A Rapid Dual VENC Scheme for Velocity-to-Noise Ratio (VNR) Optimization in Phase Contrast Magnetic Resonance Imaging

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INTRODUCTION

Velocity maps obtained using the phase contrast magnetic resonance imaging (PC-MRI) technique suffer from velocity aliasing when the velocity in the region of interest is higher than the specified velocity encoding (VENC) value of the experiment. Popular velocity unwrapping schemes adopted in clinical settings make use of two VENC acquisitions, and are dubbed dual VENC unwrapping schemes [1]. However, this velocity unwrapping schema can fail (depending on the noise level of the acquisitions) when there are multiple cycles of velocity aliasing. To overcome this setback, a multi-VENC (MV) phase overlapping approach which utilizes phase information from three or more independent VENC measurements has been proposed [2]. Such unwrapping which requires multiple acquisitions is time intensive, and motion between the acquisitions can render unwrapping more difficult making it less attractive for routine clinical use. In this work, we propose, implement and test an approach – dubbed dual VENC phase unwrapping or UDV - which utilizes dual echo PC-MRI data in which each echo is acquired with a different velocity sensitivity to unwrap velocity aliasing, without increasing scan times as is the case for MV approaches.

AIM

To test the performance of a dual VENC phase unwrapping (UDV) scheme, and compare its VNR performance against a multi-VENC (MV) method.

METHOD

- Fluid flow through a 1.59 cm inner diameter tube with mean and maximum fluid velocity of 45.7 cm/s and 66.7 cm/s respectively was measured 10 times using PC-MRI with (VENC=100 and 20 cm/s) at 3.0 T, and the images were unwrapped using the UDV scheme.
- In order to compare the UDV and MV schemes, PC-MRI measurements at VENC=100, 50, 20 and 10 cm/s were also acquired and combined using the MV scheme yielding an overlapped velocity map. The scan time of the UDV and MV acquisitions were 198 s and 396 s respectively.
- The UDV scheme was also tested on in vivo cardiac short-axis PC-MRI (VENC=150 and 20 cm/s) acquisitions containing through-plane left ventricular myocardial and blood velocities.
- VNR was calculated as the pixel wise ratio of temporal mean to standard deviation. Bland-Altman analysis was used to compare the VNRs of the DV and MV schemes.

RESULTS

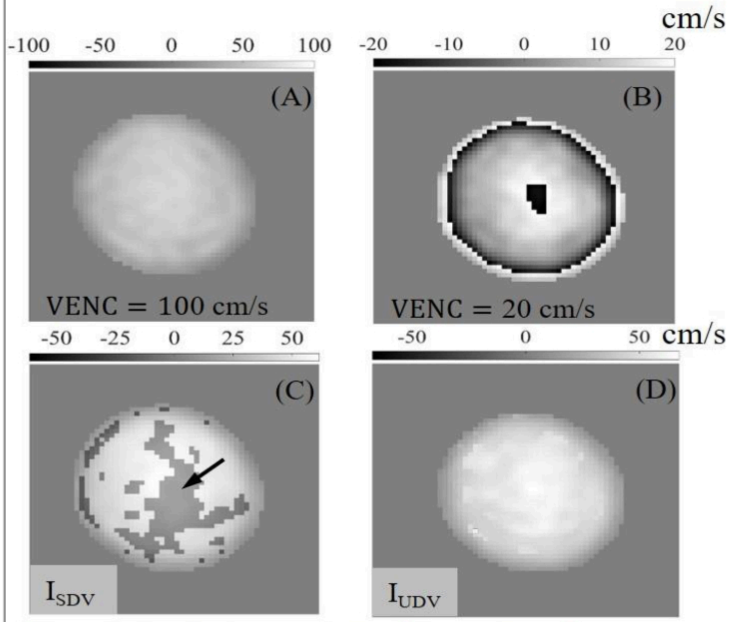
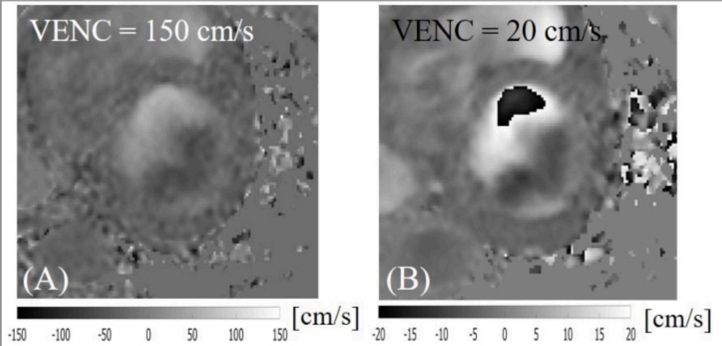


Figure 1. A velocity map obtained from a flow phantom containing velocities ranging from 5 cm/s to 80 cm/s acquired using PC-MRI at velocity encoding values (VENC) of 100 cm/s (A) and 20 cm/s (B). The velocity map in (B) is first unwrapped to produce an intermediate velocity map (I_{SDV}), which still contains some aliased pixels [black arrow] (C). The UDV algorithm then detects the aliased pixels in I_{SDV} and replaces them with the corresponding unaliased pixel from (A) to produce I_{UDV} (D).



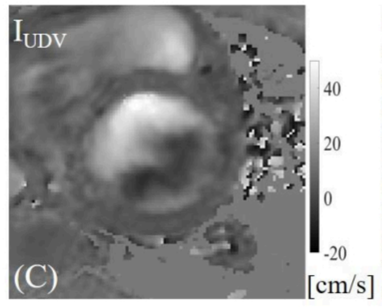
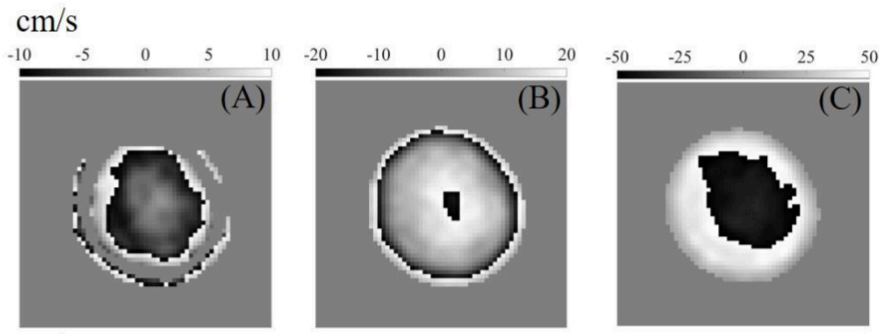


Figure 2. PC-MRI velocity maps containing left ventricular myocardial and blood velocities at a single time point in the diastolic cardiac phase using a velocity encoding value (VENC) of 150 cm/s (A) and 20 cm/s (B) respectively. The images in A and B are fed into the UDV algorithm to produce a velocity map (I_{UDV}) without velocity aliasing in the region of interest (C).



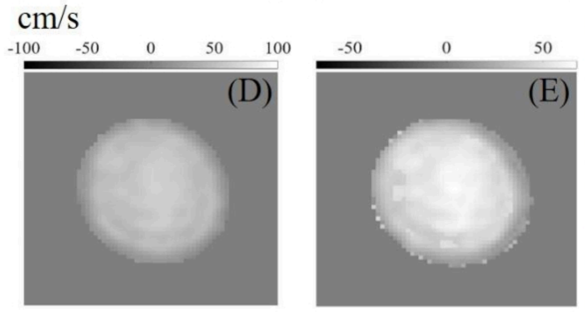


Figure 3. A velocity map obtained from a flow phantom containing velocities ranging from 5 cm/s to 80 cm/s acquired using PC-MRI at velocity encoding values of 10 cm/s (A), 20 cm/s (B), 50 cm/s (C) and 100 cm/s (D). The MV scheme uses all four acquisitions (A - D) in steps to produce an overlapped velocity map (E).

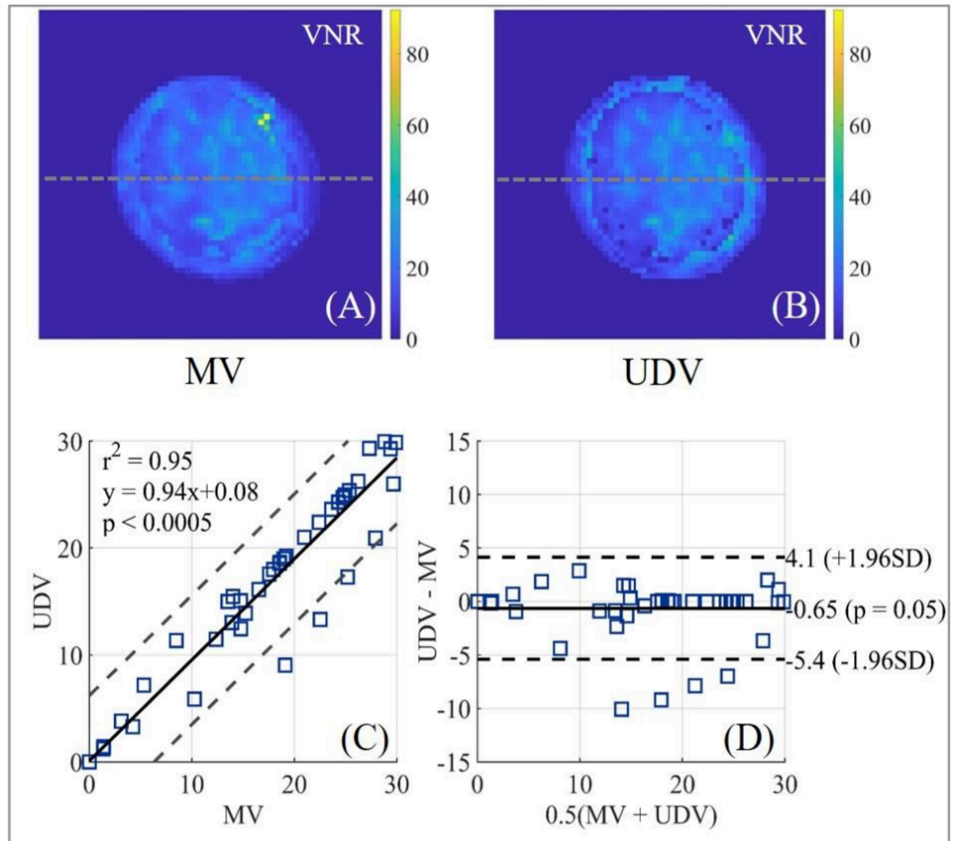


Figure 4. VNR maps obtained from the MV (A) and UDV (B) schemes show a good correlation [$p < 0.0005$ and $r^2 = 0.95$] (C) and negligible bias in Bland Altman analyses [$p = 0.05$] (D). NB: Pixels for the correlation and Bland Altman plots were obtained from the dashed lines in A and B.

CONCLUSIONS

- The UDV scheme produces fully unaliased velocity maps, and reduces the number of images (or acquisition time) needed for VNR optimization in both phantom and in vivo PC-MRI acquisitions.
- The VNR of the UDV and MV velocity maps for the flow phantom experiment were in good agreement ($p<0.0005$ and $r^2=0.95$), and showed a negligible bias ($p=0.05$). We acknowledge that the contrast in VNR between the low VENC and high VENC data is more visible for the UDV method (Figure 4, B) compared to the MV method (Figure 4, A). This contrast can be reduced by carefully choosing the low VENC value for the UDV method while optimizing the VNR of the acquisition.
- In summary, the UDV scheme is effective in unwrapping aliased pixels from a PC-MRI velocity map, and hence optimizes the VNR of the acquisition without prohibitively elongating the acquisition time of the PC-MRI experiment.

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REFERENCES

[1] Schnell S, Ansari SA, Wu C, et al. Accelerated dual-venc 4D flow MRI for neurovascular applications. J Magn Reson Imaging 2017;46(1):102-114.

[2] Ha H, Kim GB, Kweon J, et al. Multi-VENC acquisition of four-dimensional phase-contrast MRI to improve precision of velocity field measurement. Magn Reson Med 2016;75(5):1909-1919.

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