A Novel B_1^+ Mapping Method for Deuterium MRI

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INTRODUCTION

Deuterium MRI has emerged as a promising technique for imaging tumors in the body, employing an exogenous dose of a deuterated glucose solution and the direct ^{2}H detection in metabolically-active tumors using chemical shift imaging (CSI). However, achievable SNR is low and hence techniques to increase the SNR are highly desirable.

The resonant frequency for ^{2}H at 7 Tesla is 45.6 MHz (c.f. 297 MHz for ^{1}H), and hence dedicated radiofrequency (RF) transmit and detection coils are required to image both ^{1}H and ^{2}H. The safe use of RF coils on 7 Tesla MRI systems is ensured by constraining the RF transmit power such that regulatory limits on local and whole body SAR are not exceeded. These RF power levels in turn are determined via electromagnetic numerical simulations performed using a model of the RF transmitter coil and realistic virtual body models (such as those from the IT'IS Foundation, https://itis.swiss/virtual-population. The accuracy of the simulated RF coil model is critical and is typically determined by comparing simulated with measured RF transmitted (B1+) fields in a uniform phantom with tissue-mimicking dielectric properties. If the fields match, the simulation model is deemed accurate.

AIMS

The aim of this study was to develop a novel high-resolution and bias-free quantitative deuterium MRI B1+ mapping method for validating the simulation model accuracy of a 7T body RF coil. Coil modelling errors (discrepancies between the electromagnetic model and its physical implementation) are typically assessed by comparing simulated with measured B1+ fields in a phantom [1]. However, the extremely low SNR of X-Nuclei causes significant problems for conventional B1+ mapping techniques, resulting in long acquisition times, low resolution, and biased estimates. Here, we describe a novel approach which uses parametric modelling of multi-echo gradient-echo (ME-GRE) data, acquired as a function of coil transmit voltage, to extract estimates of the B1+ value at each pixel. B1+ values were compared to a conventional mapping approach for X-nuclei using chemical shift imaging (CSI) and processing with AMARES [2, 3].

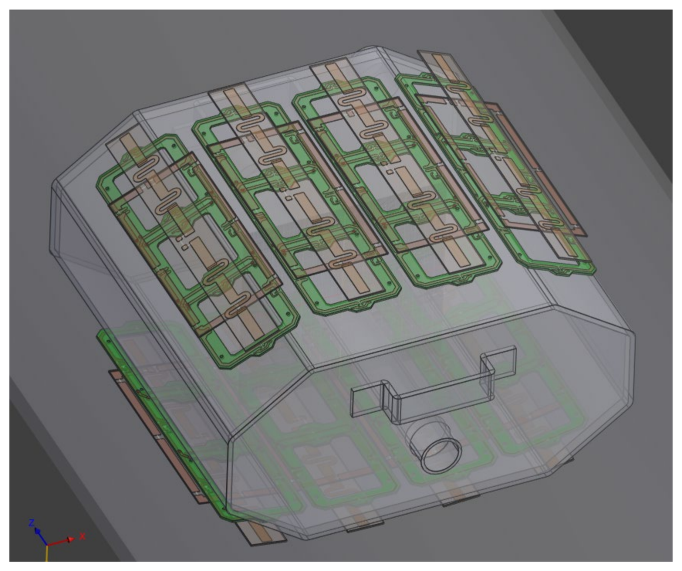

Figure 1: Schematic showing the set-up of the ^{1}H/^{2}H 7-Tesla body array coil and phantom used for simulations and measurements.

METHODS

MR experiments were performed on a 7T MR scanner (Terra.X, Siemens Healthcare, Germany) using body array coil (Tesla Dynamic Coils, The Netherlands) with 8-Tx/32-Rx (^{1}H) and 8-Tx/Rx (^{2}H) channels. Imaging was performed on a body-sized phantom (Figure 1) containing 0.59% D_2O, with dielectric properties σ = 0.935 S/m, ε = 79.55 @ 45.6 MHz.

ME-GRE experiments were performed with: voxel = 9 x 9 x 50 mm^3, TR / TE = 2500 / 5-80 ms (12 echoes), NSA = 10, voxel = 9.2 x 9.2 x 25 mm^3, Transmit_V = 10 - 300 V (30 steps), acquisition-time = 203 mins.

CSI experiments were performed with: TR / TE = 3000 / 2.3 ms, NSA = 18, BW = 1 kHz, voxel = 12.5 x 12.5 x 25 mm^3, Transmit_V = 18.5 – 370 V (20 steps), acquisition-time = 516 mins.

Data was processed using custom scripts in MATLAB (The MathWorks, USA). Parametric methods were used to model the 12-echo FID-like signals as a damped exponentially-decaying signal incorporated into the Steiglitz-McBride algorithm to remove noise and determine the magnetization at each transmit voltage. Voxel-wise fitting to a sine curve (magnetization versus transmit voltage) yielded B1+ values for both ME-GRE and CSI experiments.

Simulations were performed using sim4life (ZMT, Switzerland). A safety 'Loss Factor' was calculated as the ratio of measured to simulated B1+ (edge phantom pixels were excluded).

RESULTS

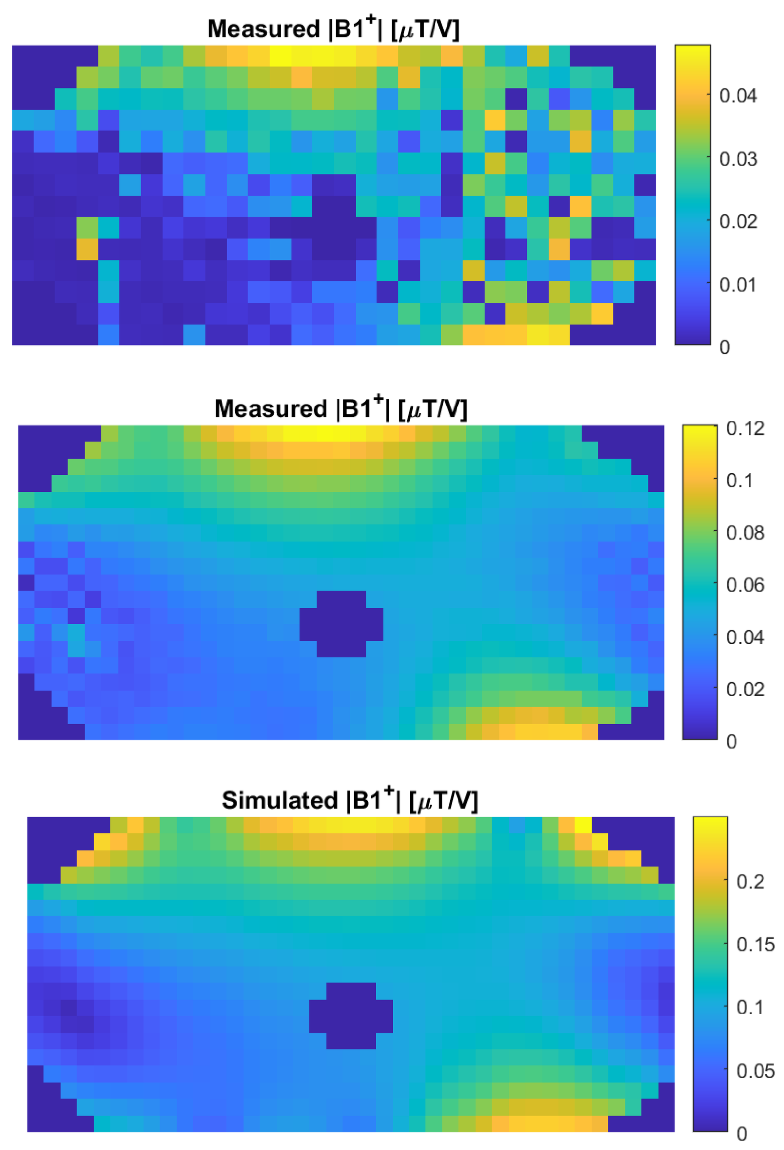

Figure 2: B1+ maps acquired using (top row) conventional CSI method with AMARES and (middle row) the new ME-GRE with parametric modelling; Bottom row: simulated B1+ map, showing close spatial correlation with the ME-GRE map. The differences in absolute values are captured in the Loss Factor.

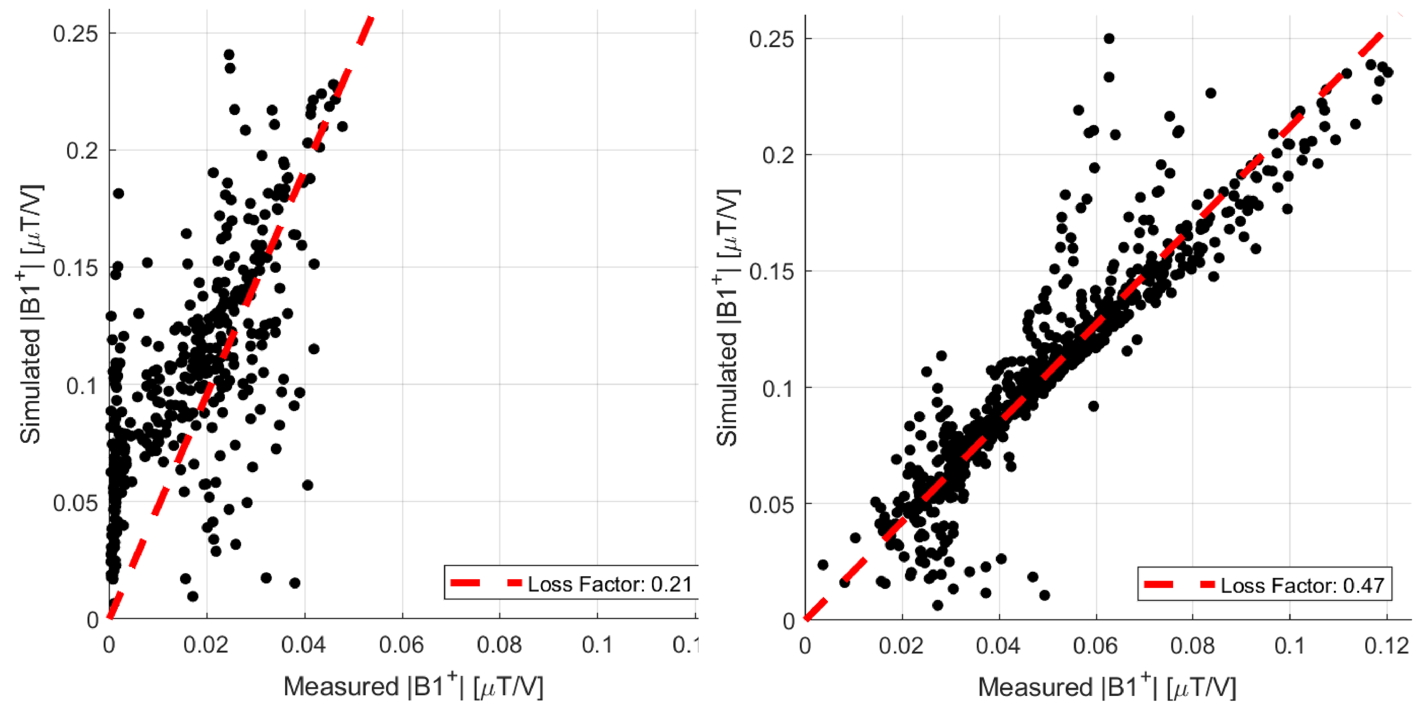

Figure 3: Scatter plots comparing measured and simulated B1+ data for (left) CSI with AMARES, and (right) the new ME-GRE with parametric modelling. The latter has a closer and more accurate, bias-free correlation with the simulated B1+ values, with Loss Factors of 0.21 and 0.47 respectively.

Figure 2 compares the measured B1+ maps from CSI-AMARES and ME-GRE, demonstrating the significantly improved SNR and spatial resolution achieved even with the reduced acquisition time with the ME-GRE technique. The spatial distribution of the ME-GRE B1+ map closely matched that of the simulated map, demonstrating that the simulation model of the RF coil is an accurate representation of the physical device. The scatter plots in Figure 3 shows that the quantified B1+ values determined using the CSI-AMARES method had a weak correlation with the simulated data when compared voxel-wise, and furthermore introduced a significant bias error as evidenced by the derived Loss Factor of 0.21 compared to 0.47 from the ME-GRE method. The correlation with the ME-GRE method was significantly improved.

CONCLUSIONS

The novel ME-GRE B1+ mapping sequence achieved high spatial resolution and accurate B1+ estimates in reasonable acquisition times, and facilitates the accurate validation of simulation models for newly-developed RF coils. The parametric approach reduces magnitude estimate bias by explicitly modelling and estimating the relaxation-rate and frequency-offset parameters governing the signal decay across echoes, and variance by incorporating multiple echo observations in the parametric model describing the FID. The technique can be easily adapted to other X-Nuclei.

REFRENCES

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