Methods for SENSE Reconstruction with Partial K-Space Acquisition

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INTRODUCTION. Partial k-space acquisition capitalizes on the conjugate symmetry of hermitian data and allows for faster image formation with fewer phase-encode steps. However, MR data are not fully hermitian because images contain spatially-varying phase . As a result, slightly more than half of the k-space is required to correct for this incidental phase variation and an estimate of a low-resolution phase image from the symmetric portion around the origin of k-space can be used. Calculation of final full k-space data is usually accomplished either by *direct* conjugate synthesis, such as homodyne reconstruction (1), or by an *iterative* algorithm, such as the method of projection onto convex sets (POCS) (2). A further acquisition speed-up can be achieved by combining partial k-space acquisitions with parallel imaging. It is intuitive that the k-space-based GRAPPA or SMASH formalisms are compatible with all partial k-space methods since the synthesis of the full-FOV image is done in k-space prior to homodyne or POCS. It has been shown, however, that direct use of homodyne reconstruction in conjunction with SENSE fails because of the loss of phase information and needs to be performed in two steps (3). Here, we demonstrate that this two step approach is only necessary for homodyne but not for POCS and evaluate the performance of the different methods with a numerical phantom and in vivo data.

MATERIALS AND METHODS. *Numerical Phantom*. Sensitivity maps for 6 circularly-arranged coils were made with a Biot-Savart calculation and were used to modulate a Shepp-Logan phantom. Aliased images with a reduction factor of 4 were made by keeping every fourth phase-encoding line (taken to be in the y-direction) and fractional k-space was achieved by removing all but 8 phase-encoding lines prior to the center line. *In Vivo Data*. T2w-FSE images (256^2) were acquired with full k-space acquisition from a human volunteer with a GE Signa 1.5T scanner using an 8-channel head array (MRI Devices). A 3D FGRE (32×128^2) scan was performed for the coil sensitivity estimates. Manipulations similar to those done with the numerical phantom were performed on phase-encoding lines so that a reduction factor of 4 was achieved and 8 lines prior to the center of k-space were kept. *Image Reconstruction*. Three methods of reconstructing partial k-space were investigated. (i) A straightforward zero-fill of the missing k-space data prior to SENSE reconstruction. (ii) Homodyne reconstruction with SENSE was implemented as described in ref 3: the k-space was split into symmetric (low-pass) and asymmetric (double conjugate) parts by filter operations, SENSE reconstruction was applied to each of the resulting images, the complex data from the double conjugate image was phase-corrected using the low-pass image, and the final image was taken as the real part of the latter. (iii) POCS reconstruction (fig 1) was performed on the undersampled, fractional k-space data using 10 iterations (which is more than sufficient for convergence), and then SENSE reconstruction is applied directly to the result.

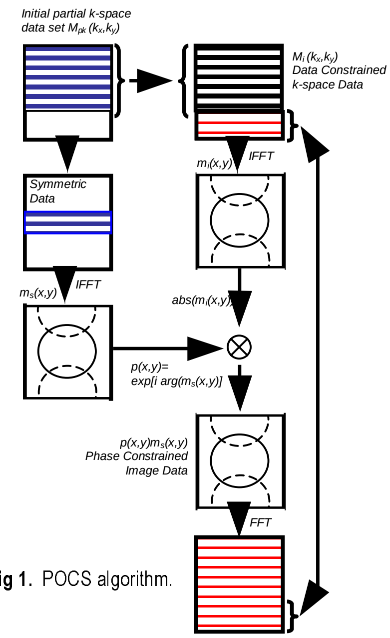

Fig 1. POCS algorithm.

RESULTS AND DISCUSSION. Phantom results are shown in fig 2 and in vivo images are shown in fig 3. In each case, the zero-filled data appears blurred (as would be expected from the effective sharp filter transition between the acquired data and the additional zeros), the POCS data has the most significant residual aliasing, and the homodyne data has the least aliasing and the best SNR performance. The critical issue for successful SENSE reconstruction is the preservation of phase information. Partial or complete loss of complex signal yields considerable reconstruction artifacts. Intuitively, then, because POCS reconstructs complex data and includes phase information, it would seem natural to use this method in conjunction with SENSE. It might also be preferred over the hybrid homodyne-SENSE reconstruction in ref 3 because the latter involves two separate SENSE steps for each image and therefore doubles the time of the total reconstruction. However, from the results shown here, when POCS is applied prior to SENSE, there is a greater level of residual aliasing artifacts. A possible explanation for this has to due with the order of the low-resolution phase-correction step that is performed in both procedures. The POCS-SENSE algorithm applies a low-resolution phase correction prior to the SENSE reconstruction, while the homodyne-SENSE reconstruction waits until after the full-FOV images are formed. Therefore, any errors produced by the low-resolution phase estimate in the POCS step will get propagated by the SENSE reconstruction and should appear as residual aliasing, but this is not the case for the homodyne-SENSE combination. POCS, however, is still required if phase information in the final image is important.

CONCLUSIONS. In order to traverse k-space as quickly as possible, it is often desired to use fractional k-space acquisition in conjunction with parallel imaging. In the case of Cartesian SENSE acquisitions in which a further reduction of k-space lines is achieved by collecting asymmetric data (e.g., fractional-echo single-shot FSE), an accurate method of generating this missing lines prior to k-space center is required. We have compared two methods: applying POCS prior to SENSE and a hybrid homodyne-SENSE combination. Simulation and in vivo data suggest that the SENSE-homodyne combination produces less residual aliasing.

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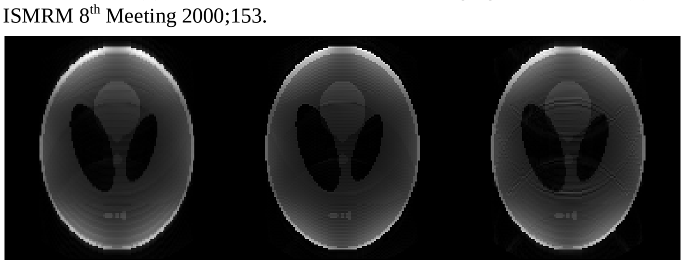

Fig 2. Reconstructed images from an undersampled (reduction factor of 4) fractional k_y (8 lines prior to k_y =0) mathematical phantom (6 coils): (A) Zero-filled, (B) homodyne-SENSE, and (C) POCS-SENSE. Significant residual aliasing is apparent in (C).

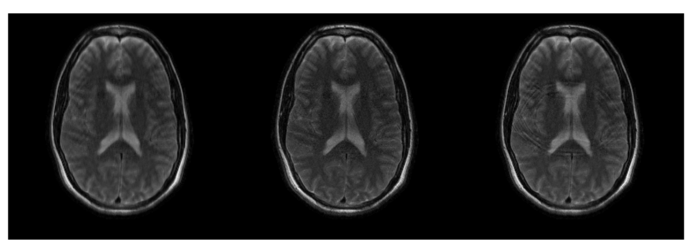

Fig 3. Reconstructed images from an undersampled (reduction factor of 4) fractional k_y (8 lines prior to k_y =0) in vivo acquisition (8 coils): (A) Zero-filled, (B) homodyne-SENSE, and (C) POCS-SENSE. Significant residual aliasing is apparent in (C).