Ultra-Fast MR Velocity Measurement using Spin-Tagging and Single-Echo Acquisition (SEA) Imaging.

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INTRODUCTION

Characterization of non-periodic motion, such as turbulent flow patterns in stenotic vessels remains a challenging problem for MR imaging. Of particular interest in this study is the development of flow characterization techniques for microfluidic lab-on-a-chip devices. Methods are being investigated to create chaotic flow patterns in these devices, which can decrease mixing times by several orders of magnitude, critical for molecular diagnostics and drug development [1, 2]. While phase encoded MR imaging can be gated to periodic motion, gating fails for non-periodic or any one-time events. Single-shot or segmented k-space acquisitions still spread the data acquisition over multiple echoes. Single-echo acquisition, or SEA imaging, acquires all of the k-space data in a single echo, creating a very short acquisition window or "shutter speed". A preliminary test of phase contrast MRI using SEA imaging showed promising results [3], but phase correction remains a significant challenge in 64 channel SEA imaging, particularly because subtraction techniques to remove background phase effects are essentially not possible for non-periodic motions. This abstract reports the use of spin-tagging pulses, combined with SEA imaging, to provide real-time visualization of the motion at frame rates of 200 frames per second. Resolution of spin tags half the coil dimensions are demonstrated through proper choice of the phase compensation pulse.

METHODS

A prototype 64 channel receiver was used in conjunction with a 64 channel array coil [4]. The array coil consists of 64 planar-pair elements each 8 cm long by 2 mm wide. A DSP system enabled real-time demodulation and display of the images. Slice selection is done parallel to the array. In lieu of phase encoding, a phase compensation gradient pulse is applied to offset the phase introduced by the receiver coil pattern.

A 9 cm diameter cylindrical gel phantom (1 g/L $CuS0_4$ solution in gelatin) was placed over the array. The gel phantom could be rotated about an axis normal to the array by a motor located outside the magnet. The array and phantom were placed inside a volume coil used for excitation. Spin-tagging pulses were applied in one or two directions using a conventional pulse-width modulated pulse train [5]. Following the application of the tags, SEA images were acquired at a rate of 200 frames per second for 16 or 32 images (80 or 160 msec), after which the tags were reapplied. SEA images were acquired with TE/TR = 3/5 msec using a gradient echo. All imaging was done on a 4.7 T/33 cm Omega scanner.

RESULTS AND DISCUSSION

Figure 1 shows six consecutive SEA images of the rotating phantom. The 2 mm tags are clearly visible, rotating with the phantom and fixed in the stationary phantoms above and below. Each image is 5 msec. apart, demonstrating that the phantom is rotating once each 20 images (100 msec), or 600 RPM. For the 9 cm diameter phantom, this gives a peak velocity of 280 cm/sec. An interesting result is that the resolution of the tags is poor as the tags align horizontally, along the long axis of the array elements. A possible solution is to choose a different value for the phase compensation gradient, in order to accentuate resolution rather than SNR.

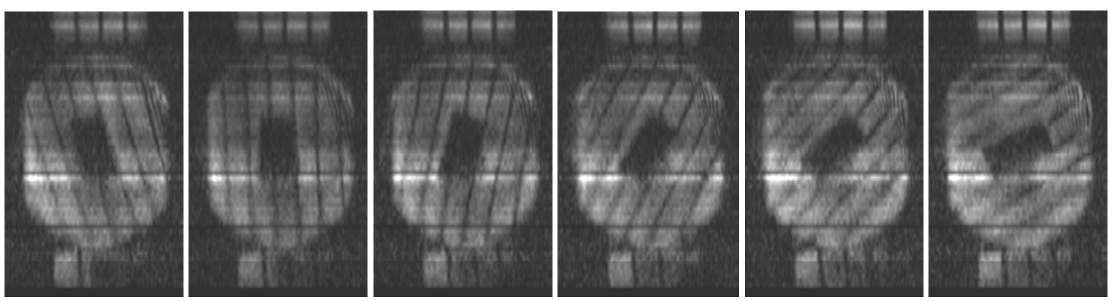

Figure 1. Six consecutive frames from a SEA movie of a rotating phantom between two fixed phantoms. Each frame is obtained in one echo, spaced 5 msec. apart. The frequency encoding direction is horizontal in these images, with spatial encoding by the array in the vertical direction.

In SEA imaging, the resolution along the short axis of the array elements is determined by the array element dimensions. However, the resolution can be enhanced by choosing a phase compensation gradient pulse strength which overcompensates for the coil phase, effectively performing edge detection [6]. To demonstrate the ability to visualize narrower tags, we applied 1 mm tags along both directions and used two different phase compensation gradient values, one accentuating SNR and the other accentuating resolution. When optimized for SNR, the resolution is essentially the element width, 2 mm, too large to visualize the spin tags reliably in horizontal direction (parallel to the array elements). When optimized for resolution, the tags are clearly visible in both directions, despite the 1 mm tag width being smaller than the coils. This represents an important feature in SEA imaging, the ability to sensitize the image to features smaller than the coil dimensions. The method presented here could provide a true "snapshot" flow imaging method, capable of imaging one-time or non-periodic events.

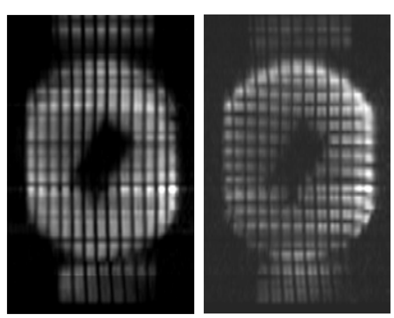

Figure 2. Left: SEA image made using a phase compensation gradient pulse equivalent to k-space line 51 of a 128 resolution phase encoded image. This value compensates for the coil phase for maximal SNR. The resolution in the direction along the narrow axis of the array elements is determined by the coil dimensions, 2 mm, causing the 1 mm wide tags to not be visualized. Right: SEA image made using a stronger phase compensation gradient pulse. The stronger pulse effectively results in edge detection, enabling visualization of the 1 mm tags, smaller than the 2 mm coil width.

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