Stent imaging using metal artifact reduction sequence

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Introduction: Magnetic Resonance (MR) image of the stented aneurysms or stenoses suffers from metal induced artifacts such as image deformation and signal loss. The main source of artifacts is severe B0 field inhomogeneity caused by the metallic object. B0 field perturbation makes spins resonate at different frequency, thereby changing the spin's spatial position and causing image artifacts. Image deformation occurs twice, first during slice selection (through-plane) and second during data acquisition (in-plane). Recent studies introduced methods for imaging metallic object by using spatial encoding along slice direction and view angle tilting technique with spin-echo sequence [1-3]. In this study, we examine a method of accurately imaging stent and its surroundings using the metal artifact reduction sequence. First we find appropriate scan parameters via B0 field simulation, and attempted high-resolution stent imaging. Parallel imaging technique was also used for scan time.

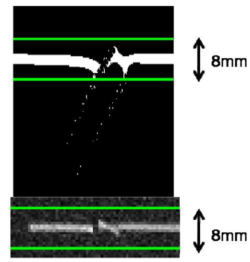

Figure 1. Simulated excitation profile (top) and acquired profile (bottom).

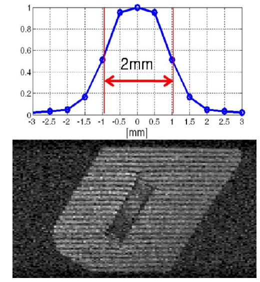

Figure 2. RF slice profile (top) and resultant stripe pattern (bottom).

Methods: A Carotid Wall stent (Boston Scientific, Natick, USA, length = 29mm, diameter = 8mm, χ ~ 1400ppm (Co-Cr)) was used for data acquisition and modeling for B0 field simulations. The B0 field perturbation was simulated using fast-Fourier transform (FT) based method [4-5]. From ΔB0, the excited spins' position profile was acquired (spatial resolution: 0.25mm, FOV: 64mm, 1.25 kHz RF BW), which was used to define the number of spatial encoding along slice direction (i.e., # of slice-encoding). Note that in clinical cases, the orientation and bendings of the stent vary. The simulation tool has built to account for these variations. A metal artifact reduction sequence (specifically slice-encoding for metal artifact correction; SEMAC [2]) was implemented on a 3T Siemens scanner (Tim Trio, Erlangen). Sinc pulse was used for both excitation and refocusing RF (time-bandwidth product = 4, duration 3.2ms, 1.25 kHz BW). At first, we used a 2mm excitation thickness followed by 2mm slice-encoding. Subsequently, the slice-encoding resolution was set to 0.5mm with 2mm excitation thickness for high-resolution stent imaging. Smaller Δz can help resolve the through-plane distortion more precisely and reduce the in-plane distortion. However, due to the RF slice profile of sinc pulse, the signal intensity near edges of excited region is reduced. To overcome this signal degradation and maintain a flat excitation profile, we repeated the acquisition shifted by 1mm from the original position. In the process of combining all resolved slices, magnitude weighting in the image domain was performed to reduce the noise and maintain a flat profile. This process was found important in the case of low signal-to-noise ratio (SNR) images. To reduce the total scan time, data was accelerated along the phase-encoding direction by factor of 2 using parallel imaging. The image was reconstructed using generalized auto-calibrated partially parallel acquisition (GRAPPA) technique. 24 auto-calibration (ACS) lines were acquired, thus effective acceleration factor was 1.68. In the reconstruction process, a modified reconstruction method was tested. We applied the GRAPPA algorithm to hybrid space data (ky, kx, z). In this way, images in the slice-direction is summed prior to GRAPPA reconstruction thereby increasing its accuracy in ACS weights calculation and reducing the reconstruction time by 3 to 4 times.

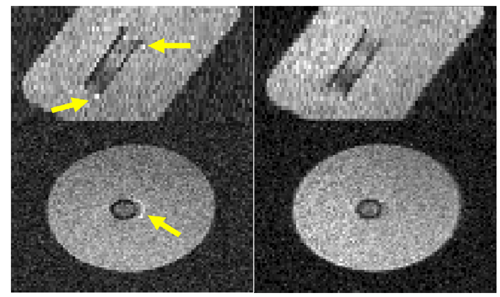

Figure 3. Spin-echo image (left) and SEMAC image (right)

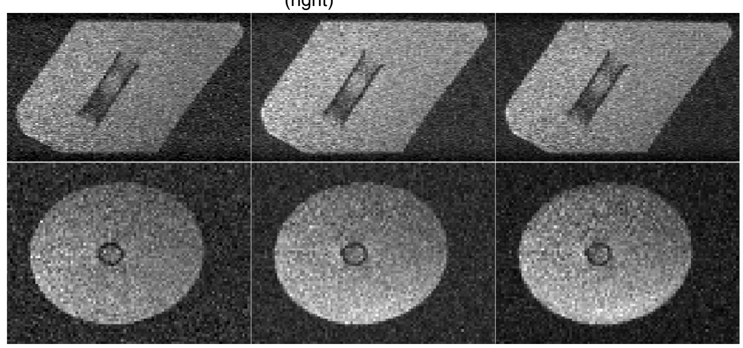

Figure 4. High-resolution SEMAC images. Unaccelerated (left), GRAPPA reconstructed (middle) and modified GRAPPA applied in hybrid space (right).

A stent embedded in an agarose phantom was imaged with the following parameters. Resolution = 1.0x1.0mm (y, x); 128x128 matrix; 26 slices were acquired to cover whole stent. For comparison, a multi-slice spin-echo and 2mm z-resolution SEMAC sequences was used with TR/TE = 500/11.5ms; readout BW = 1000Hz/pixel; # of slice-encoding = 6 (SEMAC). To illustrate high resolution imaging, a 0.5mm z-resolution SEMAC sequences was used with TR/TE = 500/13.6ms; readout BW = 950Hz/pixel; # of slice-encoding = 16. Acquisition time of a single iteration using the 0.5mm SEMAC was 17:04 sec without and 10:08 sec with acceleration. All reconstruction was performed offline using Matlab (Natick, MA, USA).

Results and Discussion: Figure 1 shows simulated and acquired excitation profile for a reasonable FOVz. Simulated profile is well matched with resolved through-plane distortion. Figure 2 shows the 90° sinc RF slice profile using the SLR transform. The lengthy transition band causes a modulated profile of spins which is shown in the bottom image of Fig. 2 by the resulting striped patterns. We expect that this problem can be solved using optimally designed SLR pulses. Comparison using a conventional multi-slice spin-echo image with our sequence is shown in Fig 3. Bright pixels (indicated by arrow) due to field inhomogeneity was reduced with SEMAC sequence (right). Note that lower part of stent wall was bent in spin-echo image. The addition of view-angle tilting gradients gave in-plane distortion to within 0.625 pixels. Figure 4 shows high-resolution image along slice-direction (0.5mm resolution) with and without parallel imaging. The use of GRAPPA shows little degradation in the images while using a modified GRAPPA approach results in increased SNR. The use of a modified hybrid space GRAPPA recon approach performed robustly for low accelerations with adequate number of ACS lines. Note that there is signal drop inside the stent for all stent images, which is most likely due to RF inhomogeneity. This issue further needs investigation.

Conclusion: We have examined a method for high-resolution stent imaging using the metal artifact reduction sequence. Scan parameter was chosen from a B0 field simulation tool developed and parallel imaging technique was used to reduce the scan time to reasonable levels. It is anticipated that using the approaches mentioned, accurate high resolution imaging near stent areas can be accomplished suitable for clinical studies.

References : [1] Lu. W, et al., MRM, 62:66-76, 2009 [2] Cho. ZH, et al., Med Phys 15:7-11, 1988 [3] Koch. KM et al., MRM, 61:381-390, 2009 [4] R. Salomir et al., Concepts in Magn. Reson B., 19B, 26-34, 2003 [5] Koch. KM et al., Proc. 16th ISMRM, 2008