Analysis of Gradient Spoiling in Phase Contrast MRI

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INTRODUCTION – 2D through-plane phase contrast MRI (PC-MRI) methods typically acquire two cardiac segmented experiments with different velocity encoding gradients interleaved on a TR basis. Phase difference processing of the two resulting phase images allows the quantitative assessment of velocity and flow [1]. The required acquisition of two interleaved experiments for cancellation of background phase errors represents a temporal resolution limitation. Suboptimal temporal resolution acts as a low low-pass filter on a vessel's velocity waveform leading to an underestimation of peak velocity and total flow. PC-MRI experiments are typically performed using spoiled gradient recalled echo (GRE) experiments. Spoiling is normally conducted using RF spoiling and a dephasing gradient played at the end of each TR to eliminate any residual transverse magnetization prior to the application of the subsequent RF pulse. The effect of gradient spoiling on artifact suppression in GRE magnitude images has been studied in detail [2]. Leupold et al. concluded that effective artifact suppression in magnitude images required $>\approx 8\pi$ dephasing over the slice thickness. An analysis of optimal artifact suppression through gradient spoiling in GRE-based PC-MRI phase images has not been described. The ***objective*** was to define time-optimal gradient spoiling for GRE-based PC-MRI to reduce the TR and improve temporal resolution.

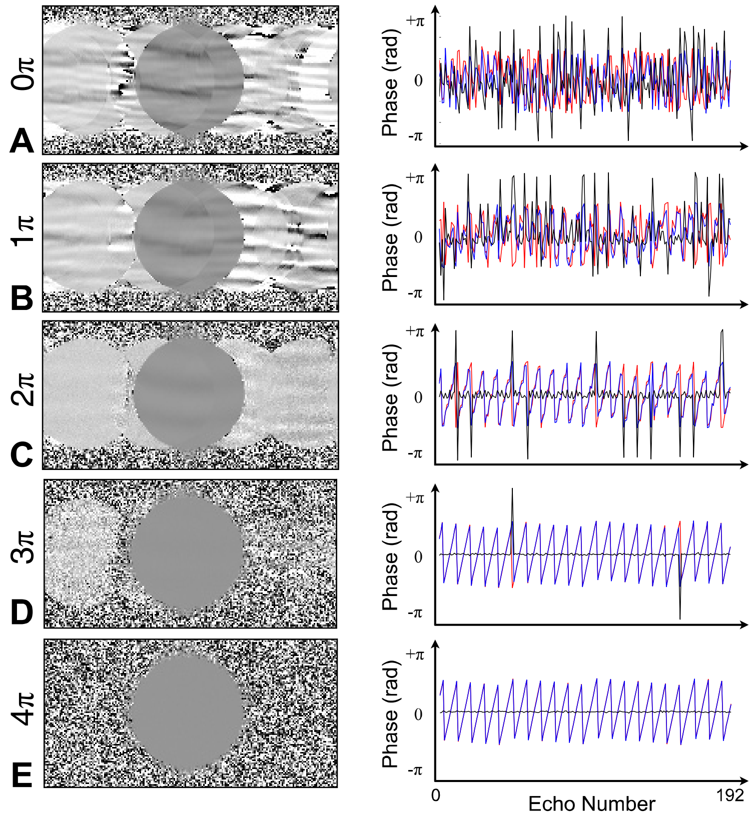

Figure 1. PC-MRI phase images of a stationary phantom (left) and measured phase as a function of echo number (right) for the interleaved PC-MRI datasets (red and blue) and the phase difference result (black) with 0π **(A)**, 1π **(B)**, 2π **(C)**, 3π **(D)**, and 4π **(E)** gradient spoiling along the through-plane slice select axis. The images were cropped in the readout direction (top/bottom).

METHODS – All imaging was performed on a 3T scanner (Siemens Trio) using a homogenous stationary phantom with T_1/T_2=102/100ms. Measurements were made using a flow compensated/sensitive velocity encoded cine spoiled gradient echo PC-MRI sequence with the following parameters: TE/TR=3.7/5.54ms, 192×192 matrix, 1.6×1.6×6mm^3 spatial resolution, 30° flip angle, 814 Hz/pixel bandwidth, 4 views-per-segment, a total scan time of 48 simulated heartbeats with a simulated RR-interval of 1000ms and 1 dummy heart beat to reach steady-state, 2D through-plane velocity encoding with VENC = 150cm/s, and a temporal resolution of 44.3ms. The pulse sequence was modified to allow a user defined gradient spoiling amount along any axis, including flow-compensating read and slice waveforms for zero effective spoiling. Images were acquired with 0,1,2,3, and 4π gradient spoiling along the slice select or readout direction. Quadratic RF spoiling was applied using a phase increment of 50° [3]. Raw data was also acquired for phantom experiments with phase encoding off. A one-dimensional Fourier transform was applied to produce a 1-dimensional projection of the circular phantom in image space. The complex value at the center of the resulting image space vector was then extracted for the flow compensated (odd echoes; blue line in Fig. 1), flow encoded (even echoes; red line in Fig. 1), and resulting phase difference (black line in Fig. 1) as a function of echo number.

RESULTS AND DISCUSSION – Artifacts in PC-MRI phase images arising from residual transverse magnetization result in spurious variations in the measured phase as a function of echo number. As expected, these spurious phase oscillations are reduced as the spoiling gradient area increases, leaving only off-resonance related phase contributions. This can be seen qualitatively in the phantom images (left column of Fig. 1) and quantitatively in the measured phase for each PC-MRI echo and the resulting phase difference (right column of Fig. 1). Artifacts in both the PC-MRI phase images and measured phase plots are effectively eliminated for 4π gradient spoiling. Gradient spoiling >4π results in the application of unnecessary gradient spoiling area, which unnecessarily lengthens the imaging TR and reduces the achievable temporal resolution. Thus, PC-MRI sequences should be optimized to use the minimum amount of gradient spoiling to minimize the TR and maximize temporal resolution. Further analysis of the effects of optimum gradient spoiling needs to be conducted in the presence of flowing spins using both phantom and *in vivo* measurements.

CONCLUSION – Efficient and effective artifact suppression in PC-MRI phase images required requires 4π gradient spoiling applied across the slice thickness. The use of additional gradient spoiling does not provide significantly more artifact suppression and leads to an increased TR and reduced temporal resolution.

REFERENCES – 1. Pelc et al. MRM 1991;7(4):229-254. 2. Leupold et al. MRM 2008;60(1):119-127. 3. Zur et al. MRM 1991;21(2):251-263.

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