Assessing Oxygenated Hemoglobin Concentration by Time-Domain Diffuse Optical Spectroscopy at 1064 nm

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Abstract: The assessment of concentration of oxygenated hemoglobin is a crucial parameter for oximetry application. We explore the possibility of using 1064 nm wavelength to assess the concentration of oxygenated, discussing possible advantages and issues.

1. Introduction

Near InfraRed Spectroscopy (NIRS) is a well-known technique used to non-invasively assess the concentration of oxygenated- and de-oxygenated hemoglobin (HbO_2 and HHb, respectively) thus gathering information on the metabolism of the tissue under analysis (e.g., brain or muscle) [1]. The use of time-domain approach in the so-called "reflectance geometry" adds advantages such as the possibility to separately assess (even if using a single acquisition) the absorption coefficient (μ_a) and the reduced scattering one (μ_s') and the capability to encode the mean penetration depth reached by photons in their arrival time [2]. Standard oximetry systems usually work using at least two wavelengths across the isosbestic point (e.g., one chosen from 650 to 750 nm and another one around 830 nm). However, in the last years new works propose the use of the 1064 nm as preferred wavelength for Diffuse Correlation Spectroscopy [3,4]. This approach has the advantage of lower energy per photon (thus lessening the safety issue), overall allowing the injection of more photons per pulse, and larger availability of high power sources (meant for telecommunication applications). From the signal point of view, the μ_s' is much lower thus increasing the penetration depth but conversely the contribution in μ_a of components such as water and lipids is higher than at shorter wavelengths thus causing a larger photons' attenuation [5]. Moreover, at 1064 nm, the extinction coefficient of HHb is around one decade lower than HbO_2 one [6], thus possibly permitting to precisely retrieve the concentration of the latter with a single wavelength.

In this work, we present a first explorative measurement of HbO_2 concentration during an arterial and venous occlusion on healthy volunteers using the only 1064 nm wavelength, comparing with the results obtained with a standard dual-wavelength (670 and 830 nm) system recording in parallel.

2. Material and methods

The experimental setup is composed of two sources: a Ti:Sa laser at 1064 nm with a repetition rate of 100 MHz and a 40 MHz driver equipped with two diode laser heads at 670 and 830 nm (LDH-P-C-670M and LDH-P-C-830M, Picoquant GmbH). For both the sources, an electrical signal synchronous with the optical pulses is generated and sent to a Time-Correlated Single-Photon Counting board (SPC-130, Becker and Hickl GmbH). For the detection, we collect light at 2.5 cm source-detector distance using a 1 mm diameter core fiber coupled through a 1x imaging system to three Silicon PhotoMultipliers modules (active area of about 1.7 mm^2). Each module was sensitive to a single wavelength, thanks to the insertion of an interference filter. The system was used to acquire in-vivo measurements during both arterial and venous occlusions in 5 healthy volunteers. Written informed consent was given by the subjects and acquisitions were approved by the Ethical Committee of Politecnico di Milano and conducted in compliance with the Declaration of Helsinki. The task consisted of 60 s rest, 180 s arterial occlusion, 240 s of recovery, 60 s of venous occlusion and 60 s of final recovery phases (overall duration: 10 minutes). Acquisitions were taken for the whole duration with an integration time of 0.5 s.

The recorded curves were then fitted to the analytical model of the photon transport in a diffusive semi-infinite medium under the diffusion approximation convolved with the instrument response function of the system. This allows one to recover values of μ_a and μ_s' for each acquisition. We took into consideration the presence of water and lipids in the tissue by estimating their contribution in absorption supposing a composition of 30% water and 70% lipids. It is worth noting that this percentage introduces only a shift in the HbO_2 concentration, without any distortion of the recovered trend. Using the 670 and 830 nm acquisitions, we computed the concentration of HHb and HbO_2 following the Lambert-Beer law for mixtures (the standard procedure used in NIRS). On the other hand, for the 1064 nm results,

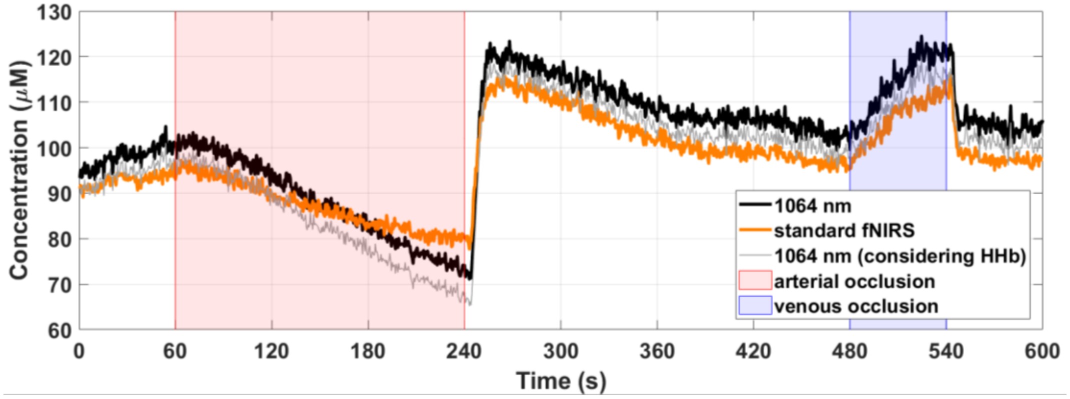

Fig. 1. HbO2 concentration computed using data at 1064 nm (black line) neglecting or not the HbO2 contribution (black and gray line, respectively) compared to what obtained with standard fNIRS system (orange line).

we neglected the contribution of the HHb thus ascribing the variation of the μ_a only to the HbO_2 concentration changes during the task. This assumption comes from the fact that the extinction coefficient is about one tenth of the HbO_2 one [6] thus potentially permitting to use a single wavelength to assess the concentration of HbO_2.

3. Results and discussion

Fig. 1 reports the trend in the HbO_2 concentration computed on one of the subjects both using the dual-wavelength (670 and 830 nm) method ("standard NIRS") as well as the 1064 nm neglecting the contribution of the HHb (orange and black line, respectively). The difference among the two approaches looks to be quite small and it mainly appears to be an offset. Only in the arterial occlusion phase, the "standard NIRS" approach shows a behavior which is characterized by two different slopes while the results obtained using the 1064 nm seems to be dominated by a single time constant.

On the other hand, neglecting the contribution of the HHb concentration does not introduce significant variation. Gray line in Fig. 1 shows the variation of HbO_2 if the concentration of HHb (computed using the standard NIRS system) is considered. As clearly visible from Fig. 1, the difference relies only in a small variation of the absolute value (always smaller than 10%) without any change in the temporal evolution of the HbO_2 concentration. Other subjects shows more or less similar behavior as the one above described.

Generally speaking, the use a single-wavelength (1064 nm) to assess the HbO_2 concentration seems to be a promising possibility for the future of the NIRS. Indeed, the availability of relatively high-power lasers at 1064 nm (devised for telecommunication applications) as well as the milder safety issues related to the longer wavelength, make this possibility a encouraging solution for the widespread use of time-domain diffuse optics in cerebral and muscle oximetry. Indeed, in this work, we show that the recovery of HbO_2 concentration during the resting/recovery and venous occlusion state are really close to the value achieved using a more complicate standard dual-wavelength fNIRS system. On the other hand, during the arterial occlusion a different behavior of the HbO_2 concentration can be observed: further investigations are needed to better understand the cause of this difference and to determine which is the more accurate representation of the physiological variation induced by the arterial occlusion.

3. Acknowledgement

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