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NEAR INFRARED SPEKTROSCOPY IN STUDY OF BRAIN OXYGENATION

The near infrared spectroscopy offers a non-invasive, real-time monitoring of cerebral oxygenation. The method is based on the specific absorption of the near infrared light at various wavelengths by the tissue chromophores, e.g. oxyhemoglobin and deoxyhemoglobin. The changes of concentrations of these chromophores depend on the tissue oxygen supply [1-5]. This functional information is of potential interest for clinical assessment of oxygenation of brain [1] and muscles [2] or for detection of breast tumors [3].

In continuous wave (CW) near infrared spectroscopy the laser light with a constant intensity at selected wavelengths is introduced into the tissue examined, and the intensity of the remitted (or transmitted) light detected by the receiver is measured. Concentrations of the chromophores are calculated using the Lambert-Beer law, and at least a number of light wavelengths equal to the number of the measured chromophores needs to be applied. Typical CW spectroscope used in clinical studies allows to monitor changes in oxyhemoglobin and deoxyhemoglobin concentration. Besides, the total haemoglobin, as the sum of the oxy- and deoxy-components, corresponds to the tissue blood flow, assuming that hematocrite remains unchanged.

The main clinical application of near infrared spectroscopy is transcranial monitoring of brain oxygenation [6]. We have introduced the CW NIRS technique in the Vascular Surgery Clinic in Warsaw for monitoring of the cerebral tissue oxygenation and brain ischaemia, during carotid surgery [7, 8]. The results of this study suggest that this method is helpful in intraoperative cerebral monitoring, especially to indicate the necessity of the shunt insertion. In the same clinic the method was used for evaluation of the effectiveness of the chemical lumbar sympathectomy [9]. We have collaborated also with National Institute of Cardiology in Warsaw on application of CW spectroscopy for monitoring of cerebral oxygenation in cardiac surgery during circulatory arrest [10] and in study of the vasovagal syncope during the tilt test [11].

Unfortunately the near infrared spectroscopy based on intensity changes is limited to applications were the trends of changes of chromophores can give clinically useful information. The assumption on pathlength in the tissue under investigation does not allow to calculate absolute values of oxy- and deoxyhemoglobine concentration and oxygenation index. Recently, new optical methods were proposed which allow for estimation of pathlength of photons travelling between emitting and receiving fibres. These techniques can be used to monitor absolute concentrations of chromophores with higher spatial resolution. These new

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approaches are based on: analysis of spatial distribution of remitted CW light intensity, frequency modulation of emitted light and analysis of the phase shift between initial and detected light waves, measurements of the times of flight of single photons.

In spatially resolved spectroscopy the optical properties of the tissue can be estimated by analysis of decay of light intensity with source-detector separation. In commercially available instrument (e.g. NIRO300, Hamamatsu Photonics, Japan), where the change of attenuation with distance is evaluated in three points located relatively far from the light source, the information on the absolute concentration of chromophores, as well as on oxygenation index can be estimated.

Frequency domain technique is based on emission of intensity modulated light into the tissue and analysis of phase shift between initial wave and light detected on the surface of the tissue [12]. Application of multidistance or multifrequency systems allow to estimate optical properties of the tissue. One commercial instrument which uses this technique (ISS Inc, USA) allows to monitor changes of the mean time of flight of photons which are directly related to phase shift and finally to determine concentrations of oxy- and deoxyhemoglobine in the tissue and oxygenation index. This technique we are presently using in Neonatology Clinic in Warsaw for assessment of cerebral oxygenation in newborns.

Time-resolved spectroscopy is based on emission of short (picosecond) light pulses and analysis of the broadening of the pulse during its travel between points of emission and detection. It was found that time-domain near infrared spectroscopy allows for evaluation of changes of optical properties as well as changes of oxy- and deoxyhemoglobin concentrations with depth discrimination [13,14]. Moreover, imaging of changes of oxygenation in large brain regions is possible when large number of emission and detection points are located on the surface of the head [15]. In last years distinct progress in instrumentation for time of flight technology is observed. Flexible, picosecond diode lasers and time correlated single photon counting electronic allow to build portable, multichannel instruments, which increase the interest of scientific teams to use this technique in clinical experiments [14, 16, 17].

Recently, at the Institute of Biocybernetics and Biomedical Engineering PAS, the time-resolved multichannel system for diffuse optical topography of the brain cortex of adult human was developed. The system consists of two semiconductor diode lasers and eight parallel detection channels for recording of distributions of times of flight of photons. The laser pulses are delivered to the tissue using two optomechanical switches, which allow to deliver the light to 18 locations on the head. Eight PCI boards with time-correlated single photon counting electronics were applied for acquisition of distributions of times of flight of photons (DTOF).

The instrument allows for recording of distributions of times of flight of photons for 32 source-detector pairs corresponding in 32 volumes in the head, forming two 4x4 grids. Acquisition of the whole map takes about 1 s.

By fitting the theoretical distributions to the experimentally obtained data, the absorption coefficient and the reduced scattering coefficient of the tissue was determined. It allows finally to evaluate the concentration of the chromophores, e.g. oxy- and deoxyhemoglobin. Phantom experiments were carried out to test spatial resolution of the maps of moments of DTOFs recorded by the system. Two-layered and semi-infinite phantoms with absorbing inclusions were constructed and tested [18]. Furthermore, the applicability of the setup in clinical environment was studied in experiments on healthy volunteers [19].

Visual and motor stimulation were applied to test sensitivity of the setup. The increase of oxygenation in motor and visual cortex was detected.

The developed portable time-resolved multichannel system for diffuse optical topography of the brain cortex may be finally used in clinical environment for bedside monitoring of the brain function.

Potential applications of the instrument as well as general perspectives and limitations of the time resolved technique with multichannel measurements in assessment of oxygenation with depth discrimination on large area of the head will be discussed.

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