Visualization of the subthalamic nuclei at high spatial resolution and high contrast with susceptibility weighted phase imaging

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Introduction: The symptoms of Parkinson's disease can be alleviated by placing electrodes into the subthalamic nuclei (STN) [1], which requires a reliable identification of shape and location of the STN. The STN can be targeted based on their relative position with respect to landmarks that can be identified unequivocally or directly based on imaging data that show the STN [2]. The former technique assumes that in every patient the STN are located at the same position relative to the landmarks. This assumption, however, is not always true [3]. The latter method requires high resolution imaging data where the STN give good contrast, such as heavily T2 weighted imaging, e.g. turbo spin echo (TSE), which exploits the high iron content of the basal ganglia as a source of contrast [4,5]. T2*-weighted imaging has been proposed very recently [6], since T2* is even more sensitive to local iron deposits than T2. The magnetic susceptibility of iron not only causes an accelerated signal decay due to field inhomogeneities but also a shift in the phase of gradient echo data. This contrast mechanism has been used in phase imaging to visualise cerebral anatomy in high detail [7]. The phase images are acquired together with the magnitude and are therefore perfectly coregistered with the magnitude. They bear complementary information and they have improved signal to noise compared to the corresponding magnitude [8]. The purpose of the present study was to develop a method to collect susceptibility weighted phase images of the STN with high spatial resolution and high contrast in a time efficient manner.

Material and Methods: Susceptibilty weighted [9] (phase) images of 6 subjects were acquired on a 3 T system (Achieva, Philips Medical Systems) using a six channel phased array head coil. Second order shimming was performed prior to the scans. The parameter space investigated consisted of different echo times (TE = 12.5, 16.1, 20.7, 25.3 and 29.3 ms), with the corresponding shortest possible repetition times of 19.36, 24.7, 29.4, 33.7 and 37.7 ms, respectively, and SENSE [10] with acceleration factors of 1, 1.5 and 1.8. The readout bandwidth was between 70 and 80 Hz per pixel. Flip angle α=13° to 16°. Matrix = 436 x 320 x 36, FOV = 240 x 167 x 54 mm^3 Reconstruction matrix = 576 x 576 x 72; acquisition time =1.46 min (TE=16.1, SENSE=1.8) to 5 min (TE=29.3, SENSE =1). Additionally, a turbo spin echo (TR=3900 ms, TE=120 ms, Matrix=256 x 188; 30 slices, 2 mm thickness), and a fast field echo scan (TR=10.3ms, TE=6 ms, α=8°;Matrix=192 x194 x 120) were performed for comparison. All scans were oriented parallel to the AC-PC line. The susceptibility weighted images were reconstructed to a voxel size of 0.45 x 0.45 x 1 mm. The phase was unwrapped using the freely available ΦUn package [11]. To obtain a uniform dynamic range the inverse tangent of the unwrapped phase was computed. Subsequent two-dimensional high pass filtering was applied in order to remove effects from background field inhomogeneities [12]. The combined magnitude/phasemask images were computed according to standard SWI processing [9]. Image distortion due to field inhomogeneities was assessed with field maps derived from the two shortest TE.

Results:

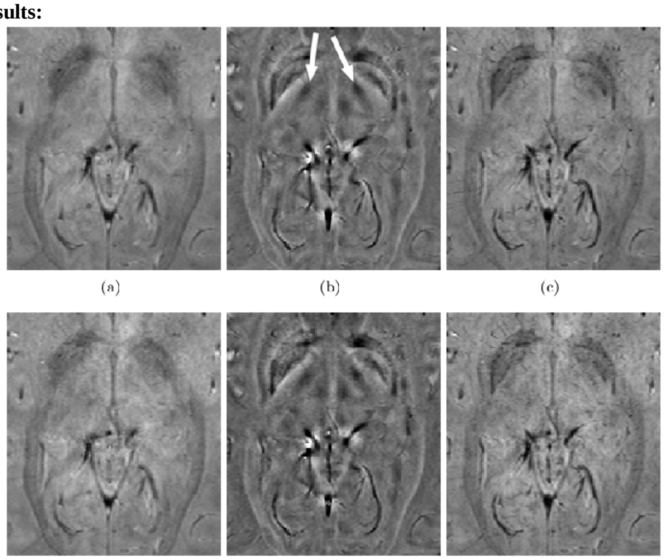

FIG. 1: Magnitude (a,d), phase (b,e) and combined images (c,f) of data acquired at TE=25.3 ms without acceleration (a,b,c) and with a SENSE-factor of 1.5 (d,e,f). Magnitude and combined images show a stronger SNR dependency on acceleration factors than the pure phase images. The STN (arrows) are much more visible in the phase than in the magnitude or the combined images.

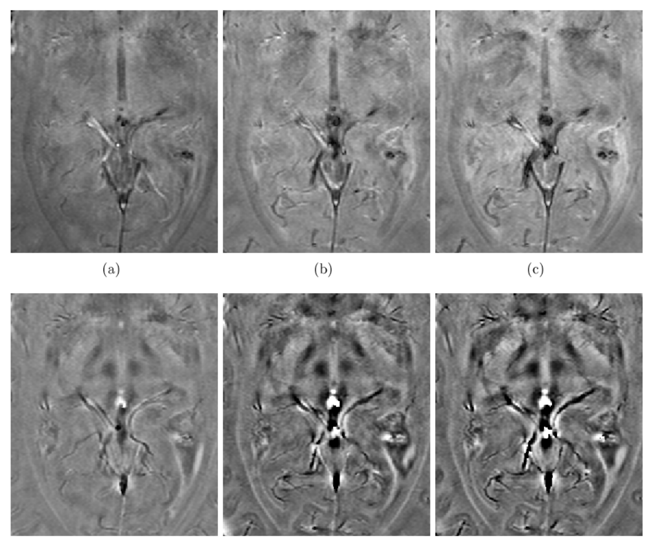

FIG. 2: Magnitude (a-c) and phase (e-f) of SWI images at 16.1, 20.7 and 25.3 ms. In the magnitude contrast is improved with echo time, whereas in the phase it is already present at short TE. In the phase the subthalamic fasciculus which connects the STN and the globus pallidus can be identified. The geometric distortions computed from the field map are less than 0.5 mm (not shown).

Discussion: High resolution images of the STN can be acquired in about 2.5 minutes using a TE of 16.1 ms and an acceleration factor of 1.5. With direct targeting of the STN the operation time could be greatly shortened, furthermore the patients can undergo surgery fully under general anesthesia, which will add to the acceptability of the treatment. Due to the low flip angle of about 15° the specific absorption rate (SAR) is very low compared to (fast) T2-weighted imaging, which is an advantage in particular at field strenghts of 3 T or more. A patient study using electrophysiological recordings to validate the coordinates of the STN is in preparation.

References: [1] Wichmann et al. Neuron 2006;52:197-204; [2] Lemaire et al. Neuroimage 2007; [3] Ashkan et al. Br J Neurosurg 2007;21:197-200; [4] Hallgren et al. J Neurochem 1958;3:4-5; [5] Schenck et al. NMR Biomed 2004;17:433-445; [6] Elolf et al. AJNR Am J Neuroradiol 2007;28:1093-1094 [7] Rauscher et al. AJNR Am J Neuroradiol 2005;26:736-742; [8] Duyn et al. Proc Natl Acad Sci USA 2007;104:11796-1180; [9] Reichenbach et al. NMR Biomed 2001;14:453-467; [10] Pruessmann et al. Magn Reson Med 1999;42:952-962; [11] Witoszynskyj et al. In Proc. Intl. Soc. Mag. Reson. Med., volume 15 2007; 2303 [12] Rauscher et al. J Magn Reson Imaging 2003; 18:175-180