Highly Constrained Back Projection (HYPR) processing for Phase Contrast MRI

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Introduction: Phase contrast (PC) MR Angiography provides anatomical and functional vascular information but its clinical acceptance has suffered from long acquisition times. Among other approaches such as parallel imaging [1] and kt-BLAST [2], PC imaging with 2D [3] and 3D [4] radial trajectories has emerged as a method for accelerated imaging. In this study, we investigate further improvements in temporal resolution by incorporating HYPR (**H**igh**Y** constrained back**PR**ojection) processing [5].

Methods: The HYPR technique achieves high temporal resolution by severe angular undersampling with an interleaved 2D or 3D radial trajectory [5]. A composite image reconstructed from the projections in multiple or all time frames is used to spatially constrain the signal backprojected from each individual time frame, which reduces streak artifacts and improves the SNR. The concept has been successfully used in CE-MRA and other temporally resolved applications. Radial PC acquisitions are well suited for HYPR processing as they are inherently sparse due to the subtraction of static background tissue. For the generation of complex difference images from PC data sets, which can be processed as magnitude images, HYPR processing is straightforward. This concept was demonstrated in a cranial PC HYPR VIPR acquisition of a volunteer on a clinical 3 T system (GE Healthcare, Waukesha, WI). The scan parameters were: fractional echo with 288 sample points, reconstructed volume = 384x384x384 voxels, FOV = 24x24x24cm^3, scan time = 4 min, 5000 projections, TR/TE = 12.5/4.8 ms, 18 cardiac phases (50 ms each). However, proper quantitative reconstruction poses the additional challenge of phase information preservation. The reconstruction chain cannot be simply separated into a real and an imaginary channel due to potential signal ambiguities. For example, a composite image reconstructed from a single vessel undergoing a sinusoidal flow waveform throughout the cardiac cycle can lead to complete signal cancellation for that vessel. We have developed an algorithm for PC HYPR processing which is illustrated in Fig. 1. In this diagram, the projection pairs are described as P_{up} and P_{down} for the two configurations of the bipolar gradients. The scheme requires the calculation of magnitude images from the 2 sets of projections and the magnitude of the complex difference image. As illustrated in Fig. 1 b, the desired parameter, flow induced phase ϕ_F, is obtained from the law of cosines:

$$\cos(\phi_F) = \frac{|\vec{F}_{up}|^2 + |\vec{F}_{down}|^2 - |\vec{CD}|^2}{2 \times |\vec{F}_{up}| \times |\vec{F}_{down}|}$$

The sign ambiguity of ϕ_F is resolved by the incorporation of a phase map obtained from the two sets of projections. The algorithm for quantitative PC HYPR processing was evaluated on numerical phantoms.

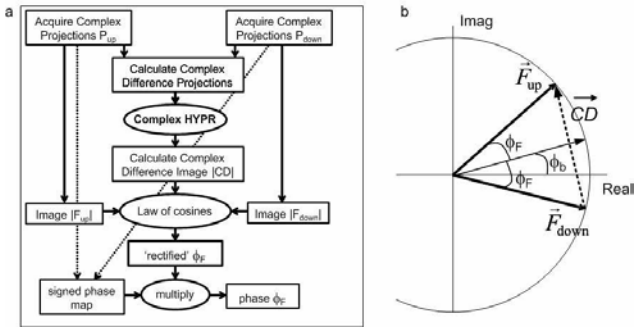

Fig. 1: *Block diagram (a) and vector diagram (b) for phase contrast HYPR processing.*

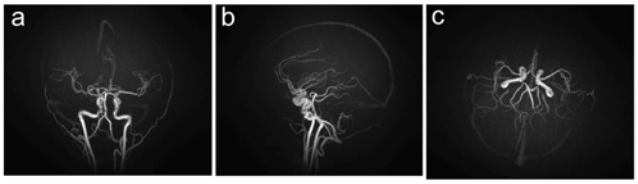

Fig. 2: *PC HYPR VIPR cine reconstruction with undersampling factor of 928 displayed as coronal (a), sagittal (b), and axial (a) MIP images from peak systole.*

Results: In-vivo results from the cranial exam with a radial undersampling factor of 928 are shown in Fig. 2. An equivalent acquisition of 384 slices over 18 cardiac phases would have required 39 hours of scan time with a full Cartesian acquisition. The example in Fig. 3 illustrates results from a numerical phantom synthesized of 4 vessels with different signal evolutions (solid lines) in the cardiac cycle. Projections were calculated with 256 readout samples divided into 20 interleaves with 40 projections per interleave. This corresponds to an undersampling factor of 10 relative to a fully sampled radial acquisition and a factor of 6.4 relative to a Cartesian scan. The waveforms obtained from PC HYPR processing (dashed) match well with the original waveforms with the largest deviations at the beginning and end of the cardiac cycle for the non-cyclic waveforms III and IV.

Conclusion: Our preliminary results showed that complex difference images with high undersampling factors could be achieved with HYPR processing. A modified algorithm also allowed for phase sensitive reconstruction of projection data. The simulation results suggest that quantitative PC flow imaging can be accomplished with HYPR processing to obtain faster sampling rates within the cardiac cycle or reductions in scan time. We are currently implementing the 2D and 3D phase sensitive processing for in vivo studies and will validate the waveform fidelity in phantoms and in-vivo to determine suitable protocols for various vascular regions.

Acknowledgements: This research was supported by the NIH (1R01HL72260-01). We gratefully acknowledge GE Healthcare for their assistance and support.

References: [1] P. Thunberg, et al, MRM, 50: 1061-8, 2003 [2] C Baltes et al, MRM 54:1430-8, 2005 [3] A. Barger et al, MRM 43:503-9, 2000 [4] T. Gu et al., ASNR 26:743-9, 2005 [5] C Mistretta et al., MRM 55:30-40, 2006

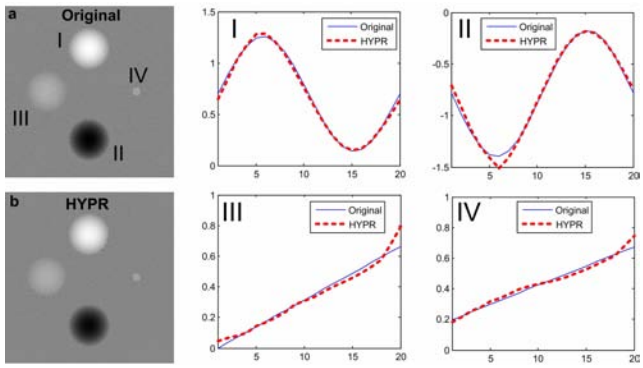

Fig. 3: *Numerical phantom with four circular objects representing vessels with through-plane flow (I-IV) at time frame 8 (a) and the corresponding HYPR frame (b) and their waveforms from an ROI analysis in the four regions.*