Twelve- to Sixteen-Fold Accelerations of Contrast-Enhanced MRA Using Highly Parallel MRI with a 32-Element Array

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Introduction

The limited temporal window associated with passage of vascular contrast agents, along with the limited duration of feasible breath-holds, generally constrains the volumetric coverage and/or the resolution of clinical MR angiography studies. As a result, angiographic acquisitions are typically targeted to limited regions of vascular anatomy. Numerous studies have demonstrated that MRA can benefit substantially from acceleration using parallel imaging techniques [1,2,3]. Moderate levels of acceleration have been achieved to date. Accelerations at the level of an order of magnitude, however, would allow marked improvements in volumetric coverage, temporal resolution, and/or spatial resolution, potentially allowing changes in the traditional paradigm of targeted acquisitions.

In this work, a 32-channel MR system and a 32-element array capable of highly parallel imaging were used to accelerate volumetric contrast-enhanced MR angiography studies of pulmonary, renal, and peripheral vessels by more than an order of magnitude in a series of adult subjects.

Methods

Eleven healthy adult subjects were studied using a 32-channel imaging system comprised of four synchronized eight-channel GE EXCITE system cabinets linked to a whole-body 1.5T TwinSpeed scanner [4,5,6]. A 32-element coil array designed for highly accelerated imaging was used for imaging [4]. The array, pictured in Fig. 1A, consists of two regular 4 x 4 grids of rectangular loop elements placed above and below the subject. MR angiography was performed using a 3D spoiled gradient echo sequence, and accelerations were applied along each of the two phase-encoded dimensions to minimize SNR degradations associated with parallel imaging [7]. A low-resolution sensitivity reference was obtained prior to accelerated imaging, and parallel image reconstruction was performed using either a Cartesian SENSE [8] or a generalized encoding matrix (GEM) [9] reconstruction.

MR angiograms were obtained at clinical spatial resolution with the following parameters: acceleration factor of 12 (4 x 3), matrix size after reconstruction = 256 x 256 x 180, FOV = 44 cm x 44 cm x 40 cm, TE = 1.9 ms, TR = 4.6 ms, flip angle = 25°, bandwidth = 62.5 kHz. 0.1 mmol/kg body weight of gadopentetate dimeglumine were injected into the right antecubital vein at 2cc/sec, followed by a 20cc saline flush at 2cc/sec. Imaging was initiated approximately 18 sec following contrast administration, based on the arterial transit time determined using a test bolus, and three volumetric data sets were acquired in successive breath-holds.

Dynamic MR angiograms were obtained at high temporal resolution with the following parameters: acceleration factor of 12 (4 x 3) to 16 (4 x 4), matrix size after reconstruction = 128 x 128 x 128, FOV = 36 cm x 36 cm x 36 cm, TE = 1.3 ms, TR = 3.4 ms, flip angle = 25°, bandwidth = 62.5 kHz. Because of the high temporal resolution, no timing bolus or bolus tracking preparation was required. Contrast injections were otherwise similar to those described above.

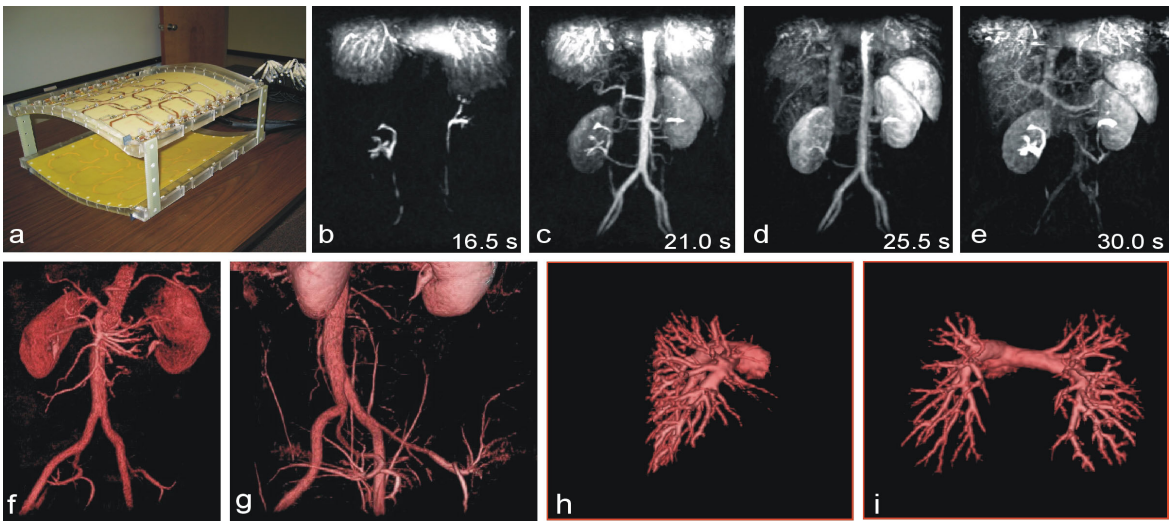
Results

Reconstructed data sets without appreciable artifacts were obtained in all subjects. Despite expected losses in signal-to-noise ratio, high arterial image quality was observed in raw images and maximum-intensity projections (MIPs). Fig. 1 shows sample results from three subjects. For Fig. 1b-e, a 54-second acquisition was reduced, by a factor of 12, to 4.5 seconds, and multiple data sets were acquired dynamically during inflow of the contrast agent. Successive time-resolved frames are shown, clearly depicting passage of contrast from the arterial to the venous system. Fig. 4f shows a volume-rendering of a high-resolution data set reduced from an impractical 4 minutes 24 seconds to a single 22 second breath-hold. Fig. 4g is a zoomed and rotated view from a later phase, in which fine detail of the mesenteric blood vessels, renal arteries, and pelvic arteries can be appreciated. Fig. 4h and i show two rotated volume-rendered views of the pulmonary arterial phase of a dynamic MRA study accelerated by a factor of 16 from 58 seconds to 3.8 seconds per volume.

Discussion

The competing constraints of spatial and temporal resolution in contrast-enhanced MR angiography studies, in combination with their high intrinsic contrast-to-noise ratio, make them prime candidates for highly accelerated parallel MRI. Three-dimensional imaging sequences also offer a particular synergy with parallel imaging, not only because of the availability of multiple directions suitable for acceleration, but also because highly parallel MRI enables large volumetric acquisitions with otherwise prohibitive imaging times, and the resulting gains in baseline SNR serve to offset at least in part the SNR losses associated with parallel imaging. No approaches such as TRICKS or undersampled PR were required for the current MRA studies, though highly parallel imaging may also be combined with these techniques for further gains in imaging speed, assuming sufficient SNR remains to support such accelerations.

The large volumetric coverage achieved in these studies allowed visualization of entire arterial trees at clinical spatial resolution and/or several-second temporal resolution. For contrast-enhanced MRA, highly parallel imaging promises to provide the volumetric coverage and speed of multidetector CT while preserving the inherent contrast mechanisms associated with MRI.



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