Quantitative SENSE Spectroscopy of Gliomas at 3T

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Introduction: 3D MRSI has been successfully employed to extract information about brain tumor cellularity and cell membrane breakdown, cellular energetics, and neuronal activity through its ability to differentiate signals coming from choline (Cho), creatine (Cr) and N-acetyl aspartate (NAA) molecules [1]. One limitation of acquiring MRSI data for brain tumor patients is the long minimum data acquisition time for conventional PRESS localized spectroscopy, which is proportional to the total number of phase encode steps. Sensitivity encoding (SENSE) is a 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 [2]. Dydak et al. have applied the SENSE method for MR spectroscopy on phantoms and volunteers at 1.5T [3]. In this study, we investigated the feasibility of acquiring SENSE spectroscopic imaging of gliomas at 3T. Using acquired spectral peak heights, the results were quantitatively compared with the clinically accepted fully or elliptically sampled spectra in tumor and normal regions.

Materials And Methods: Five volunteers (5 females, mean age=25) and six patients (4 Grade IV, 1 Grade III, 1 Grade II, 2 female, 4 male, mean age=44) were scanned on a 3 T clinical MR scanner (GE Healthcare, Milwaukee, 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. Normal appearing white matter (NAWM) regions were defined on SPGR images and contrast enhancing (CE) and FLAIR abnormality (FL) regions were segmented using an in-house region growing algorithm for the patients. All the ^{1}H 3D MRSI were acquired using PRESS volume localization with CHESS water suppression and VSS pulses for outer volume suppression with TR=1.1s and TE=144 ms. SENSE spectral data acquisition was implemented on the traditional PRESS sequence. SENSE spectra were acquired using a reduction factor (R) of 2 in both x and y directions resulting in a total of R=4 on a 16x16x8 spectral array. This reduced the total scan time from 37:42 min to 9:28 min. Elliptical k-space sampling, which restricts the data acquisition to a central elliptical region [4], was utilized for comparison. Three types of ^{1}H 3D MRSI - full (12x12x8, 21:12 min), elliptical (12x12x8, 9:28 min), and SENSE (16x16x8, R=4, 9:28 min) - were acquired for all volunteers. Because of clinical scan time limitations, only elliptical and SENSE spectra were acquired for 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. Spectra from individual coil elements were processed and combined using the smoothed coil sensitivities in parallel on a Linux cluster using software developed in our laboratory [5]. SENSE data reconstruction for spectra was implemented using Matlab 7.0 (The Mathworks Inc., Natick, MA). SENSE magnitude spectra were unaliased with the MATLAB routine after pre-processing. For each spectrum, the water baseline was removed, and 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 right end of the spectrum. Geometry factor (g) maps were computed for each SENSE spectra. Metabolite SNRs of the SENSE spectra were compared with the theoretically expected values using the metabolite SNR values of the full and elliptically sampled spectra in volunteers by the following formula,

$$SNR_{Sense} * g \Big/ \sqrt{time_{Sense}} = SNR_{Full} \Big/ \sqrt{time_{Full}} = SNR_{Elliptical} * (\Delta x_{Full} / \Delta x_{Elliptical}) \Big/ \sqrt{time_{Elliptical}} .$$

Ratio of the full to the elliptical spectral voxel sizes ($\Delta x_{Full}/\Delta x_{Elliptical}$) were estimated from the volunteers' data. A Wilcoxon signed rank test was utilized to assess if the choline, creatine, or NAA ratios between the tumor and NAWM were similar for the elliptical and the SENSE spectra. A Mann-Whitney rank sum test was utilized to assess if the FL and CE regions had significantly higher Cho/NAA values than NAWM for SENSE or elliptical spectra for the patients.

Results: The median of the geometry factors was 1.59±0.11 (max = 2.38) for the volunteers and 1.58±0.10 (max = 2.72) for the patients. After correcting for the time difference and the effect of the geometry factors, the median ratio of the full SNR to the SENSE SNR in volunteers was 0.96 for Cho, 0.98 for Cr, and 0.99 for NAA. This observation suggested that the effective spatial resolution of the SENSE spectra matches that of the full spectra (1cc). Figure 1 displays the NAA SNR calculated from the SENSE spectra versus the full spectra after they were corrected for time difference and the effect of the geometry factors for a volunteer from the whole PRESS box. It was observed that the slope of the regression was 1.0382 in this case, leading to a conclusion that the expected spectral SNR for SENSE was correctly met. Metabolite SNRs were also compared between volunteers' time corrected elliptical and full spectra, and it was observed that median ratio of the full to the elliptical SNR was 0.45 for Cho, Cr, and, NAA. This observation suggested that the effective spectral voxel size was 2.2 times larger for the elliptical case than the full case ($\Delta x_{Full}/\Delta x_{Elliptical}=0.45$), which was also discussed in previous studies [4]. The mean ratio of the mean levels of Cho, Cr, and NAA in FL versus NAWM for the patients were (0.91±0.32, 0.78±0.32, 0.51±0.20) for the elliptical, and (1.02±0.38, 0.76±0.44, 0.46±0.22) for the SENSE spectra. The mean ratio of the mean levels of Cho, Cr, and NAA in CE versus NAWM for the patients were (0.47±0.31, 0.37±0.22, 0.15±0.06) for the elliptical, and (0.67±0.31, 0.44±0.15, 0.13±0.15) for the SENSE spectra. Wilcoxon signed rank results showed that the ratio of the mean levels of Cho, Cr, and NAA of FL to NAWM region and CE to NAWM region were not significantly different ($p>0.31$ for all) between the elliptical and SENSE spectra. Both CE and FL regions had significantly higher ($p<0.05$) Cho/NAA ratios than NAWM for both SENSE and the elliptical spectra. Figure 2 shows an example glioblastoma multiforme case, where both SENSE and elliptical spectra depict the tumor region clearly. Figure 3 shows an example volunteer case in which a spectrally normal pattern is observable both with the SENSE and full spectra.

Figure 1. Expected SENSE versus Full NAA SNR

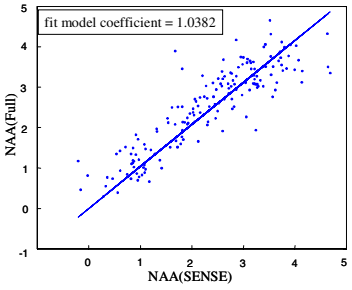
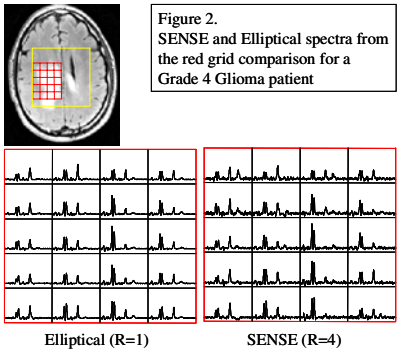
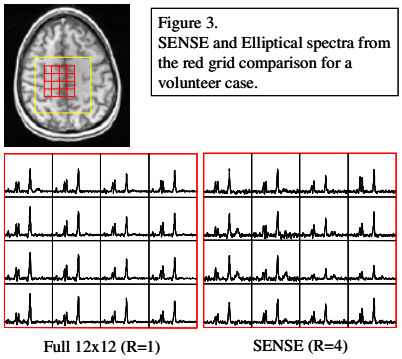


Figure 2.
SENSE and Elliptical spectra from the red grid comparison for a Grade 4 Glioma patient



Elliptical (R=1) SENSE (R=4)

Figure 3.
SENSE and Elliptical spectra from the red grid comparison for a volunteer case.



Full 12x12 (R=1) SENSE (R=4)

Discussion: SENSE MRSI has been implemented for imaging gliomas at high field, and was quantitatively compared to elliptical k-space sampling which results in the same scan time. SENSE spectra were calculated to have an effective spatial resolution of 1 cc, whereas elliptical k-space sampling with this acquisition time was estimated resulting in 2.2 cc effective spatial resolution. Both SENSE and elliptical k-space spectra resulted in similar spectral patterns over the PRESS box, and had the ability to distinguish tumor from normal tissue for this limited patient population. In some voxels, SENSE spectra were observed to have more residual aliasing of lipid peaks than the elliptical spectra. Further studies will investigate ways of reducing this artifact. In conclusion, SENSE spectra reduced scan time from 37:42 min to a more clinically acceptable 9:28 min for a 16x16x8 array with better effective spatial resolution than the elliptical sampling.

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[1] Nelson SJ. Mol Cancer Ther 2003;2(5):497-507. [2] Pruessmann KP et al. Magn Reson Med 1999;42(5):952-962. [3] Dydak et al. Magn Reson Med 2001;46(4):713-722. [4] Li X et al. AJNR Am J Neuroradiol. 2005 Apr;26(4):760-9. [5] Nelson SJ. Magn Reson Med 2001;46(2):228-239.