ISC Symposium l: Cutting edge MRI-based neuroscience research (Neuroradiology)

SY11-1

Direct Imaging of Myelin Using Ultrashort Echo Time (UTE) Magnetic Resonance Imaging Sequences

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Myelin is a lamellar membranous structure consisting of alternating protein and lipid layers, which forms myelin sheath that insulates the axon from electrical activity and functions to increase the rate of action potential transmission. It is of critical importance to evaluate the integrity of myelin in white matter for the diagnosis and assessment of many neurological diseases including multiple sclerosis (MS). However, myelin protons have very short T2*s and are not directly detected with conventional clinical magnetic resonance imaging (MRI) sequences. Ultrashort echo time (UTE) sequences with nominal TEs as short as 8 μs have been introduced for direct imaging of myelin protons. However, myelin protons only represent a small fraction of the total signal from white matter of the brain, with dominant signal from the long T2 water components. Adiabatic inversion recovery prepared UTE (IR-UTE) sequences have been developed, in which a Silver-Hoult inversion pulse is used to invert and null the long T2 components in white matter. Myelin has ultrashort T2* and is not inverted due to fast relaxation during the long adiabatic inversion process, and is detected by subsequent UTE data acquisition.

Here we present direct imaging of myelin using two-dimensional (2D) and 3D UTE and IR-UTE sequences on high performance spectrometers and clinical scanners. The sequences were first applied to biologically derived bovine myelin lipid phantoms (type-I bovine brain extract obtained from Signa-Aldrich Corp, St. Louis MO) either in the powder form or in D2O suspension. T2* was measured with UTE imaging at a series of TEs ranging from 8 μs to 5 ms. Then the sequences were applied to cadaveric human brains from donors without and with MS. Finally the UTE sequences were applied to healthy volunteers (ages 27-42) and MS patients, with IRB approval before the MR scan.

High signal was achieved with UTE and IR-UTE imaging of bovine myelin extract in powder and in D2O suspension, confirming that myelin protons are directly visible with UTE sequences on a clinical 3T scanner. Short T2*s of ~200 μs were demonstrated for myelin protons in the powder form. Slightly longer T2*s of ~300 μs were observed in myelin D2O suspension. Obvious myelin loss was observed in MS lesions as confirmed by clinical MR sequences. Partial myelin loss can only be observed by IR-UTE sequences, rather than clinical MR sequences. Intact myelin maps were generated for healthy volunteers, while MS patients showed different degrees of myelin loss. Our studies demonstrate that the 2D and 3D IR-UTE sequences allow high contrast morphological imaging of myelin. Those sequences can also be used for quantitative evaluation of the MR properties (such as T1 and T2*) and tissue properties (such as proton density). The IR-UTE techniques are likely to improve the specificity of MRI for the diagnosis of MS, and provide improved understanding of the natural history of the disease as well as monitoring of drug therapy.

Keywords : Myelin, Direct imaging, UTE, T1, T2*

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Deep Learning in MRI Reconstruction, Enhancement and Analysis

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This talk will discuss some of our recently developed deep learning methods for MRI reconstruction, enhancement, and analysis, as briefly described below.

1) MRI Reconstruction. In clinical applications, both T1-weighted MRI and T2-weighted MRI are routinely acquired in MRI protocols for providing complementary information to each other. However, the acquisition time for each sequence is non-trivial, making clinical MRI a slow and expensive procedure. To significantly shorten MRI acquisition time, we have developed a deep learning approach to reconstruct T2-weighted MRI from T1-weighted MRI and highly under-sampled T2-weighted MRI. Our method can achieve 8 or higher acceleration rate while keeping high image quality of the reconstructed T2-weighted MRI.

2) MRI Enhancement. Ultra-high-field 7T MRI scanners provide MR images with much higher resolution and better tissue segmentation than 3T MR images. However, due to higher costs, currently 7T MRI scanners are less available than 3T MRI scanners. This motivated us to propose a framework that can jointly generate high-resolution 7T-like MR image and its tissue segmentation map from low-resolution 3T MR image. Specifically, we have developed a novel joint reconstruction-segmentation framework that cascades deep Convolutional Neural Networks (CNNs) to improve both resolution and segmentation of 3T MRI with guidance from training 7T MRI. The evaluation on pairs of 3T and 7T MR images from 15 subjects revealed higher accuracy in both resolution enhancement and tissue segmentation, compared to those directly from the 3T MRI. Also, our method performed the best among other state-of-the-art methods.

3) MRI Analysis. We have also developed various learning-based brain measurement methods for the first-year brain images with the goal of early detection of autism such as before 1-year-old. This effort is aligned with our recently awarded Baby Connectome Project (BCP), which is acquiring MR images and behavioral assessments from typically developing children, from birth to five years of age. Besides, we have also developed a novel deep learning method for robust, accurate and fast registration of any pair of individual brain images. Finally, for early diagnosis of Alzheimer's Disease (AD) with the goal of potential early treatment, we have further developed a novel landmark-based deep learning method.

All these deep learning techniques will be introduced in this my talk.

Keywords : Deep learning

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Cerebral blood flow territory imaging using ASL and its applications

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Arterial spin labeling (ASL) is an MR imaging technique for perfusion measurement with no need of exogenous contrast material and ionizing radiation. In ASL, the protons in arterial blood are used as an endogenous tracer after magnetically labeled by radiofrequency (RF) pulses. As a variant of ASL, territorial ASL allows depiction of flow territory by using RF pulses tailored to label a single or a subset of arteries. In stroke, the ability to visualize cerebral blood flow territories may help localizing an embolus and/or assessing collateral circulation. This talk will review the technical aspects of territorial ASL imaging and demonstrate the application in internal carotid artery stenosis.

Keywords : Arterial spin labeling, ASL

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A New Kid On the Block: Hyperpolarized Carbon-13 MRI for Clinical Metabolic Imaging

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Hyperpolarized carbon-13 (13C) magnetic resonance imaging (MRI) is a revolutionizing noninvasive metabolic imaging method that has been used in both pre-clinical and clinical studies. Dissolution dynamic nuclear polarization (DNP) offers an exciting method for assessing real-time in vivo metabolism with a huge gain in sensitivity over the conventional 13C MR methods within a clinically feasible short scan time. This talk will overview the background on DNP and hyperpolarized imaging methods, and present recent research utilizing this technique in pre-clinical studies as well as phase I/II clinical trials in neuro-oncology.

Keywords : Hyperpolarized carbon-13, Dynamic nuclear polarization, Brain tumor, Metabolism, Cancer imaging

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SY11-5

High Spatial Resolution fMRI using Constrained Evolution Reconstruction

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fMRI with high spatial resolution is beneficial to localize neuronal activation more accurately [1-6] for neuroimaging, but is limited by various factors such as prolonged acquisition time and low SNRs. The conventional fMRI acquisition method, commonly using single-shot EPI, usually suffers from low spatial resolution and image distortion, despite its fast imaging speed. One typical solution to achieve high resolution for fMRI is parallel imaging, also including simultaneous multi-slice imaging. However, the acceleration factor of parallel imaging is usually limited by the number of elements in phased array coils and the g-factor. Compressed sensing (CS) has been introduced to fMRI to accelerate signal acquisitions [7, 8]. These methods include: CS accelerated GRE fMRI [9], k-t FOCUSS based on shared temporal information[10], k-t FASTER based on low rank constraints of matrix completion [11], prior image constrained CS (PICCS), TV-based CS [12], among others. However, the acceleration capability needs further exploration.

In this study, we will introduce a new high resolution fMRI method, Dual-TRACER, based on Temporal Resolution Acceleration with Constrained Evolution Reconstruction (TRACER) [13], with accelerated golden angle variable density spiral sampling. The image reconstruction in this method is based on the hypothesis that temporal changes are small at short time intervals. In addition, we use the Dual-TRACER method with SLIDER (SLIce Dithered Enhanced Resolution) technique to obtain high resolution isotropic fMRI images, while maintaining temporal resolution comparable with conventional acquisitions.

Results show that Dual-TRACER can provide reliable functional images with a high in-plane spatial resolution (1 x 1 mm2) under high acceleration factors. By using the super resolution SLIDER technique, thinner slice thickness is achieved. The proposed technique was demonstrated in visual stimulus fMRI, as well as finger somatotopy mapping which was only reported at 7T scanners previously. Compared with other methods, Dual-TRACER provides better signal recovery, higher fMRI signal sensitivity and more reliable activity maps. The improved spatial resolution and maintained temporal resolution are beneficial to neuroscience research.

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