INCREASING DIFFUSE CORRELATION SPECTROSCOPY DEPTH SENSITIVITY AND BRAIN BLOOD FLOW SPECIFICITY

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Continuous, accurate monitoring of cerebral perfusion may reduce morbidity and mortality in patients in critical care. While physiological monitoring helps assess the impacts of perfusion changes in the brain, a technology able to directly, continuously and non-invasively monitor cerebral blood flow (CBF) is needed.
Diffuse correlation spectroscopy (DCS) is an established optical modality which enables non-invasive measurements of cerebral blood flow (CBF). Similar to near-infrared spectroscopy (NIRS), DCS uses red and near-infrared light to interrogate biological tissue, but, instead of quantifying hemoglobin concentration and oxygenation from measures of light attenuation, DCS quantifies an index of blood flow (BF_i) by measuring the light intensity temporal fluctuations generated by the dynamic scattering of moving red blood cells. The technology has been extensively validated against gold standards and its clinical utility in infants has been demonstrated. As with continuous-wave (CW) NIRS, the effectiveness of CW-DCS in measuring CBF is hampered in the adult population by limited depth penetration and extra-cerebral contamination. These two limitations so far have precluded the wide adoption of optical monitoring techniques in health care settings.
Our goal is to advance DCS to see deeper into the human brain and to isolate cerebral blood flow from scalp signals. To this aim we have developed a range of approaches which, either individually or together, significantly improve performance over current CW-DCS technology.

We have first proposed and demonstrated operation of DCS in the time-domain (TD-DCS)[1], which offers dramatic improvements in brain sensitivity when considering late arriving photons. Transform limited, high power, Gaussian pulse-shaped laser sources and photon counting detectors with high efficiency and temporal resolution, and reduced after-pulsing probability, dark count rate, jitter and hold-off time are needed to maximize performance. Our current prototype uses commercially available components with several limitations[2], which we are trying to overcome by developing custom components. For the detectors, a commercially available solution is the use of superconducting nanowire single-photon detectors (SnSPD). These detectors reach up to 90% efficiency, have extremely low noise and great timing response, but they are very expensive and require a bulky cryogenic cooling system with a turn-on time of several hours.

The use of SnSPDs allows us to use longer wavelengths in the range of 1064 nm, instead of the typical NIRS wavelengths (680-850 nm). At 1064 nm absorption is comparable, but the scattering is considerably lower than at 800 nm, providing increased penetration depth. The use of longer wavelengths also offer a 15-20 times increase in the number of photons available for detection.
Another novel technology we are developing in our lab is acousto-optic modulated interferometric DCS. Instead of resolving in time photons that have travelled longer paths, we use short pulse ultrasound plane waves to tag the light field at specific depths, permitting separation of cerebral from extra-cerebral blood flow. This method in combination with a heterodyne interferometric detection technique permits separation of the light that was frequency shifted by the ultrasound. Moreover, this method allows us to use camera based parallel multi-speckle detection instead of photon counting detectors which are less costly and are commonly available with sensitivity and appropriate speed in the >1000 nm spectral range.

These emerging technologies are developed with the contribution of my coworkers at the Optics @ Martinos, and of our collaborators at Boston University and MIT Lincoln Laboratory.
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