Accelerated 3D Time-Resolved MR Angiography using Cartesian HYPR LR Reconstruction

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INTRODUCTION

In many MR applications, it is desirable to achieve high spatial and temporal resolution at the same time, such as contrast-enhanced MR angiography (CE-MRA). However, fully-sampled Cartesian acquisition for large matrices is extremely time consuming and precludes the simultaneous achievement of both goals. Several Cartesian undersampling methods, such as CAPR [1], TRIPPS [2] and variable density random sampling [3], combined with view-sharing, parallel imaging, compressed sensing [3] or other reconstruction techniques [4], have been reported to address this problem. Recently, Highly constrained backPRojection (HYPR) [5] and HYPR with Local Reconstruction (HYPR LR) [6] have been shown to achieve high spatial and temporal resolution as well as high SNR using radial acquisition patterns. Here we present a general reconstruction method that fits most Cartesian undersampling schemes and its implementation is straight forward.

MATERIALS AND METHODS

The proposed method is a Cartesian-based reconstruction method under the HYPR LR framework. Although it is applicable to most Cartesian undersampling techniques mentioned above, here we use TRIPPS acquisition to illustrate its implementation, as shown in Fig. 1. In the TRIPPS approach, the center of the ky-kz plane is fully sampled and points along zig-zag radial lines extend into the outer region, undersampling each time frame. A composite image is generated by summing the k-space data of all or a subset of the time frames, averaging if points are sampled in more than one time frame, and performing a 3D fast Fourier transform (FFT), i.e. $I_C = FT^{-1}(K_C)$. A weighting image is produced for each time frame by calculating the ratio of a blurred time frame (B_t) to a blurred re-sampled composite image (B_c). Because each time frame is more densely sampled in the center, zero filling produces the blurring and no further filtering is required, i.e. $B_t = FT^{-1}(K_t)$. B_C is produced by resampling K_C at the same Cartesian points as K_t followed by zero-filling 3D FFT, i.e. $B_C = FT^{-1}(K_C \cdot S_t)$, where S_t is a binary matrix representing the sampling pattern of K_t. The final HYPR image can then be expressed the same way as HYPR LR with radial sampling, i.e. $I_H = I_C \cdot I_W = I_C \cdot \frac{B_t}{B_C}$. In the case of the Cartesian scheme, the formula can be significantly simplified as Eq. 1.

$$I_H = FT^{-1}(K_C)\cdot\frac{FT^{-1}(K_t)}{FT^{-1}(K_C \cdot S_t)} \qquad (1)$$

The proposed method was applied in a 3D time-resolved CE MRA volunteer head study at 3T. Imaging parameters included a matrix size of 384 (freq) × 326 (phase) × 64 (slice) over an FOV of 22.0 (S/I) × 18.7 (A/P) × 6.4 (R/L) cm^3 for a native resolution of 0.57mm× 0.57mm× 1.0mm, 75% of fractional echo readout. BW = ±125 kHz, TE/TR = 1.4/3.8ms. 36 time frames, resolved at 2.2 seconds, were acquired over 80 seconds total. Each time frame was undersampled by a factor of 36. After reconstruction, the slice selection direction was interpolated to the same resolution as the in-plane for display.

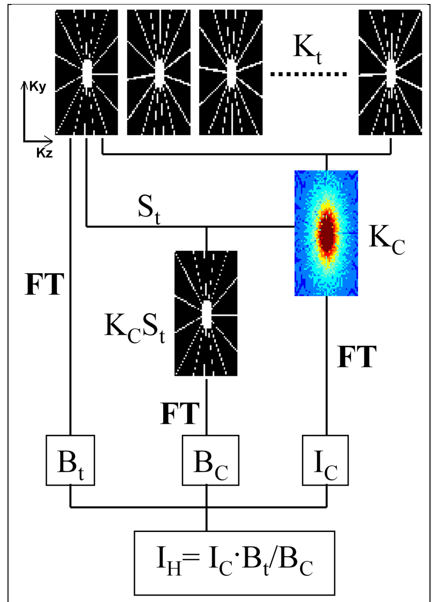

Fig. 1. Diagram of Cartesian HYPR LR. The K_t patterns specifically relate to TRIPPS method, but it should be interpreted as a generic Cartesian undersampling scheme. The color map of K_C indicates how often the k-space points are sampled (red means more sampling).

RESULTS AND DISCUSSION

Fig. 2 shows the results from the CE-MRA volunteer study. Saggital, coronal and axial views show excellent SNR with high resolution in all three dimensions. Even with the high undersampling factor, no apparent artifacts are present in the Cartesian HYPR LR reconstructed images.

While Eq. 1 represents the simplest case of the proposed Cartesian HYPR LR, it can be easily extended in the following two ways. First, a user-defined filter F can be introduced to further achieve customized low-pass filtering properties, such as including only the center fully sampled region to form the image B_t and B_C. Second, if the composite image is still significantly undersampled, Kc could be weighted to correct for reduced sampling density in the periphery prior to performing the 3D FFT. In all, a more general form of Eq. 1 can be written as

$$I_H = FT^{-1}(K_C \cdot W_C)\cdot\frac{FT^{-1}(K_t \cdot F)}{FT^{-1}(K_C \cdot S_t \cdot F)}$$

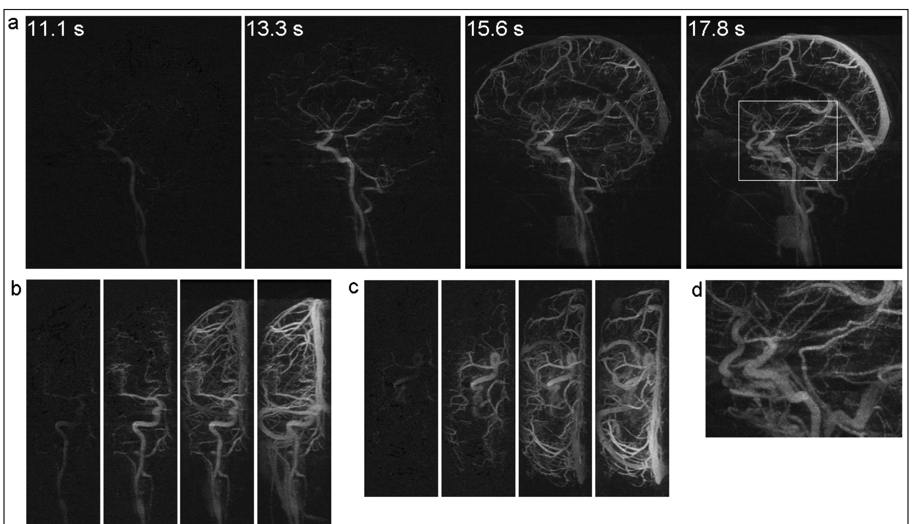

Fig. 2. Three view results from 3D time-resolved CE MRA volunteer study. (a) Saggital; (b) Coronal; (c) Axial; (d) zoomed-in sagittal image. Slice select direction was interpolated to the same resolution as the in-plane.

CONCLUSIONS

The proposed Cartesian HYPR LR method has been shown to have great potential for 3D time-resolved Cartesian undersampling sequences. It can achieve high spatial and temporal resolution while keeping high SNR. It can also be combined with a parallel imaging technique with great simplicity and another acceleration factor of 2 or 4 can be expected [1] for better temporal resolution. Future work will include applying this method to CE MRA of the lower extremities CE-MRA, where Cartesian sampling techniques match the shape of the anatomical structure better than radial sampling approaches.

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