Vastly undersampled Isotropic Projection Reconstruction and HYPR for Time Resolved CE-MRA of the Peripheral Vessels

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Introduction

Vastly undersampled Isotropic Projection Reconstruction (VIPR) [1] techniques have been successfully utilized for time-resolved contrast-enhanced MR angiography (CE-MRA) studies. There are several benefits of a VIPR k-space trajectory, including the more benign nature of undersampling artifacts, which can facilitate higher undersampling factors. Due to the geometry of the legs, however, and the fact that the A/P extent of the image object is much smaller than the S/I or L/R extents, it has previously been thought that other k-space trajectories are more valuable for such an application. In this work we apply the VIPR k-space trajectory to peripheral run-off studies and apply HYPR LR [2] reconstruction to obtain images with isotropic spatial resolution and temporal resolution superior to those obtained by conventional time-resolved methods and other k-space trajectories.

Materials and Methods

Mathematically, the HYPR LR reconstruction algorithm can be represented as:

$$I_H(t) = I_C \cdot W_t = I_C \cdot \frac{F \otimes I_t}{F \otimes I_C^t} \quad , \qquad \text{(Eq 1)}$$

where the final time frame image, $I_H(t)$, is calculated by multiplying a well-sampled composite image, I_C, by a vastly undersampled weighting image, W_t. The weighting image is the quotient of the undersampled time frame, I_t, blurred by a kernel, F, and the reprojected composite image, I_C^t, blurred by the same kernel. In this application, the blurring kernel was designed with the specific geometry of the vascular anatomy in mind. The HYPR LR blurring kernel was 2x2 pixels in the A/P and L/R directions and 5 pixels in the S/I direction.

Data from eight healthy volunteers were acquired using the above technique on a 3T MR750 scanner (GE Healthcare, Waukesha, WI). Four of the exams were conducted using a 32-channel torso coil, while the remaining 4 exams were conducted using an 8-channel torso coil. The 32-channel coil has the added advantage of an inherent PILS effect, wherein images produced by each of the coil elements are less affected by artifact and noise signal originating from outside the element's sensitive region [3]. Volunteers were intravenously administered a gadolinium-based contrast agent (MultiHance, Bracco Diagnostics Inc, USA) at a rate of 3 ml/sec. The contrast volume per injection did not exceed 0.1 mmol/kg. Scan parameters were varied on a volunteer-by-volunteer basis. Matrix sizes of 480 x 480 x 480 or 512 x 512 x 512 were acquired over an isotropic field of view of 480 mm. This leads to isotropic spatial resolution of 1mm and 0.9375 mm, respectively. TRs varied from 4.2 ms to 4.9 ms based on resolution, resulting in temporal resolutions of 4.2 seconds to 4.9 seconds.

Results

Figure 1 shows the results of a run-off study performed on a healthy volunteer with the 32-channel torso coil (not corrected for gradient non-linearity and cropped to a rectangular FOV). A matrix size of 480^3 was reconstructed using 1,000 projections per undersampled time frame, corresponding to an acceleration factor of 230 and a temporal resolution of 4.2 seconds. The composite image contained 45,000 projections. Contrast dynamics are depicted with high fidelity. Contrast filling of the major arteries as well as small muscular perforators in the upper calf can easily be seen.

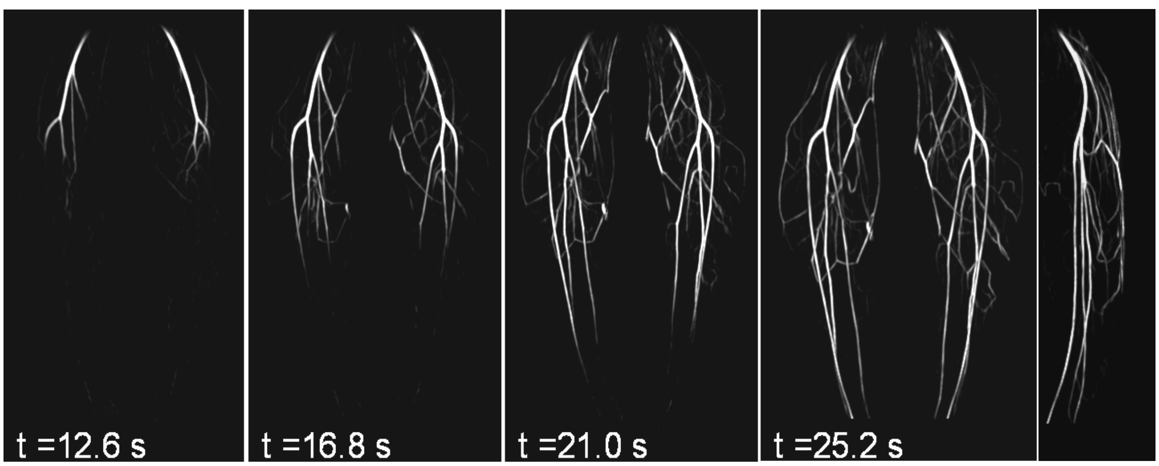

Figure 1: Coronal MIPs of four consecutive time frames and sagittal MIP of a single leg at t = 25.2 seconds. Spatial resolution: 1mm isotropic. Temporal resolution: 4.2 seconds.

Discussion

When applied to peripheral run-off studies, the VIPR acquisition technique has certain advantages over other trajectories. First, VIPR naturally acquires isotropic spatial resolution, due to the 3D radial sampling trajectory. Hybrid PR trajectories can achieve in-plane resolution similar to that shown in this work, but the through plane resolution is either substantially lower, or scan time is substantially greater. Second, the benign nature of the undersampling artifacts associated with VIPR trajectories leads to the ability to undersample individual time frames more aggressively. Previously, undersampling factors of 50 have been reported for peripheral studies using a stack-of-stars technique [4]. This work exhibits acceleration factors of 230 and higher. Third, data acquired using the VIPR trajectory are well-suited for HYPR LR processing. Previous work has shown advantages of the HYPR LR reconstruction algorithm over the original HYPR algorithm, demonstrating improved image quality and higher waveform fidelity [5]. The success of the HYPR LR algorithm relies on the ability of the blurring kernel to mitigate undersampling artifacts. HYPR weighting images produced using undersampled hybrid PR acquisitions of the peripheral vessels may suffer from severe streak artifacts. This is especially problematic when an unmitigated streak in a weighting image lies along the length of a long, contrast-filled vessel in the composite image. Undersampling artifacts from a VIPR acquisition resemble noise more than structured, high intensity streaks, and are more adequately diminished by the HYPR LR blurring kernel. We also are exploring the use of alternate reconstruction techniques to further improve image quality and temporal waveform fidelity. We believe there are many promising benefits of the combination of a VIPR k-space trajectory and HYPR image processing for time-resolved imaging of the peripheral vessels.

References

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