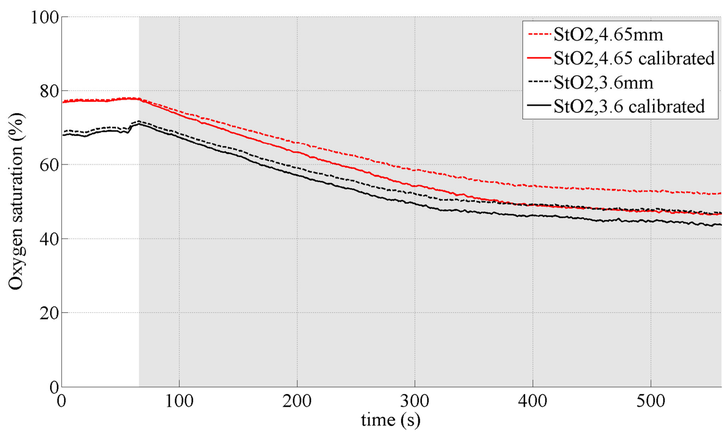

Fig.4: In-vivo data showing two arterial occlusions at two different positions on the arm of a subject. Calibrated lines are solid.

$$RS = \frac{380.8 * ATT^{-2.838}}{1 + 380.8 * ATT^{-2.838}}$$

Eq.1: Sigmoid function describing RS of the device when ATT is known (fig.3)

$$StO_{2cal} = StO_2 + (RS - 1) \times p_{cal}$$

Eq.2: Calibration function employed to generate fig. 4 and 5. p_{cal} has to be measured with the oximeter and RS can be computed with eq.1 when ATT is know.

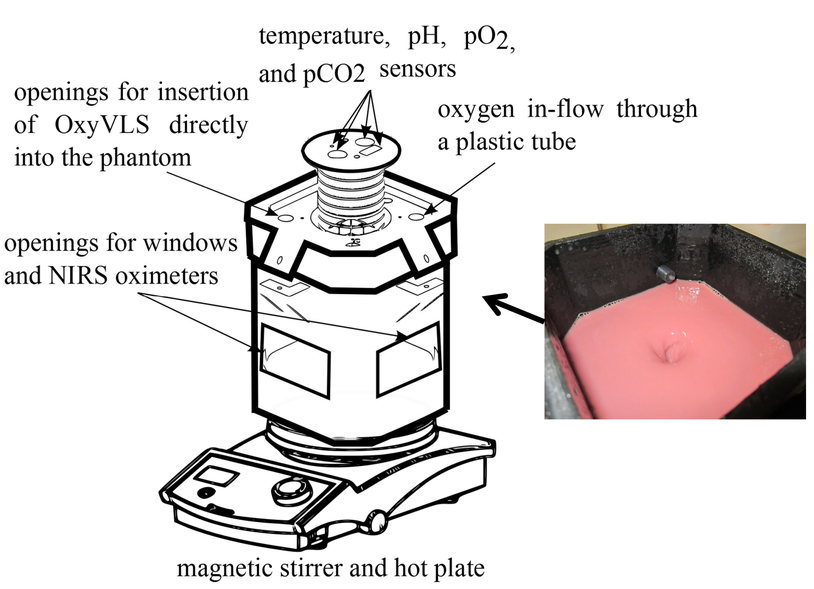

Fig.1: In-vitro set-up containing the phantom

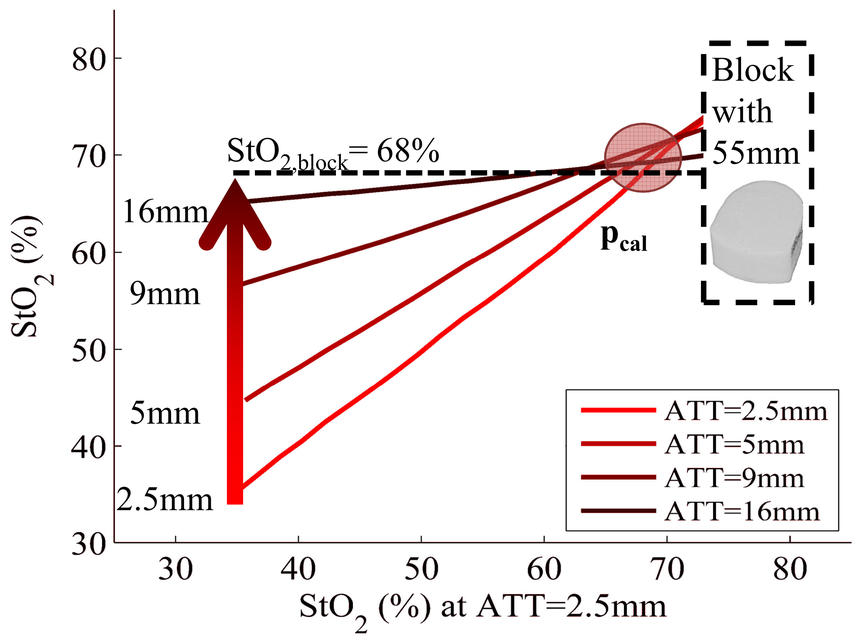

Fig.2: Response of the NIRS oximeter as ATT increases

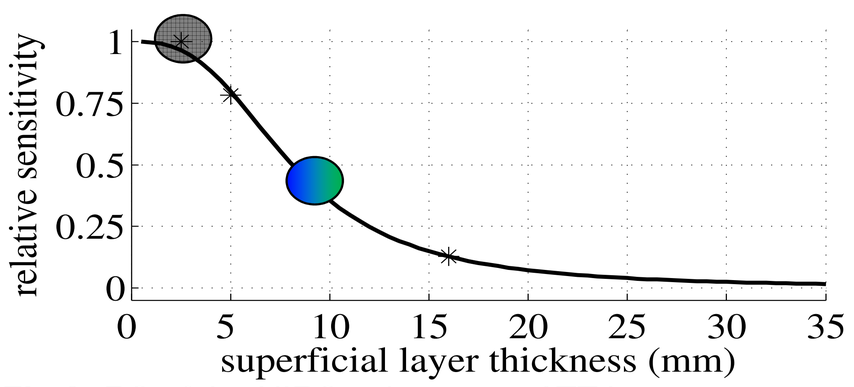

Fig.3: RS of the NIRS oximeter as ATT increases

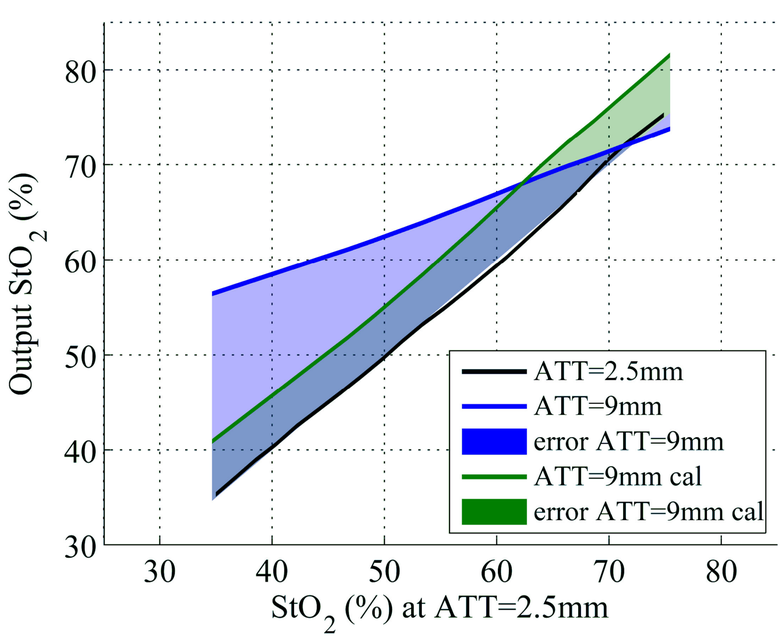

Fig.5: Calibrated in-vitro data at ATT=9mm compared to ATT=2.5mm and the corresponding errors

[1] MA Franceschini et al, "Influence of a superficial layer in the quantitative spectroscopic study of strongly scattering media." Appl. Opt., 37(31):7447–7458, Nov 1998.