3D Time-Resolved Contrast-Enhanced MRA with Sliding Subtraction

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Introduction

Multi-phase angiography is necessary for the diagnosis of vascular disorders involving arteriovenous shunting, retrograde flow, and collateral circulation. Physicians typically employ X-ray digital subtraction angiography (DSA) to study the dynamic filling of vessels; however this technique is expensive, time-consuming, and invasive. A noninvasive technique would be preferable, yet other modalities currently cannot achieve adequate signal-to-noise ratio (SNR), spatial resolution, and temporal resolution. We present a MRA technique that could serve as an alternate to X-ray DSA in certain clinical scenarios.

Time-resolved MRA has evolved considerably in recent years due to advances in scanner hardware and software. Much research has focused on the use of undersampling strategies to trade off SNR for spatial and temporal resolution (1-3). However, the primary goal of time-resolved MRA lately has been to acquire an arterial phase image without the need for timing the arrival of contrast. This technique goes one step further by imaging with fast enough temporal resolution to make the change between consecutive images imperceptible.

Materials and Methods

Images were acquired from healthy volunteers on a 1.5 T whole body MR scanner (Avanto, Siemens Medical Solutions, Erlangen, Germany) with an 18-channel head/neck coil array. A 3D multi-phase FLASH pulse sequence with a radial *k*-space trajectory (cylindrical sampling) was used to acquire a lateral view of the intracranial vasculature in one hemisphere, including the sagittal sinus (FOV: 220 × 220 × 75 mm, image matrix: 192 × 192 × 30, spatial resolution: 1.1 × 1.1 × 2.5 mm, 10 phases, true temporal resolution: 3.5 s/frame, TR/TE: 2.4/0.9 ms, receiver bandwidth: 1000 Hz/pixel, flip angle: 25º, angular undersampling factor (views:read-out points ratio) = 50%, read-out/through-plane partial Fourier factors = 75%/75%, through-plane GRAPPA (4) acceleration factor/reference lines: 2/8, ordering interleaved in-plane inside centric through-plane). A single dose of a gadolinium-based contrast agent (Magnevist, Berlex, Wayne, NJ) was administered with a power injector in an antecubital vein at an injection rate of 4.0 ml/s, starting simultaneously with the imaging protocol.

Images were reconstructed offline with a complete reconstruction engine written in MATLAB (MathWorks, Natick, MA) with memory and speed optimizations. First, the apparent temporal resolution was reduced to 0.3 s/frame (10× upsampling) by creating new time frames with the sliding window method (5). Next, a "sliding subtraction" was performed in which the subtraction mask for each frame consisted of the frame 3.5 s (duration of a single full acquisition) prior. Since vessel signal is assumed to be a monotonically increasing function with time before recirculation, negatives values in the subtraction images would indicate noise or recirculation, and were consequently set to zero. Then, maximum intensity projections (MIPs) were generated. Finally, windowing parameters are dynamically adjusted to display each frame optimally.

Results

Figure 1 shows a typical time series of sagittal subtracted MIPs of the intracranial vasculature. In-plane spatial resolution is 1.1 mm, and frames are separated by 0.6 s although the temporal resolution could be set even faster. Note that there is little residual enhancement in the vessels due to the sliding subtraction, which provides artery-vein separation. Since the acquisition is also 3D, each time frame may be reformatted to better resolve through-plane spatial relationships of vessels.

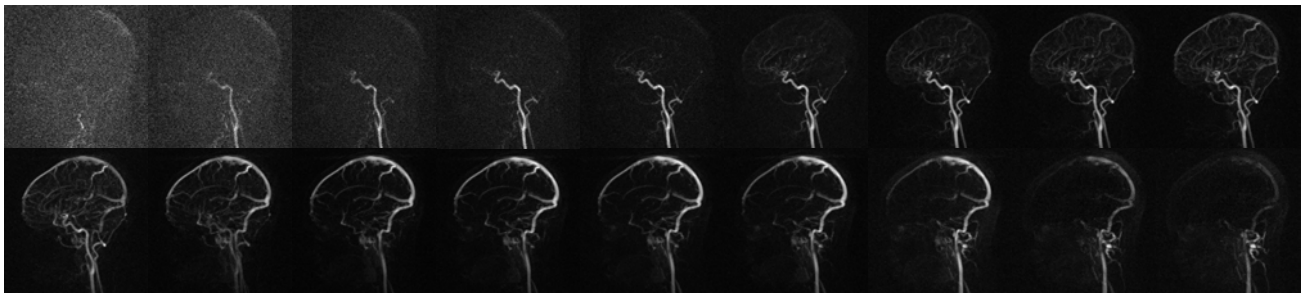

Figure 1

Discussion

This technique builds on a similar, previously reported technique (6) with an even faster frame rate and a novel subtraction method that simulates the narrow bolus of X-ray DSA exams. Although the spatial resolution does not match that of X-ray DSA, for many clinical situations 1.1 mm in-plane resolution, with the option for 3D reformatting, is sufficient. The noninvasive nature and very high temporal resolution of this technique make it attractive as an alternative or adjunct to X-ray.

The sliding window reconstruction does not produce truly uncorrelated time frames, but these frames aren't simply interpolations either. The radial trajectory ensures that low spatial frequency data is acquired with each read-out so that vessels enhance uniformly; with a Cartesian sliding window approach, vessels can appear high-pass filtered as they enhance. A 3D acquisition is necessary to fully capture tortuous vessels without the intravoxel dephasing associated with a thick-slice acquisition. Thicker through-plane resolution boosts SNR while still allowing good results when reformatting just off-axis. The impulse response function of contrast-enhanced signal vs. time is narrower with the sliding subtraction method than the traditional method using only a single subtraction mask. As a result, the order of vessel filling may be better resolved in time. Second, the technique is less susceptible to motion artifact since less time between minuend and subtrahend images improves coregistration. Third, edge partitions which may not be fully in steady-state at the beginning of the acquisition due to a non-ideal slab-select profile contribute noise when the subtraction mask is chosen near the beginning; the later masks in the sliding subtraction method do not exhibit this problem.

References

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