Chapter 13
Implications of NIRS Brain Signals

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ABSTRACT

Near Infrared Spectroscopy (NIRS) is commonly used for functional brain studies. With this method, brain signals can be easily obtained, but the interpretation of these signals still remains unclear. This chapter provides a simple model to interpret the NIRS signal, which is based on the following assumptions: 1. The NIRS signal may reflect Hb levels only in the capillaries and not in large vessels; 2. The brain has a lighter color than the other tissues, indicating that the Hb concentration in brain tissue is very low and intensity level of the NIRS signal is very high; 3. A photon that hits a large vessel is too weak to be detected in the surrounding high signal environment; 4. Cerebral blood flow (CBF) can be separated into cross-sections (the number of capillary beds) that are multiplied by the velocity. This model can explain the typical signal pattern observed during task performance, where oxy-Hb levels increase and deoxy-Hb levels slightly decrease.

INTRODUCTION

Electromagnetic waves (EMWs) with a wavelength between 700 nm to 2500 nm (near infrared light, NIR) penetrate biological tissue more easily than other wavelengths, and this wavelength range is termed the tissue window. A light with a wavelength longer than this window has low penetration properties and thermal effects. The shorter end of this window is visible and ultraviolet (UV) light, which have very low penetration properties; EMWs with wavelengths shorter than this window, UV have chemical effects on the biological tissue. NIR light is, therefore, the safest and the most commonly used with biological tissues. Norris reported the water content of food using NIR light, which was the first application of NIR light to biological materials (Norris, 1956). Because the spectrum of absorption coefficients in the NIR region of oxy-hemoglobin (oxy-Hb) is different

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from that of deoxy-hemoglobin (deoxy-Hb), we can detect oxy-Hb and deoxy-Hb concentrations *in vivo* using NIR light. The first clinical application of NIR was the pulse oximeter, which is currently a widely used technique in intensive critical care units. The Tokai University group and Hitachi Group reported oxy-Hb mapping of the rat brain (using optical CT) (Shinohara, 1991). This method could not be used for humans, however, because head size is a limitation in NIR light penetration. Hitachi-Medico developed a new imaging system using NIR light, optical topography, which uses multiple sources and detectors on the head. This method can detect Hb concentration changes in the brain through the skull and skin and achieve two-dimensional Hb mapping of the brain; this method can thus be used in functional brain studies. There are several instruments that use the NIR to detect Hb concentrations in the brain based on this idea, which have different commercial names depending on the developers. However, there is no currently accepted model that can interpret the optical signals obtained from the brain.

In the current study, I propose a method to interpret NIRS signals from the brain using these instruments.

BACKGROUND

Bear and Lambert's law (1) defines the absorption of material as follows:

$$I = I_o e^{-\mu_a L} \tag{1}$$

where I_o, I, μ_a and L stand for intensity of input light, the detected intensity of light, the absorption coefficient and the optical path length, respectively. The absorption coefficient μ_a is defined as

$$\mu_a = \varepsilon \bullet c \tag{2}$$

where $\boldsymbol{\varepsilon}$ and $\boldsymbol{c}$ stand for the extinction coefficient and the concentration of the material, respectively. The extinction coefficient depends on the material, such as oxy-hemoglobin (oxy-Hb) or deoxy-hemoglobin (deoxy-Hb) concentrations. Figure 1 shows a spectrum of extinction coefficients of oxy-Hb and deoxy-Hb.

The two curves cross at approximately 800 nm, which is called an isosbestic point. Many instruments use the wavelengths from both sides of this point to obtain the hemoglobin concentrations. We can easily obtain the μ_a by measuring

Figure 1. Wavelength dependency of the extinction coefficients of oxy-Hb and deoxy-Hb