Exploring the feasibility of 1064 nm for Time Domain NIRS Tissue Oximetry

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Abstract: We carried out oximetry measurements on 11 subjects rotating through a set of 8 wavelengths including 1064 nm. We found that 1064 nm works very well, having high SNR and low water-related error. © 2026 The Author(s)

1. Introduction

Near-infrared spectroscopy (NIRS) is a non-invasive diffuse-optics technique that quantifies tissue composition (like oxygenation) by extracting absorption and reduced-scattering coefficients (μ_a, μ_s'). Time-domain NIRS (TD-NIRS) improves this by detecting photon arrival times to form a distribution of times of flight (DTOF), enabling coefficient extraction through curve fitting and depth-selective analysis [1]. TD-NIRS is widely used for oximetry, typically employing one wavelength below and one above 800 nm [2]. Common pairs include 690 and 830 nm, though 1064 nm has gained interest due to its position near a water-absorption minimum, higher number of photons per optical power, reduced scattering, and good laser availability [3]. Previous literature on NIRS performed at 1064 nm shows that it is possible to evaluate relative changes of blood saturation and total haemoglobin, although the absolute values are not correct [3]. Here, we extend this work by testing wavelength combinations pairing 1064 nm with options from 690–900 nm for in-vivo measurements. We also implemented Monte Carlo (MC) simulations to evaluate the physiological parameters quantification accuracy of various wavelength pairs including 1064 nm. MC modeling is widely regarded the gold standard for photon-transport simulations in biological tissue [4], allowing us to use predefined parameters as ground truth to evaluate the fitting accuracy and analyze the quantification accuracy of physiological parameters.

2. Materials and Methods

For the in-vivo measurements, we used a supercontinuum laser SuperK FIANIUM (NKT Photonics, Denmark), outputting white light into an acousto-optic filter SuperK SELECT (NKT Photonics, Denmark), which filtered its light at 690, 750, 785, 800, 830, 860, 900 and 1064 nm in quick succession, performing a complete rotation of these 8 wavelengths in 10 ms. Light was delivered with a probe to the left forearm of the volunteers, with a source-detector separation of 2 cm. The light was detected by custom-built Silicon Photomultiplier detector module with fiber. The electrical signals for detection and synchronism were handled with an SPC-130 (Becker and Hickl, Germany). For each volunteer, a blood pressure cuff was wrapped around their right bicep and manually inflated in accordance with the following order: 1 minute of baseline at 0 mmHg, 3 minutes of arterial occlusion at 250 mmHg, 4 minutes of recovery at 0 mmHg, 1 minute of venous occlusion, 2 minutes of recovery at 0 mmHg. The measurements were approved by the Ethical Committee of Politecnico di Milano and were conducted in compliance with the Declaration of Helsinki. The data was in the form of DTOF curves for each wavelength, which contain the time of arrival of photons from which it's possible to extract the absorption coefficient μ_a at that wavelength. From the Beer-Lambert Law, one can then obtain the concentrations of the oxigenated haemoglobin HbO2 and deoxigenated haemoglobin Hb. In general, for wavelengths commonly used in NIRS, the absorption is mostly due to HbO2 and Hb. For 1064 nm there is also a high absorption due to water, so when extracting HbO2 and Hb we assume a fixed concentration of water. We varied the water concentration within reasonable biological limits to observe the effect on the extracted blood saturation and amount.

For the simulation, we first considered an idealised scenario without instrument effects and generated time-resolved DTOFs using MC simulations for a range of oxygenation states (StO2 = 45–80%) in a homogeneous

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medium. Simulations were performed at 690 nm, 785 nm, 830 nm, and 1064 nm, and the MC-generated DTOFs are fitted to recover μ_a. The discrepancy between the recovered and ground-truth μ_a gives rise to the relative absorption error $\delta\mu_a$. We also studied how this affects the retrieved StO2, and evaluated a relative error δStO_2 for it. We tested multiple wavelength pairs, including the conventional combination (690 nm + 830 nm) and several pairings involving 1064 nm (1064 + 690, 1064 + 785, 1064 + 830 nm).

3. Results

For the in-vivo measurements, there were some combinations of wavelengths clearly outperforming others in terms of noise and signal. To evaluate the performance of a wavelength pair we looked at the coefficient of variation for the total Hb during baseline as can be seen in Figure 1A. 1064 nm works well if paired up to a second wavelength below 800 nm, performing similarly well to the standard pair of 690 and 830 nm. To evaluate the error relative to the water concentration, we observed what happened if instead of the expected 0.7 we had 0.6 or 0.8, and found an error of less than 10% for 1064 nm paired to 800 nm or lower wavelengths, which is sufficient for clinical applications.

For the Monte Carlo simulations to retrieve μ_a, we found that across all tested wavelengths, including 1064 nm, $\delta\mu_a$ remained within 0-10 %, which is satisfactorily low. The δStO_2 is shown in Figure 1B. The best performance was achieved for 690 + 830 nm and 1064 + 690 nm, both yielding δStO_2 values within 0–5%.

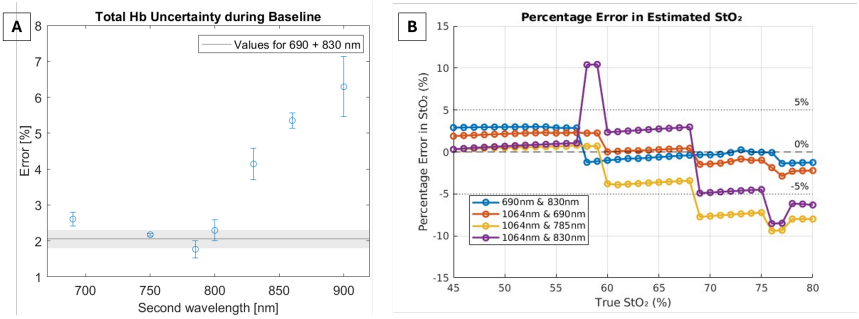

Fig. 1. (A) Coefficient of variation of total Hb during baseline for 1064 nm paired up to various wavelengths compared to standard 690 + 830 nm. (B) Error in extracted blood saturation versus true blood saturation in MC simulations for various wavelength pairs.

4. Conclusion

This study verified that 1064 nm is a suitable wavelength for carrying out oximetry measurements through TD-NIRS if paired up with a second wavelength below 800 nm, with a particularly good performance if paired up with 690 nm. Further work should explore a broader and finer range of wavelengths to find its best pair as well as compare the performance of wavelength-specific instrumentation for this type of measurement.

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