Rapid Acquisition of Targeted High Resolution Human Brain Images Using a Combined SENSE, Inner Volume Imaging, and Multi-Shot EPI Spin Echo Sequence at 7T

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Introduction

Achieving high spatial resolution approaching 100 microns in human MRI is constrained first by available signal strength, and second, by limitations on acceptable acquisition times for the large data sets required. Signal limitations can be mitigated using higher field strengths, such as 7T, and larger parallel receive array sizes. Long scans are problematic due to increased artifacts caused by physiological and patient motion effects, and the reduction in temporal resolution. To address such constraints, a variety of rapid imaging techniques have been developed: parallel imaging methods such as SENSE enable reduced data sets to be obtained with aliasing removed by reconstruction [1]; reduced-FOV "Zoom" methods restrict the regions where signal is recorded from to minimize FOV sizes for shorter scans [2], and multiple gradient echo methods such as EPI rapidly acquire k-space information using single or multi-shot scans [3]. Several of these methods overlap in their potential application for high-resolution imaging, but have largely not been integrated or optimized for ultra-high field studies. Here we demonstrate the combination of SENSE and Zoom imaging based acceleration with a multi-shot EPI spin echo sequence at 7T using a 32 channel array, to achieve 160 to 350 µm resolutions in various *in vivo* human brain regions in a few minutes, with 46 to 429 fold accelerations obtained for multi-slice and 3D protocols.

Methods

Parallel Zoom Imaging - To achieve Zoom imaging, an inner volume (IVI) approach [2] was implemented consisting of an x-selective 90 followed by a slice selective 180 between balanced crushers. To optimize SENSE with IVI, images were acquired at 10 'R' factor accelerations from 1 to 10 using SENSE only, and then repeated again using IVI only to reduce the FOV by the same factors, 'Z'. SENSE and IVI were then combined for a total reduction, R_{TOT}, of 8, where $R_T = R*Z$. Here, the total reduction contribution of SENSE was step-wise increased nine times from R = 1 to 8, with IVI correspondingly decreased at each step to maintain an eight-fold acceleration. All data sets were acquired with a 32-channel head coil, FBIRN phantom, 10 dynamics, TR/TE = 125/32 ms, 96x96 points, and a 210x210x3mm full FOV. SNR was measured pixel wise across dynamics as mean signal over the standard deviation.

Human Imaging – The combined SENSE-IVI spin echo scan was performed in awake human subjects with a multi-shot EPI readout to obtain a variety of high-resolution brain images using a 7T Philips Achieva System, and a 32 channel Nova head coil with volume transmit. Readout reduction was accomplished using anti-aliasing filtering, with the shim voxel localized to the reduced-FOV. EPI factors were maximized to achieve the target TE with the readout bandwidth minimized. The following table summarizes scan parameters applied:

Region	TR/TE *(ms/ms)*	NSA	EPI *(F)*	SENSE *(R)*	IVI *(Z)*	R_T *(F*R*Z)*	Voxel Size *(µm x µm x mm)*	FOV Size *(PExRO)*	WFS *(pixel)*	TA *(m:s)*
Thalamus	3038/75	16	19	1.8	3.50	120	300x300x2.0	60x60mm	45.19	4:09
Hippocampus	3032/64	16	21	2.2	2.84	131	300x300x2.0	74x55mm	51.58	4:06
Ventricle	3032/64	20	23	2.0	2.35	109	300x300x2.0	89x50mm	54.79	6:06
Lentiform	3035/70	14	21	1.8	3.00	113	250x250x2.0	70x70mm	58.84	5:03
Cortex	3038/76	2	11	2.0	2.10	46	160x160x1.5	100x100mm	60.85	2:54

3D Volume Acquisition - A 65 slice 3D spin echo scan was executed using SENSE-IVI, MS-EPI with SPIR fat suppression to achieve 350µm x 350µm x 2.5 mm resolution in an awake human subject, with a 55x70 mm FOV, an EPI factor of 25, TR/TE = 2500/64 ms, NSA = 2, in plane and slice SENSE factors of 2.2 and 3, respectively, and IVI phase encode FOV reduction of 3 for a 495 fold combined acceleration, and a total scan time of 6 min 18 sec.

Results

SENSE and IVI demonstrated comparable SNR up to R = 5 (figure 1). However, beyond 5, as much as a seven-fold greater loss was observed for SENSE due to increasing *g*-factor. This coincides with observed SENSE-IVI SNR trends when combined for $R_T = 8$. Here, greater SENSE contributions lowered the SNR four to five times versus large IVI contributions. However, slight SENSE acceleration between R = 1 and 2 demonstrated superior SNR performance versus IVI only. All MS and 3D human images (figure 2) achieved 160 to 350 µm with scan time reduced 46 to 129 fold for durations between 3 to 6 minutes, with no visible distortions, blurring, or signal loss. Visible contrast was established between gray and white matter, CSF, blood vessels, with a variety of features defined: globus pallidus (GB), putamen (PT), internal capsule (IC), caudate nucleus (CN), red nucleus (RN), thalamus (TH), pons, third ventricle, corpus callosum (CC), and hippocampus (HP). Hippocampal layers are visible, with potential contrast of the pulvinar, pons and corpus collosum striations, and fine blood vessels.

Conclusions

Using a combined SENSE-IVI, MS-EPI approach with a multi-slice spin echo scan, we have demonstrated resolutions as low as 160 µm for *in vivo* human brain imaging with effective accelerations up to 131 in a single slice, 495 fold in 3D images. Future work will focus on resolutions from 100 to 200 µm, faster accelerations, and smaller FOV sizes. This method provides parameter flexibility to optimize spatial resolution, scan time, and SNR, including EPI factor, in plane and slice SENSE reductions, and readout and phase encode reduced-FOV sizes.

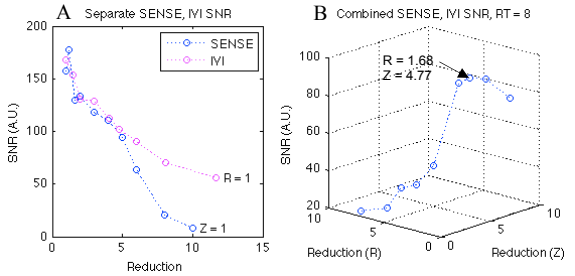

Figure 1 – A) Mean SNR for various SENSE and IVI reductions, B.) Mean SNR measured for combined SENSE-IVI, total reduction = 8.

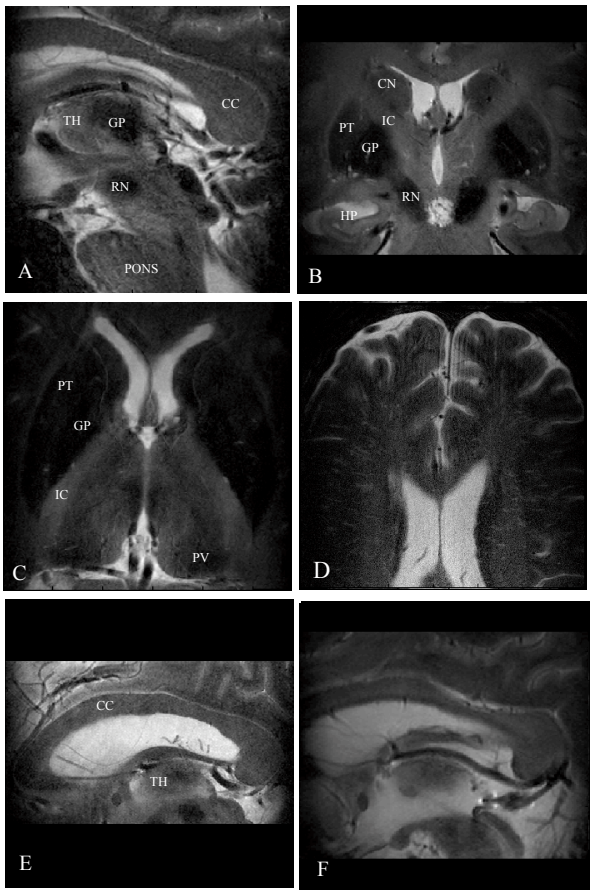

Figure 2 – Various SENSE-IVI, MS-EPI *in vivo* human images: A.) 300 µm thalamus, B.) 300 µm midbrain/hippocampus, C.) 250 µm lentiform, D.) 160 µm cortex near central sulcus, E.) 300 µm corpus callosum, third ventricle, and F.) 350 µm ventricle acquired with 65 slice 3D sequence.

References [1] Pruessmann KP, MRM 42: 952-62 (1999) [2] Feinberg D, Radiology 156: 743-747 (1985) [3] Butts K, MRM 31: 67-72 (1994)