Improvement of midbrain nuclei susceptibility contrast in T1-weighted SPGR for image guided deep brain stimulation

N-K. Chen[1], and G. S. Young[2]

[1]Brain Imaging and Analysis Center, Duke University, Durham, NC, United States, [2]Radiology, Brigham and Women's Hospital, Boston, MA, United States

Introduction

Deep brain stimulation (DBS) is one of the most effective available therapies for long term treatment of tremor associated with Parkinson Disease (PD), a common neurodegenerative disorder, and has recently received FDA approval for this disorder. During a typical DBS surgery, stereotactic image guidance is used to insert unilateral or bilateral stimulating electrodes through burr holes by reference to one or more pre-operative volumetric MRI datasets registered to the patient's brain by means of one of a number of commercially available stereotactic navigation software and hardware.

Widely available clinical magnetic resonance imaging (MRI) scanners with field strengths of 1.5 and 3.0 Tesla can now routinely acquire stereotactic T1-weighted image (T1WI) guidance datasets with the whole brain coverage and sub-millimeter spatial resolution, as required for stereotactic surgical navigation, in under 10 minutes using radiofrequency spoiled three dimensional gradient recalled echo (3D-SPGR) sequences. Targeting the midbrain nuclei on these 3D-SPGR T1WI remains problematic because of the poor image contrast in T1-weighted imaging between the nuclei and adjacent structures. Recent reports have addressed this issue by demonstrating improved contrast of the midbrain nuclei to surrounding structures using T2-weighted fast spin echo images (T2WI), diffusion-weighted images (DWI), inversion spin preparation techniques (IR-FSE, T1-FLAIR etc) among other methods. However, an additional acquisition for midbrain nuclei contrast improvement increases the scan time. Furthermore, the surgical planning based on two MRI data sets (i.e. stererotacic T1WI and an extra T2WI) is susceptible to errors because (1) an unavoidable subject movement between T1WI and T2WI scans, (2) inconsistent image distortions between T1WI and T2WI, and (3) other potential registration inaccuracy (e.g. due to the incapability of correcting for the partial volume effect in the registration software). It is highly desirable that both high midbrain nuclei contrast and stereotactic T1WI can be derived from a single data set.

Here we propose a novel image acquisition and reconstruction procedure capable of providing both stereotactic T1WI and high midbrain nuclei contrast without an extra T2WI scan. Acquisition parameters of SPGR are chosen in such a way that (1) a good T1 contrast, well suited for stereotactic image guidance, is obtained from the magnitude reconstruction, and (2) high midbrain nuclei contrast can be achieved by performing a 3D region of interest (ROI) based susceptibility weighted imaging (SWI) reconstruction [1]. The developed image acquisition and reconstruction procedure significantly improves the conventional imaging protocols used for image guided DBS.

Methods

A volumetric T1WI (for stereotactic surgical navigation) was acquired with a 3D-SPGR pulse sequence was the following scan parameters: TR 25msec, TE 10msec, flip angle 25 degree, in-plane matrix size 256 x 256, in-plane FOV 24cm x 24cm, voxel size 0.94mm x 0.94mm x 1mm. In addition to conventional magnitude image reconstruction, both real and imaginary components of the 3D-SPGR images were captured at the time of scanning. Phase information derived from this data set was transferred to an off-line workstation for a 3D ROI based SWI reconstruction.

A cubic ROI (approximately 5cm x 5cm x 1cm) centered on the midbrain and containing the STN was manually selected on the magnitude T1WI. A phase unwrapping procedure based on the algorithm reported by Cusack et al [2], but restricted to the region within the ROI, was applied to the data within the voxel only. After phase unwrapping, the values in the ROI were spatially smoothed with a cubic smoothing spline function. The smoothed unwrapped phase values were then subtracted from the original unwrapped phase values in order to remove phase variations due to the large scale field inhomogeneities, while retaining the local susceptibility contrast related to brain parenchymal iron deposition. The resulting phase image reflecting only the local susceptibility contrast was then linearly recombined with the magnitude image, as described by Haacke et al. [1] and Rauscher et al. [3] to produce a regional composite SWI image. The regional SWI data was then fused with the whole brain T1-weighted 3D-SPGR surgical planning dataset by replacing the magnitude data within the 3D ROI with the SWI data and linearly scaling the brightness of the edge pixels to match the original image.

Results and Discussion

MR images obtained with our protocol are presented in Figure 1. As shown in Figure 1a, the magnitude reconstruction of the acquired data provides an image with T1 weighting, which is suitable for stereotactic surgical navigation. By applying the developed 3D ROI based SWI reconstruction procedure, midbrain nucleus signals with an improved susceptibility contrast are generated. A composite image is then produced by combining the whole brain T1WI and the regional SWI, as shown in Figure 1b. It should be noted that, in Figure 1b, the display windowing / leveling can be adjusted differently for signals inside and outside the chosen cubic region, so that the gray/white matter contrast and the midbrain nuclei susceptibility contrast can be optimized simultaneously. In our implementation, the signals from the chosen cubic region are uniformly elevated, to remove the abrupt signal transition across the boundary of the chosen cubic region, as shown in Figure 1c. In comparison to the original magnitude reconstructed SPGR data (Figure 1a), the generated composite image (Figure 1c) has a greatly improved midbrain nuclei susceptibility contrast.

In conclusion, we have developed a novel image acquisition and reconstruction procedure to provide both high T1 contrast for stereotactic navigation and a good midbrain nuclei contrast for surgical planning, without an extra T2WI scan. In comparison to the previously used approaches, the new MRI procedure produces two types of image contrast from a single data set and thus eliminates potential errors in image registration. The new technique should prove valuable for an accurate image guided DBS.

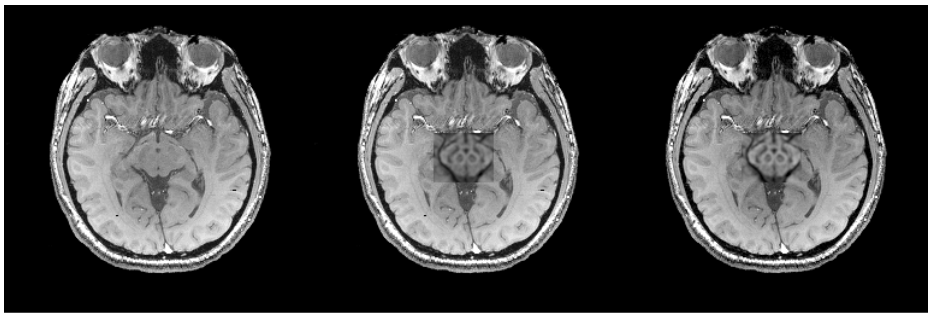

Figure 1: (a) An SPGR image for stereotactic surgical navigation. (b) The midbrain nuclei susceptibility contrast improvement in the chosen 3D ROI. (c) The signal intensities in the 3D ROI are linearly scaled so that the brightness of the edge pixels matches the original image.

References:

[1] Haacke EM, Magn Reson Med. 52: 612-8, 2004. [2] Cusack R, Neuroimage. 16:754-64, 2002. [3] Rauscher A, J Magn Reson Imaging. 18:175-80, 2003.

Acknowledgment: NIH R21 EB005690