Biomedical Optics for Imaging the Human Brain

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Bedside monitoring of cerebral health is important for a variety of diseases, including traumatic brain injury, hydrocephalus, sepsis, and stroke, where inadequate perfusion can lead to ischemia and neuronal damage. Non-invasive methods for evaluating cerebral perfusion exist, including functional magnetic resonance imaging (fMRI) and transcranial Doppler ultrasound, but are either limited in their ability to do long term monitoring or fail to differentiate between different brain regions.

Optical imaging methods exist, such as Near-Infrared Spectroscopy (NIRS), which can be used at the bedside and continuously, therefore overcoming some of the challenges of disease monitoring. NIRS is a non-invasive optical technique, using near-infrared light with at least two different wavelengths to be transmitted through the intact scalp and skull to illuminate the brain. An optical fiber is placed in a specific scalp location to deliver an optical signal, while a separate optical fiber, typically placed a couple of cm away from the illumination point, collects the light that has probed the cerebral tissue. The main absorber for near-infrared light in brain tissue is hemoglobin, and the light absorption properties of hemoglobin depend on its level of oxygenation. Accordingly, this optical method can be used to assess changes in tissue perfusion and oxygenation, which can be related to changes in cerebral activation. The benefit of NIRS over other imaging modalities measuring brain activation is portability and increased information content, assessing all aspects of hemoglobin changes (in comparison to fMRI, which is primarily sensitive to deoxy-hemoglobin), with high temporal resolution.

In this talk, basic principles and advances in NIRS for measuring cerebral functional activation will be summarized. Furthermore, applications for monitoring traumatic brain injury and prediction of patient outcome will be highlighted. For this, we have recently demonstrated that hemodynamic changes can be correlated with intracranial pressure (ICP) changes, therefore enabling non-invasive ICP sensing. Measuring intracranial pressure is typically a highly invasive procedure, in which a ventricular catheter or pressure sensor is placed into the brain. To improve the availability of ICP measurements in non-intensive care patients and to reduce the invasiveness and underlying risks of ICP sensing, we developed a non-invasive method based on optical data, combined with a transfer function approach and machine learning. Experimental designs will be presented, which are based on changing ICP baseline in non-human primates through adjusting the height of a saline reservoir connected to the lateral ventricle via a catheter. ICP was precisely measured with an invasive pressure sensor and the hemodynamic response

was quantified via NIRS. Results from these animal studies will be presented, demonstrating that non-invasive ICP sensing is possible. An outlook for clinical translation will be given as well.