Non-invasive measurement of hemoglobin

OR

The origin of the PPG signal.

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Non-invasive optical measurements: SPO2 and Hb

**Hemoglobin (Hb):** Total amount of Hb in 1 cc of blood. Hematocrit (H): Relative Volume of RBC in blood. 
H = Hb*3

**NEW**

SPO2 = HBO2/(Hb+HBO2)

40 Years on the market

ORSENSE, Israel

Masimo, USA
Spectrum of Hemoglobin in NIR region

Blood Absorption coefficient

\[ \mu_a = \mu_{aHBO_2} \cdot S + \mu_{aHb} \cdot (1 - S) \]

Hb and SPO2 are major absorbers

\[ S = \left( \frac{HbO_2}{HbO_2 + Hb} \right) \times 100 \% \]
Light is scattered by Red Blood Cells

Mie model of the sphere is widely used to describe the scattering of RBC
PPG signal: arterial pulsation

Optical signal Fluctuation
Two possible mechanics of PPG

Classic Model (Volumetric) :
Change of number of particles (volume) due to the pressure wave:

Alternative Model (Scattering Driven) :
Change of scattering properties due to the change of the scattering due to the shear rate changes
Volumetric Model

Light penetrates through the finger in the Red-NIR spectral range.
Non volumetric optical pulse signal in vitro

The intensity fluctuation observed in rigid cuvette in vitro (a) - no RBC aggregation, (b) RBC can aggregate.
PPG volumetric model is tested in vivo

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Pulsatile blood flow in human bone assessed by laser-Doppler flowmetry and the interpretation of photoplethysmographic signals

There was pulse when the blood volume As has been assessed by LDF is constant

FLOW variations can result in the PPG like arterial signal!
Signal modulation by scattering
Parametric Slope Definition

The PPG signals for 670nm (red) and 940nm (Infrared)

\[ \gamma = \frac{AC(\lambda_1)/DC(\lambda_1)}{AC(\lambda_{ref})/DC(\lambda_{ref})} \]

\[ PS = \frac{\hat{\partial} \ln(I(\hat{\lambda}, t))/\hat{\partial} t}{\hat{\partial} \ln(I(\hat{\lambda}_{ref}, t))/\hat{\partial} t} \]

The PPG signals for 670nm (red) and 940nm (Infrared)
PS as for Red-NIR region

Reference Wavelength 940nm
Hb=15 g/dl,
SPO2 - 97%
General expression of PS for volumetric model

\[ I(t) \equiv I_0 (\mu_{\text{tissue}}) \cdot I (\mu_d^* \cdot x(t)) \]

\[ \mu_{d}^* = \sqrt{\alpha \cdot \mu_a^2 + \beta \cdot \mu_a \cdot \mu_s \cdot (1 - g)} \]

\[ \mu_s = H \cdot (1 - H) \cdot \sigma_s / V_{RBC} \quad I \approx \exp[ -\mu_d^* \cdot x(t)] \]

Scattering cross section is calculated by Mie

\[ PSV = \left[ \frac{\partial \ln I(\lambda) / \partial (x_b)}{\partial \ln I(\lambda_{\text{ref}}) / \partial (x_b)} \right]^{1/2} = \left[ \frac{\alpha \mu_a(\lambda) + \beta \cdot \mu_a(\lambda) \cdot \mu_s(\lambda)(1 - g)}{\alpha \mu_a(\lambda_{\text{ref}}) + \beta \cdot \mu_a(\lambda_{\text{ref}}) \cdot \mu_s(\lambda_{\text{ref}})(1 - g)} \right]^{1/2} \]

\( H \) – is the blood hematocrit \hspace{1cm} \( H = Hb*3 \)

\( x(t) \) – changes with pulsation
General expression of PS (PSS) for scattering driven model

\[ \mu^*_d (t) \quad \text{Time dependent parameter} \]

\[ PSS = \frac{\partial \ln(I(\lambda, t, x)) / \partial t}{\partial \ln(I(\lambda_{ref}, t, x)) / \partial t} = \frac{\partial \ln(I(\lambda_{ref}, t, x)) / \partial \mu^*_d}{\partial \ln(I(\lambda_{ref}, t, x)) / \partial \mu^*_d (\lambda_{ref}, r(t), c(t))} \left[ \frac{\partial \mu^*_d (\lambda)}{\partial t} / \frac{\partial \mu^*_d (\lambda_{ref})}{\partial t} \right] \]

\[ R_2 = \frac{\sqrt{\alpha \cdot \mu^2 (\lambda_{ref}) + \beta \cdot \mu (\lambda_{ref}) \cdot \mu^' (\lambda_{ref}, t)}}{\alpha \cdot \mu^2 (\lambda) + \beta \cdot \mu (\lambda) \cdot \mu^' (\lambda, t)} \]

\[ R_3 = \frac{\partial \mu^'(\lambda_{ref}, t) / \partial c}{\partial \mu^'(\lambda_{ref}, t) / \partial c} \]

\[ PSS = R_1 \cdot R_2 \cdot R_3 \]

\[ R_1 = \frac{\mu (\lambda)}{\mu (\lambda_{ref})} \]
Comparison between PSV and PSS and experimental PS vs. wavelength for SPO2=100%,
Experimental Results: spectrophotometric measurements

PS goes up when the HB goes down, below 610nm
Experimental Results: LED’s based measurements

PS decreases where Hb increases for 610nm
Theory: PSV dependencies on Hb

PS increases with Hb, below 600nm: **WRONG DIRECTION!**

VOLUMETRIC MODEL
PS decreases when Hb increases: **RIGHT DIRECTION!!!**

Scattering Driven Model
Conclusions

- Scattering fluctuation can result in the pulsatile component of the optical signal
- Shear rate changes might be responsible for these fluctuation
- RBC aggregation-disaggregation might be responsible for the scattering fluctuations
- Volumetric Model fails to explain PS hemoglobin dependencies
- Parametric Slopes derived from the scattering driven model explains the experimental dependences on Hb
THANK YOU!