Metal Artifact Reduction using Slice Encoding with Shear Correction

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INTRODUCTION: Two techniques have recently been described which achieve nearly distortion-free MRI of tissue around metal within clinically feasible acquisition times: Slice Encoding for Metal Artifact Correction (SEMAC) [1] and Multi-Acquisition with Variable Resonance Image Combination (MAVRIC) [2]. Both SEMAC and volume-selective MAVRIC-Hybrid [3] use View Angle Tilting (VAT) [4] to compensate for readout distortion. Implementation of VAT is simply the reaplication of the slice gradient during readout. However, VAT imposes a limitation in order to avoid RF-profile-related blurring [5]: the readout period has to be less than the length of the main lobe of the RF profile. There are two main implications: (1) the readout duty cycle is limited, and (2) decreasing the readout bandwidth (RBW) reduces the RF bandwidth, thus increasing the extent of slice distortion. Therefore, decreasing the readout bandwidth can result in increased scan time in order to fully encode the slice distortion. Unlike VAT, SEMAC acquires through-slice information (Fig. 1a) that allows the use of an alternative, shear correction. Therefore, we propose to replace VAT with a shear processing method in SEMAC to avoid these VAT-related limits while maintaining readout distortion correction.

METHODS: Figure 1 demonstrates how SEMAC corrects for slice distortion by using extra slice encoding (as phase encoding is independent of $B_0$ variations). Instead of using VAT to correct for readout distortion, a $z$-varying readout shift is applied by multiplying a linear phase in $k$, that is a function of the slice distance. Using a metallic implant phantom with a quadrature head coil, we demonstrate the improvement in SNR using lower RBW acquisitions. Common acquisition parameters were: coronal; TR 1.4 s; FOV 24×19 cm²; slice thickness 3 mm; number of slices 20; ETL 8; matrix 256×204; ZPE 10; RF time-bandwidth product 3.2; half Fourier acquisition. SNR was calculated using two identical acquisitions and the NEMA method [6]. Next, two patients with spinal fusion hardware were scanned, using a receive spine coil, with standard 2D FSE and SEMAC with both VAT and shear correction. FSE and SEMAC imaging parameters were: axial; TR 105-115 ms; TE 6 s; FOV 24×24 cm²; matrix 384×256; slice thickness 4 mm; number of slices 20-40; ETL 16-18. Additional SEMAC parameters were: ZPE 10; RF time-bandwidth product 3.2; half Fourier acquisition; scan time 4-8 min. Additional FSE parameters were: NSA 2; no phase wrap; slice flow compensation; coil intensity correction (PURE); scan time 2-5 min.

RESULTS: Figure 2 shows phantom images acquired using SEMAC with VAT and shear correction. Halving the RBW results in increased SNR by a factor of $\sqrt{2}$. However, with VAT, the increased RF pulse-width ($P_{RF}$) in order to accommodate the longer readout results in increased distortion (Fig. 2d) and TE, and lower SNR. The increased distortion can only be corrected by increasing ZPE which will result in increased scan time). Shear correction (Fig. 2e) avoids the timing limitations and provides high SNR images as expected, while maintaining distortion correction in $x$ and $z$. Figure 3 shows axial T2-weighted images of the spine from two patients with metallic implants. Shear correction and VAT compare well in the distortion correction. Shear correction with lower RBW potentially allows better depiction of nerve roots, which is crucial in the diagnosis of pain.

DISCUSSION: Shear correction is simple to implement and avoids timing limitations imposed by VAT. The limitation is more significant when acquiring at lower receive bandwidths or higher readout resolution. Shear correction maintains effective distortion correction in SEMAC. However, it is more sensitive than VAT to the slice profile and slight ghosting can be occasionally observed when the excited slice is wider than the phase-encoded sections (Fig. 1b). Although not shown here, the technique is also applicable to the MAVRIC-Hybrid technique.

CONCLUSION: We have demonstrated a shear correction method to resolve readout distortion in SEMAC without VAT-related limitations, allowing for higher SNR images to be acquired in similar scan times.

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Figure 1: (a) Extra phase encoding (ZPE) is performed to resolve slice distortion. (b) VAT is typically done to compensate for readout distortion. An equivalent result can be achieved by using shear correction, which avoids the timing limitations imposed by VAT.

Figure 2: Coronal images and sagittal reformats of a shoulder implant phantom acquired using (a,c,d) VAT and (b,d) shear-corrected SEMAC at two readout bandwidths (RBW). (a) VAT and (b) shear are comparable at high RBW acquisitions. (c) However, when the RBW is reduced, increased slice distortion occurs (arrows) in order to satisfy the RF main lobe requirement from [5]. Also, the minimum TE is increased due to increased echo spacing. (c) It is possible to run VAT without following the RF limitation but this can result in blurring [5]. (e) shows that shear with lower RBW can avoid the timing limitation while maintaining distortion correction.

Figure 3: Axial T2w images of the spine from two patients acquired using standard 2D FSE and SEMAC with VAT and shear correction with the readout bandwidth denoted in brackets. Both VAT and shear-corrected SEMAC resolved the artifact (arrows) from the metallic instrumentation used to hold an artificial disc in place. All SEMAC acquisitions require the same scan time.