Average and Time-Resolved Dual Velocity Encoded Phase Contrast Vastly undersampled Isotropic Projection Imaging

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Introduction

The velocity to noise ratio (VNR) of phase contrast data is linearly proportional to the magnitude of the first moment of the bipolar applied. In general, the bipolar induced phase can only be resolved to $\pm\pi$; however, additional information or assumptions can extend that range. Dual VENC techniques, utilize a second velocity encoding to provide additional phase information which can be used to unwrap aliased pixels. These techniques would generally require a 75-100% increase in scan time [1,2], due to the extra velocity encoding; however given that the ability to unwrap the data is limited more so by intravoxel dispersion, the high VENC data set may be acquired at an accelerated rate. In the case of PC VIPR, a 3D radial under sampling method [3], additional undersampling may be implemented to reduce the acquisition time of the high VENC, thus reducing the required increase in scan time. Combining a Dual VENC approach, spatio-temporal filtering, and an efficient encoding scheme allows for high resolution 4D velocimetry with minimal phase error.

Methods

Separate time-resolved and time-averages sequences were developed with additional velocity encodes. In the time-averaged case high VENC projections were interweaved with low VENC projections sharing a single velocity encoding. This sharing allows for a 25% reduction in the acquisition time of the high VENC image in addition to gains from undersampling. In the time resolved case, high VENC projections were added, and placed at the end of a normal low VENC acquisition. This ensures that the low VENC projection sets have continuous temporal resolution and do not suffer from segmentation errors. All velocity encoding was performed using a balanced four-point encoding scheme to reduce the TE/TR.

High and Low VENC phase images were then reconstructed. In the time resolved case an adaptive temporal filter was used to reduce streak artifacts and boost the SNR of individual phases. This filter was designed independently for the high and low VENC images to ensure acceptable quality in high VENC images and maximize temporal resolution in the low VENC images. Phase correction of the low VENC images was then performed using a simple rounded difference method. Anti-aliasing filters based on divergence free assumptions were then applied to reduce correction errors. Complex difference images were then computed with a modified phase weighting function to allow for values beyond $\pm\pi$. Both basic and time resolved images were acquired at 384^3 on a 1.5 T GE Signa scanner, and compared to scans taken with a single VENC, with equivalent imaging time in both phantom models and several volunteers.

Results

Phantom results find that depending on the temporal and spatial intra voxel distribution, the high to low VENC ratio should be limited to 2 for the time averaged case and 3-4 for time resolved cases. Balanced velocity encoding gradients were shown to be superior in reducing the effects of dephasing. Equal scan time anatomical comparisons show a two fold increase in SNR as predicted, as well as enhanced vessel wall depiction (Figure 1). Volunteer velocity images show a low number of correction errors at high to low VENC fraction of 2x (Figure 2). Time resolved images are practically limited to a VENC ratio of 2, by SNR limitations.

Discussion

We have presented methods for improving the SNR/VNR in PC VIPR exams with a minimal increase in scan time and artifact. These methods were shown to be effective in correcting aliased pixels. Further work will be performed to explore to use of this method for assessing stenotic vessels, where jets often force the use of VENCs greater than 150 cm/s.

References

1. Lee *et al.* MRM 1995; 33:122 2. Pipe *et al.* Proc. MRA Club 2005 3. Gu *et al*. AJNR. 26:743-749

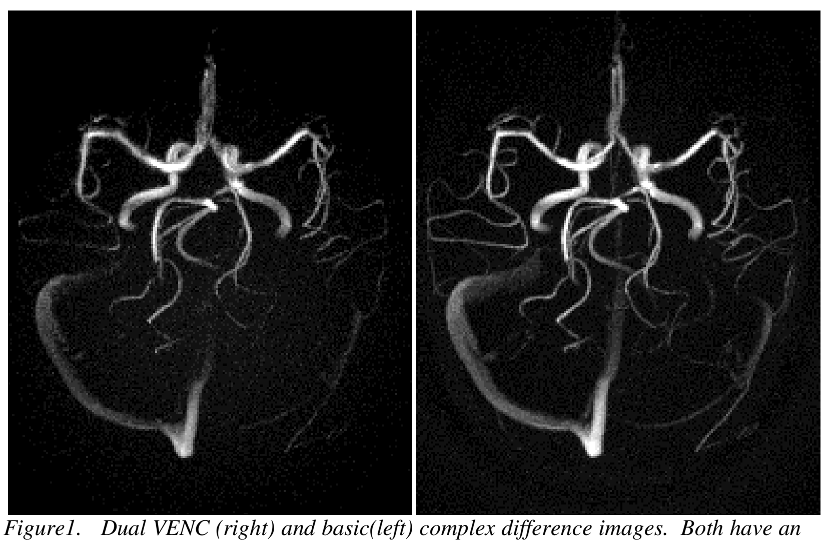

Figure1. Dual VENC (right) and basic(left) complex difference images. Both have an aliasing free velocity range of ± 80 cm/s. Images were acquired in 4 min.

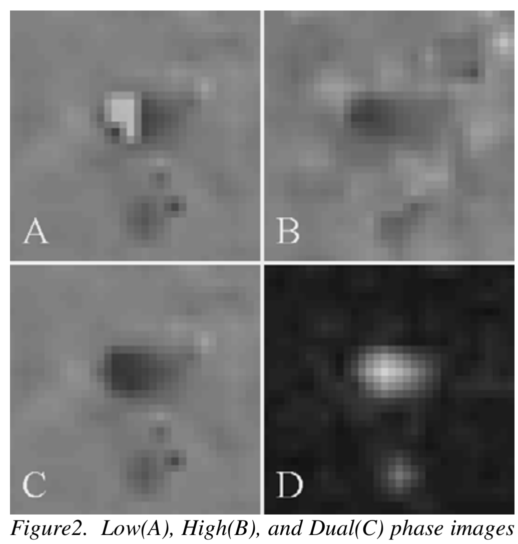

Figure2. Low(A), High(B), and Dual(C) phase images and the corrected complex difference image(D)