Pure phase encode MRI in the vicinity of metal structures

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INTRODUCTION:

In recent years MRI has been increasingly employed in patients having metallic implants and in radiologic interventions where metallic instruments are used. The challenges resulting from various metal related artifacts: introvoxel dephasing, slice selection distortion / variations, misregistration, RF eddy currents and gradient eddy currents are well known [1,2]. Many efforts have been made to address this challenge, for example view angle tilting (VAT) [3] and its variations [4,5]. However, near metal MRI remains an unmet need. Pure phase encode single point imaging (SPI) [6] is immune to artifacts due to B_0 inhomogeneity, susceptibility differences and chemical shift. The method is however inefficient which has limited its clinical implementation. SPRITE imaging techniques have been developed to increase acquisition efficiency of the pure phase encode approach [6]. Pure phase encode is ideal for addressing near metal artifacts since it varies G instead of t to encode the spins. The most successful near metal images were obtained by the variations of VAT [4,5], which modifies VAT by adding additional phase encode gradients. The presented work proves the robustness of pure phase encode MRI to B_0 inhomogeneity by showing 3D SPRITE phantom images of samples with significant metal content. The paper also outlines the robustness of SPRITE to the gradient eddy currents induced by switching pulsed field gradients, which has enabled new high pressure MRI study inside metallic containers at variable temperature and pressure [7]. An eddy current self-compensated SPRITE sequence allows us to acquire geometrically correct images inside highly conductive cylindrical metal containers [8].

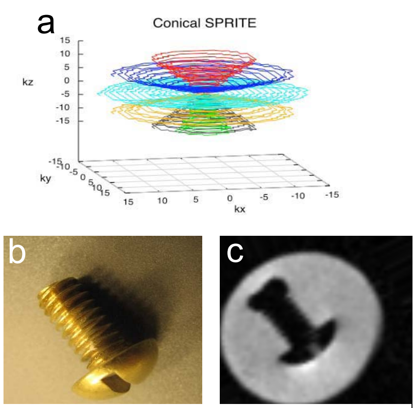

Fig. 1: 3D Conical-SPRITE phantom images of the doped water phase surrounding an immersed copper screw.

METHODS:

Conical-SPRITE [9] is a 3D, pure phase encode, Single Point Ramped Imaging with T_1-Enhancement (SPRITE) MRI method. K-space is sampled with a system of modified Archimedean spiral trajectories mapped to conical surfaces, Fig. 1(a). Conical-SPRITE is employed in this work to image the doped water phase surrounding an immersed copper screw.

The family of SPRITE methods include Standard, Radial, Spiral and Sectoral SPRITE according to their k-space trajectories. Compared with frequency encode imaging, all SPRITE techniques are less sensitive to the eddy currents in the metal structure induced by switching pulsed field gradients because of the implicit gradient stabilization during TR. Recent studies have focused on eddy current effects on SPRITE. An extreme example shows that the standard SPRITE method is robust to catastrophic eddy currents.

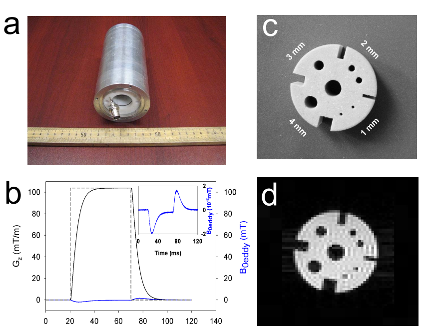

Fig. 2: Imaging inside aluminum vessel (a). Measured eddy currents (b). Phantom photo (c) and Standard SPRITE image (d) with catastrophic eddy currents present.

RESULTS AND DISCUSSION:

Fig. 1(b) shows a photo of a copper screw, submerged in water. Fig. 1(c) shows a slice from the 3D Conical-SPRITE image. The slice thickness is 1 mm. It should be noted that the water was heavily doped to reduce the scan time. The 3D image took 45 seconds with no signal average. The RF heating issue for SPRITE in vivo applications, i.e., specific absorption rate (SAR), is not so troublesome as it appears. SPRITE employs an RF pulse train but the RF duty cycle is actually low. RF pulse length is on the order of µs while the interval between consequent RF pulses (i.e., TR) is on the order of 1 ms.

SPRITE techniques are immune to static B_0 inhomogeneity and are also insensitive to dynamic eddy currents. Fig. 2 (a) & (b) shows a highly conductive metal structure and the severe eddy currents induced and measured with MFGM approach [10]. Such conductive metal structures are critical elements in some MRI applications [7]. It was carefully centered inside the gradient set along the B_0/G_z axis in a 2.4 T small bore superconducting magnet. The goal was imaging with a Birdcage RF coil which was within the aluminum tube, Fig. 2 (a). The gradient rise time from 10 % to 90 % was 10 ms due to severe eddy currents generated by the aluminum tube. A resolution phantom was imaged with 2D 'Standard' SPRITE, Fig. 2 (c) & (d). 'Standard' SPRITE yields geometrically correct images even with catastrophic eddy currents present. K-space is traversed from side to side by switching the gradient in equal steps from – G to G, as illustrated in Fig. 3(a). After a period of time following gradient turnon, eddy current effects enter a steady stage such that linear eddy currents and $B_0(t)$ shifts are constant for each k-space step. Centric k space points carrying most information of the image are acquired during the eddy currents equilibrium.

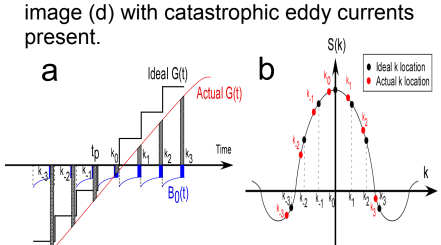

Fig. 3: 'Standard' SPRITE immune to eddy currents. Gradient waveform and B_0 eddy currents (a). Eddy currents effects on k-space of a uniform object (b).

CONCLUSION:

3D artifact free metallic part image is presented using Conical-SPRITE. The potential use of SPRITE in vivo is discussed and is a very real possibility. Combining acceleration techniques such as parallel imaging and compressed sensing, SPRITE is promising to perform near metal imaging in clinical applications.

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