An Application of Highly Constrained Backprojection (HYPR) to Time-Resolved VIPR Acquisition

J. V. Velikina[1], C. A. Mistretta[1], K. M. Johnson[1], O. Wieben[1]

[1]Medical Physics, University of Wisconsin - Madison, Madison, WI, United States

INTRODUCTION

In many MR applications it is desirable to have high spatial and high temporal resolution. Among other approaches, radial acquisitions have been proposed for accelerated sampling schemes. 3D MR angiography acquisitions using radial sampling in two dimensions and phase encoding in the third dimension [1, 2] allow undersampling factors up to 6 relative to that required by the Nyquist theorem. When radial sampling is extended by distributing the projections over a sphere in 3D as in VIPR [3], undersampling factors up to 50 can be achieved without sacrificing image quality. Nevertheless, some applications, such as 3D flow encoding for pressure mapping in small vessels [4], would benefit from further accelerations in acquisition speed. Recently proposed techniques, such as k-t Blast [5, 6] and interleaved biplane projections [7], rely on *k*-space data correlation and use training datasets to guide iterative reconstructions in order to improve acquisition speed for time-resolved series. Most recently, HighlY constrained backPRojection method (HYPR) has been introduced [8]. HYPR is a non-iterative, unfiltered, constrained backprojection reconstruction in which individual time frames are obtained by limiting the backprojected information to voxels defined to be vessels in the composite image generated from all acquired projections. Here, we present HYPR VIPR, an application of the new technique to 3D radial sampling scheme.

THEORY AND METHODS

The data for HYPR VIPR is acquired in the form of time frames containing interleaved isotropically distributed k-space radial projections. All of the acquired data are combined to obtain a composite image *C*, either by filtered backprojection (FBP) or by regridding followed by inverse Fourier transform. Then an image space profile *P* of each projection (obtained by 1D inverse Fourier transform from the *k*-space projection) is backprojected into its Radon plane. The weights in the backprojection are proportional to the intensities of the cross-section of the composite image by the corresponding Radon plane. The contributions from all projections in the time frame are averaged. The reconstruction formula is

$$H(x,y,z)=\frac{1}{N_{pr}}\sum_{R(x,y,z)} P(r,\theta,\phi)C(x,y,z)/P_C(r,\theta,\phi),$$

where $P(r,\theta,\phi)$ and $P_C(r,\theta,\phi)$ are the Radon projection values of the time frame and composite images for the plane (r,θ,ϕ), N_{pr} is the number of projections in the time frame, and the sum is taken over the set *R(x,y,z)* of all Radon planes that contain the point *(x,y,z)*. While all terms in the reconstruction formula can contribute to the stochastic noise in the HYPR image, it was shown in [8] that the SNR of each time frame is dominated by that of the composite image. Hence, fewer projections can be acquired in each time frame without SNR loss as long as the total number of projections is large enough.

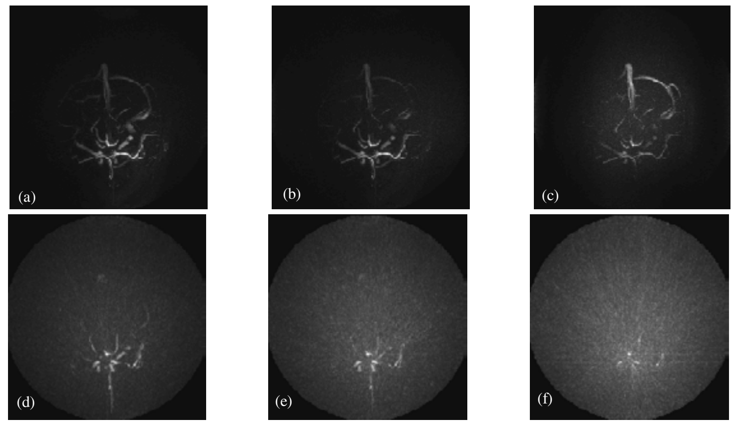

Figure 1. Time frame reconstructed using HYPR (a-c) with (a) 972, (b) 486, (c) 162 projections per time frame. (d-f) FBP reconstruction from (d) 972, (e) 486, (f) 162 projections.

RESULTS AND DISCUSSION

We tested the HYPR VIPR algorithm on a time-resolved PC VIPR acquisition. The time series consisted of 18 frames of 256x256x256 images. According to the Nyquist criterion, fully sampled *k*-space for one such image would require 100,000 projections. During a ten minute scan, we acquired the total of 17496 projections with 192 samples per projection in order to reconstruct relatively artifact-free time series using traditional VIPR technique of applying the tornado filter and regridding [3]. The *k*-space projections were then undersampled and the time series was reconstructed using the HYPR algorithm from 972, 486, and 162 projections per time frame. No tornado or other temporal filter was used in the HYPR reconstruction. Figure 1(a-c) demonstrates the MIPs of the first time frame HYPR reconstruction, while Figure 1 (d-e) contains MIPs of the same time frame reconstructed using FBP. Table 1 lists the following parameters of the reconstruction experiments: number of projections per time frame, undersampling factor relative to the Nyquist criterion, and SNR relative to the fully sampled VIPR reconstruction. As predicted by the SNR equation [8], the HYPR time frames have large SNR compared with the conventional FBP reconstruction for the same number of projections. This SNR increase is due to the fact that the composite mask assists in the reconstruction of individual time frames permitting a significant departure from the square root of acquisition time SNR dependence.

	HYPR reconstruction			FBP reconstruction		
Number of projections	972	486	162	972	486	162
Undersampling factor	100	200	500	100	200	500
Relative SNR	.93	.47	.27	.24	.17	.13

Table 1. Comparison of HYPR and FBP parameters

CONCLUSIONS

The HYPR method can be used to increase the SNR of time frames or to reduce scan time and increase the number of time frames for fixed SNR and artifact level. In the case of 3D VIPR acquisitions, application of HYPR allows achieving acceleration factors on the order of up to 600.

REFERENCES

1. Peters DC *et al., MRM* 2000; **43**: 91-101.
2. Vigen KK *et al., MRM* 2000; **43**: 170-176.
3. Barger AV *et al., MRM* 2002; **48**: 297-305.
4. Johnson K *et al., ISMRM* 2005, Miami, FL, Abstract 598.
5. Tsao J *et al., MRM* 2003; **50**: 1031-43.
6. Hansen MS *et al., ISMRM* 2005, Miami, FL, Abstract 684.
7. Huang Y *et al., ISMRM* 2005, Miami, FL, Abstract 1707.
8. Mistretta CA *et al., MRM,* to appear.