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Cerebral blood flow imaging. Relation to blood rheology

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Abstract

A number of techniques allow imaging of the cerebral blood flow (CBF). Flow-sensitive time-of –flight (TOF) magnetic resonance imaging (MRI) demonstrates good representation of the flow but the extracranial hemodynamics could be assessed by color duplex ultrasound of the carotid arteries. Computerized tomography (CT), Xenon enhanced or CT perfusion with iodinated contrast, single- photon emission computed tomography (SPECT) with HMPAO, positron emission tomography (PET) with radiolabeled water, contrast perfusion-weighted and non-invasive MRI technique using continuous arterial spin labeling (CALS) provide precise assessment of cerebral perfusion with measurement of blood flow velocities.

The contrast agents used have hemorheological and vessel wall effects.

Keywords: Cerebral blood flow, Doppler ultrasound, functional neuroimaging, blood rheology

Cerebral blood flow (CBF), is the blood supply to the brain in a given time. In an adult, CBF is typically 750 milliliters per minute or 15% of the cardiac output. This equates to 50 to 54 milliliters of blood per 100 grams of brain tissue per minute. The CBF is determined by a number of factors, such as viscosity of blood, vascular tone and the net pressure of the flow of blood into the brain, known as cerebral perfusion pressure (CPP), which is determined by the body's blood pressure (BP).

CBF is equal to CPP divided by the cerebrovascular resistance (CVR):

$$CBF = CPP / CVR \text{ or } CBF = BP / CVR$$

The cerebral autoregulation is a process, which aims to maintain adequate and stable CBF regardless of the changes of systemic BP or CPP. The stability of CBF is accomplished by altering the blood vessels diameter through constriction or dilatation [1].

The conventional neuroimaging methods – computed tomography (CT) and magnetic resonance imaging (MRI) are good enough to estimate the state of brain morphology. However the contemporary diagnosis and treatment options need:

- To define the cerebral physiology by application of different stimuli (CO_2 inhalation, cognitive or movement tasks etc.), which lead to local CBF changes.
- To identify areas of abnormal blood flow in cerebral pathology: stroke, vascular malformations, carotid stenoses or occlusions, traumatic brain injury, vascularized brain tumors, resistant epilepsy, psychiatric diseases.
- To estimate the therapeutic choice and to do the CBF measurement as earlier as possible after the brain injury.
- To monitor the effectiveness of contemporary thrombolytic therapy and surgical interventions.

This important information for the therapeutic behavior is achieved by the so-called functional neuroimaging methods.

The Doppler ultrasound is one of those methods. It provides information about the change of velocity and direction of moving erythrocytes in the major arteries of the neck and the proximal segments of intracranial arteries, and other parameters of blood flow in the examined vascular segment. It can thus identify and characterize stenosing arterial section or change in the direction of flow.

Conventional B-mode imaging, color Doppler flow imaging, power Doppler imaging and B-flow imaging are the ultrasound techniques for evaluation of blood flow and morphology of the carotid and vertebral arteries [2]. Among these sonography methods, the power Doppler shows the highest value for blood-flow volume quantification, while B-flow ultrasound correlates best with the MR phase-contrast imaging [3].

The functional transcranial Doppler sonography (TCD) constitutes a complementary neuroimaging tool for examination of the cerebral hemodynamic reserve through assessment of the cerebral autoregulation and the cerebral vasomotor reactivity [4]. This non-invasive and ease-of-use method provides information about the changes of the blood flow velocities in the basal cerebral arteries following changes of arterial blood pressure or CO_2 concentration [5, 6]. The Doppler measurement of cerebral blood flow velocity was found comparable to CBF assessment by functional MRI [7]. Extended application of TCD in enhancing intravenous thrombolysis in acute stroke, emboli monitoring, right-to-left shunt detection and vasomotor reactivity provide important information about the pathophysiology of cerebrovascular ischemia [8]. TCD can be used as a monitoring tool during cardiac surgery and cerebrovascular operations to determine critical hemodynamic changes in cerebral arteries and for emboli detection [9].

The Perfusion Computed Tomography (PCT) with infusion of iodinated nonionic contrast material is a technique that allows rapid qualitative and quantitative evaluation of the cerebral perfusion by generating maps of cerebral blood flow (CBF), cerebral blood volume (CBV), and mean transit time (MTT). Dynamic CT perfusion imaging with acetazolamide challenge shows prolonged MTT in brain areas with hemodynamic impairment due to reduced perfusion pressure [10].

The Positron emission tomography (PET) is a radioisotope method using intravenously or inhaled applied Radioligand (radiolabeled molecules) with a short half-life, emitting positrons. PET explores the pathophysiology of the disturbances of the cerebral circulation and in particular investigation of cerebral blood flow in cerebral infarctions. Currently, PET is an indispensable method that provides accurate, quantitative *in vivo* regional measurements of both cerebral blood flow (regional distribution, blood volume) and cerebral metabolism (oxygen extraction, consumption of glucose) [11]. Functional investigation of the cerebrovascular reserve with acetazolamide is also performed. The PET using oxygen-15-labeled water [15 O-H_2O], is considered one of the gold standards for the study of regional CBF (rCBF).

The depiction of changes in cerebral perfusion in various cerebrovascular diseases by another functional radioisotope method - SPECT (Single Photon Emission Computerized Tomography) with radioligands 99mTc-ECD and 99mTc-HMPAO is important for early detection of changes in rCBF after cerebral hemodynamic impairment [12]. Focal hypoperfusion corresponding to the clinical symptoms is established after injection of 99mTc-HMPAO in the first hour after the onset of ischemic stroke. SPECT with acetazolamide stimulation is also used for the preoperative assessment of perfusion reserve in patients with compromised hemodynamics and for prediction of postoperative results [13].

PWI (Perfusion-Weighted Imaging) is an MRI sequence that provides hemodynamic data of the brain, based on the movement of perfused contrast material – gadolinium, its injection changing the magnetic susceptibility of blood. PWI evaluates the blood flow in the brain microvasulature, where rCBF, regional cerebral blood volume (rCBV) and regional mean transit time (rMTT) can be calculated. PWI registers haemodynamic perfusion disturbances in the brain parenchyma during the first few hours after ischemic stroke [14].

Emphasizing the importance of neuroimaging techniques such as PCT and PWI attention should be paid to the contrast materials used: contrast image intensifier in CT and gadolinium for enhancement images in MRI study and their effect on the rheological properties of blood. A number of in vitro and in vivo studies reveal their effects on blood viscosity, platelet aggregation and red cell morphology and aggregation behavior. The hemoreological effects depend on the osmolality, viscosity, absolute iodine, ionic or nonionic nature of X-ray contrast [15, 16, 17].

The side effects of the contemporary nonionic low osmolality contrasts for computed tomography and gadolinium derivatives in Magnetic Resonance Imaging are minimized in consideration of the relative contraindications for use [18, 19].

A contemporary MRI method to display CBF is the so-called ASL-perfusion (Arterial Spin Labeling). ASL perfusion MRI uses magnetically labeled arterial blood water as an endogenous tracer for measuring CBF, and is less invasive and less expensive than earlier approaches using radioactive tracers or paramagnetic contrast agents.

As a rapid, noninvasive, and quantitative technique, ASL has clinical application in detecting blood flow abnormalities in patients with acute ischemic stroke and cerebral neoplasms [20].

In conclusion, the choice of imaging method for evaluation of CBF depends on the options of the neuroimaging instrument (appropriate resolution, X-ray load, need of contrast enhancement, time measurement of CBF, price) and the clinical indications and therapeutic targets for the individual patient.

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