Neuroimaging 1: Basic Neuroimaging (Educational course)

SY01-1

MR Diffusion in Neuroimaging (DWI, DTI, DKI)

Masaaki Hori, Shigeki Aoki

Department of Radiology, Juntendo University School of Medicine, Tokyo, Japan

Diffusion-weighted imaging (DWI) is an MR imaging technique for visualization of molecules (usually water molecules) with motion probing gradient (MPG) pulse. Diffusion tensor imaging (DTI) can be used to evaluate anisotropy of diffusivity in one voxel with use of 6 or more MPG pulse. In addition to conventional MR sequence parameters, such as echo time and repetition time, DWI specific imaging factors including b value (the strength of effect of MPG), numbers and directions of MPG and diffusion time are important factors for the contrast and metrics on DWI.

Moreover, as quantified metrics derived from diffusion MRI data, apparent diffusion coefficient (ADC) and fractional anisotropy (FA, DTI data needed) have been used in evaluation of normal central nerves system (CNS) structure and microstructural changes in disease process in vivo. And DTI data can be used to generate 3 dimensional white matter tractography, which provide stereoscopic anatomical information of white matter fibers in CNS.

However, DWI and DTI measurements are based on an assumption of a Gaussian shape for the underlying probability density function of diffusion of water molecule. That is, the water molecules can go far with time without barriers. In the real CNS tissue is a complex environment and there are many spatial barriers including cell body, myelin, and cell organelle, the decay of diffusion MRI signal is affected by many factors such as water restriction and intra- and extracellular water exchange and variation in tissue compartment sizes. Hence, different approaches not relying on the previously mentioned assumption are required to address the factors affecting the signal in diffusion-weighted sequences.

Therefore, more dedicated, non-Gaussian diffusion analysis methods have been introduced. Diffusional kurtosis imaging (DKI) is one of the most popular methods using non-Gaussian diffusion analysis and reports of its clinical use has increased in number because DKI may reflect microstructural changes and damage of CNS tissues and has the potential to provide new information beyond that provided by conventional diffusion metrics.

In this lecture, brief review of the basic of DWI, DTI and DKI and clinical application of the techniques for CNS disorders will be demonstrated.

Keywords : Diffusion-Weighted Imaging, Diffusion Tensor Imaging, Diffusional Kurtosis Imaging

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MR perfusion in neuroimaging

Roh-Eul Yoo

Department of Radiology, Seoul National University Hospital, Seoul, Korea

Perfusion-weighted MR imaging (PWI) has been a key to opening a new era in imaging-based diagnosis of various CNS pathologies. Three main perfusion-weighted imaging techniques which are being used in our clinical practice today: 1) Dynamic susceptibility contrast (DSC) PWI, 2) Dynamic contrast-enhanced (DCE) MR imaging, and 3) Arterial spin labeling (ASL) PWI. DSC-PWI and DCE-MRI require the use of gadolinium-based contrast agent, while ASL-PWI is a noninvasive perfusion MR technique that uses magnetically labeled water as a diffusible tracer to measure cerebral blood flow (CBF) values. DSC-PWI is dependent on the susceptibility effect caused by paramagnetic gadolinium on $T2^*$-weighted imaging. In ASL-PWI, magnetically labeled water molecules reduce the longitudinal magnetization vector, which in turn leads to the reduced image signal. Subsequently, subtraction of the labelled image from the control image provides CBF map on ASL-PWI. Dynamic contrast-enhanced (DCE) MR imaging is based on T1 shortening induced by a gadolinium-based contrast bolus passing through tissue. Various quantitative model-based and semiquantitative model-free pharmacokinetic parameters, that reflect microcirculatory structure and function, can be derived using the technique. This lecture will focus on the clinical use of the three aforementioned perfusion-weighted imaging techniques in neuroimaging (e.g. tumor, stroke, seizure).

Keywords : Dynamic susceptibility contrast (DSC) PWI, Dynamic contrast-enhanced (DCE) MR imaging, Arterial spin labeling (ASL) PWI

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MR Angiography and Vessel Wall Imaging in Neuroimaging

Bum-Soo Kim

Department of Radiology, The Catholic University of Korea, Seoul, Korea

Time-of-flight (TOF) MRA is still most widely used MRA technique in the evaluation of neurovascular disease. TOF technique has advantage of no-contrast injection to obtain images with relatively high spatial resolution. TOF techniques derive contrast between flowing blood and stationary tissues by manipulating the magnitude of the magnetization, leading to a large signal from moving blood and a diminished signal from stationary tissues. 3D TOF MRA methods are well suited for imaging the intracranial vessels owing to the small voxels, short echo times, and inherently high SNRs. Intracranial vascular diseases such as stenoocclusive disease, arteriovenous malformations (AVMs), and aneurysms are commonly evaluated using 3D TOF MRA in good diagnostic efficiency. Meanwhile, TOF MRA is not impervious to signal loss caused saturation of slow/turbulent flowing blood (carotid bulb, post-stenotic dilatation, arterial tortuosity, giant aneurysm etc.) and by dephasing of magnetization (metallic implant including aneurysm clip or stent).

Contrast enhanced (CE) MRA is less dependent on blood inflow or phase-shift effects. The T1 shortening of blood by injected contrast media provides room for shorter repetition time and less in-plane saturation of vessel, large fields of view can be imaged to demonstrate large vascular areas in a short acquisition time. In the evaluation of neurovascular structures, where very short transit time from arteries to veins exists, proper injection of contrast media and timed acquisition of CE MRA are important for optimal image quality. Time-resolved (TR) CE MRA, providing dynamic information by acquisition from arterial to venous opacification, can also be used to determine bolus arrival time, and it is feasible with injection of small amount of contrast media.

Atherosclerosis is an important cause of stroke. Vessel wall imaging can depict the morphologies of atherosclerotic plaques, arterial walls, and surrounding structures in the intracranial and cervical carotid arteries Differentiating vulnerable from stable plaques and characterizing atherosclerotic plaques are getting important parts in the clinical management of stroke.

Keywords : MR angiography, MRA, Vessel wall imaging, Time-of-flight MRA, Contrast enhanced MRA