# Spiral imaging with view angle tilting for application to metal artifact correction

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**Introduction:** Previously reported view angle tilting (VAT) technique effectively reduces image distortion caused by chemical shift or susceptibility difference induced B0 inhomogeneity [1]. VAT with slice-encoding enables MR imaging near metallic implants [2]. This method called SEMAC (slice-encoding for metal artifact correction) resolves through plane distortion by spatial encoding, and corrects in-plane distortion by VAT. Typical frequency range induced by metal implants is about ±15kHz at 1.5 Tesla [3]. Accordingly, with 1kHz RF bandwidth, less than 30 slices and about 16 slice-encodings maybe sufficient which used as typical imaging parameters in [2]. However, at 3T, the frequency range is doubled, thus more slices and slice-encodings needed. Therefore, scan time will greatly increase in case of 3T. Turbo spin-echo sequence enables fast imaging [4], but specific absorption ratio (SAR) limits the length of echo-train. Generally, non-cartesian sequence such as spiral can enable fast-imaging. Nevertheless, spiral is sensitive to B0 inhomogeneity. Thus in this study, we investigated the capability of applying VAT technique on spiral and possibility of metal object imaging.

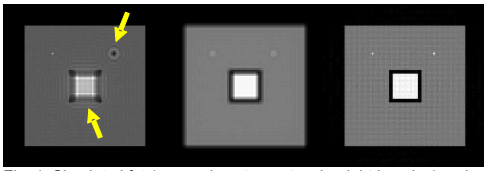

Fig. 1. Simulated fat (arrowed center rectangle, right impulse) and water (gray, left impulse) phantom without noise. Without (left) and with VAT (middle) and de-blurred (right) assuming spiral acquisition showing the applicability of spirals.

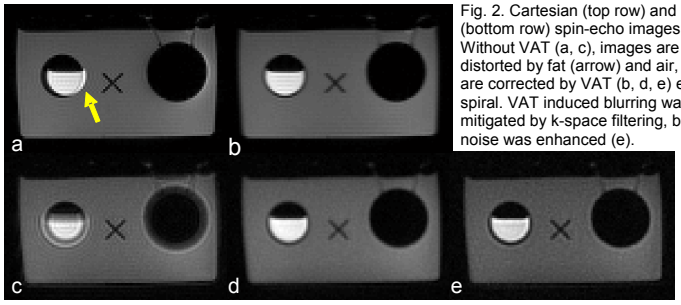


Fig. 2. Cartesian (top row) and spiral (bottom row) spin-echo images. Without VAT (a, c), images are distorted by fat (arrow) and air, these are corrected by VAT (b, d, e) even in spiral. VAT induced blurring was mitigated by k-space filtering, but noise was enhanced (e).

**Methods:** VAT applied to non-cartesian trajectory was first introduced by Jung et al., which was projection acquisition [5]. VAT was also applied to BLADE trajectory (PROPELLER) [6]. Therefore, we assumed that the VAT can be applied to spiral readouts in a similar fashion. To verify this concept, we simulated fat-water phantom model with simple MR signal acquisition equation. The overall view angle can be defined as $\tan^{-1}(k_z max/k_r max)$, which can be applied in general for all trajectories. The Most common drawback using VAT is image blurring due to k-space weighting by slice profile modulation [7]. This blurring can be negated by dividing out the Fourier transform of slice profile. Also, for spirals, long readout duration cause severe blurring and cannot be de-blurred therefore we limited the readout length to be relatively short. The spin-echo spiral with VAT sequence was implemented on Siemens 3T scanner (Tim Trio, Erlangen). The VAT gradient was same as slice-selection gradient. To reduce VAT induced blurring, we used sinc RF bandwidth (BW) of 625Hz (6.4ms, TBW 4) and 32 interleaves spiral (FOV 192mm, matrix 128x128, 2.67ms of readout). Phantom was consisted of fat, air ball and simple 'x' structure. For comparison, cartesian spin-echo images (with same RF and similar readout duration (2.5ms, 200Hz/Px)) were acquired.

To investigate the possibility of metal object imaging, Niobium ($\chi$=237ppm, 2mm diameter x 2mm height cylindrical shaped) phantom was used. First, 2D images were acquired using both sequences. The sequence was further modified to enable SEMAC. We used 28 slice-encodings and 34 slices in SEMAC acquisition. Total scan time of 40 minutes in Cartesian SEMAC which was reduced by half in spiral (TR/TE = 700ms/14ms).

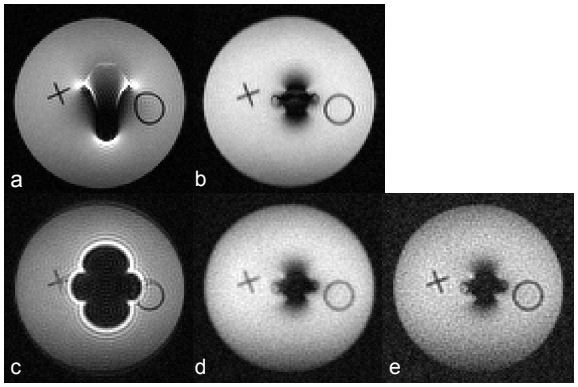


Fig. 3. Cartesian (top row) and spiral (bottom row) 2D spin-echo images of Niobium phantom. 4ms, 1kHz sinc RF was used for both sequence. 390Hz/Px, 1.28ms readout (from echo) for cartesian, and 64 interleaves,1.6ms readout for spiral. Without VAT (a, c), images are severely distorted by metal, these are reduced by VAT (b, d, e) even in spiral. VAT induced blurring was mitigated by k-space filtering, but noise was enhanced (e).

**Results and Discussion:** Figure 1 shows simulated images of spiral with and without VAT. With an appropriate imaging parameter, VAT induced blurring is tolerable and this can be almost removed by filtering. In figure 2, we can see similar blurring in both cartesian and spiral acquisition if readout duration are similar. From images of figure 1 and 2, we verified view angle tilting on spiral is possible. This means VAT can be applied to any non-cartesian trajectory. Spiral VAT also works even in metal object as shown in Figs. 3 and 4. Just as in 2D imaging, we can control VAT induced blurring by decreasing RF bandwidth without cost of scan time. However, in case of spiral SEMAC, RF BW cannot be shorten enough due to frequency range near metal object. Thus RF BW and number of spiral interleaves should be carefully selected. We found the ratio of 1/RFBW (main lobe duration/2) and readout duration is meaningful index for expecting amount of blurring. Spiral images in figure 4, there are some residual artifact near metal object. These are maybe eddy-current effect due to metal. We should investigate this with other metallic object.

**Conclusion:** We have shown view angle tilting technique is applicable on spiral sequence. MR imaging near metal object with spiral VAT is also possible.

**References :** [1] Cho. ZH, et al., Med Phys 15:7-11, 1988 [2] Lu. W, et al., MRM, 62:66-76, 2009 [3] Koch. KM et al., JMRI, 32:773-787, 2010 [4] Hargreaves. BA et al., JMRI, 31:987-996, 2010 [5] Jung KJ, MRM 19:349-360, 1991 [6] Li G, et al., Proc. 16th ISMRM, 2008 [7] Butts. K, et al., MRM 53:418-424, 2005

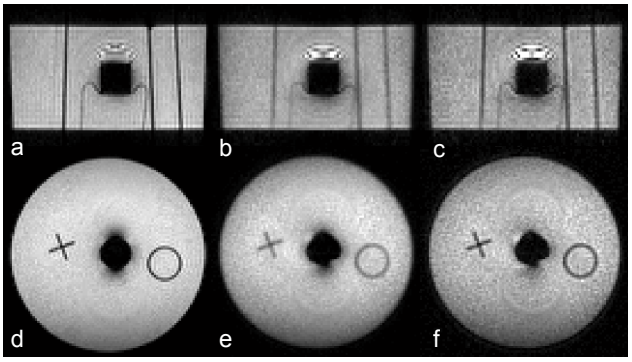


Fig. 4. Cartesian (a, d) and spiral (b, c, e, f) SEMAC images. B0 direction is down to up in coronal plane (bottom row). Images in top row show axial plane. Spiral SEMAC give similar images, but still remain distortion near metal object (Niobium). With filtering, VAT induced blurring were reduced (c, f), but noise were enhanced and still blur. 4ms 1kHz sinc RF, 128 PE lines, 780Hz/Px, 0.64ms readout (from echo) for cartesian and 64 interleaves, 1.6ms readout for spiral.