

Analysis of the Optical Signals Associated with the Electrical Stimulation of Peripheral Nerves

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Abstract: We report the possible origins of optical responses to electrical stimulation of the median nerve in human subjects. The optical signals are ~0.2% in amplitude, and peak ~100 ms after the 0.1 ms stimulus.

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1. Introduction

We have recently proposed a non-invasive method for evaluating the optical response to electrical stimulation in the peripheral nervous system using near-infrared spectroscopy (NIRS) [1]. Our proposed method involves dual-wavelength (690, 830 nm) recordings with a temporal resolution of 20-40 ms in response to single electrical stimulation pulses of 0.1 ms in duration and 1.5 Hz repetition rate, so that our targeted time scale for the optical signals is in the tens-hundreds of millisecond range. Electrical stimulation and optical recordings occur at a separation of ~10 cm along the nerve, similar to the case of electrical stimulation/electrical recordings in conventional nerve conduction studies. There are a number of studies reported in the literature that involve electrical stimulation of peripheral nerves and optical recordings at the brain [2] or spinal cord [3] in rats, or at the brain in human subjects [4]. There is also a prior report of optical recordings of fast optical signals (2 kHz acquisition rate) in electrically stimulated peripheral nerves (0.3-ms pulses at a 20 Hz repetition rate) [5], which did not yield a clear optical response on the targeted time scale of milliseconds.

We have found that the optical intensity signals associated with electrical stimulation in peripheral nerves peak after about 100 ms post-stimulation, and are characterized by an amplitude in the order of a few tenths of a percent. Such signal amplitude is comparable to that of signals associated with optical fiber/skin coupling effects, as reported in optical measurements on a piglet model [6]. Therefore, we are investigating the potential contributions to the measured optical signals in peripheral nerves from optical coupling changes at the optical fiber/skin interface. We report a series of experiments that study the presence of skin motion under the conditions of our nerve electrical stimulation protocol, and we discuss how the associated mechanical coupling effects may contribute to the optical signals observed in response to nerve stimulation under baseline and vascular occlusion conditions.

2. Methods

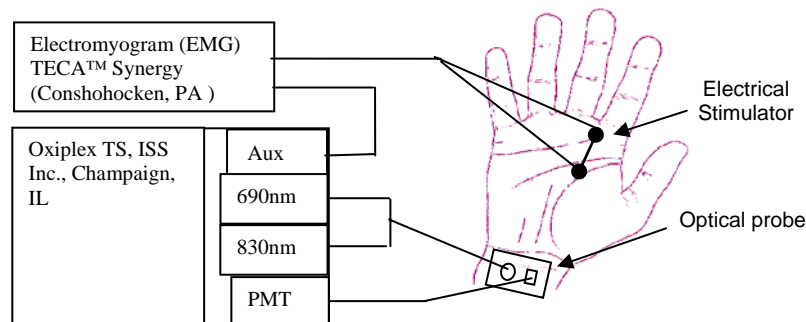


Fig. 1. Experimental setup for optical measurements on the

We report measurements on the right median nerve of 2 healthy subjects. A TECA Synergy electromyogram machine (Conshohocken, PA) was used to provide the electrical stimulation. The electrical stimulator was placed on the median nerve on the palm such that a sensory nerve action potential was observed through recording electrodes placed on the median nerve on the wrist. The near-infrared tissue spectrometer (OxiplexTS, ISS Inc., Champaign, IL) provides laser diodes emitting at 690 and 830 nm. We have placed an optical probe with one source optical fiber (delivering light at both 690 and 830 nm), and one detector optical fiber with a source-detector separation of 1.5 cm

on the subject's wrist as shown in Fig. 1. 0.1-ms electrical pulses were provided at a repetition frequency of 1.5 Hz and synchronized with the tissue spectrometer through an auxiliary input channel. The level of current was set at the minimum current needed to obtain an optical signal, which ranged from 10 to 40 mA. Data were acquired at a rate of 25 Hz (one data point every 40 ms). After a one-minute baseline acquisition (during which we provided 90 electrical pulses), we applied a pressure cuff to the upper arm, and we inflated it to a pressure of 50 mmHg to achieve venous occlusion, for five minutes, or 450 pulses. A folding average procedure was applied to the stimulation window starting 40 ms before the stimulus to 600ms after the stimulus.

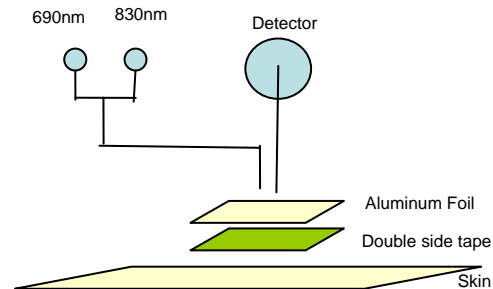


Fig. 2. Aluminum foil experimental setup

The aluminum foil experiments were done under previously stated protocol on the sural nerve [1]. To investigate the presence of skin motion, we performed an experiment where the skin was covered by a reflecting aluminum foil and the source-detector separation was reduced to 400 μ m. In this case, the signal was generated by the fact that the optical fibers are coupled to the aluminum foil via an optical prism, and the illumination spot on the aluminum foil overlaps with the area of sensitivity of the detector fiber. A double sided adhesive tape ensured that the aluminum foil was in secure contact with the skin. Changes in intensity therefore will solely be due to the skin movement and to the associated changes in the amount of light reflected by the foil into the collection fiber. The sural nerve was stimulated at 1.5 Hz with a pulse of 0.1 ms at a current level of 14 mA. The probe was lifted and replaced 2 mm distal after each one minute trial (90 electrical pulses) from 0-14 mm below the left lateral malleolus.

3. Results

Figure 3 shows the optical data of subject 1 during baseline stimulations (Fig. 3. Left) and venous occlusion (Fig. 3. Right). During subject 1 baseline, the change in intensity was a decrease of $\sim 0.1\%$ at both wavelengths, but during venous occlusion, the change in intensity at 830nm was $\sim 0.2\%$ while at 690nm was $\sim 0.1\%$, showing a wavelength dependence. Figure 4 shows the optical data of subject 2 during baseline stimulations (Fig. 4. Left) and venous occlusion (Fig. 4. Right). During subject 2 baseline and venous occlusion, there is a decrease in intensity of $\sim 1\%$ with no wavelength separation in either trial. Figure 5 shows the results from the aluminum foil experiments at 3 different probe positions on the sural nerve, 4mm, 6mm, and 14mm below the left lateral malleolus. The three curves in figure 5 show that the skin motion can influence the optical data by increasing ($\sim 0.15\%$) or decreasing ($\sim 0.16\%$) the signal.

4. Discussion

In our studies on both the median nerve and the sural nerve, we have found repeatable, characteristic optical signals in response to electrical stimulation. We are currently studying the origin of these signals, and the extent of potential contributions to these signals from changes in the optical coupling between the skin and the light sources/optical detector induced by motion. The experiments reported here, involving the reflective aluminum foil on the skin, were devised to detect skin motion independent from any optical changes occurring within the underneath tissue. The optical signals back-reflected from the aluminum foil (Fig. 5) show that there is skin motion to some extent, and that its associated geometrical effects depend on position and/or on the probe placement (pressure on the skin, etc.). Any motion-induced geometrical effects would perturb the boundary conditions of this diffusion problem, and as such are not expected to have any significant wavelength dependence. Such wavelength independence of motion-induced geometrical effects is the guiding criterion in the interpretation of the potential origin of the optical response to electrical stimulation in peripheral nerves. We have presented data from two subjects, one data set (Fig. 3) showing a wavelength dependence of the optical signal under venous occlusion conditions, and the other (Fig. 4) showing a wavelength-independent optical response both at baseline and during venous occlusion. These results suggest that the geometrical perturbation caused by skin motion may contribute to the optical response that we detect, as suggested by the weak wavelength dependence of the optical signals under different hemodynamic conditions. On the other hand, the wavelength dependence of the optical signal detected in Fig. 3 cannot be fully explained by

motion-induced geometrical effects. More detailed studies of the spatial and spectral features of the optical signals in response to electrical stimulation will allow for a more quantitative assessment of the potential contributions from skin motion, and for a more specific interpretation of their physiological origin.

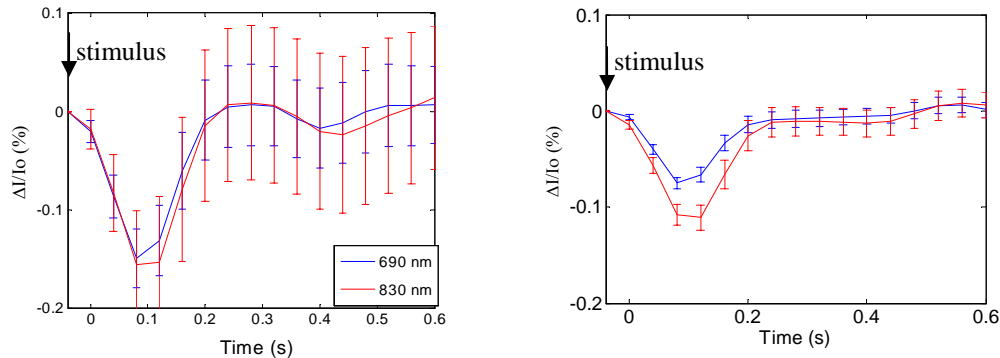


Fig. 3. Optical signals obtained from subject 1 during electrical stimulation only (left) showing no wavelength separation (both $\sim 0.1\%$ change) and electrical stimulation during venous occlusion (right) showing wavelength separation with 830nm (red) having a larger decrease, $\sim 0.1\%$ than 690nm (blue), $\sim 0.07\%$.

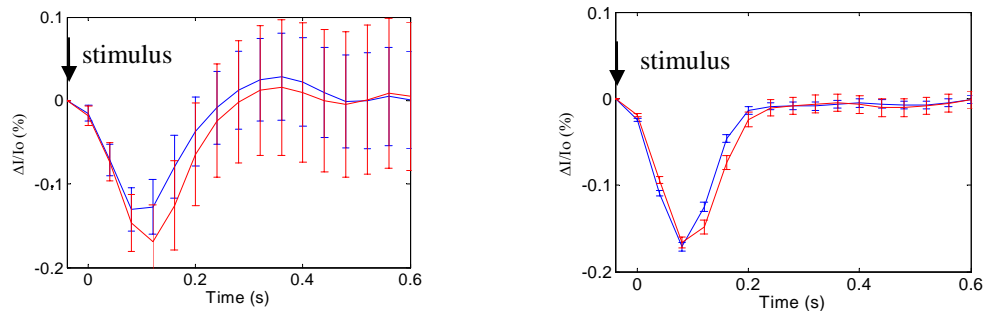


Fig. 4. Optical signals obtained from subject 2 during electrical stimulation only (left) and electrical stimulation during venous occlusion (right) both exhibiting $\sim 0.15\%$ change and no wavelength separation.

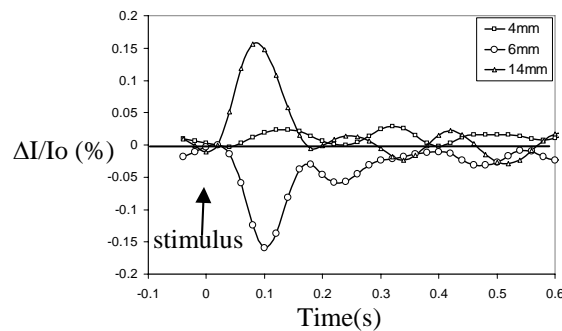


Figure 5. Results of aluminum foil experiment showing different effects of skin motion on the measured optical signal at three different positions on the sural nerve.

5. References

- [1] Y. Tong, J. M. Martin, A. Sassaroli, P.R. Clervil, P. R. Bergethon, and S. Fantini, "Fast optical signals in the peripheral nervous system," *J. Biomed. Opt.* **11**, 044014 (2006).
- [2] D. M. Rector, R. F. Rogers, J. S. Schwaber, R. M. Harper, and J. S. George, "Scattered-light imaging *in vivo* tracks fast and slow processes of neurophysiological activation," *Neuroimage* **14**, 977-994 (2001).
- [3] S. Sasaki, K. Sato, K. Shinomiya, and Y. Momose-Sato, "Postnatal changes in intrinsic optical responses to peripheral nerve stimulation in the *in vivo* rat spinal cord," *Neuroimage* **20**, 2126-2134 (2003).
- [4] J. Steinbrink, M. Kohl, H. Obrig, G. Curio, F. Syre, F. Thomas, H. Wabnitz, H. Rinneberg, and A. Villringer, "Somatosensory evoked fast optical intensity changes detected non-invasively in the adult human head," *Neurosci. Lett.* **291**, 105-108 (2000).
- [5] S. Lebid, T. Ward, R. O'Neil, C. Markham, and S. Coyle, "Towards dual modality nerve assessment using electrical and optical techniques," *Proc SPIE* **5855**, 399-402 (2005).
- [6] S. Fantini, D. Hueber, M. A. Franceschini, E. Gratton, W. Rosenfeld, P. G. Stubblefield, D. Maulik, and M. R. Stankovic, "Non-invasive optical monitoring of the newborn piglet brain using continuous-wave and frequency-domain methods," *Phys. Med. Biol.* **44**, 1543-1563 (1999).