Time-Resolved MR Angiography with Limited Projections

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Introduction

Highly constrained backprojection (HYPR) was developed for time-resolved MRI [1]. It incorporates a composite image as the prior knowledge of the object, and thus significantly leverages the undersampling factor and improves the signal-to-noise ratio (SNR) of temporal images. However, the reliability of HYPR reconstruction relies on the uniformity of signal dynamics. Under non-uniform dynamics, certain data sparsity is required to reduce reconstruction artifacts. A better understanding of the advantages and potential limitations of the HYPR algorithm is needed as part of the development of this new technique. In this study, computer simulations were performed to investigate signal modulations under differences in data sparsity and temporal dynamics reflecting dynamic contrast-enhanced MR angiography. *In vivo* studies were also performed with Gd-DTPA for abdominal MR angiography in a canine model to demonstrate the application of HYPR for 3D time-resolved MRA.

Methods

The original HYPR algorithm was slightly modified to $\text{HYPR image}(x,y,z) = C(x,y,z) * \left[\sum P(r,\theta,\phi) / \sum P_c(r,\theta,\phi)\right]$, where $C(x,y,z)$ is the time-averaged composite image, $\sum P(r,\theta,\phi)$ is the unfiltered backprojection of the limited raw projections, and $\sum P_c(r,\theta,\phi)$ is the unfiltered backprojection of the corresponding projections calculated from the composite image. The modification reduces sensitivity to near-zero values in the denominator of the original algorithm, thus avoiding the thresholding process. On the other hand, the modified algorithm requires two unfiltered backprojections, compared to only one in the original algorithm. This lengthens the reconstruction time. Beyond these technical details, the two algorithms behave similarly. Therefore, the results of this study also apply to the original algorithm.

Simulations varied the size of structures representing arterial and venous cross-sections, the distance between vessels, and the temporal contrast enhancement profiles. The effect on the number of projections per HYPR time-frame under various conditions was also examined. A stenosis model was developed to investigate the artifactual impact on stenosis detection. Two 3D contrast-enhanced studies were performed with Gd-DTPA for abdominal MR angiography in a canine model. Sixty-four 2D projections at different angles were acquired during contrast passage to fill the full 3D k-space. The projection angle was rotated by manipulating the logical axes of a 2D fast spoiled gradient echo sequence with the following parameters: FOV=25x25cm, 256x256 matrix, slice thickness=250mm, TR=3.9ms, flip angle=20°, BW 125KHz, temporal resolution ~1 sec/projection. The angles of the 64 projections were chosen in a bit-reversed order to more evenly cover the k-space over time (2). Eight projections were grouped for HYPR reconstruction which gave a temporal resolution of 8 secs per 3D data set. Sliding-window reconstruction was applied to interpolate the temporal resolution to 2 secs.

Results

HYPR reconstruction of a sparse model (Fig.1 a-e) and a dense model (Fig.1 f-j) are shown to illustrate the process of reconstruction and the cause of artifacts under different situations. The temporal profiles of arterial and venous signals of the two models are shown below for comparison. When contrast dynamics vary over space, large vessels (e.g. veins) tend to introduce more signal interference to small vessels (e.g. arteries) in HYPR, particularly when the vessels are in close proximity. Using more projections per time point reduces cross-talk of adjacent vessels while increasing temporal blur. In any case, the reconstruction artifacts are manifest as intensity modulations rather than structural interference, and therefore have little impact on structural diagnosis. This was also verified by the simulation with the stenosis model. In vivo, “true” temporal resolution of 8 secs is achieved in the 3D MRA study with 1 mm isotropic spatial resolution over a 25 cm FOV (Fig.2). With sliding-window reconstruction every 2 secs, the first-pass arterial and venous enhancements are clearly separated in 3D. The SNRs of the temporal data sets are similar to the composite data set acquired over 64 secs.

Discussions and Conclusion

In our *in-vivo* studies, the cross-talk between arterial and venous signals does not have a major impact on the separation of arterial and venous enhancements during the first pass. However, we found the enhancement of the background tissue signals significantly increases the vascular signals in the steady state in HYPR images. This is due to the much larger volume of background tissues relative to the vessels. Therefore, more projections should be used in HYPR reconstruction of the steady state images to reduce the cross-talk from tissues.

In conclusion, the reliability of HYPR reconstruction depends on data sparsity and/or uniformity of temporal dynamics. In contrast-enhanced MRA, data sparsity and signal uniformity are in general satisfied to produce HYPR-reconstructed images with limited artifacts. An attractive feature of HYPR is that SNR is not sacrificed by improved temporal resolution. Therefore, HYPR reconstruction has potential to greatly improve time-resolved MRA in clinical practice.

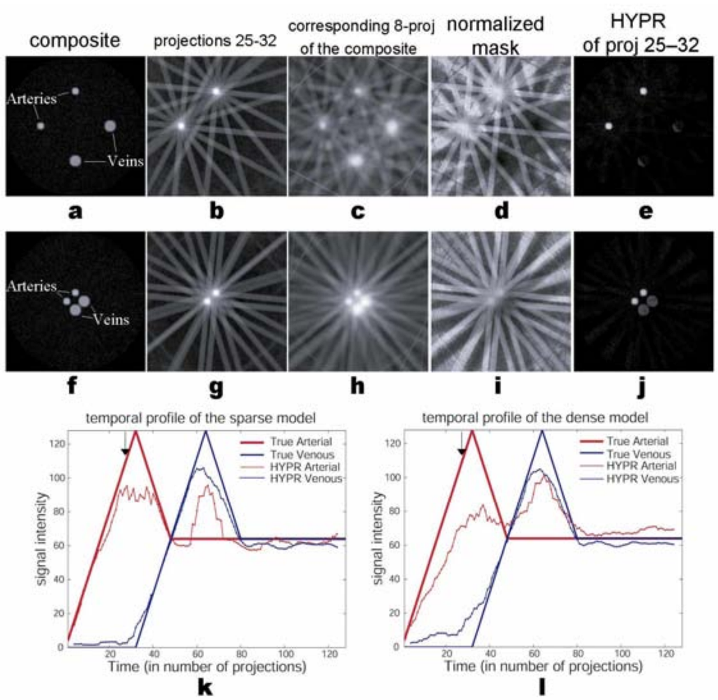

Figure 1. Simulation of HYPR reconstruction of a sparse vascular model (a-e) and a dense model (f-j). The modulation of temporal profiles of the two models are shown in k and l for comparison. The HYPR images correspond to the time frame indicated by the arrows in the temporal profiles.

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References

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2. Spielman, DM et al. MRM 1995;34:388-394.

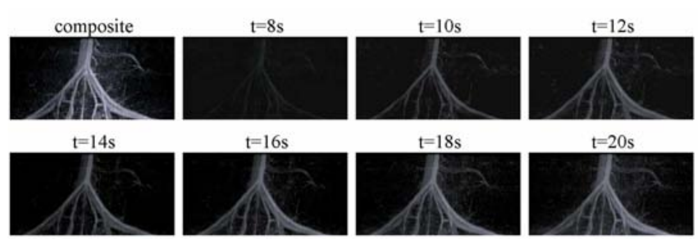

Figure 2. 3D contrast-enhanced MRA study in a canine model. Two-sec temporal resolution is achieved by 8-projection HYPR with sliding window reconstruction. The SNRs of the 2-sec 3D data sets are comparable to the composite data set acquired in 64 secs.