Midbrain nuclei visualization improved by susceptibility-enhanced 3D inversed Double Echo Steady State (iDESS) imaging

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Introduction

Imaging anatomical structures in human midbrain, such as substantia nigra (SN), is important for investigating Parkinson's Disease (PD) because this region is related to the disease pathology. In addition to clinical diagnosis, MRI has been used as guidance for placement of electrodes in Deep Brain Stimulation (DBS) surgery of PD patients [1-2]. Conventionally, T2* gradient echo method (i.e., SPGR) can be used to visualize small nuclei in midbrain. However, clear visualization of midbrain nuclei remains challenging because: (1) the SPGR contrast in midbrain can still be low even with long echo time (i.e., > 20ms), and (2) the differentiation of small structures in midbrain requires high contrast-to-noise ratio (CNR) efficiency. To address the first issue, recent studies applied Susceptibility Weighted Image (SWI) processing to enhance image contrast in midbrain by incorporating both magnitude and phase information [1,3]. To achieve higher CNR efficiency, a previous study demonstrated acquisition of three Steady State Free Precession (SSFP) echoes, each from a separate pathway, for imaging midbrain nuclei [4]. Here, we show that susceptibility-enhanced 3D inversed Double Echo Steady State (iDESS) can be used to further enhance image contrast in midbrain nuclei. Results from 1.5 Tesla MRI also demonstrate that iDESS has high potential to improve Deep Brain Stimulation (DBS) guidance in PD.

Material and method

To allow T2* contrast to evolve and phase to accumulate, long TE (> 20ms) is used in SPGR while imaging midbrain nuclei. It can be seen in Fig. 1(a) that a great portion of time is vacant after RF excitation and imaging efficiency is suboptimal. By inserting multiple SSFP echoes in one TR, imaging efficiency can be improved [4]. In Fig. 1(b), inversed Double Echo Steady State (iDESS) acquires PSIF (I1) and FISP (I2) sequentially in each TR. While FISP is formed by gradient echo (FID), PSIF undergoes spin-echo process from the previous TR. iDESS composite images are generated as:

$$I_{iDESS} = [mag(I1) + mag(I2)] \times exp^{i*[pha(I2)-pha(I1)]} \ldots \text{(Eq.1)},$$

where *mag* and *pha* are magnitude and phase operators, separately. In Fig. 1(b), the effective phase accumulation of PSIF and FISP are almost equal except for the opposite polarities. Thus, the iDESS phase accumulation is doubled through Eq.1, which is advantageous for SWI processing.

Experiments were performed on a 1.5T MRI scanner (GR Signa, Milwaukee, WI, USA) with both 3D SPGR and 3D iDESS (axial view, matrix 256x233x24, voxel size of 0.86x0.86x2mm^3, TR=60ms, $TE_{SPGR}/TE_{PSIF}/TE_{FISP}$=53/8/53ms). Images from a normal volunteer (32yr, male) were shown with both image reconstruction and SWI processing from k-space data.

Results

Figure 2 compares SPGR (Fig. 2(a)) and iDESS (Fig. 2(b)) images. Both images were processed by SWI procedures. Compared to SPGR in Fig. 2(a), iDESS in Fig. 2(b) presents stronger hypo-intensity in both red nucleus (RN) and substantia nigra (SN). Fig. 2(c) plots signal intensity in SPGR and iDESS along the dashed line in Fig. 2(a). The signal hypo-intensity corresponding to RN and SN are pointed by yellow arrows in Fig. 2(c). Fig. 2(c) shows that iDESS generates higher contrast than SPGR in both RN and SN.

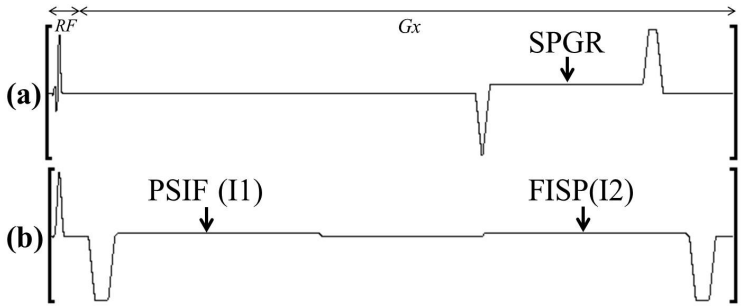

Figure 1. Sequence diagram of (a) SPGR and (b) iDESS. In Fig. 1(a), long TE is used to allow T2* contrast to evolve and phase to accumulate. In iDESS of Fig. 1(b), PSIF and FISP are acquired in an inversed order than conventional DESS (Double Echo Steady State) acquisition. Compared to SPGR, iDESS enables improved imaging efficiency and also doubled phase accumulation.

Discussion

Theoretically, in a gradient-echo-based sequence, multiple echo pathways can be acquired with proper sequence design [5-6]. In this study, we showed that imaging efficiency is improved by inserting multiple echoes in one TR. Experiment results demonstrate that iDESS generates higher image contrast in midbrain nuclei compared to SPGR. Acquiring PSIF at the beginning of TR is beneficial because it enables both higher PSIF magnitude and higher PSIF phase accumulation. In contrast, if acquired at the end of TR, PSIF may present both low SNR (due to excessive T2 decay) and low phase accumulation (due to spin-echo refocusing). Clinically, results from 1.5 Tesla are significant because they reveal the potential of iDESS to improve DBS guidance in PD. Therefore, we conclude that susceptibility-enhanced 3D iDESS can be used to efficiently obtain high contrast image for visualization of midbrain nuclei.

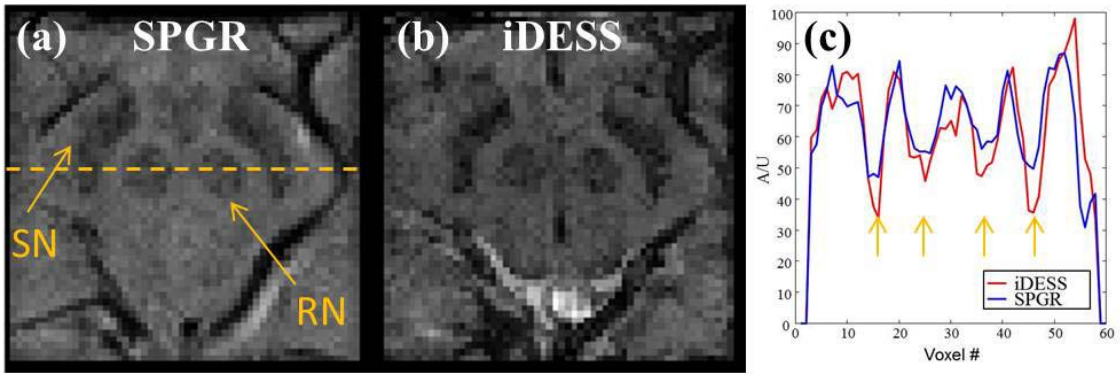

Figure 2. Cropped images (51.6 mm x 51.6 mm) comparing (a) SPGR and (b) iDESS. Both SPGR and iDESS images were processed by SWI procedures. Compared to SPGR in Fig. 2(a), iDESS in Fig. 2(b) presents stronger hypo-intensity in both red nucleus (RN) and substantia nigra (SN). Fig. 2(c) plots SPGR and iDESS signal intensity along the dashed line in Fig. 2(a). The signal hypo-intensity corresponding to RN and SN are pointed by yellow arrows in Fig. 2(c). Fig. 2(c) shows that iDESS generates higher contrast than SPGR in both RN and SN.

Reference

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