Elliptical SENSE with Effective 9 Fold Scan Time Reduction for Small FOV 3D MR Spectroscopic Imaging of Glioma Patients at 3T

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Introduction: Addition of 3D MRSI to the anatomical MR imaging for patients diagnosed with gliomas has been shown to provide better brain tumor localization, treatment planning, and assessment of treatment response [1]. Although 3D MRSI provides a vast array of molecular information like brain tumor cellularity, energetics, and neuronal activity level, conventional phase-encode sampling results in long MRSI data acquisition times ranging up to 30+ minutes. Elliptical *k*-space sampling is a fast data acquisition strategy, which acquires an elliptical central portion of the *k*-space, and it has been shown to result in accurate spectral definition with slightly lower spatial resolution [2]. Sensitivity encoding (SENSE) is another fast data acquisition method proposed for reducing the scan time by acquiring fewer phase encodes, and later resolving the resulting aliasing using the coil sensitivity information of the phased array coils [3]. Application of SENSE method for spectroscopic imaging of human brain at 1.5 T [3] and glioma patients at 3T [2] has been reported. In this study, we have implemented a combined elliptical SENSE data acquisition strategy with an effective 9 fold scan time reduction that results in 4:36 min scan time for a 16cm in plane small FOV (16x16x8) spectral array. We have shown its application for imaging glioma patients at 3T, and quantitatively compared it to the current clinical elliptical MRSI protocol in tumor and normal regions.

Materials And Methods: Phantoms, volunteers (2 females, 1 male, mean age =26), and six glioma patients (4 Grade IV, 2 Grade III, 1 female, 5 male, mean age=53) were scanned on a 3 T MR scanner (GE Healthcare, Waukesha, WI) equipped with an eight channel RF coil (MRI Devices Inc, Gainesville, FL). The imaging protocol included the acquisition of axial T1 weighted SPGR, axial T2 weighted FLAIR, and proton-density weighted coil sensitivity images. FLAIR abnormality (FL) regions excluding cavity areas were segmented using an in-house region growing algorithm for the patients. Proton density weighted coil sensitivity images for each coil element were divided by the square root of the sum of squares of the coil sensitivities from all the coil elements, and smoothed to reduce the anatomy related inhomogeneities by applying median and low-pass homomorphic filters. Elliptical SENSE spectral data acquisition was implemented in a custom PRESS MRSI sequence. 16x16x8 elliptical SENSE (R_x=2, R_y=2, 4:36 min) and 16x16x8 original elliptical (17:32 min) data were acquired from phantom and volunteers using PRESS volume localization with CHESS water and VSS outer volume suppression (TR/TE=1.1s/144 ms). The original elliptical spectral array size was reduced to 12x12x8 (9:28 min) for patients due to scan time limitations. Elliptical only spectra from individual coil elements were processed and combined using software developed in our laboratory [4]. Data reconstruction for elliptical SENSE spectra was implemented using Matlab 7.0 (The Mathworks Inc., Natick, MA). Elliptical SENSE spectra were first placed on a respective rectangular grid, and pre-processed like the original elliptical spectra to create aliased 8x8x8 spectra. These spectra were unaliased 4 fold in both x and y directions taking into account the aliasing problem of small FOV spectroscopy [5]. Tikhonov's simple regularization was utilized to condition the inversion problem. Regularization parameters were 1 for Cho, Cr, NAA region, and 8 for lipid region. Elliptical SENSE data reconstruction resulted in a 32x32x8 array. Spectra from the elliptical and elliptical SENSE spectra were quantified using in house software [4]. The signal to noise ratio (SNR) of Cho, Cr, NAA, and lipid were estimated by normalizing their heights with the standard deviation of the spectral noise calculated from the left end of the spectrum. Geometry factor (g) maps were computed for elliptical SENSE spectra. Lipid contaminated voxels were detected as the ones that had abs(Lip)>abs(NAA) within the normal regions. Spearman rank correlation coefficients were computed to assess the similarity of Cho/NAA ratio between the elliptical and the elliptical SENSE spectra. A Mann-Whitney rank sum test was utilized to assess if the tumor regions had significantly different Cho/NAA values than normal regions for elliptical SENSE or elliptical spectra for the patients.

Results: Elliptical SENSE *k*-space sampling reduced the scan time from 37:42 min to 4:36 min for a 16x16x8 array. The median of the median of geometry factors was 1.25±0.04 (max =1.3) for the volunteers and 1.33±0.11 (max =1.55) for the patients. After correcting for the time difference, the median ratio of the elliptical SNR to the elliptical SENSE SNR in patients was 1.24 for Cho, 1.22 for Cr, and 1.11 for NAA, which was smaller than the geometry factor. The small increase in SNR in elliptical SENSE spectra was thought to be an effect of the noise reduction due to regularization. Table 1 shows median Cho to NAA ratio for elliptical and elliptical SENSE data and their correlations, along with the number of lipid contaminated voxels for all the subjects. Cho/NAA ratios were significantly ($p<0.001$) correlated for all subjects between the two methods. Regularization resulted in less lipid contamination in elliptical SENSE data. The median Cho/NAA ratio calculated from the elliptical spectra for patients were (0.86, 0.54, 0.75, 0.78, 0.67 and 0.63) in normal regions and (1.06, 0.66, 0.95, 1.61, 0.74 and 0.91) in tumor regions. The median Cho/NAA ratio calculated from the elliptical SENSE spectra for patients were (0.82, 0.49, 0.67, 0.7, 0.64 and 0.59) in normal regions, and (1.01, 0.66, 0.92, 1.02, 0.63 and 0.83) in tumor regions. Tumor regions had significantly higher ($p<0.05$) Cho/NAA for both techniques for the second, third, fourth, and sixth patients. The elliptical spectra had significantly higher Cho/NAA in the tumor region for the first patient, but the elliptical SENSE spectra did not show any difference between the two regions. The Cho/NAA ratio was not significantly different for both techniques in the fifth patient. Figure 1 shows data from a patient with a glioblastoma multiforme, where both elliptical SENSE and elliptical full field of view spectra depict the tumor region clearly, and they were highly correlated ($r = 0.79$, $p<0.001$). Figure 2 shows data from a volunteer for both the elliptical SENSE and elliptical spectra, which show very similar spectral patterns with high correlation ($r = 0.88$, $p<0.001$).

Table1. Median Cho/NAA for elliptical (**E**) and elliptical SENSE (**ES**) with their Spearman rank correlation coefficient (**r**) and p–value (**p**), and the number of lipid contaminated voxels for the whole PRESS box.

	phantom	volunteer1	volunteer2	volunteer3	patient1	patient2	patient3	patient4	patient5	patient6
E med(Cho/NAA)	0.53	0.46	0.53	0.45	0.87	0.55	0.79	0.8	0.68	0.68
ES med(Cho/NAA)	0.52	0.45	0.55	0.45	0.83	0.5	0.69	0.71	0.64	0.7
r	0.9	0.82	0.73	0.88	0.75	0.6	0.25	0.29	0.71	0.79
p	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
E/ES # Lipid voxels	0/0	0/0	0/0	0/0	1/3	1/0	13/8	24/23	1/1	26/13

Discussion and Conclusion: Elliptical SENSE MRSI has been implemented for imaging gliomas at high field with an effective 9 fold scan time reduction to 4:36 min. The results of elliptical SENSE spectra correlated well with the clinically accepted elliptical spectra. Higher lipid aliasing was observed for elliptical SENSE spectra but this was reduced by using a higher regularization parameter for the lipid region. Elliptical SENSE spectra also had the ability to distinguish tumor regions like the elliptical spectra.

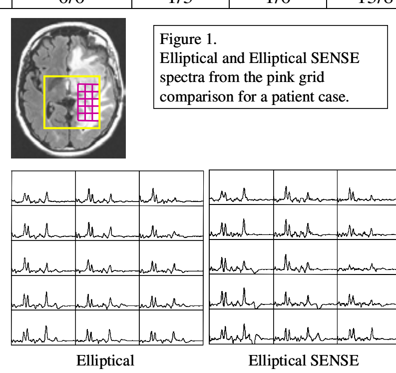

Figure 1.
Elliptical and Elliptical SENSE spectra from the pink grid comparison for a patient case.

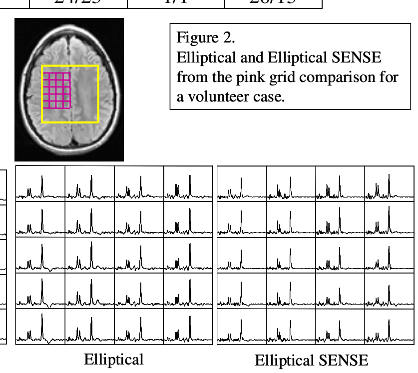

Figure 2.
Elliptical and Elliptical SENSE from the pink grid comparison for a volunteer case.

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[1] Nelson SJ. Mol Cancer Ther 2003;2(5):497-507. [2] Ozturk-Isik et al. Proc. ISMRM, 13th Annual Meeting, Seattle, WA 2006. p.1779. [3] Dydak et al. Magn Reson Med 2001;46(4):713-722. [4] Nelson SJ. Magn Reson Med 2001;46(2):228-239. [5] Ozturk-Isik et al. Magn Reson Med 2006;55(5):1164-9.