# High resolution in-vivo brain frequency shift and susceptibility imaging at 3T

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**INTRODUCTION:** Visualizing small brain structures such as the hippocampus and the nuclei in the basal ganglia and the cerebellum is highly challenging at 3T with conventional anatomical images. These structures are small but vital for normal brain functions and are implicated in a number of neurological diseases. Locating them with MRI is difficult due to the lack of clear contrast for the inner structures of these regions. Ultra-high field (7T and higher) has shown some promising potentials with increased frequency shift and magnetic susceptibility contrast (1). Generating this contrast on a clinical 3T scanner however is challenging with current acquisition techniques. In this study, we demonstrated a novel method for generating high-resolution (375 mircon) and high-contrast frequency shift and susceptibility maps at 3T. The resulting maps allowed detailed delineation of many complicated brain structures. The technique may facilitate the application of susceptibility imaging in studying the hippocampus in Alzheimer's disease and for surgical guidance in deep brain stimulation.

**MATERIALS AND METHODS:**
The key idea is to acquire as many gradient echoes as possible during each TR and to combine the phase together to maximize the SNR (Fig. 1). In vivo human brain imaging was performed on a GE MR750 3.0T scanner with an 8-channel head coil using a modified multi-echo 3D spoiled-gradient-recalled (SPGR) sequence. The first image set, covering the whole brain and part of cerebellum, was acquired with $TE_1$ = 15 ms, echo spacing = 2.303 ms, 10 echoes, TR = 80 ms, FA = 20º, 512x512x120 data matrix, voxel size = 0.375x0.375x1 mm$^3$. The second one, covering the whole cerebellum and brain stem, was acquired with $TE_1$ = 5 ms, echo spacing = 2.303 ms, 16 echoes, FA = 20º, 320x320x180 data matrix, and 0.5mm isotropic spatial resolution. Image phase from different coils and echoes was unwrapped (2), weighted using magnitude and then combined. The background phase was removed, and the resulting phase was converted to frequency shift and was used for susceptibility mapping using the LSQR method without additional constraints (2).

**RESULTS:** Both frequency shift and susceptibility shows good contrast of deep brain regions (Fig.1), allowing visualization of dorsalmedial nucleus, the striated structure of the internal capsule, and small iron-rich nuclei, including red nucleus, sub-thalamas nucleus, substantia nigra, red nuclei, and mammillary body. Susceptibility map shows excellent contrast of hippocampus with surrounding tissue (Fig. 3). The susceptibility variations in different layer of hippocampus structure are obvious. Susceptibility map also shows especially good contrast of the cerebellar nuclei including dentate nucleus, globose nucleus, fastigial nucleus and emboliform nucleus (Fig.4).

**DISCUSSION**: The optimized multi-echo SPGR sequence and related processing methods allows high-resolution phase and susceptibility imaging with excellent details. There are many nuclei inside thalamus, which typically not easy to detect with conventional imaging contrasts. The phase and susceptibility shows good delineation of dorsalmedial nucleus. Previously, high resolution of hippocampus has been done at 7T with spin echo, gradient echo, and susceptibility weighted imaging (SWI). We showed that hippocampus can also be visualized at 3T with high resolution, due to its large variation of susceptibility across different cell layers. Previously, SWI has been used for high resolution imaging of cerebellar nuclei at 7T (6). Here we showed that susceptibility mapping can also allow excellent delineation of these structures at 3T. These methods can be used as the clinical guidance for the deep brain stimulation and for locating the hippocampus and can also be useful at 7T to further push the resolution to higher levels.

**REFERENCES:** (1) Duyn et al, PNAS, 2007. (2) Li et al, NeuroImage, 2011. (5) Thomas et al, J MRI, 2008 (6) Diedrichsen et al, NeuroImage 2011

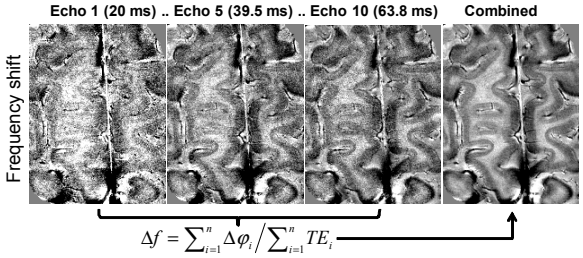


Fig. 1 Optimized image acquisition and processing scheme

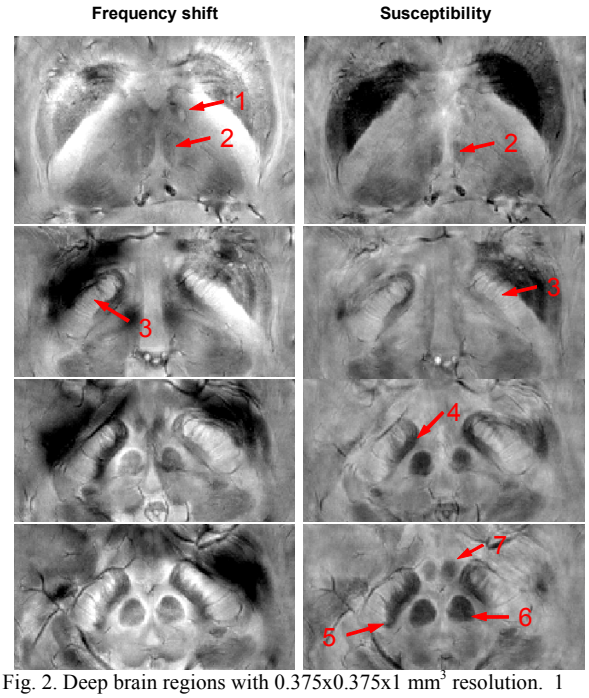


Fig. 2. Deep brain regions with 0.375x0.375x1 mm$^3$ resolution. 1 cross-section of the mamillothalamic tract, 2 dorsalmedial nucleus of thalamus, 3 posterior limb of the internal capsule, 4 Sub-thalamus nucleus, 5 substantia nigra, 6 red nucleus, 7 mammillary body

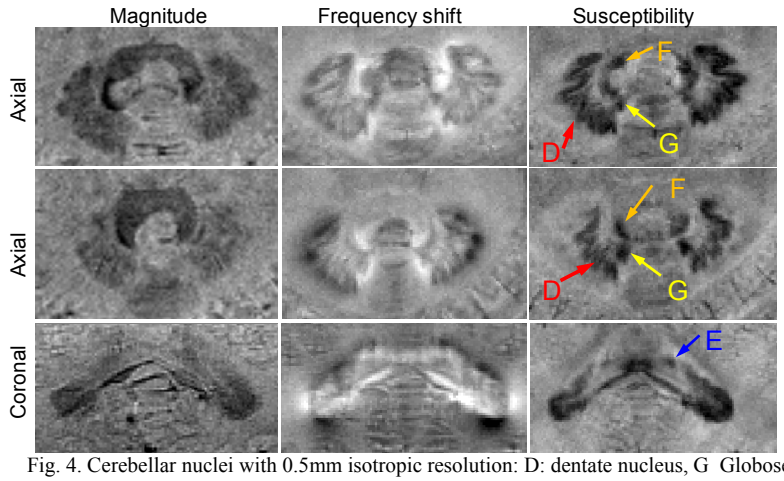


Fig. 4. Cerebellar nuclei with 0.5mm isotropic resolution: D: dentate nucleus, G Globose Nucleus, F Fastigial nucleus. E. Emboliform nucleus.

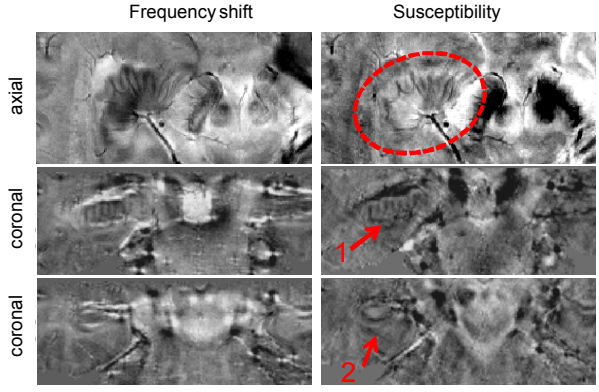


Fig. 3. Hippocampus: 1 Hippocampal head, 2 Hippocampal body.