

Clinical Image Quality Assessment of CS-Reconstructed Brain Images

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Introduction: Compressed Sensing (CS) is a relatively new approach for MR image reconstruction from undersampled k-space data [1,2]. While acceleration techniques like SENSE [3] and GRAPPA [4] are common in routine clinical protocols, the role of CS in clinical imaging remains an open question. In this work, we perform a double-blind assessment of CS-MRI image quality by neuroradiologists. Our focus is to identify the diagnostic value of CS images. In the long term, we seek to understand how sampling and reconstruction schemes may be altered to improve clinical utility.

Methods: Data were collected on a GE Signa 3T EXCITE HDx system using an 8-channel head coil, from five patients scheduled for routine neuro-MRI. We chose two sequences from a widely-used seizure/epilepsy protocol: 1) a 512x346 multi-slice coronal T2, and 2) a 320x192 multi-slice coronal FLAIR, with scan times of 4:10 and 5:12, without parallel imaging, respectively. Example sum-of-square (SOS) images appear in Figure 1. CS reconstruction was performed offline via Equation 1 using retrospective variable-density downsampling along the phase-encoding axes [2]. In Equation 1, s are the measured k-space data, Φ is the undersampled Fourier transform, C denotes the coil sensitivity maps, Ψ represents the Daubechies4 wavelet transform, c is a vector of wavelet coefficients, and λ is a manually-chosen regularization parameter. The CS-reconstructed images and a sum-of-squares reference image from fully-sampled data were randomly ordered and uploaded to the Synapse™ PACS system. Image quality was assessed by two blinded readers. The signal-to-noise ratio (SNR) was calculated as: $SNR = s_t/\sigma$ and contrast-to-noise ratio as: $CNR = (s_{gm} - s_{wm})/\sigma$, where s_t is the mean thalamus signal intensity, s_{gm} is the mean gray matter signal intensity, s_{wm} is the mean white matter signal intensity, and σ is the standard deviation of the background noise. Qualitatively, a scoring system (1-poorly defined, 2-seen, 3-well defined) was used for many anatomical features (basal ganglia, circle of Willis, GW junction, cerebellar structures, brainstem, subarachnoid space, hippocampus, fornix, ventricles, and red nucleus).

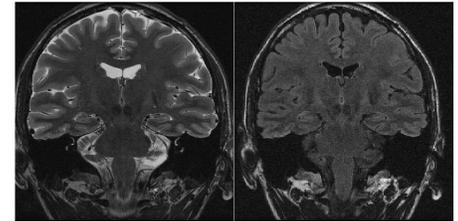


Figure 1: SOS T2 (left), FLAIR (right)

$$\min_c \|s - \Phi C \Psi^* c\|_2^2 + \lambda \|c\|_1$$

Equation 1

Results: For each patient and sequence, two image slices were chosen for evaluation.

Quantitative Evaluation: Tables 1 and 2 show the average SNR and CNR measurements, respectively, for each sequence and acceleration factor. **Qualitative Evaluation:** Table 3 shows the average qualitative scoring from each reader, in which averages were taken over all of the anatomical features listed above. The results are highlighted based upon their diagnostic value (see Table 3 caption).

	coronal T2	coronal FLAIR
SOS	12.8/13.6	12.5/11.4
2x	14.8/17.3	14.5/13.2
3x	19.8/24.8	14.8/12.5
4x	22.9/25.8	16.1/14.3

Table 1: SNR (reader1/reader2)

	coronal T2	coronal FLAIR
SOS	8.2/7.3	3.9/1.7
2x	10.9/10.1	5.0/2.8
3x	12.9/13.1	6.1/3.2
4x	15.6/14.7	6.8/3.6

Table 2: CNR (reader1/reader2)

	coronal T2	coronal FLAIR
SOS	2.9/3.0	2.7/2.9
2x	2.8/2.6	2.1/2.2
3x	2.3/2.4	1.4/1.9
4x	2.0/2.0	1.1/1.3

Table 3: average qualitative scoring (reader1/reader2); (scoring: 1-poorly defined, 2-seen, 3-well defined); (green-diagnostic quality; yellow-some of diagnostic quality; red-none of diagnostic quality)

Discussion: Coronal T2: The qualitative scores for the SOS and 2x images are very similar. At 2x acceleration and in some cases at 3x acceleration, the images are of diagnostic quality. Both SNR and CNR are higher in the 2x image, which may be a result of denoising in the CS reconstruction. At 4x acceleration, the scores begin to severely degrade and the diagnostic utility of these images is very questionable. The images were very blurry and the readers observed ringing artifacts, which we believe are due to high sidelobes of the point-spread function. The analysis indicates the potential for 3x acceleration of this sequence using CS. Coronal FLAIR: The SNRs and CNRs using CS are greater than for the SOS images, however the qualitative scoring for the CS-reconstructed images is much lower. In contrast to the coronal T2, only some of the 2x-accelerated images are of diagnostic quality. Again, the readers noted these images were blurry with noticeable ringing artifacts. We believe that the low-resolution nature of the fully-sampled data limits the potential benefits of CS for this particular sequence.

Conclusion: This preliminary study suggests that CS can be used to accelerate existing clinical protocols without significant loss in image quality. Further acceleration may be realized in 3D and/or dynamic imaging, in which there exist additional dimensions to downsample. We are currently working with a 3D SPGR sequence from the same seizure/epilepsy protocol with the expectation of greater achievable acceleration.

References: [1] Candes et al., IEEE IT 2004; [2] Lustig et al., MRM 2007; [3] Pruessmann et al., MRM 1999; [4] Griswold et al., MRM 2002;