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Near-Infrared Diffuse Correlation Spectroscopy (DCS) for Assessing Deep Tissue Blood Flow

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Many diseases are associated with abnormal blood flow such as stroke, peripheral arterial disease (PAD), and cancer. An occlusive stroke/PAD is an interruption of the blood flow to the brain/skeletal muscle, which may impair or even destroy the cerebral/muscular function. The abnormal vasculature and/or high metabolic demand in tumors may generate abnormal blood flow compared to the surrounding normal tissues. The various treatments for these diseases share the common goal of modifying blood flow in some way. These treatments include improving blood flow to the ischemic tissues or shutting down the blood flow to cancer cells. Therefore, measurement of tissue blood flow may provide information for diagnosis of various tissue diseases, and for monitoring of therapeutic effects.

A variety of methods are currently used for the measurement of blood flow and velocity [1]. In the clinic, however, blood flow measurements are required to be noninvasive, continuous, and fast while still providing accurate and useful quantitative flow information in deep tissues. Duplex ultrasonography can noninvasively image large and deep vessels in three dimensions with relatively high spatial (~mm) and temporal (~ms) resolution. Imaging modalities for evaluation of deep tissue blood flow at the level of microvasculature include positron emission tomography (PET), single photon emission computed tomography (SPECT), Xenon-enhanced computed tomography (Xenon-CT), dynamic perfusion computed tomography (PCT), dynamic susceptibility contrast magnetic resonance imaging (DSC-MRI), and arterial spin labeling MRI (ASL-MRI). These techniques use endogenous (ASL-MRI) or exogenous tracers (PET, SPECT, XeCT, PCT, DSC-MRI), and their temporal (seconds to minutes) and spatial (several millimeters) resolutions vary. However, these imaging modalities have several limitations that preclude their routine use in clinics. PET, SPECT, and Xenon-CT require exposure to ionizing radiation, and MRI methods cannot be used in patients with pacemakers, metal implants, or claustrophobia. Furthermore, most of these methods require large and costly instrumentation, and are largely incompatible with serial/continuous measurements. Other surface-sensitive imaging techniques for measurement of microvascular flow include scanning laser Doppler, laser speckle imaging and Doppler optical coherence tomography (DOCT). These methods are used primarily for noninvasive monitoring of blood flow in tissues located at a few hundred microns below the tissue surface.

Apparently, there is a critical need to develop bedside techniques that can monitor microvascular blood flow in deep tissues noninvasively, frequently and inexpensively. Recently, an emerging near-infrared (NIR) diffuse correlation spectroscopy (DCS) was developed which can directly measure the motions of moving scatterers (primarily red blood cells) in biological tissues [2,3]. DCS uses a coherent NIR light source to penetrate deep tissue, and monitors temporal light intensity fluctuations caused by moving red blood cells in tissue microvasculature to calculate flow index. DCS offers several attractive new features for blood flow measurement such as noninvasiveness, high temporal resolution (up to 100 Hz) [4], portability [5], and relatively inexpensive and large penetration depth (up to several centimeters) [3]. Furthermore, DCS can be easily and continuously applied at the bedside in the clinic [6-8].

DCS measurements of blood flow variation in various tissues/organs have been validated against other standards, including power Doppler ultrasound [9], laser Doppler [10], Xenon-CT [11], Doppler ultrasound [12], fluorescent microsphere measurement [13], and ASL-MRI [7]. The utility of DCS technology for bedside monitoring of tissue blood flow has been recently demonstrated in tumors [3,6,9], brains [10,11,14], and skeletal muscles [7,8]. The early stages of the studies focused on blood flow in animal models (e.g. murine tumors, rat and piglet brains). More recently, the DCS technique has been a key component in a variety of clinical studies (e.g. human cancers of prostate, breast and head and neck, cerebral functional activities, cerebral stroke, traumatic brain injury, skeletal muscle physiology). In these investigations, DCS measurements show promise for quantification of tissue hemodynamic status, for diagnosis of vascular-related diseases (e.g. cancers, stroke, PAD), and for continuous monitoring and evaluation of therapeutic effects (e.g. chemotherapy, radiation therapy, photodynamic therapy, arterial revascularization). It is anticipated that with more clinical applications in large patient populations, DCS might emerge as an important method of choice for bedside diagnosis and management of vascular/flow-related diseases and therapies.

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