Robust phase contrast correction with parallel imaging

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Target Audience: Radiologists, cardiologists, MR physicists

Purpose: Accurate velocity and flow quantification using phase-contrast (PC) imaging is of critical interest in cardiac MRI, in particular for the evaluation in congenital heart diseases of shunts and regurgitation and in acquired heart diseases to evaluate stenosis or coarctation. However, eddy currents, gradient non-linearity, concomitant fields and chemical shift introduce velocity errors that result in inaccurate velocity and flow measurements[1]. Previously, we presented a novel post-hoc non-linear background phase method[2] that outperforms the linear fitting background correction[3] and is feasible for replacing the gold-standard static phantom correction[4]. However, all fitting background correction techniques require that static tissue be detectable and reflect the background phase. There are often scanning situations in which aliased static tissue, a.k.a. FOV aliasing or phase-wrap artifacts, can arise--for example, if the phase Field of View (FOV) is reduced (<1) to improve temporal resolution or breathhold duration. Although the aliased static tissue lies outside the vessels of interest, it results in erroneous phase fitting and hence a catastrophic correction result. Here, we explore the use of parallel imaging with sensitivity encoding (SENSE)[5] to negate this failure of the phase correction method. Specifically, SENSE can unwrap FOV aliasing[6] by utilizing a coil sensitivity map having a phase FOV larger than the acquired PC image, covering the full anatomy in the phase-encode direction, resulting in reconstructed images without confounding aliased static tissue

Methods:

Acquisition: Two volunteers were scanned at 3T (GE MR750w) with a 32-channel GEM coil. 2D-CINE PC images were acquired using FOV = 35 cm, 6 mm slice, TR = 5-6 ms, TE = 3-3.5 ms, VENC = 1500 mm/sec, 4 views per segment, matrix size=196x128, reconstructed CINE phases = 30.

For each subject, two pulmonary and aortic planes containing mild and severe FOV aliasing were acquired without SENSE, and with SENSE acceleration factors of R=1 and 1.5, reconstructed using the vendor's online product SENSE-based (ASSET) reconstruction. Static phantom acquisition of the same planes and repetition were also acquired.

Post-hoc correction: Linear-only[3] and nonlinear self-calibrated phase-contrast (SCPC)[2] post-processing was applied using Matlab 2013b. In both cases, the static tissue detection incorporated an automated iterative removal of outliers and a higher weighting of velocities from the quiescent cardiac phase to reduce effects from flow artifacts at systole. For SCPC over-fitting was prevented.

Analysis: Velocities within a 4-cm radius region at isocenter (near the great vessels) after linear correction, non-linear correction and without correction were compared with ground truth stationary phantom correction[2].

Aortic (Qs) and pulmonary (Qp) flow ratios (Qp/Qs) were extracted afterwards. The same ROI contours were used in all analyses, using the static phantom result as the ground truth.

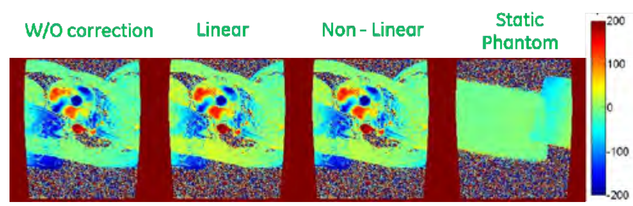

Figure 1: Illustrated failure mode in a severe FOV aliasing aortic plane in one volunteer with respect to the ground-truth static phantom. Increased velocity offsets in a 4-cm radius region at isocenter are observed after correction, linear (17mm/s) and non-linear (11mm/s), versus no correction (-4mm/s) with respect to static phantom.

Results: Figure 1 illustrates how severe FOV aliasing can make the background correction fitting algorithms fail for an aortic plane. Aliasing was considered to be severe when aliased static tissue overlapped remote static tissue, and mild when aliased static tissue did not overlap. Severe aliasing results in erroneously higher mean velocity values in static tissue, which imparts errors to the fitting procedure. Two different pulmonary planes are shown in Figure 2, and at different acceleration factors. It can be observed that SENSE completely removed FOV aliasing in both cases without affecting image quality. Table 1 shows the Qp/Qs obtained by combining the mild aliasing and severe aliasing pulmonary and aortic planes for the three different acquisition modes and the four post-processing techniques. Qp/Qs values were off by more than 20% after linear and non-linear post-hoc correction when SENSE was not used. When SENSE was used, all Qp/Qs values were close to 1 as expected for a healthy subject.

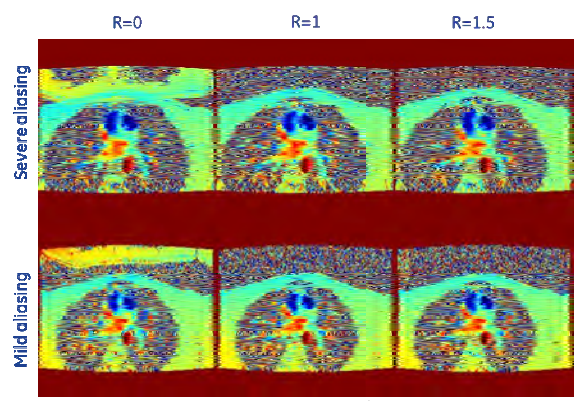

Figure 2: Velocity-encoded images in mm/s for mild and severe FOV aliasing pulmonary planes in one volunteer for (from left to right): Without SENSE and with SENSE R=1 and R=1.5 acquisitions.

	W/O Correction	Linear	Non-linear	Static Phantom
WITHOUT SENSE				
Mild Aliasing	1,02	1,26	1,21	0,98
Severe aliasing	1,01	1,29	1,23	0,94
SENSE R=1				
Mild aliasing	1,04	1,03	1,03	1
Severe aliasing	1,02	1,03	1,02	1,04
SENSE R=1.5				
Mild aliasing	1,04	1,02	1,02	0,99
Severe aliasing	1,02	1,04	1,03	1,04

Table 1: Qp/Qs ratios for one volunteer when combining the mild aliasing and severe aliasing planes from pulmonary and aorta before and after linear, non-linear SCPC and static phantom correction.

Discussion and Conclusion: Parallel imaging using SENSE removes the FOV aliasing, even when no undersampling was applied (R=1). This property of SENSE reconstruction avoids the failure mode of PC-MRI background correction post-hoc algorithms that require static tissue to reflect the background phase. The presence of FOV aliased static tissue causes the fitting algorithm to use background phase values from incorrect areas of the FOV, as seen in column 1 of Figure 2 (back appears on top of the FOV). Depending on the amount of aliased static tissue versus non-aliased detected static tissue, the fitting surface can be completely flipped in the FOV phase direction. In this work, we have only used a moderate ASSET acceleration factor of 1.5. Higher acceleration factors could significantly increase background noise, reducing the overall image quality. The use of robust post-hoc methods is of interest in order to improve the cardiac MRI exam's workflow eliminating the acquisition of static phantom to remove the residual phase errors while ensuring accurate velocity quantification.

References: 1. Gatehouse PD, J Cardiovasc. Magn. Reson. 2010;12:5. 2. Tan EK. ISMRM 2014. 3. Walker PG, JMRI1993;3:521-530. 4. Chernobelsky A, J Cardiovasc. Magn. Reson. 2007;9:681-685. 5. Pruessmann KP, MRM 1999;42:952-62. 6. King KF, 2nd International Workshop on Parallel Imaging, 2004