Noise Considerations in Slice Encoding for Metal Artifact Correction

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Introduction: To enable MR imaging around metallic implants, an innovative imaging technique called SEMAC (Slice Encoding for Metal Artifact Correction) has been recently proposed [1]. SEMAC consists of a novel pulse sequence (Fig. 1) and a correction procedure (Fig. 2). The SEMAC sequence extends a view-angle-tiling (VAT) spin echo (SE) sequence with additional z-phase encoding of each excited slice. While in-plane distortions are addressed by VAT [2] during the acquisition, through-plane distortions are handled by the correction procedure. Figure 2 illustrates that the additional z-phase encoding resolves arbitrarily distorted excitation profiles of all slices. Subsequently, all spins inside the region-of-interest can be positioned back to their voxel locations. As the correction procedure sums the resolved spins from multiple slices at each voxel, great care has to be taken to avoid degrading the signal-to-noise ratio (SNR) of the resultant images.

Methods and Results: Direct summation of the signals resolved from multiple slices usually results in severe signal loss, as the signals can have different relative phases. As the spins excited in different slices precess at different RF transmit frequencies, any timing mismatch in echo acquisition results in the relative phases between slices. While summing the magnitude of the resolved spins removes the relative phases, the magnitude operation causes the background noise to become Rayleigh-distributed, which is no longer zero-mean [3]. Summing the non-zero mean noise degrades the resultant SNR. To address this issue, we eliminate the timing mismatch in echo acquisition by carefully adjusting the RF phase reference and/or the receive phase reference, as shown in Fig. 1. When no relative phase exists between the slices, the resolved spins in each voxel can be coherently summed without taking the magnitude operation.

As the SEMAC sequence incurs N_z (the number of z-phase encoding steps) times longer scan time, the SNR in each slice is improved by N_z. However, this gain in SNR is counteracted by the correction procedure, as each pixel in the corrected image has contribution from N_z excited slices, but many of which only contain background noise (see Fig. 2). Therefore, summing the resolved signals from different slices corrects through-plane distortions at a cost of increased noise. Ideally, the correction of through-plane distortions at a voxel should only involve the slices that contain the signals arising from this voxel. To that end, a heuristic threshold is selected to differentiate the signals from background noise. As the signals are generally much stronger than background noise and the frequency dispersion in each voxel is limited, the threshold is the median magnitude of all spins resolved from multiple slices. Only the spins with magnitudes greater than the threshold are included in the correction procedure.

We scanned a gel phantom containing a shoulder implant with an 8-channel head coil using a gradient echo (GRE) localizer, followed by SEMAC with TR/TE = 380/11ms, 24 slices (2.5 mm thick), 256x128 matrix, and 20 cm field-of-view (FOV). Figure 3 shows the comparison results of the phantom study obtained from a spin-echo (SE) sequence, SEMAC without and with noise reduction. SEMAC without noise reduction does not discriminate background noise from the signals and perform magnitude operation during the correction procedure. Using a similar protocol, with 32 slices, each 3mm thick, TR/TE = 540/11ms and 256x128 matrix over 24cm FOV, we scanned the spine of a volunteer with spinal implants. Figure 4 show the comparison results of the spine study obtained from a SE sequence, SEMAC without and with noise reduction. As can be seen from both examples, SEMAC with noise reduction not only corrects the severe artifacts in the SE results but also significantly improves the SNR in the corrected results.

Conclusion: SEMAC corrects through-plane distortions by summing the resolved signals from multiple slices. This can lead to the degradation in SNR without careful consideration of noise. This work describes two approaches to noise reduction, namely eliminating the relative phases between the slices and excluding the slices containing only background noise. Maintaining high SNR of the correction results is important for incorporating SEMAC with various acceleration techniques such that high-quality MR images near metallic implants can be obtained with reasonable scan times.

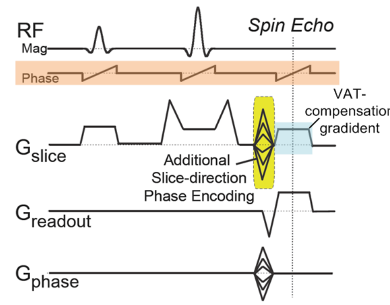

Fig.1: Diagram of a SEMAC sequence. The RF phase reference and/or the receive phase reference must be carefully adjusted such that no relative phase exists between the slices and the resolved spins in each voxel can be coherently summed without taking the magnitude operation.

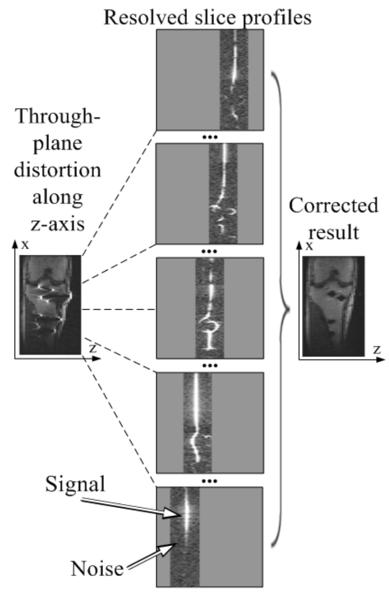

Fig. 2: Illustration of the correction of through-plane distortions. The SEMAC sequence excites multiple slices with no gap in between and resolves the arbitrary distorted excitation slice profiles with the additional z-phase encoding. The correction is done by combining the signals resolved from different slices at each voxel, but many of which only contain background noise.

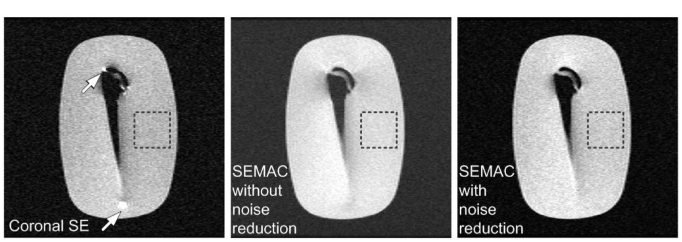

Fig.3: Comparison of the phantom images using spin echo (left), SEMAC without (middle) and with (right) noise reduction. Dashed boxes highlight an uniform region for measuring empirical SNRs, which are 10, 4, and 16 for the SE, SEMAC without and with noise reduction, respectively.

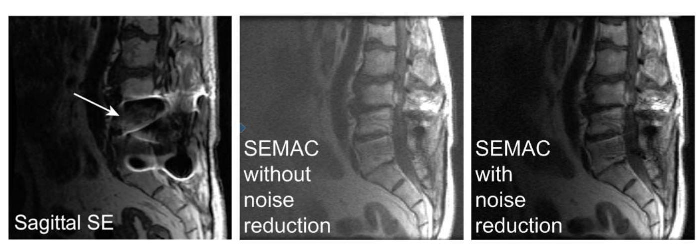

Fig.4: Comparison of the spine images using spin echo (left), SEMAC without (middle) and with (right) noise reduction. Clearly, SEMAC with noise reduction not only corrects severe metal artifacts but also significantly improves the SNR in the resultant image.

References: 1. W. Lu, et al. ISMRM, 838, 2008. 2. Cho et al. Medical Physics 1988; 15:7-11. 3. D. Nishimura, Principles of Magnetic Resonance Imaging.
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