Evaluation of off-resonance correction with and without an acquired field map in variable-density contrast enhanced spiral perfusion imaging

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Introduction: Spiral images can suffer from off-resonance related blurring artifacts that significantly impact image quality. One application of spiral scanning that requires off-resonance correction is CMR perfusion imaging during adenosine stress [1]. The perfusion sequence described in [1] collects a field map with each image for off-resonance deblurring. While this results in sufficient off-resonance performance, it requires two additional spiral interleaves reducing the efficiency of data collection by 20% for an 8 interleaved sequence. For perfusion imaging, timing is critical as all of the data for multiple slices need to be obtained in a single cardiac cycle. An automatic deblurring algorithm that did not require acquisition of a field map and produces robust images with adequate off-resonance correction would be ideal for this application.

Methods: CMR perfusion imaging was performed during adenosine stress (140µg/kg-min) and at rest in 8 subjects scheduled to undergo cardiac catheterization for evaluation of chest pain on a 1.5T scanner. Subjects with prior coronary artery bypass surgery were excluded. Perfusion images were acquired during injection of 0.1mmol/kg Gd-DTPA at 3 short-axis locations using a saturation recovery (SR) interleaved variable-density spiral pulse sequence with an integrated field-map for off-resonance correction during reconstruction. The VD spiral design was an interleaved linear-in-time trajectory with an initial relative density of 1.2 and a final relative density of 0.4 (where 1 corresponds to Nyquist sampling). Sequence parameters included: SR time 80 ms, FOV 320-340mm^2, nominal resolution 2.0 mm^2, 8 spiral interleaves, FA 30^0, TR/TE 10ms/1ms. Two additional interleaves were included for generation of a low-resolution field map. We compared the performance of our gold standard semi-automatic reconstruction (abbreviated SA) [2,4] to automatic reconstruction (abbreviated FA) [3,4], and to a standard gridding reconstruction without off-resonance correction (abbreviated UC). The automatic reconstruction utilizes a two-stage procedure as described in [3]. A central portion of the k-space data is extracted and reconstructed several times, at different off-resonance frequencies. A pixel by pixel objective function based frequency search is employed to calculate a low resolution field map. This process is then repeated with the full k-space data at nominal image resolution and utilizing the low-resolution field map as a starting point. The semi-automatic reconstruction utilizes an acquired low-resolution field map in place of the first stage, but the second stage remains identical to the automatic reconstruction. Both automatic and semi-automatic reconstructions utilize a Chebyshev polynomial fit to the off-resonance phase evolution during the readout [4].

Two cardiologists blindly evaluated 8 data sets of spiral stress perfusion images at the three slice positions for the severity of blurring on a five point scale. (1 - severe blurring, 2 mod-severe blurring, 3 mild-moderate blurring, 4 mild blurring, and 5 minimal to no blurring). Data sets were intentionally chosen to include a range of image quality and images both with and without perfusion defects. The images were cropped to 50% of the original FOV so that only the region of the heart was evaluated. The reviewers were also told to choose the reconstruction with the least blurring for the data set, but were allowed to call a tie if two reconstructions were essentially equivalent. The mean score from the two reviewers were compared using a repeated-measures ANOVA. The mean score of the deblurred images (FA or SA) were also compared to the scores from the uncorrected data-sets using a paired t-test. Additionally, the structural similarity index (SSIM) [5] was computed to obtain a quantitative measure of the differences between reconstruction methods. The structural similarity test took SA as the gold standard, and was compared against FA and UC.

Results: The mean scores for the UC, SA, and FA were 3.9, 4.2 and 4.3 respectively (p=0.2), and there was a trend towards automatic reconstruction (FA/SA) being superior to UC (p=0.14). The lack of statistical significance is likely due to the small sample size. However, the FA reconstruction was chosen as the best reconstruction (including ties) 68% of the time, and automatic reconstruction (FA or SA) in 75% of the cases. In only 2 cases were the UC images ranked or tied for the least blurred images. The computed SSIM was higher between SA and FA as compared to the SSIM between SA and UC (0.83 ± 0.09, 0.77 ± 0.10, p = 0.0003). That p-value is obtained via a two tailed t-test.

Discussion: Due to the short readout duration of our spiral pulse sequence uncorrected images produced images with minimal blurring. Fully automatic or semi-automatic reconstructions produced the least blurring in 75% of the cases, with FA being the preferred images overall. This result justifies utilization of a FA method for reconstruction of spiral perfusion images for adenosine stress perfusion imaging with spiral pulse sequences, which eliminates the need for acquiring a field map with each perfusion image.

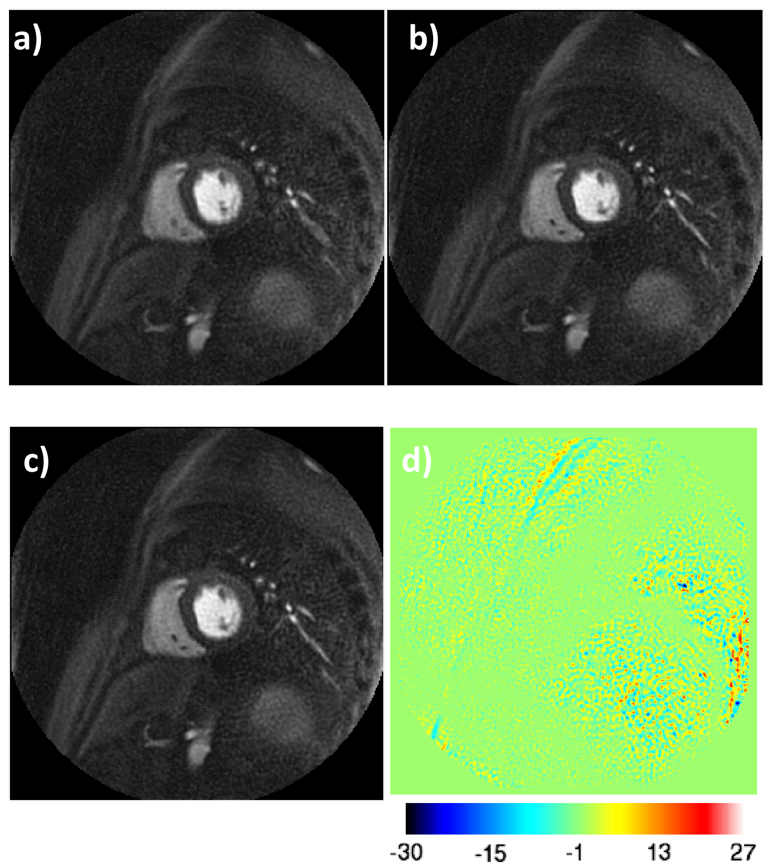

Figure 1: (a) uncorrected (b) semi-automatic (c) full automatic reconstructed spiral perfusion images demonstrate minimal off resonance artifacts. Difference images between semi-automatic and full automatic show only minor differences in the region of the heart. (scale is in percentage)

References: [1] Salerno et al. Magn Reson Med 2011; 65:1602-1610 [2] Chen et al. Magn Reson Med 2008; 59:1212-1219 [3] Chen et al. Magn Reson Med 2006; 56:457-462 [4] Chen et al. Magn Reson Med 2008; 60:1104-1111 [5] Wang et al. IEEE Transactions on Image Processing 2004; Vol 13 No 1