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System for photoacoustic spectroscopy using narrow-band ultrasonic transducers

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Background, Motivation and Objective. Photoacoustic (PA) spectroscopy is a useful tool to analyse several physiological parameters of biological tissue. Studies have shown, for example, its application to estimate blood oxygen saturation (SO_2) based on different optical absorption profiles of oxyhemoglobin (HbO_2) and deoxyhemoglobin (Hb). Thus, SO_2 can be estimated by means of PA signal acquired using light excitation with different wavelengths and this estimative can be used for diagnostic purposes. In this study, we developed a device for PA spectroscopy using ultrasound narrowband ultrasonic transducers to detect the PA waves. To evaluate the developed system, solutions of copper chloride II ($CuCl_2$(II)) and nickel chloride II ($NiCl_2$(II)) were used. Absorption spectra were obtained based on the PA signal amplitude and exponential fitting of the initial compressive part of PA signal generated in solution illuminated by laser pulses, at normal incidence. Results were compared to optical absorbance measured using a commercial spectrophotometer. In addition, spectroscopic PA images of a phantom mimicking arteries filled with $CuCl_2$(II) solution were obtained.

Methods. Solutions of $CuCl_2$(II) and $NiCl_2$(II) in water were prepared, using concentration of 1% and 10% in mass, respectively. Three mixtures of $CuCl_2$(II) and $NiCl_2$(II) were prepared using solutions with 25-75%, 50-50% and 75-25% proportions. PA signals were acquired using a one-element transducer (Olympus, U8517028) with central frequency 1 MHz. A laser system (Quantel, Brilliant B) connected to an optical parametric oscillator (OPO) operating at wavelengths of 680-950 nm was used for excitation. The laser beam was delivered to the sample through an optical fiber bundle. Beam energy was monitored using a power meter (Coherent, Fildmax II). PA images of phantom were acquired using an ultrasonic system (Sonix RP) and a linear transducer with measured central frequency 5MHz (L14-5/38).

Results. Normalized PA signal amplitude spectra were in excellent agreement with results obtained with the spectrophotometer for all samples. The exponential fit of the initial compressive part of PA signal resulted in absolute optical absorption values, which were in accordance with expected values. PA images of phantom presents the borders of arteries filled with $CuCl_2$(II) and was co-registered with B-Mode image resulting in an final image that show information of phantom background and arteries. Normalized PA signal amplitude spectra of arteries region in PA images also present results in agreement with spectrophotometer.

Discussion and Conclusions. The results showed that the developed system for PA spectroscopy using narrow-band transducers can characterize optical absorption of solutions. Exponential fit of initial compressive part of PA signal can generate absolute values of optical absorption coefficient, but may not be practical for in vivo applications because of the dependence of normal laser incidence.

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Keywords. Photoacoustic; Spectroscopy; Blood Oxygenation; Narrow-band Transducers; Optical Absorption.