Sensitivity Mapping for Parallel Imaging of Hyperpolarized ^{13}C Compounds

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Introduction

While real-time imaging of metabolism with hyperpolarized ^{13}C compounds in vivo can open significant new avenues for MRI, it also adds challenges to the imaging process. Most importantly, imaging needs to be completed in less than a minute, to prevent signal loss from T_1 decay. Hyperpolarized signals are non-equilibrium signals, and imaging them through parallel imaging does not incur the typical $1/\sqrt{R}$ SNR penalty of conventional equilibrium parallel imaging (1). Moreover SNR can be increased through parallel acquisition of such signals, as less T_1 decay is incurred during the imaging process. Parallel imaging requires coil sensitivity profiles (CSPs) to unwrap the aliased signal. Typically, in auto-calibrated acquisitions, a few additional lines at the center of k-space are acquired to generate these CSPs. These extra lines of k-space contribute to the final image SNR, and no significant signal loss is incurred by the extra acquisition. For parallel imaging of hyperpolarized signals however, shortening the acquisition time correlates directly with increasing SNR; the acquisition of these extra lines for auto-calibration would be undesired, should it not be absolutely needed. We propose here a new method of generating CSPs in a phantom completely filling the field of view (FOV), prior to any image acquisition, and using them for reconstruction of accelerated data. At the low resonance frequency of ^{13}C (16.06MHz@1.5T), coil loading factors are small, thus samples do not significantly affect CSPs. These CSPs can be acquired at the ^{13}C frequency, using an adequate phantom. Unfortunately, ^{13}C labeled material (needed for good SNR CSPs) is prohibitively expensive, and its use can become unreasonably expensive for a large torso array. More conveniently, however, the CSPs can be acquired at the ^{23}Na frequency (practically free of charge, by using phantoms filled with 150mM NaCl), by a slight retuning of the preamplifiers and transmit/receive coil. These CSPs are acquired once, immediately after a rigid geometry multi-channel coil is built. The coil is then retuned to ^{13}C frequency. CSPs can be generated in any slice of interest at the 13C frequency through registration of fiducials, which are present for both CSP acquisition and any imaging exam. We demonstrate good agreement between images reconstructed through a sum of squares (SoS)(fully sampled) of signals from multiple coils, and images artificially under-sampled and reconstructed using the "canned", ^{23}Na and ^{13}C CSPs.

Methods

A rat, single channel transmit, 4 channel receive array was built and initially tuned to ^{23}Na. Fiducial spheres 1 cm in diameter, filled with a CuSO4 doped solution, were permanently affixed to the backplane. A 250mL cylindrical phantom was filled with saline for the ^{23}Na CSP acquisition ($0.01), and with 480 mM 1-^{13}C acetate solution doped with 6 mL Gd-DTPA ($500) for the ^{13}C CSP acquisition. ^{23}Na CSP's were initially acquired. The coil was then retuned to ^{13}C, and ^{13}C CSPs were also acquired. During the ^{13}C/^{23}Na CSP acquisition exams, ^{1}H images were also acquired for registration purposes (the ^{13}C/^{23}Na coil array was used within a head coil for ^{1}H imaging.). All scanning was done on a 1.5T GE Signa MR scanner. Sprague-Dawley rats were then imaged. ^{1}H fiducial localizer images were acquired using a True-FISP sequence. Hyperpolarized ^{13}C pyruvate was then injected into the rat, and ^{13}C coronal images were acquired from the rat body with 24x24 spatial resolution over a 12cm FOV. Data were then transferred to a workstation. An automated process was developed to segment and uniquely label each fiducial sphere (2). A rigid transformation between the phantom CSP and the ^{13}C pyruvate images was determined. The CSPs were then re-sampled into the space of ^{13}C images using the rigid transformation given by the fiducial spheres. ^{13}C images were reconstructed using four methods: A SoS of the fully sampled k-space and a SENSE reconstruction on a down sampled 12x24 matrix with 8 auto calibration lines was initially performed. The down sampled 12x24 dataset was then reconstructed using the pre-acquired ^{13}C-acetate CSP's. Last, the down sampled 12x24 dataset was reconstructed using the pre-acquired Na CSPs.

Results and Discussion

The registration process is shown in Figure 1. The ^{1}H image of the ^{13}C-acetate phantom and fiducial spheres is shown in Figure 1a), the rat and fiducial spheres are shown in 1b), and 1c) shows the phantom fused with the anatomic image after the registration process. The fiducial spheres can be localized with a precision of 0.1mm (2). The fusion between the anatomical image used for ^{13}C acquisition and one of the CSPs re-sampled in this plane is shown in Figure 1d) (note reduced FOV). Parallel reconstruction results are shown in Figure 2, all with a 12cm FOV. Traditional SoS reconstruction of the full 24x24 matrix is shown in 2a). An aliased reconstruction of the sub sampled 12x24 matrix is shown in 2b). Figure 2c) shows SENSE reconstruction utilizing auto calibration lines and the sub sampled matrix of 2b) yielding a 1.5x speed up. Pre-acquired ^{13}C-acetate coil sensitivity profiles are used in SENSE reconstruction in 2d) and pre-acquired Na CSP in 2e) yielding a 2x speed up. Note the good agreement between all 4 reconstructions. Also note, than in the latter 2 cases, for the case of hyperpolarized pyruvate, 10% SNR can be gained by moving from a 16x24 acquisition (needed for auto-calibrated SENSE), to a 12x24 acquisition (needed for canned CSP reconstruction). This improvement can be obtained free of charge (^{23}Na CSPs), or at a potentially significant expense (^{13}C CSPs).

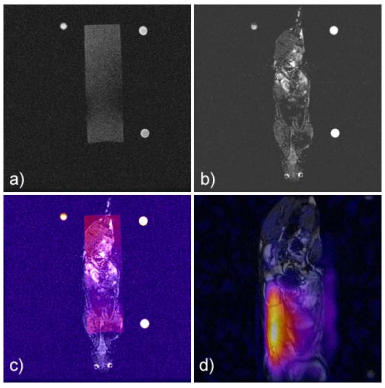

Figure 1: *Registration process. (a) H1 image of C13 phantom with CuSO4 spherical fiducials, (b) H1 image of rat and fiducials, (c) fusion of (a) and (b) demonstrating alignment, (d) H1 image of rat overlaid with (1 of 4) C13 coil sensitivity map (reduced FOV).*

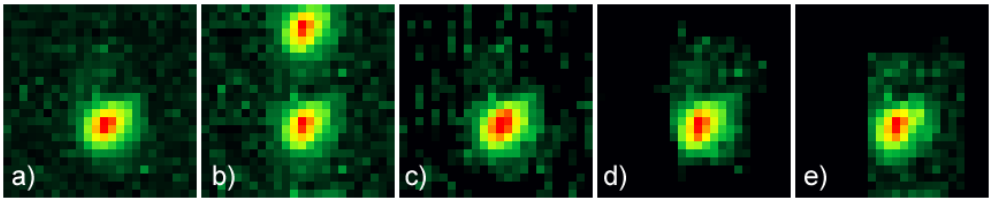

Figure 2: *Comparison of conventional, self-calibrated parallel imaging and parallel imaging with pre-acquired coil sensitivity profiles, 12cm FOV. Reconstruction of the pyruvate frequency, lactate frequency reconstruction is similar, data not shown. (a) Fully sampled sum of squares reconstruction(24x24), (b) undersampled reconstruction (12x24 grid), (c) SENSE reconstruction from self calibrated data (12x24, 8 ACS, R=1.5) (c) SENSE reconstruction using pre-acquired C13 CSP (matrix 24x24, R=2) (d) SENSE reconstruction using pre-acquired Na CSP (24x24, R=2).*

References: 1. Lee R, et al., MRM 55(5), 2006. 2. Mallozzi, et al., ISMRM 2004