Accelerated Dual Velocity Encoded Phase Contrast VIPR

E. J. Nett[1], K. M. Johnson[1], C. J. Francois[2], D. Lum[2], and O. Wieben[1,2]
[1]Medical Physics, University of Wisconsin, Madison, Wisconsin, United States, [2]Radiology, University of Wisconsin, Madison, Wisconsin, United States

Introduction: Recently, several novel approaches for rapid MRI imaging have allowed for the acquisition of volumetric, time-resolved, phase contrast (PC) imaging with three-directional velocity encoding. One of these methods, PC vastly undersampled isotropic projection (PC VIPR) [1], a truly 3D radially undersampled acquisition, provides high resolution anatomical and velocity information in clinically feasible scan times. These data are used for the generation of MR angiograms and for comprehensive velocity and flow measurements including the derivation of additional hemodynamic parameters such as trans-stenotic pressure gradients and wall shear stress (WSS).

One challenge of 4D PC MRI is the choice of the proper velocity encoding (Venc). If chosen too low for the vessel of interest, velocity aliasing occurs. If chosen too high the velocity-to-noise ratio (VNR) suffers (VNR ~ 1/VENC). In addition, angiograms derived as complex difference images from PC MR data sets provide improved vessel details when acquired with lower Venc (see Fig. 1). This challenge can be addressed with the acquisition of two or more scans with different Venc settings [2, 3, 4]. However, this approach significantly lengthens the already long scan duration. Here we investigate a dual Venc acquisition that utilizes (1) a low Venc data set to provide a good VNR and basis for the calculation of PC angiograms and (2) a high Venc data set to address velocity aliasing. In order to minimize the scan time penalty, additional radial undersampling is utilized for the high Venc acquisition, introducing undersampling artifacts yet maintaining the spatial resolution. This study examines the effect on high Venc undersampling on the VNR of the resultant image for various high-to-low Venc ratios. The phase error is decreased as the high to low Venc ratio increases. However, the VNR gain is limited by the undersampling of the high Venc images.

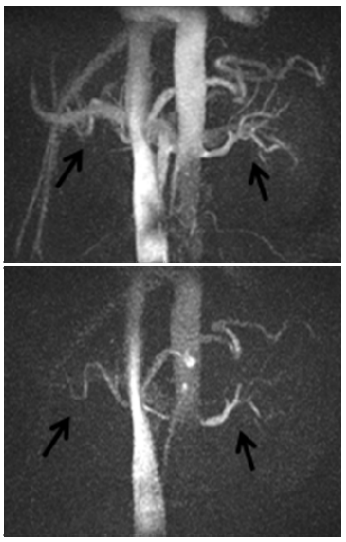

Fig 1: PC VIPR renal angiogram acquired with a low Venc of 40 cm/s (top) and a high Venc of 120 cm/s (bottom). The lower Venc image has a much higher VNR and provides more vessel detail compared to the high Venc image

Methods: PC VIPR data were acquired with a dual-echo PC VIPR trajectory with retrospective cardiac gating on a clinical 1.5T system (GE Healthcare, Waukesha, WI). Typical scan parameters were: 1.0 mm^3 isotropic spatial resolution with a scan time of approximately 5 min, imaging volume: $24x24x24cm^3$, and 10,000 projections.

In a phantom experiment consisting of a tube loop filled with blood mimicking fluid connected to a programmable MR compatible flow pump (CompuFlow 1000 MR, Shelley Medical Imaging Technologies, London, ON, CA), PC VIPR images were acquired at four different Vencs: 30 cm/s, 60 cm/s, 90 cm/s, and 120 cm/s. The pump generated a constant flow rate of 10 ml/s with a mean velocity of ~ 45 cm/s and a maximum velocity of ~ 100 cm/s in the tube. Each scan was acquired twice for a subsequent velocity-to-noise (VNR) analysis. A dual Venc image reconstruction algorithm was implemented that combined image data from a low Venc and the high Venc (120 cm/s) acquisition to correct phase wraps in the low Venc. Velocity maps were reconstructed and VNR analysis was performed using each of the three lower Venc settings as well as and with four undersampling factors (50%, 25%, 12%, and 5%) for the high Venc by using subsets of the acquired projections during reconstruction. Dual Venc cranial PC VIPR data were acquired in a healthy volunteer with Vencs of 20cm/s and 40 cm/s. The acquisition parameters were similar to those above.

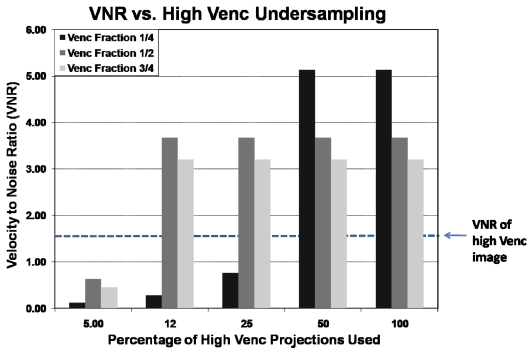

Fig 2: Comparison of VNR in a phantom of phase unwrapped PC VIPR images for different low to high Venc ratios at different high Venc undersampling percentages.

Results: Fig. 2 summarizes the result of the phantom analysis. With a high to low Venc ratio of 4 to 1, it is possible to obtain a 3x gain in VNR and an increase in VNR efficiency (VNR/time) from 1.75 to 2.56. However for accurate unwrapping, the gain requires a 50% increase in scan time. With a high to low Venc ratio of 2 to 1, a 2 fold increase in VNR can be obtained at the cost of only 12% increase in scan time. In this case, the VNR efficiency is increased to 3.28 from 1.7. Smaller Venc ratios decrease the sensitivity of the phase unwrapping to errors in high Venc caused by undersampling and noise. Figure 3 shows the in vivo results for a low Venc and a high Venc velocity image and the corrected low Venc image obtained with12% of the high Venc data. In the phase correct image, multiple small vessels are well resolved that cannot be seen in the high Venc image and the phase errors are corrected.

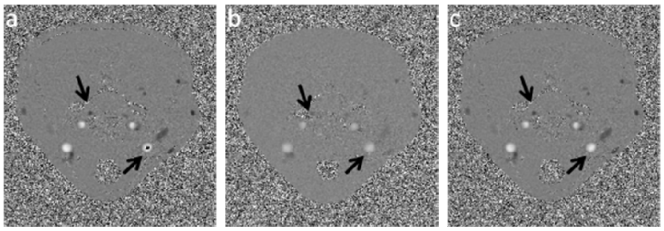

Fig 3: PC VIPR velocity images acquired with a Venc of 20 cm/s (a), a Venc of 40 cm/s (b), and phase corrected image with dual Venc reconstruction (c). In (c), velocity aliasing is removed (arrow) and a higher VNR is apparent.

Conclusions: We have presented a method for improving the VNR in phase contrast exams with a minimal increase in scan time. The phantom results demonstrate that if the high to low Venc ratio is increased, higher VNR gains can be achieved but the acceptable undersampling is reduced. A good compromise between high VNR gains and only modest increases in scan time is achieved with a high to low Venc ratio of 2:1 with a scan time increase of only 12%. This method will allow for more accurate velocity measurements, particularly in vascular areas that have wide ranges of velocities of interest including arterial and venous systems (e.g. congenital heart disease and hepatic vasculature) and advanced hemodynamic analysis (e.g. calculation of WSS). The achievable VNR gain depends on particular scan parameters and possibly the actual image contrast; therefore, dual Venc parameters will need to be tuned to specific applications. Further research is ongoing to determine the optimal parameters for *in-vivo* acquisitions in various vascular territories.

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