Imaging Oxygenation, Metabolic Rate & Cerebrovascular Reserve with MRI

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Highlights

- New developments in MRI technologies now allow the assessment of vascular physiology beyond diffusion/perfusion.
- Tissue Oxygen Extraction Fraction (OEF) can be evaluated by quantitative measurement of oxygenation level in cerebral veins.
- Rate of oxygen utilization can be estimated by the arterio-venous difference in oxygen content.
- Cerebrovascular Reserve (CVR), the blood vessel's vasodilatory capacity, can be determined by gas/pharmacologic challenges while dynamically acquiring MR images.

Target audience: Clinicians and scientists with an interest in brain vascular physiology and/or its application in acute and chronic cerebrovascular disease, including advances in MR imaging methods relevant to vascular evaluation such as perfusion, oxygenation, metabolism, and cerebrovascular reserve.

OUTCOME/Objectives: Upon completion of this lecture, participants will be aware of the availability of emerging techniques to measure Oxygen Extraction Fraction (OEF), Cerebral Metabolic Rate of Oxygen (CMRO2), and Cerebrovascular Reserve (CVR), all using non-invasive MRI technologies on a standard 3T. The participants will also be able to describe the general principle of each technique, potential scope of applications, as well as their advantages and limitations.

PURPOSE: Diffusion and perfusion measurements are the current standard in MRI assessment of cerebrovascular diseases, in particular in acute stroke. The evaluation of other physiologic parameters may provide complementary or even more sensitive measures in terms of diagnosis and treatment monitoring. Unfortunately, some of these newer parameters have been very difficult to measure, especially using MRI methods. This lecture will review several emerging techniques that have the potential to overcome some of these difficulties.

METHODS/RESULTS/DISCUSSION: Tissue OEF is directly related to cerebral venous oxygenation as a greater extraction fraction by the tissue would mean that there is less oxygen left in the venous blood. Therefore, OEF can be evaluated by the determination of venous oxygenation of the brain. One principle by which blood oxygenation can be measured with MR is that blood oxygenation has a direct and calibratible relationship with its T2 relaxation time. The practical obstacle has been the difficulties in isolating pure blood signal in the brain, as blood is always partial volumed with gray matter/white matter/CSF in a voxel. Over the past few years, a number of methods have been proposed to effectively separate the blood from the surrounding tissue, thereby allowing accurate quantification of blood T2. Some of these methods are based on spin labeling/tagging (1) and others are based on the intravoxel-incoherent-motion (IVIM) mechanism (2). With these recent advances, it is becoming feasible to measure regional oxygenation within 5 minutes in humans.

Tissue CMRO2 can be evaluated based on the difference in oxygen content between the arterial and venous vessels, often referred to as the Fick principle. To obtain an estimation of CMRO2, three parameters are needed, venous oxygenation, arterial oxygenation, and CBF. Venous oxygenation can be determined by the technique described above. Arterial oxygenation can be measured by non-invasive pulse oximetry method. CBF can be determined by arterial-spin-labeling, dynamic-susceptibility-contrast, or phase-contrast MRI. Existing data suggest that global CMRO2 can now be determined within 5 minutes and regional values within 10 minutes.

The key requirement for CVR assessment is to identify a physiologic maneuver that is safe, practical, and can be performed inside MRI. Although it is well known in anesthesiology literature that CO2 is a potent vasodilator and it is safe to induce a transient increase in arterial CO2 content, only recently has the experimental setup become practical and almost routine inside MRI. One can increase arterial CO2 by inhalation of CO2 gas mixture, breath-hold, or injection of pharmacologic agent such as acetazolamide.

CONCLUSION: Emerging techniques to assess OEF, CMRO2, and CVR may become useful additions in studies of normal vascular physiology and pathophysiology in cerebrovascular disease.

REFERENCES: 1) Lu & Ge, MRM 2008; 60:357. 2) Guo & Wong, MRM 2008; 68:1458.