Reduction of Eddy Currents Induced Image Artifacts in Coronary MRA Using a Linear-Centric-Encoding (LCE) SSFP Sequence

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Introduction: Segmented SSFP (steady-state free precession) sequence has been demonstrated to yield higher signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) than conventional gradient-echo sequence in coronary MRA[1]. However, SSFP is sensitive to off-resonance frequencies resulting from local field inhomogeneities. Eddy current induced by gradient switching is one source of such field imperfections. The k-space trajectory of a conventional ECG gated, segmented SSFP sequence in phase-encoding (PE) direction moves from central to outer lines in both positive and negative directions in each segment (Fig. 1a). The sign as well as magnitude of the PE gradient alternates from excitation to excitation, inducing oscillating eddy currents. This results in discontinuities of phase (Fig. 1c) and ghosting in images. Such artifacts can be alleviated by reducing large change of gradient in PE direction[2]. The purpose of this study was to develop a linear-centric-encoding (LCE) PE order SSFP sequence to reduce eddy currents induced image artifacts in coronary MRA. In-vivo studies were performed to evaluate the efficacy of such LCE scheme over conventional alternating-centric-encoding (ACE) PE scheme.

Methods: Fourteen healthy volunteers were scanned at 1.5T (Sonata, n = 6) and 3.0T (Trio, n = 8) Siemens whole-body scanners. Both scanners are capable of operating at a maximum gradient strength of 40 mT/m and a slew rate of 200 mT/m/ms. A twelve-element cardiac phased array coil was used at 1.5T for signal reception. At 3.0T, an 8-channel cardiac phased array coil was used.

A segmented 3D, cardiac gated, breath-hold, SSFP sequence was used for coronary artery imaging. The whole k-space of each slice was covered in four heartbeats with 31 - 35 lines acquired in each heartbeat. Figure 1 illustrated the order of k-space coverage in one segment of ACE (a) and LCE (b) schemes. The k-space trajectory in LCE scheme traveled unidirectionally toward one side of k-space in each segment. The upper k-space of each slice was collected in the first two segments and the lower half was covered in the next two segments.

Coronary artery images were acquired from each subject using ACE and LCE schemes, respectively. Imaging parameters included: TR/TE = 3.2/1.3 msec, flip angle = 62° - 70°, readout bandwidth = 980 Hz/pixel, matrix size = $(122\text{-}140) \times 384$, $(1.2\text{–}1.7) \times (0.9\text{-}1.0)$ in-plane resolution. Slab thickness = 18 mm, number of partitions = 6 (12 after sinc-interpolation). Total imaging time for acquiring one slab was 24 cardiac cycles. Synthesizer frequency was adjusted when necessary[3] to reduce obvious off-resonance artifacts in ACE scheme. Same adjustments were applied to LCE acquisition.

Image quality was blindly evaluated by one of the authors on a scale of 1 (poor) to 4 (excellent). The results were presented as mean ± standard deviation. Comparison between two different data acquisition schemes was performed using a paired t-test.

Results: Figure 2 shows coronary images from 1.5T (a, b) and 3.0T (c, d) using ACE and LCE schemes. Image artifacts are substantially reduced in LCE images (b, d) as compared to those acquired with ACE scheme (a, c). Image quality is significantly improved at both field strengths using LCE order (1.5T: ACE / LCE = 2.2 ± 0.8 / 3.0 ± 0.6, $p = 0.02$; 3.0T: ACE / LCE = 2.1 ± 1.1 / 3.0 ± 0.8, $p = 0.01$).

Conclusions: By using an LCE SSFP sequence, image quality was significantly improved in coronary MRA. Image artifacts supposed to be caused by eddy currents were substantially reduced at both 1.5T and 3.0T.

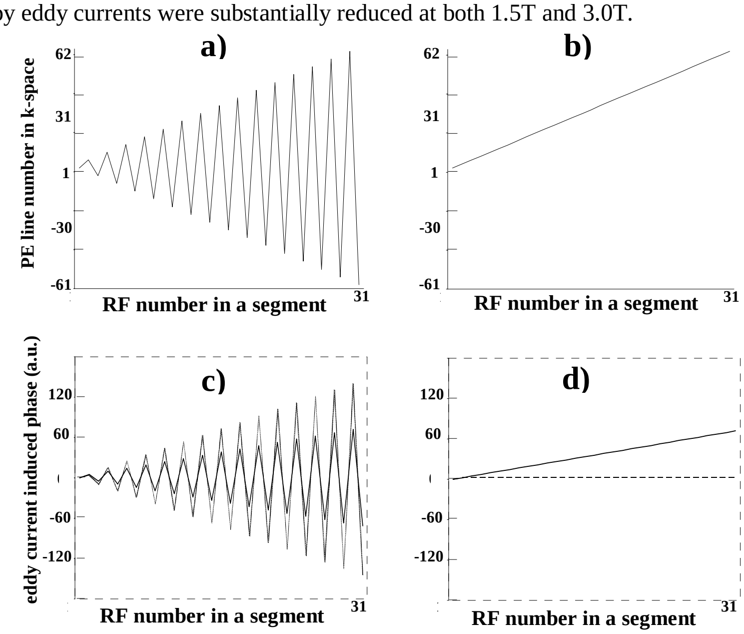

Figure 1. Order of k-space coverage in one segment with ACE (a) and LCE scheme (b). Alternating gradient in ACE induces oscillating eddy currents while LCE scheme induces constant eddy current. Eddy currents induced phase in each TR (dashed line) and cumulative phase (solid line) in one segment are illustrated in (c) and (d). (Assuming exponential decay term of eddy current $\tau >> TR$).

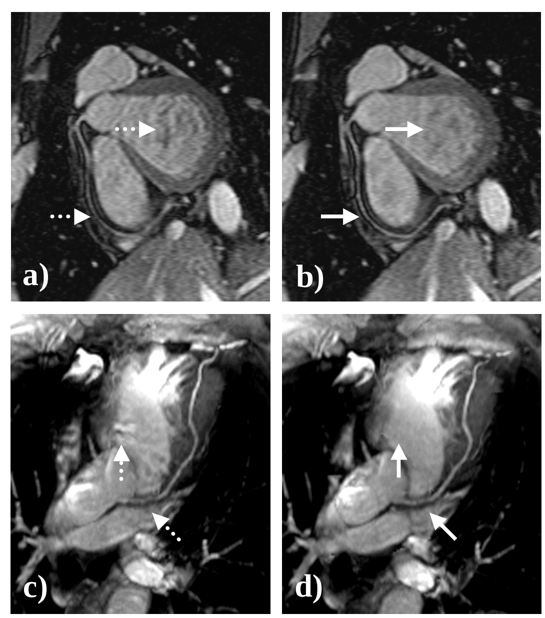

Figure 2. Apparent image artifacts in ACE images (a, c) are markedly reduced in LCE images (b, d) as indicated by arrows.
Images are acquired at 1.5T (a, b) and 3.0T (c, d), respectively.

References:
1. Deshpande VS et al. *MRM.* 46 : 494-502. 2. Scheffler K et al. Proc ISMRM 2003:294. 3. Deshpande VS et al. *MRM.* 49 : 803-809.