Time-Resolved 3D MR Angiography of the Abdomen with a Real-Time System

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INTRODUCTION

Contrast-enhanced MR Angiography requires synchronization of the data acquistion with the bolus arrival. In abdominal MRA the data acquisition also has to be coordinated with a breathhold to avoid severe motion artifacts. Methods that address these issues include injecting a test bolus [1], automatic monitoring of signal intensity in the abdominal aorta (SmartPrep) [2], and the display of a sagittal 2D slice to detect the contrast arrival in real-time [3].

These approaches acquire a single 3D data volume upon the detection of the contrast arrival and the initiation of the breath hold. However, it is desirable to achieve information on the temporal evolution also. Fain *et al.* [4] developed a custom-made real-time system that acquires thick 2D slices embedded into a fluoro-triggered 3D acquisition. Here we present a real-time system implemented on a standard MR scanner that acquires time-resolved 3D data throughout the scan and initial results on five volunteers.

MATERIALS AND METHODS

Block *et al.* [5] developed a MRA real-time system that runs on an standard Ultra Sparc II workstation (Sun; Mountain View, CA) which is connected via a Bit3 adapter to a 1.5 T scanner (General Electrics; LX, Milwaukee, WI). This design allows for synchronized data transfer, reconstruction, and on-the-fly modifications of scan parameters.

In the initial phase of the scan, a 3D sagittal volume is interactively positioned over the heart and abdominal aorta. Every 2 seconds the central *k*-space views are updated, four receiver channels are reconstructed separately on a 128x128x8 grid, and displayed as MIP images on the realtime system. Once the bolus is detected in the right ventricle the breathhold is initiated and thereafter the acquisition is switched to the prescribed coronal volume centered over the abdomen.

Our data acquisition scheme uses elliptical centric view ordering [6] and separates k-space into elliptical annuli of equal volume, labeled regions A, B, C, ... as the *k*-space radius increases. Fig. 1 illustrates these regions and the timing diagram for their acquisition. In the first phase of the scan, only the central k-space region (A) is acquired. The images have lower spatial resolution, but can be rapidly acquired and reconstructed with minimal latency.

Upon contrast detection and the start of the breathhold, a coronal volume with high resolution is acquired. The central ellipse is updated every other time frame while the annulli with higher spatial frequencies are only acquired once. The central ellipse is further reduced after enhancement of the veins to increase the scan efficiency while still providing information on the contrast kinetics. The corners of k-space in the k_y-k_z plane (~24% of the data) were not sampled to cover a larger imaging grid instead [7].

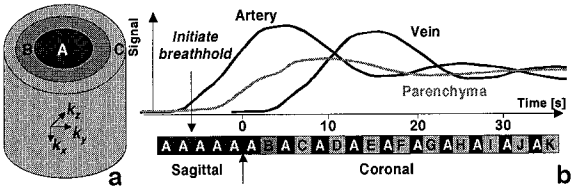

Fig. 1 K-space is divided into elliptical annuli (a). Timing diagram of the acquisition in respect to contrast enhancement in the renal arteries, veins, and parenchyma (b). When the bolus is detected in the right ventricle, the breathhold command is initiated. Once a stable breathhold is establish from bellows, high resolution data are acquired from a coronal volume.

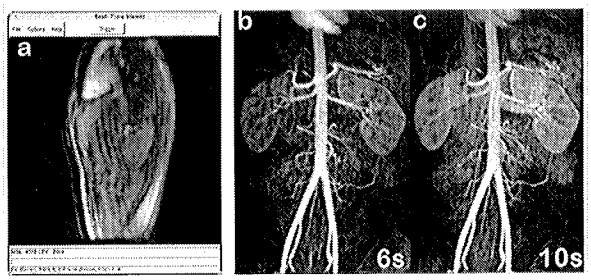

Fig. 2 The realtime system displays sagittal MIP images with high temporal resolution to monitor contrast arrival. High resolution images (b,c) are generated upon scan completion.

Five healthy volunteers (3 female, 2 male, age 21-32) were scanned. Typical scan parameters were: 256 samples readout direction, 192 phase encodes in k_y and 40 in k_z, FOV = 36x27 cm, 2.8 mm slice thickness, 62.5 kHz bandwidth, 45° flip angle, TR/TE = 4.3/1.8 ms, phased array torso coil, injection: 36 ml at 2cc/s. Total scan time with these parameters is 39 s if the regions are 2 s long.

Bellows were used to record the breathing motion. All volunteers were able to maintain the breathhold throughout the scan. However, if they would have started to breathe prior to the end of the scan, regions with corrupted data could have been disregarded in the reconstruction, resulting in a loss of spatial resolution.

RESULTS AND DISCUSSION

The latency of the system from completed data acquisition to display of the MIP image was less than 1 s. The MIP of a sagittal 3D volume provides more contrast than thick slab 2D techniques and thus simplifies monitoring of contrast arrival (Fig 2a). During the coronal acquisition images are reconstructed for each incoming A region on a smaller grid (256x192x8) to keep up with the incoming data stream. Time-resolved high resolution images (512x384x80) are generated after scan completion (Fig. 2b and c) and require ≈ 80 s per time frame. These image volumes share high-spatial frequency data while the contrast-defining central region is updated for each reconstructed time frame.

CONCLUSIONS

The implemented realtime system provides interactive scan control and immediate feedback for MR Angiography on a standard scanner. Detection of the contrast arrival and the end of the dynamic phase can be used to trigger of acquisition schemes. Time-resolved elliptical-centric data acquisition allows high quality 3D time frames and omits the need for a predermined breathhold length. It provides information on general flow patterns and may be beneficial in the presence of aortic aneurysms, occlusions, and dissections. The system worked very reliably for our volunteer exams and an evaluation with patients will follow.

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