Broad Oversampling With TIme Efficiency (BOWTIE) for Increased SNR

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Introduction: Cartesian and radial continuous sampling (a.k.a., Total Sampling Time (TST)) sequences have previously been shown to increase SNR without increasing acquisition time [1,2]. The relative improvement in SNR is expected to be approximately equal to the square root of the ratio of total sampling time of the TST acquisition over Cartesian sampling time. A prior implementation of Cartesian TST did not overlap the phase encoding table with the readout dephaser, which prolonged the TR relative to a radial implementation. Broad Oversampling With TIme Efficiency (BOWTIE) overlaps the phase encoding and readout lobes throughout sampling to create a hybrid radial/Cartesian sequence as depicted in Figure 1. By sampling during the traversal to the edge of k-space, the BOWTIE trajectory collects traditionally unacquired data for signal to noise gain. In this study, a BOWTIE sequence was developed and used in imaging both phantoms and human volunteers.

Methods: A BOWTIE FLASH sequence was created to sample throughout the duration of the image-plane gradients. Overlapping phase encoding and readout gradients yields the Cartesian/radial hybrid trajectory shown in Figure 1. For these sequences, slice refocusing must be completed prior to data sampling.

Image reconstruction was performed offline with Matlab (Mathworks. Nattick, MA). The data was convolution gridded onto a two times over-sampled grid. A modified iterative density compensation function (DCF) estimation method (Figure 2) similar to [3] was used to find an empirical estimate for the DCF according to the ideal trajectory. All data except data from the first ramp and last ramp were used to reconstruct the images. The Cartesian data set was reconstructed using convolution gridding to normalize any SNR loss due to the gridding process.

All imaging experiments were performed with a 1.5 T Siemens Sonanta (Erlangen, Germany) clinical scanner. Images from a small distilled water phantom and an asymptomatic human volunteer were collected. Imaging parameters used were TE = 5.6 ms, TR = 12 ms, FOV = 300, FA = 15 degrees, bandwidth per pixel = 390 Hz, and slice thickness = 5mm. The human volunteer imaging experiments were conducted in compliance with the institution's IRB; patient informed consent was obtained. The ratio of mean signal within a region of interest within the object to the standard deviation of the signal in an artifact-free region of interest in the background yielded SNR for the image.

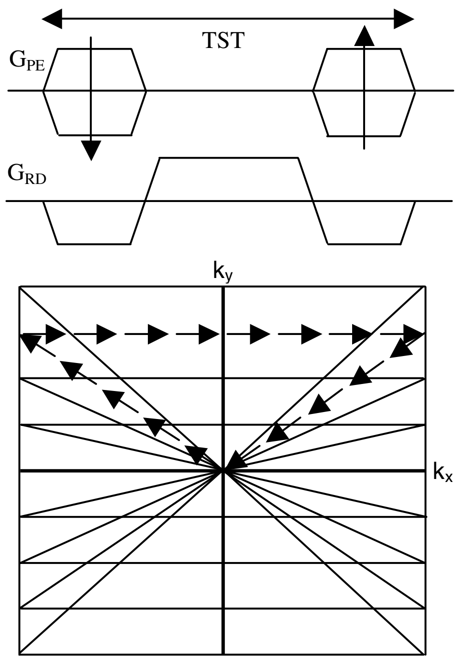

Figure 1: Pulse sequence diagram and corresponding K-space trajectory representing the BOWTIE trajectory. One PE line shows the trajectory with arrows for better visualization.

Results: Figures 3a and 3b show images of an asymptomatic human volunteer. SNR was computed to be 20.4 and 27.5 for an image based on the Cartesian fraction (Figure 3a) alone and the entire BOWTIE trajectory (Figure 3b), respectively. This is an overall SNR improvement of about 35%; the theoretical gain was expected to be near 50%. Phantom data showed only a 16% increase in SNR and exhibited more artifacts (not shown).

Discussion: This work presents the preliminary utility of the BOWTIE trajectory as a faster alternative to Cartesian TST. The trajectory should provide oversampling starting at the center of k-space and moving out radially in a bowtie pattern as well as the traditional Cartesian data, leading to theoretical and observable increases in SNR. In this implementation, positive gains in SNR are observed as predicted. Differences between the predicted increase and observed increase are potentially affected by the choice in gridding and density compensation parameters which are known to influence background levels after deconvolution.

Conclusion: The TST BOWTIE sequence shows an increase in SNR compared to traditional Cartesian sampling. As is, a 35% SNR improvement at no time cost is significant. Improvements in methodology for image reconstruction will likely improve image quality. This method could be applied to virtually any conventional pulse sequence to boost SNR without a significant increase in imaging time.

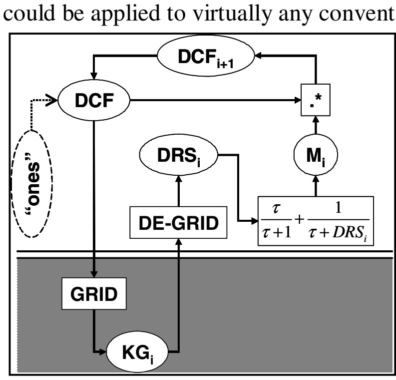

Figure 2: Iterative Grid / De-Grid (IGDeG) Density Compensation. Iteration begins with an arbitrary initial guess of one at each sample for a DCF.

References: [1] Winkelmann et.al., IEEE TMI, 24, 254-262, 2005. [2] Bookwalter et.al., Proc. ISMRM 2005, Poster 2371. [3] Pipe et.al., MRM, 41, 179-189, 1999. [4] Duyn et. al., JMRI, 132, 150-153, 1998.

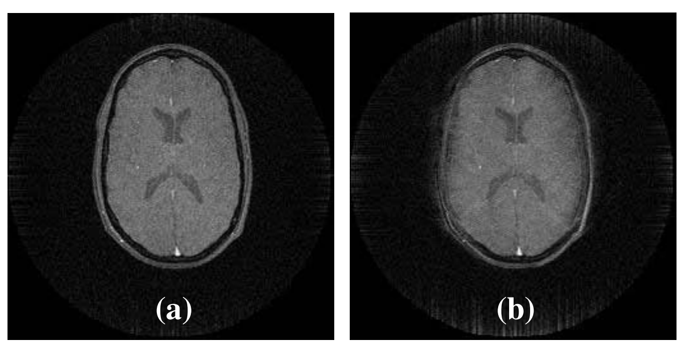

Figure 3: In vivo images from an asymptomatic volunteer using only the Cartesian data potion for image (a) and the entire BOWTIE trajectory for image (b).