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Metabolic Imaging of Traumatic Brain Injuries Using Ultrahigh-Resolution ^{1}H-MRSI

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Synopsis

Traumatic brain injury (TBI) is a significant public health problem that contributes to a large number of injury-induced deaths each year. MRSI has long been recognized as a powerful tool for detection of neurometabolic alterations induced by TBI; however, most existing MRSI studies of TBI are limited by low resolution which severely reduce the detection sensitivity. In this study, we performed MRSI scans on TBI patients using a newly developed ultrahigh-resolution ^{1}H-MRSI technique. Our experimental study yielded very encouraging results and showed that ultrahigh-resolution MRSI can capture neurometabolic alterations induced by TBI effectively.

Introduction

MRI studies of traumatic brain injury (TBI) have grown significantly over the past decade. Many advanced MRI methods, such as diffusion tensor imaging (DTI), susceptibility-weighted imaging (SWI), perfusion-weighted imaging, and fMRI, are being used to detect many of the functional and pathophysiological alterations resulting from TBI, and have provided significant insights and understanding of TBI [1,2]. MR spectroscopic imaging (MRSI) has long been recognized as an ideal tool for detection of neurometabolic alterations induced by TBI[3]. However, clinical and research applications of whole brain ^{1}H-MRSI of TBI have been extremely limited due to several long-standing technical barriers, including long data acquisition time, poor spatial resolution, low SNR and overwhelming background water and lipid signals. As a result, most existing MRSI studies of TBI were carried out in low resolution (e.g., 10×10×7.5 mm^3 nominal resolution) or using single-voxel techniques[3]. The partial volume effects associated with low-resolution/single-voxel techniques can “dilute” abnormal metabolic changes and reduce the sensitivity for detection; it has also been recognized that these techniques cannot distinguish focal from diffuse injury. In this study, we performed ^{1}H-MRSI experiments on TBI patients using a newly developed ultrahigh-resolution MRSI technique known as SPICE. The latest version of SPICE can cover the whole brain of 240×240×120 mm^3 with 2.0×2.4×2.0 mm^3 nominal resolution in a 10-minute scan. Our experimental study yielded very encouraging results and showed that ultrahigh-resolution MRSI can capture neurometabolic alterations induced by TBI effectively.

Method

The in vivo scans were performed on a 3T MR scanner (Siemens Skyra) with IRB approved at the Fifth People's Hospital of Shanghai, China. The MRSI data were acquired using the latest version of SPICE (SPectroscopic Imaging by exploiting spatiospectral CorrElation)[4,5]. The data acquisition scheme has the following novel features: a) FID acquisitions with an ultrashort-TE (1.6 ms) and very-short-TR (160 ms), b) no water/lipid suppression, c) variable density sampling of (k, t)-space, d) rapid and extended k-space coverage with EPSI trajectories, and e) incorporation of navigators for detection and correction of field drift and subject head motion. The data acquisition scheme achieves a nominal resolution 2.0×2.4×2.0 mm^3 with whole brain coverage (FOV: 240×240×120 mm^3) in a 10-minute scan.

Reconstruction of the spatiospectral function from the SPICE data is accomplished using a union-of-subspaces model, incorporating pre-learned spectral basis functions [4,5,7]. These spectral basis functions include the resonance structures of the detectable molecules (generated using quantum mechanical simulations) and their lineshape functions pre-learned from training data. Spectral quantification is done using an improved LCmodel-based algorithm that incorporates both spatial and spectral priors [9]. QSM is extracted from the water spatiospectral information [6].

To identify the injured region, diffusion-weighted imaging (DWI) (TR/TE = 11200/106 ms, resolution = 2×2×2 mm ^{3}, FOV = 256 mm, 70 slices, b = 1000/2000/3000 s/mm ^{2}, 30 directions for each b value and 12 b = 0 images), 3D MPRAGE imaging (TR/TE/TI = 2500/2.26/900 ms, resolution = 1.0×1.0×1.0 mm ^{3}, FOV = 256 mm, 176 slices) and Fluid-Attenuated Inversion Recovery (FLAIR) imaging (TR/TE = 9000/89 ms, resolution = 0.5×0.5×2.0 mm ^{3}, FOV = 240 mm, 82 slices) were performed in the scan session. The regions of interest were identified from the Trace and fiber orientation distribution (FOD) images calculated from the DWI image using Syngo workstation and MRTRIX3 software [8].

Results and Discussion

Figure 1 shows the high-resolution metabolic maps (includes N-acetylaspartate (NAA), creatine (Cr), choline (Cho) and myo-inositol (mI)) reconstructed from the 1H-MRSI data, which cover the whole brain (FOV: 240×240×120 mm ^{3}). Figure 2 shows Trace image and FOD image as well as the QSM and NAA maps obtained from the MRSI data. As can be seen, the large cerebral contusion lesion can be identified from the QSM map. The NAA reduction is shown in regions of both the large cerebral contusion lesion and the small diffuse axonal injury (DAI) lesion. The spatially resolved spectra are presented in Fig. 3. A reduction in NAA can be observed from the spectra in both cerebral contusion lesion and DAI lesion and the reduction is more significant in the cerebral contusion region. The capability to detect the millimeter DAI lesion is of great importance in TBI metabolic study.

Conclusions

We have successfully performed in vivo metabolic imaging experiments on TBI patients using ultrahigh-resolution ^{1}H-MRSI. Our experimental results show that neurometabolic changes in both cerebral contusion lesions and small size DAI lesions can be captured by the high-resolution metabolite maps and its corresponding localized spectra. Our study may lay the foundation for further investigation and application of ultrahigh-resolution metabolic imaging for studying neurometabolic alterations in TBI.

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Figures

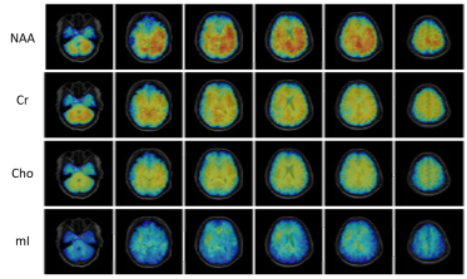

Figure 1. Reconstructed high-resolution metabolite maps including NAA, Cr, Cho and mI. The FOV covers the whole brain (240×220×120 mm^3) and the MRSI acquisition takes 10 minutes.

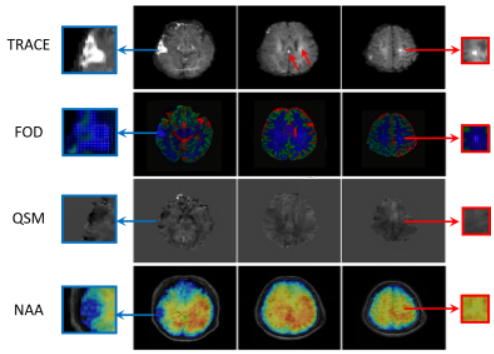

Figure 2. The Trace DWI, FOD, QSM and NAA maps of the slices where both the cerebral contusion lesion and diffuse axonal injury (DAI) lesion exist. Both the cerebral contusion and small DAI lesions can be identified from the NAA map where the NAA concentration is lower than in the surrounding tissues. The large cerebral contusion lesion can also be identified from the QSM image.

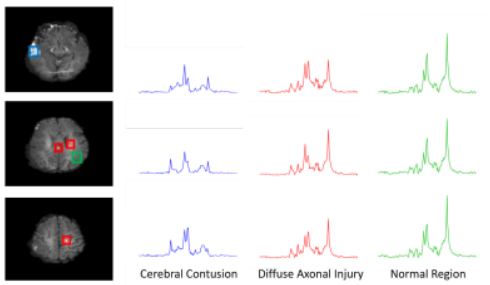

Figure 3. Representative spectra in the cerebral contusion region, diffuse axonal injury region and the normal tissue region. The reduction in NAA can be observed from both the cerebral contusion region and the diffuse axonal injury region.