Accelerated MRSI Using Randomly Undersampled Spiral-Based k-Space Trajectories

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TARGET AUDIENCE: MRSI investigators, Image reconstruction scientists.

PURPOSE: We present an acquisition-reconstruction method (random SENSE+TV) to accelerate MRSI by random undersampling of k-space data, while maintaining acceptable reconstruction quality as measured by a normalized root-mean-square error (RMSE) of the reconstructed metabolite maps. Random SENSE+TV yields lower RMSEs of metabolite maps compared to other methods with the same scan time and is able to achieve a factor of 4.5 acceleration with the same reconstruction quality as the fully-sampled data.

METHODS: Uniformly undersampled spiral acquisition1 uses spiral trajectories with fixed radius and undersamples by uniformly skipping interleaves. In contrast, random SENSE+TV uses spiral trajectories with different radii to randomly undersample the data in (kₓ, kᵧ, k₉) space (Fig 1). Sensitivity encoding technique (SENSE)2 with total variation (TV) regularization is used for reconstruction as in: min x_cart ∑ᵢ sensitivities cart x_cart = y_cart where x_cart(x, y, f) is the reconstructed Cartesian data, y_cart is the observed non-Cartesian k-space data from the iᵗʰ coil, Cᵢ is the sensitivity of the iᵗʰ coil, Fᵢ is the undersampled Fourier transform, A_cart2spiral is the 3D Cartesian-to-spiral operator, TV(·) is the total variation operator, λ is a regularization parameter. We demonstrated the feasibility of random SENSE+TV on a healthy volunteer with single-slice (1-cm thick) MRSI acquired fully-sampled at 3T and then retrospectively undersampled. Full sampling used 6 angular and 2 temporal interleaves, voxel size 0.56 cc, FOV xy = 24 cm x 24 cm, 32x32 voxels, 320 k₉ points over a readout duration of 320 ms with spectral bandwidth of 1kHz. The PRESS excitation (9 x 9 x 1 cm) was positioned entirely within the head. The water component was suppressed using both chemical shift selective imaging (CHESS)4 and additional spectrally selective water suppression pulses. TR and TE were 1.8 s and 87 ms. Lipids were suppressed using the outer volume suppression (OVS)5. Eight different spiral trajectories were used to achieve R=3 and R=6. The duration of the spirals was in a range from 0.47ms to 2ms. Two comparisons were made. First, we compared the RMSEs of reconstructed metabolite maps from four acquisition-reconstruction methods with the same scan time. The methods included fully-sampled (but fewer number of averages to match the scan time of other methods), denoised fully-sampled (using a Schatten 1-norm regularization6), TV-regularized SENSE, and random SENSE+TV. We acquired 50-averages (Navg = 50), fully-sampled (R = 1), non-Cartesian MRSI data in 18 minutes, reconstructed with SENSE, and used the reconstructed data as (low noise) ground truth. Second, we compared the acquisition time required for the fully-sampled data and random SENSE+TV to achieve the same RMSE of the reconstructed NAA map to determine how much we can accelerate MRSI using random SENSE+TV.

RESULTS: For the first comparison, at R=3 (shown in Fig 2), the fully-sampled, denoised fully-sampled, uniform SENSE+TV, and random SENSE+TV methods yielded (27.5, 24.1, 27.2)% RMSE of the reconstructed (NAA, Cr, Cho) maps, respectively. At R=6, the fully-sampled, denoised fully-sampled, uniform SENSE+TV, and random SENSE+TV methods yielded (54.0, 44.3, 57.0)% RMSE of the reconstructed (NAA, Cr, Cho) maps, respectively. For the second comparison, random SENSE+TV with an acquisition time of 1.44 minutes yielded the same RMSE of the reconstructed NAA map as the fully-sampled data with an acquisition time of 6.48 minutes.

DISCUSSION: Random SENSE+TV generally yielded lowest RMSEs of the reconstructed maps, compared to other methods with the same scan time. Random SENSE+TV improves the reconstruction quality by undersampling not only in (kₓ, kᵧ) space, but also along the k₉ axis, which introduces artifacts that are less-structured. Further, random SENSE+TV imposes a prior knowledge on the structure of the data, which improves the condition of the problem. Limitations in this study include that the undersampling that was done only in (kₓ, kᵧ) space, but also along the k₉ axis, which introduces artifacts that are less-structured. Further, random SENSE+TV imposes a prior knowledge on the structure of the data, which improves the condition of the problem. LIMITATIONS: Future work includes extensions to full-brain coverage and incorporation of modeling9-10 for strong subcutaneous lipids.

CONCLUSION: As demonstrated through in vivo results, random SENSE+TV reduces RMSEs of metabolite maps compared to other methods with the same scan time. Furthermore, by using random SENSE+TV, a factor of 4.5 acceleration is achievable while keeping equivalent reconstruction quality as the fully-sampled data, as measured by the RMSE of reconstructed NAA maps.

REFERENCES: