

COMPARISON BETWEEN DIFFERENT PULSE HEMOMETER SENSORS BY MONITORING FRACTIONAL OXYGEN SATURATION OF HEMOGLOBIN

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Abstract— In addition to the perilous pitfall of pulse oximeter which is its disability to detect carboxyhemoglobin (COHb) and methemoglobin (metHb) concentrations, other shortcomings of pulse oximetry are also cumbersome or even dangerous. A finger probe for example will not be able to show a result at very low perfusion of tissues. This case is available when the patient is under shock or has a low blood pressure. Finger sensor, ear clip, nose bridge clamp and forehead sensor are used by monitoring oxygen saturation of hemoglobin. Some of the pitfalls of the standard pulse oximetry can be avoided using the appropriate sensor for the case under consideration. After an introduction in pulse oximetry we will show in this article the differences between these sensors mainly used by this valuable technique. Plethysmogram signal, which is an important measured variable by this in-vivo method, will be studied from three sensors under various conditions. Also the time delay which is a vital parameter by detection of oxygen saturation will be considered. The difficulties by the calculations of fractional hemoglobin concentrations using the different sensors will be discussed before the advantages and shortcomings of each sensor and the possible enhancement will be shown. At the end a decision will be taken to choose the suitable sensor for the calculation of hemoglobin concentration and its fractional oxygen saturation by our used method.

Keywords— Pulse oximetry limitations, pulse oximetry sensors, hemoglobin concentration

I. INTRODUCTION

Pulse oximetry is one of the most significant technological advances in clinical monitoring. It is a non-invasive photometric technique that provides information about the blood oxygen levels of patients, a key vital signal, and heart rate. Pulse oximetry has widespread in clinical applications. It is used in operating rooms, recovery rooms, intensive care, emergency medical aids, sleep medicine, home and other fields of medical care [1] [2]. Despite their wide applications for monitoring the oxygen saturation (SaO_2) suffer the currently used pulse oximeters from a lot of shortcomings discussed inter alia in [3] [4] [5] [6] [7] that can be minimized or even eliminated. The most serious disadvantage of these devices is that they show erroneous readings by patients with carbon monoxide poisoning. The oxygen carrier in blood, namely hemoglobin of the red blood cell,

has a higher affinity (more than 250) for carbon monoxide (CO) than that for oxygen. The patient can not feel the effect of carbon monoxide (called silent killer) clearly before a serious sequences happen. Pulse oximeter overestimates oxygen saturation by CO-Poisoning and displays high normal readings of oxygen saturation SpO_2 (more than 90%), where as the real value of oxygen saturation SaO_2 is very low, so that the patient may suffers from life threatening complications. Hence pulse oximeter is disallowed to be used under these conditions, which may be not already known. Fig. 1 shows the effect of CO on pulse oximeter readings.

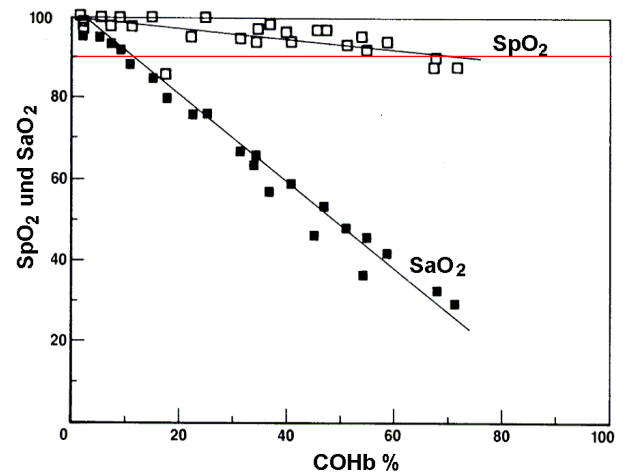


Fig. 1 Effect of COHb: Oxygen saturation measured with pulse oximeter SpO_2 and the real saturation measured invasively SaO_2 [8] [9]

A similar effect, but may be a little pronounced as CO on pulse oximeter reading (Fig. 2) have other compounds like nitrites and aniline derivatives, which are two of the most common causes of methemoglobin toxicity. Methemoglobin is the oxidized form of hemoglobin in which the iron in the heme component has been oxidized from the ferrous (+2) to the ferric (+3) state. This renders the hemoglobin molecule incapable of effectively transporting and releasing oxygen to the tissues. There are many different effects of methemoglobinemia, all varying, depending on severity of the case. Headaches, cyanosis, fatigue, tachycardia, weakness, coma,

and death are all possible effects by high methemoglobin fractions in blood.

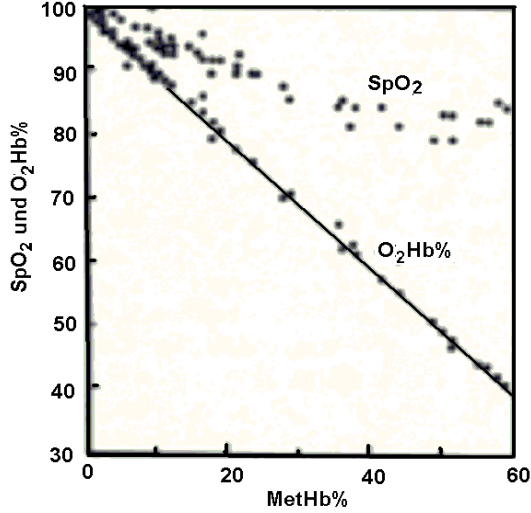


Fig. 2 Effect of MetHb on oxygen saturation. SpO₂ : Oxygen saturation measured with pulse oximeter. SaO₂ : the real saturation measured invasively [8] [9]

It is clear from the preceding introduction that the fractional oxygen saturation, which is the ratio of oxygenated hemoglobin concentration [HbO₂] to the total hemoglobin concentration, have to be calculated. Concentrations of reduced hemoglobin [RHb], oxygenated hemoglobin [HbO₂], carbon monoxide hemoglobin [COHb] and methemoglobin [MetHb] form the total hemoglobin concentration [Hb_{TOTAL}]. By pulse oximeter only the functional oxygen saturation SpO₂ of hemoglobin, which is the ratio of [HbO₂] to the sum of [HbO₂] and [RHb], is measured. Oximetry calculations are applied according to Lambert-Beer law, when a non scattering probe is irradiated with light having the incident intensity I_0 , the intensity of transmitted light I decays exponentially with the absorption coefficient α of that probe and its thickness d .

$$I = I_0 \cdot e^{-\alpha \cdot d} \quad (1)$$

Two LEDs of different wavelengths are needed to calculate the SpO₂ by a pulse oximeter.

The signal attenuation caused by tissue is a combination of reflection, absorption and scattering. To calculate the different hemoglobin concentrations with a device called pulse hemometer the modified Lambert-Beer law is used, where transmission and reflection terms are considered.

$$I = A \cdot I_0 \cdot e^{-\eta \cdot \alpha \cdot d} + \delta \quad (2)$$

Where A , η and δ are wavelength dependent constants. At least four light sources with different wavelengths have to be used to distinguish between the different hemoglobin components.

$$\alpha(\lambda) = \sum_{\mu} \epsilon_{\mu}(\lambda) \cdot c_{\mu} = \epsilon_{\text{Hb}} \cdot c_{\text{Hb}} + \epsilon_{\text{HbO}_2} \cdot c_{\text{HbO}_2} \quad (3)$$

II. MATERIALS AND METHODS

Three different sensors are developed to calculate the fractional oxygen saturation from different parts of the body (Fig. 3). An electronic circuit is also developed to drive the LEDs and to detect signals from PDs. The measured signals have been digitalised using DAQ-card NE6250 from National Instruments and processed with LabVIEW. Measurement from various body portions like fingertip, ear lobe and forehead of different adults are hold.

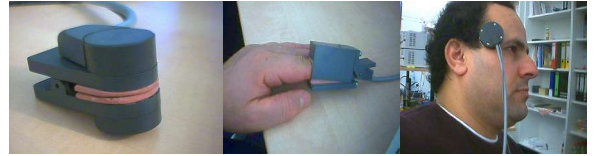


Fig. 3 Effect of MetHb on oxygen saturation

The selection of the appropriate sensor for the calculation of the fractional oxygen saturation depends on different factors. The wavelength of the currently inexpensive LEDs in the market with enough intensities for the irradiation of the portion of the body under consideration is an important parameter. LEDs and PDs are variable parameters. In the last few years fast development are achieved in this field, which is expected to continue in the next years. For the finger sensor high intensity LEDs between 600 nm and 880 nm, which can differentiate between absorption of the different hemoglobin components, have to be used in order to detect a transmission signals with the PD at the other sides of the finger. Ear lobe absorbs less light than the fingertip at the different wavelengths, which enables the use of a wider range of wavelengths. Using the reflectance pulse hemometer enables the use of wavelengths in a broad spectrum. The distance between light emitting sources and detectors can be chosen to achieve the desirable signal noise ratio (S/N) and according to the body portion and the wavelength used. Fig. 4 shows the absorption coefficients of the different hemoglobin components.

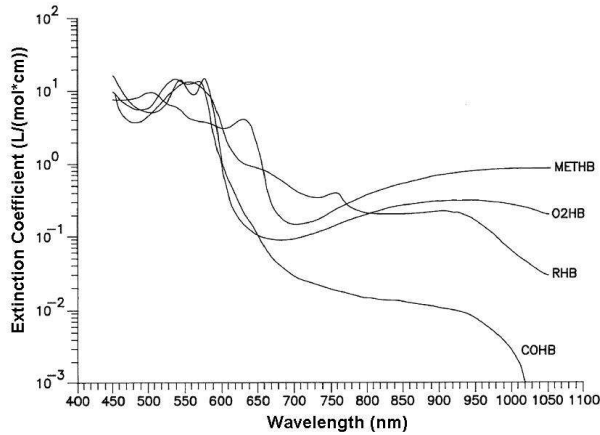


Fig. 4 Light absorption of hemoglobin components at different wavelengths

III. RESULTS AND DISCUSSION

A high S/N can be under normal conditions achieved using the fingertip sensor (Fig. 5). An ear lobe sensor has a smaller S/N than that of the fingertip. The currently used reflectance pulse oximeter has a very smaller S/N than that of the transmission pulse oximeters.

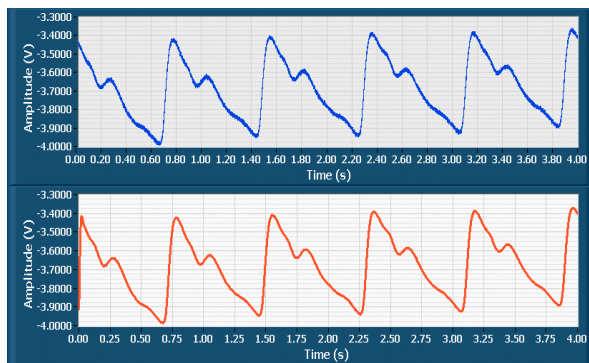


Fig. 5 Pulse signal detected with a fingertip sensor: unfiltered (upper) and filtered (bottom) signal

In order to calculate the oxygen saturation and hemoglobin concentration the earlobe have a definite structure, which can be easier approximated as the structure of the finger or the forehead (fig. 6). The differences in the structure between different peoples are not significant.



Fig. 6 Ear tissue anatomy [10]

The finger has a more complicated structure which makes it more difficult to simulate the light propagation through it with a compact solution of a theory like diffusion theory. Also the deviations of the measurements of different probes are expected to be higher.

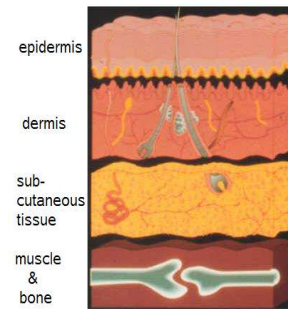


Fig. 7 Approximation of finger tissues

The reflectance pulse oximetry has to be applied at a uniform structure of the body. Different portions of the body have different interactions with the light. The forehead is a suitable position, where it is also easy to apply the sensor (fig. 8). The detected signal (fig. 9) is also greater than some other central portions of the body like chest or abdomen [11].

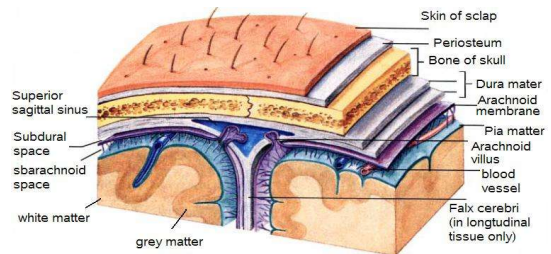


Fig. 8 Tissues of Forehead

We have measured many signals at different portions of the body. The largest pulse signal is obtained at a portion of the neck, below which the carotid artery run (fig. 10). For the optical measurement of fractional oxygen saturation or other blood constituents is this portion not suitable because of the variable optical properties of blood in the large artery. Measurements have to be applied at locations, where the blood distribution in tiny arteries is uniform and its flow is laminar. The optical properties of tissues like blood will vary under turbulent flow.

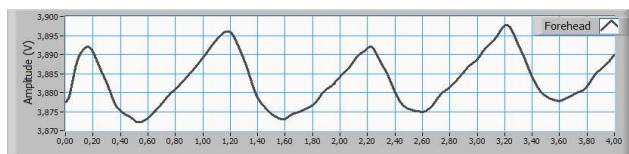


Fig. 9 Pulse signal detected from forehead

The forehead sensor is most suitable for the measurements. Under low tissue perfusion (by cold extremity or under shock) delivers the transmission sensor no results. The measurement of the reflectance sensors will be not affected, because the central parts of the body are still well perfused. Also time delay by reflectance pulse oximeter is one to two minutes less than that of the fingertip one under these conditions [12].

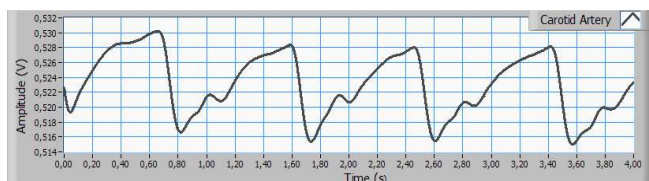


Fig. 10 Pulse signal detected above carotid artery

IV. CONCLUSIONS

Fractional oxygen saturation which considers the carbo-monoxihemoglobin and methemoglobin has to be measured utilizing more development on pulse oximeter. Also the non-invasive measurement of hemoglobin concentration using a similar technique is required. In addition to the used method, the sensor selection and location of its application are so important to achieve these objectives. The design of an optical multisensor which makes use of the transmitted and the scattered light will have a higher accuracy, new ap-

plications and more flexibility. The sensitivity of the reflectance pulse oximeter to noise and motion will be eliminated by utilizing a ring scattering pulse hemometer.

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