

Improved SNR in Phase Contrast Velocimetry with 5-Point Balanced Flow Encoding

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INTRODUCTION

Phase Contrast (PC) MRI can be used for quantitative and qualitative assessment of complex hemodynamics; however a maximum measurable velocity (V_{enc}) must be set that sacrifices noise performance for dynamic range improvements. Lowering the V_{enc} can improve velocity measurements since $noise_{vel} \sim V_{enc}$ but will introduce unwanted velocity aliasing. Multi- V_{enc} techniques that utilize additional velocity encoding steps to unwrap phase aliasing can significantly improve the dynamic range for improved noise performance [1]. However, current techniques can lead to significant increases in intravoxel dephasing and scan time limiting clinical benefits [2]. In this work, we have developed a novel 5-point, three directional velocity encoding scheme that efficiently reduces noise while maintaining high velocity sensitivity with minimal increases in scan time and intravoxel dephasing.

THEORY

While traditional multi- V_{enc} approaches generally share only a single referenced encoding point between high and low V_{enc} datasets, we propose to perform multi- V_{enc} flow encoding with a standard 4-pt balanced acquisition plus one flow compensated encoding. The velocity is first estimated by determining a velocity estimate, $V_{estimate}$, from the phase differences between all 4-pt encodings with the flow compensated position. That velocity estimate can then be utilized to unwrap the phase ϕ from processing using only 4-pt data:

$$\phi_{un-aliased} = \phi + 2\pi \cdot NI \left(\frac{Av_{estimate} - \phi}{2\pi} \right)$$

where N.I. is nearest integer and A is the velocity encoding

matrix. For 5-pt encoding, the V_{enc} is thus not only defined by the bipolar gradients (i.e. first gradient moments) used for velocity encoding but by the maximum velocity that can still be unaliased for a given first moment. Conversely, for a given V_{enc} this encoding scheme allows a 62% increase in the first moment leading to 62% increase in the velocity the noise ratio (VNR). Relative to the commonly used 4-point referenced encoding this translates to a 15% increase in the first moment limiting intravoxel dephasing. Additionally, since the flow compensated flow encoding does not directly influence the final result and is not flow dependent, it can be acquired at significantly lower spatial and temporal resolution, which in standard reconstructions would bias the velocity [3].

METHODS

All MR experiments were performed on a 3 T MRI system (Magnetom TRIO; Siemens Medical). 5-point flow encoding was introduced into a time-resolved 3D spoiled gradient echo phase contrast sequence with interleaved velocity encoding and used to image pneumatically controlled rotational and translational phantoms. It was compared to standard 4-point references encoding at the same V_{enc} and 4-point balanced encoding with the same first moment magnitude. To evaluate the effectiveness of 5-point encoding in-vivo and assess acceleration of low resolution images, 2D navigator gated, CINE, aortic PC images were acquired in 3 healthy volunteers with both 4-point and 5-point sequences. Common parameters include: Resolution = 1.4 mm x 1.4 mm, FOV=360, navigator window = ± 5.0 mm, flip angle = 5° , no view sharing, readout bandwidth = 450 Hz/pixel, TR=5.10ms, $V_{enc}=150$ cm/s. 5-point exams had an insignificantly extended TE of 2.673 ms compared to the 4-point point referenced which had a TE of 2.633.

RESULTS

Figure 1 shows L/R velocity phantom images from all three velocity encoding schemes. 5-point images show the same SNR as 4-point balanced images without the aliasing. Phantom noise measurements show a noise level of 9.51 ± 1.02 cm/s for 5-point, while 4-point referenced acquisition showed a noise level of 15.56 ± 1.34 cm/s. This represents a noise improvement of 1.633 agreeing almost exactly with the theoretical ratio of 1.633. Representative velocity images from in-vivo aortic exams are shown in Figure 2. 5-point images show significant improvements in SNR compared to 4-pt encoding with the same V_{enc} . The acquisition of PC images with 4-pt encoding with the same first moments used for 5-pt encoding results in identical VNR but V_{enc} reduced by 62% (figure 2, right columns) and therefore substantial phase aliasing which was effectively removed by the phase unwrapping procedure used for 5-pt encoding. Accelerated 5-point images are shown in Figure 3, showing that a significant reduction in temporal and spatial resolution of the 5th (flow compensated) encoding point has limited effect on the final image. The full dynamic range of the 5pt method is maintained with as little a 0.1% increase in scan time compared to the standard balanced 4-pt methods.

DISCUSSION

5-point velocity encoding allows for a 62% increase in SNR for 3-directional velocity encoding with as little a 0.1% increase in scan time. Additionally, since the 1st moment magnitude is similar to 4-point referenced encoding schemes intravoxel dephasing should also be similar. Additional SNR efficiency gains may be possible with the addition of modest use of existing phase unwrapping techniques.

REFERENCES

[1]Lee *et al* MRM 33(1):122-126 [2]Pipe,J. MRM 49(3):543-50 [3]Lin *et al* ISMRM'08 p249

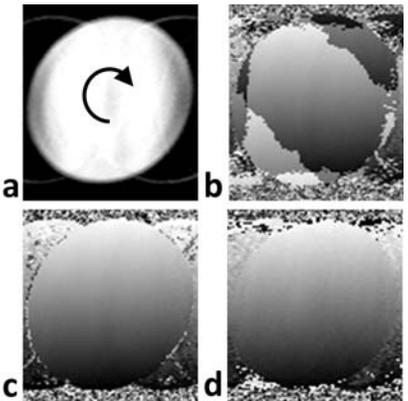


Figure 1. Magnitude image showing phantom rotation (a) and corresponding L/R velocity images from 4pt balanced (b), 5pt balanced (c), and 4pt referenced encoding (d).

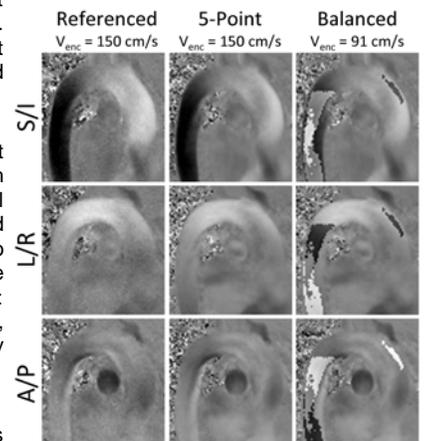


Figure 2. Source velocity images from 4-point referenced, 4-point balanced, and 5-point acquisitions

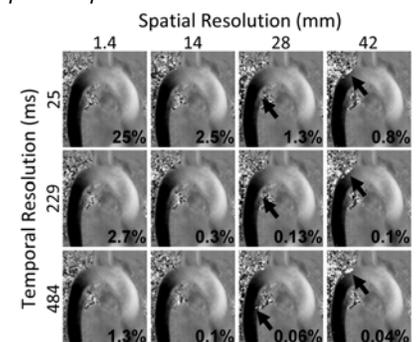


Figure 3. 5-point Velocity images with low resolution acquisition of the flow compensated, unwrapping point. Arrows point to locations of uncorrected velocity aliasing, while images are labeled with the percent increase in scan time.