Parallel Phase-Encoded images with hyperpolarized gas

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PURPOSE

Hyperpolarized (HP) ^{3}He MRI has been successfully applied for lung ventilation mapping in humans over the last ten years [1], opening a route for dynamic studies or multiparametric breath-hold investigations that are critically dependent on the scan duration. In proton MRI, the development of RF-coil array techniques has brought spectacular improvements, through enhanced SNR with phased image reconstruction (PIR) [2] and because accelerated scans can be achieved based on parallel phase encoding (PPE) [3, 4]. Yet, up to now HP-gas MRI with RF-coil arrays has not been performed. This is most probably due to the need of dedicated hardware and know-how, both to produce large amounts of HP gas and to simultaneously acquire multiple signals at an unusual NMR frequency. Neither HP-gas production units nor coil arrays for ^{3}He MRI are commercially available today, and manufactured MRI units do not usually come with built-in multi-channel ^{3}He options. Besides, specific features of HP substances, such as non-renewable magnetization and Fourier-domain filtering due to RF- and T_1-depolarization effects, have to be accounted for in view to perform accelerated parallel acquisition. Standard calibration procedures and reconstruction algorithms may fail to achieve optimal performances. The present work demonstrates the implementation of a ^{3}He, four-channel RF-coil array on a 0.1 T whole-body MRI unit and a preliminary investigation of dedicated PPE approaches. To achieve this initial step on PPE ^{3}He, a 0.1 T system was chosen to make use of narrower acquisition bandwidths and corresponding higher SNR that is possible with respect to the longer T2* at low field [5]. The narrower bandwidth sets an additional constraint on the achievable minimum scan time that could be advantageously released with PPE acceleration.

MATERIAL AND METHODS

Imaging was achieved with a 0.1 T MR unit (Sopha-Imaging, France), retuned to the ^{3}He frequency of 3.29 MHz and equipped with a third-party four-channel digital NMR console (TECMAG, Texas). RF calibrations were done with a HP 4194 network analyzer (Hewlett-Packard, California).

An RF-coil array was designed with 4 rectangular, figure-of-eight flexible coils, made of double-sided Cuflon™ printed circuits and arranged to fit by pairs on the top and bottom insides of the torso coil used for transmission. The latter was a detachable vertical pair of coils with an anatomically-reshaped Helmholtz geometry [5]. The RF-coil array was 30 cm long and gave a free access of 43 cm (horizontal) by 26 cm (vertical). Each flexible coil exhibited unloaded quality factors of 330, decreasing by 13% when loaded by a 75 kg human subject. The geometrical parameters of these coils and the degree of overlapping for both the top and bottom pairs were determined by computations over a digital phantom that mimics an axial section of the human lung, using a compromise between a low g-factor [4] and a high SNR in the case of a bidimensional acceleration factor R of 2 x 2 (horizontal and vertical). For 1D acceleration of R = 2 that was performed here, the final geometry gave a maximal g-factor of 1.2 at the phantom center. Inductive decoupling was intrinsically achieved between non-adjacent coils and with an interconnected capacitor array for adjacent coils. Finally, home-built preamplifiers were inductively linked to the coils using small pick-up coils and a double-tuned overcoupled arrangement [6].

^{3}He was polarized on site [7]. For each scan, 50 ml of pure ^{3}He, polarized at 10%, were mixed in N_2 up to 500 ml and transferred to a Tedlar™ bag. For in vitro experiments the dose was transferred to a 1.5-liter, 3 cm-thick Altuglass™ phantom that was eventually completed with N_2. The phantom materialized the digital phantom used for computations (see Figure). For in-vivo experiments the dose was inhaled by a healthy volunteer.

A spoiled gradient-echo sequence was implemented to acquire up to 2 images in a row, with TR/TE = 18.4 / 6.1 ms, bandwidth of 97 Hz/pixel, 25 % echo asymmetry. A 34 cm FOV along the readout axis (horizontal) by 22.3 cm explored with centrically reordered phase-encoding steps (vertical) was set for three scan conditions:

A) Full/Accelerated dual scan: First image with a 64x42 matrix, R = 1 and $\alpha = 12.6°$ - Second subsequent image with a 64x21 matrix, R = 2 and $\alpha = 17.9°$.

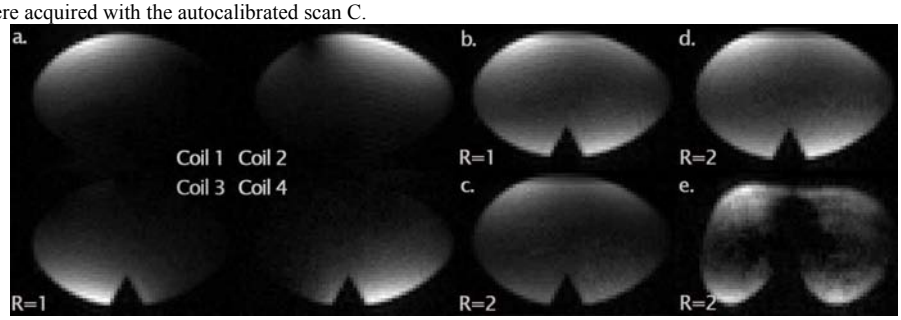
B) Dual full scan: Consecutive images with 64x42, R = 1, and $\alpha = 12.6°$.

C) Single autocalibrated accelerated scan: First 21 lines of 64 points with R = 1, and $\alpha = 12.6°$ - Last 10 lines with R = 2 and $\alpha = 17.9°$.

Images from full A and B scans were reconstructed by standard Fourier transform of each coil output followed by the sum-of-squares PIR algorithm [2]. Image from accelerated A scan was reconstructed using the GRAPPA algorithm [8] calibrated with the first 21 lines of the full A scan. The accelerated C scan used its own 21 first lines for autocalibrated GRAPPA reconstruction. In this latter case, the last ten lines were corrected by a factor 0.709 to compensate for the flip angle variation.

RESULTS

Sensitivity maps were provided by full scans (A, B) for each coil. The SNR on the corresponding PIR images ranged between 6 at the phantom center and 30 close to the coils, in good agreement with the computed sensitivity distribution. For accelerated scans A with constant R = 2, SNR was found to be within a few percent of the SNR from the second full B scan when both SNR were normalized by their respective first-scan SNR in each dual acquisition. Similarly, first accelerated in vivo images were acquired with the autocalibrated scan C.



a. *Sensitivity maps: Individual-coil images obtained on the ^{3}He phantom with full scan A*
b: *First PIR image from full scan A*
c: *Accelerated image reconstructed from second scan A*
d: *Autocalibrated PPE image of the ^{3}He phantom with R=2*
e. *Autocalibrated PPE image of the human lung with an axial slice thickness of 25 mm, TR/TE = 35.4/ 10.9 ms, bandwidth of 39,3 Hz/pixel*

DISCUSSION AND CONCLUSION

Even with low polarized gas doses, fairly good SNR was observed both *in vitro* and *in vivo*. Phantom images with true scan time reduction R = 2 have been reconstructed while the SNR could be kept constant as foreseen [9]. Here, this was made possible by increasing the flip angle so to maintain the Fourier-domain decaying filter identical. A set of ten additional (auto)calibration lines was found large enough to insure reconstruction without noticeable artifacts. Here GRAPPA was efficiently processing centric reordered data. Numerical simulation showed that linear ordering would lead to more artifactual reconstructed images. The autocalibrated accelerated scan would be even more beneficial in the case of higher resolution images, which do not require a larger set of autocalibration lines. Complementarily, for dynamic studies, series of low resolution scans would be advantageously implemented without autocalibration lines but with an initial calibration image. Finally, the original approach followed here for hyperpolarized ^{3}He could also be profitable to any investigations with prepared magnetization, which could even include proton at time scales shorter than T_1.

REFERENCES

1. E. J.R. van Beek et al., JMRI 20, 540 (2004) **2.** P.B. Roemer et al., Magn. Reson Med. 16, 192 (1990) **3.** D.K. Sodickson et al., Magn. Reson Med. 38, 591 (1997) **4.** K.P. Pruessmann et al., Magn. Reson Med. 42, 952 (1999) **5.** L. Darrasse et al., C.R.A.S. 324, 691 (1997) **6.** A. Raad et al., Magn Reson Imaging 10, 55 (1992) **7.** J. Choukeiffe et al,11th ISMRM meeting, 1391 (2003) **8.** Griswold et al, Magn. Reson Med. 47, 1202 (2002) **9.** J. P. Mugler et al., 13th ISMRM meeting, 485 (2005)

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