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SPATIALLY RESOLVED BLOOD OXYGENATION MEASUREMENTS USING TIME-RESOLVED PHOTOACOUSTIC SPECTROSCOPY

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1. INTRODUCTION

Photoacoustic spectroscopy relies on the generation of acoustic waves as a result of the absorption of short pulses of light in tissue. The absorption of the optical energy produces rapid heating and a consequent pressure rise in the illuminated volume, which generates acoustic waves that propagate away from their origins and are detected at the tissue surface. By measuring the time-of-arrival of the acoustic waves, the spatial distribution of photoacoustic sources can be determined. When optical excitation in the near-infrared wavelength range is used, the waves originate predominately from blood vessels due to the relatively strong absorption by haemoglobin. The amplitude of the photoacoustic signal is determined by the local concentration of haemoglobin, its oxygenation, and by the optical absorption and scattering in the surrounding tissue. Since blood exhibits wavelength-dependent changes in absorption as a result of varying concentrations of oxy- (HbO_2) and deoxyhaemoglobin (Hb)[1], blood oxygen saturation (SO_2) can be determined by making multi-wavelength measurements of the amplitude of the photoacoustic signals originating from a blood vessel.

By using an array of acoustic transducers, the principle of photoacoustic spectroscopy could be incorporated into photoacoustic imaging. Photoacoustic imaging has already been used for mapping the brain of small mammals *in vivo*[2] and blood vessel phantoms[3]. Combining photoacoustic spectroscopy with imaging would not only allow the reconstruction of a structural image with high spatial resolution (<100μm) but also the mapping of SO_2 in the microvasculature and hence the collection of functional information[4]. This technique may be particularly suitable for the study of the development of microvasculature in tumours, skin grafts and inflamed or healing tissue. However, photoacoustic spectroscopy for the quantitative measurement of SO_2 still requires experimental validation and an assessment of its accuracy.

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The aim of this study was to demonstrate for the first time the ability of photoacoustic spectroscopy to make quantitative, non-invasive, spatially resolved measurements of SO_2 and to assess the accuracy of the technique by comparing the photoacoustically determined values to independent SO_2 measurements made with a CO-oximeter.

2. BACKGROUND & METHODS

Short laser pulses were used to generate photoacoustic signals in a tissue phantom, which contained three blood filled capillaries in a scattering medium with optical properties similar to extravascular tissue (Figure 1). The spatial distribution of absorbed optical energy produced by the excitation laser pulses is directly related to the spatial distribution of the optical properties of the Intralipid suspension and the blood-filled capillaries. This is illustrated in Figure 1a, which shows the distribution of absorbed optical energy along the line of sight of a single-element ultrasound detector as indicated by the dashed arrow. Starting from the surface, the absorbed energy shows a steady decrease with depth, which is determined by the optical properties of the Intralipid. Peaks of absorbed optical energy due to the presence of haemoglobin occur wherever a capillary is situated. The conversion of optical energy to heat and the subsequent thermoelastic expansion produces a pressure source, which emits an acoustic pulse that is measured by the ultrasound transducer. This principle is illustrated in Figure1b, which shows the three distinct photoacoustic signals generated in the capillaries. Under conditions of stress confinement, i.e. where the optical excitation pulse is shorter than the time it takes the stress wave to travel across the source region, the spatial pressure distribution is directly proportional to the distribution of absorbed energy.

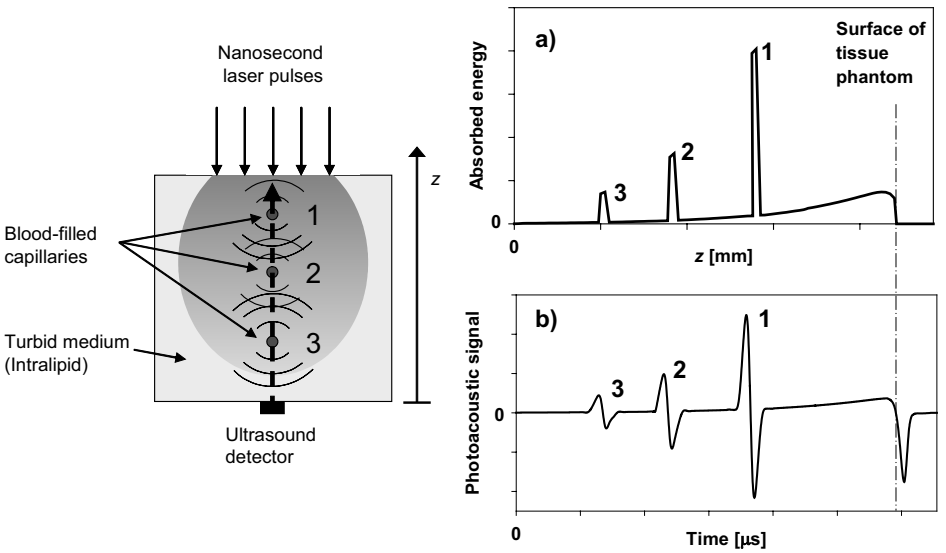

Figure 1. The tissue phantom consisted of an Intralipid bath and three capillaries through which blood was circulated. Figure 1a shows the depth profile of absorbed optical energy along the line-of-sight of the ultrasound detector. Figure 1b shows a schematic of a typical photoacoustic signal detected in the phantom.