Improved generalized series reconstruction for 3D MRI using shaped data

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Introduction: Dynamic contrast-enhanced MRI requires simultaneous high spatial and temporal resolution for high sensitivity and specificity. To overcome this trade-off, image reconstruction techniques from partial data, like keyhole [1], RIGR, TRIGR [2-4] have been proposed. For 3D keyhole and RIGR schemes, partial data are usually acquired by sampling a rectangular region (RS) in the centre of k_y-k_z space. In this study, we explored the use of a new star-shaped (SS) data truncation window in k_y-k_z space. The SS truncated data was reconstructed using two different approaches and compared with the conventional TRIGR reconstruction (RS truncation window) using the same k-space reduction factor. Synthetic phantom data as well as DCEMRI data from patients with breast and abdominal cancer were used to validate the techniques.

Theory: The central regions of k-space contribute significantly to the signal energy and larger the fraction of k-space acquired, the better the reconstruction. For a given k-space fraction, we found that using a star-shaped region to limit the data captures significantly larger fractions of signal energy than a rectangular region [5]. Other optimal shapes are possible but were ruled out as they were incompatible with generalized series reconstruction. We used the fast algorithm of [4] to reconstruct all TRIGR images. SS-TRIGR is a one-step process that performs TRIGR extrapolation using all data points collected using the SS-mask. Weighted-average extrapolation decomposes the SS-mask into 2 diamond shaped regions as shown in Fig. 1 (black dotted lines). Two independent TRIGR reconstructions are performed, one for each mask and their weighted average is used as the final estimate, the weighting being inversely proportional to distance from the mask boundary. RS-TRIGR was also done in a single step, performing TRIGR extrapolation using all data points acquired along the rectangular region.

Methods: All simulations and reconstructions were done using MATLAB. All patient scans were performed after obtaining prior informed consent on a 1.5 T GE Signa scanner. Dynamic, contrast enhanced full k-space data sets on data were obtained using a 3D fast spoiled GRE sequence after administration of 10-15cc of Gadolinium contrast. This was subsequently truncated using a rectangular or a star-shaped window to generate partial k-space data that was then reconstructed using the different extrapolation schemes. Typically, 15% of k-space data was used yielding a reduction factor of 6. The scan parameters were as follows- flip 15º, bandwidth $\pm$ 62.5 KHz, TE/TR 1.4ms/3.9 ms, acquisition matrix 256x192x36, 20/36 cm FOV (breast/abdomen), slice thickness 3-4.2 mm. Comparison of the techniques was done by analyzing contrast uptake curves on different regions of interest (ROIs). ROIs of different sizes were chosen in order to assess the accuracy and resolution of the reconstruction techniques. Typically, tumors were chosen as ROIs and in the absence of tumours, small enhancing structures (like blood vessels) were used as ROIs. The signal enhancement curves through the ROIs were used to compute errors in initial slope of contrast uptake, an important indicator of tumor malignancy. The difference images were also examined for reconstruction quality and artifacts.

Results: All comparisons were carried out with respect to the images reconstructed from the full k-space acquisition ("gold standard"). Reconstruction of a breast data set with large tumor resulted in slope errors of 0.2% using SS-TRIGR, 0.4% using weighted averaging and 0.5% using RS-TRIGR, while mean errors on small tumors were 1.1%, 1.2% and 7.1% respectively, using 15% of k-space. Error images for the small-tumor breast data are shown in Fig. 3. Results on abdomen data at 15% of k-space show an average slope error of 3.1% with SS-TRIGR, 5.4% using weighted average and 20% using RS-TRIGR for small enhancing regions, while errors for larger regions are 2.5%, 2.7% and 3.4% respectively. Comparison of contrast enhancement curves through a large and a small ROI for the different method are shown in Figure 2a-b. It can be seen that in larger regions, the curves obtained using all the three methods are fairly comparable, while in smaller regions, reconstructions using an SS mask, perform better than an RS mask.

Conclusions: We have demonstrated on simulations and on DCEMRI data from patients the feasibility of obtaining accurate reconstructions with a reduction factor of 6 by acquiring data in a star-shaped region. The errors in contrast uptake curves are much smaller using the star-shaped mask compared to the rectangular mask of the same area. This becomes pronounced for small enhancing structures confirming that a larger fraction of the k-space energy is captured by the star-shaped mask. For larger enhancing structures, the performance of both methods were comparable. Further work needs to be done in assessing the clinical utility of this technique.

References:

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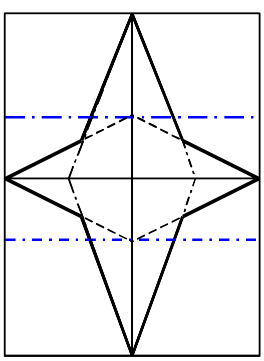

Figure 1. Data truncation masks in k_y-k_z plane- Conventional rectangular (blue dotted) and proposed star-shaped (black solid). Star mask can be decomposed into two diamond shaped regions (black dotted)

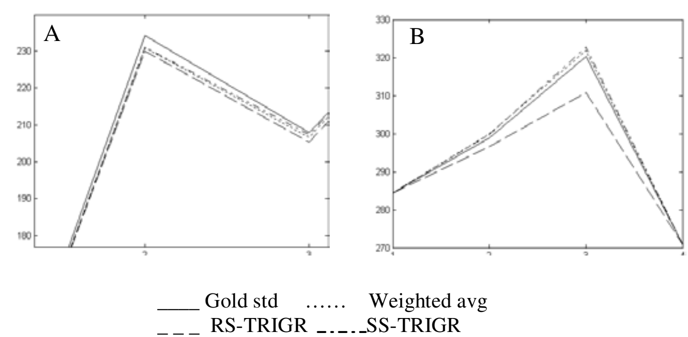

Figure 2. Signal enhancement curves through a large vessel (A) and a small tumor (B). The SS-TRIGR curves follow the true curve closely.

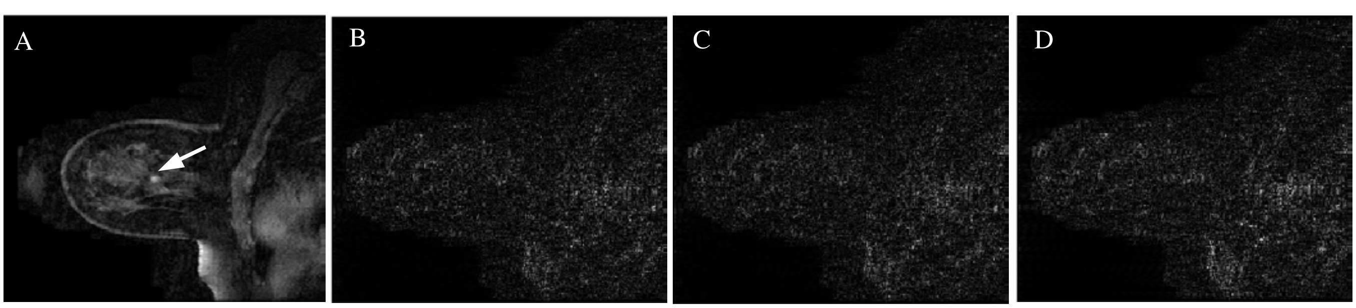

Figure 3. One slice from a full k-space 3D data set showing a small 5 mm diameter enhancing tumour (A). The error images from partial data reconstructions are shown (scaled down by a factor of 3) with SS-TRIGR (B), weighted average SS-TRIGR (C) and conventional RS- TRIGR (D).