A simple and accurate method for 13C coil sensitivity estimation

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Introduction:

Metabolic imaging with Magnetic Resonance (MR) allows a selective identification of molecules and molecular distribution mapping within various organs. However, both weak nuclear polarization levels and low natural abundance reduce the MR experiment sensitivity. Hyperpolarization methods have been proposed to enhance the polarization of nuclear spins such as ^{13}C and the feasibility of using ^{13}C hyperpolarization enhanced MRI to monitor pyruvate metabolism in the heart [1]. Efficient imaging of such molecules, however, requires new multifrequency RF coils.

Typically, an exam in which hyperpolarized compounds are injected involves at least two coils: one tuned at the ^1H frequency, and one at the ^{13}C frequency. Alternatively, a single, dual-tuned ($^1H/^{13}C$) coil can be used. However, when the coil are tuned at lower frequency with respect to ^1H frequency, such as for ^{13}C experiments, the SNR (Signal-to-Noise Ratio) decreases, thus reducing the data quality. Since the SNR performance increases as the sensitivity of the coils it is important to estimate this parameter for an optimized coil design. Coil sensitivity can be estimated by using magnetic field mapping methods applied at a fixed point in space and many methods have been described in literature, divided into probe and imaging techniques.

The purpose of this work is to verify the accuracy of perturbing spheres method, which is able to provide, in a fast and easy way, coil sensitivity estimation. In particular, we describe the application of the method by testing two ^{13}C quadrature birdcage coils and demonstrating its efficacy for coil sensitivity estimation.

Materials and Methods:

The coil sensitivity is an important parameter that characterizes the RF coils performance. It is defined as the magnetic field (B_1) induced by the RF coil at a given point per unit of supplied power P, as follows:

$$\eta = \frac{B_1}{\sqrt{P}} \tag{1}$$

The reciprocity theorem allows to use the same quantity defined in Eq. (1) to characterize both the transmit and receive performance of an RF probe. The perturbing sphere method for the coil sensitivity η estimation has recently been applied to map the RF fields from MRI coils [2]. This method consists in inserting a small metallic sphere inside the cavity of the coil and measuring the frequency shift f_1 with respect to the unloaded coil, caused by the sphere perturbation. Successively, the following equation is used [3]:

$$\eta = \frac{1}{2}\sqrt{\left(\frac{\mu_0}{\pi^2\, B_w\, r_S^{\,3}}\right)\left(\frac{f_1^{\,2} - f_0^{\,2}}{f_0^{\,2}}\right)} \tag{2}$$

where B_1 is the rotating component of magnetic field, B_W and f_0 are, respectively, the –3dB bandwidth and the coil resonant frequency and r_s is the sphere radius. Eq. (2) is valid in a region of zero electric field, therefore it can be used for low frequency tuned coils, when the electric field at the centre of birdcage volume cavity is negligible. The coil sensitivity was evaluated for two birdcage coils using steel spheres and with the birdcages in loaded conditions (phantoms filled by saline solutions which simulate the loaded conditions).

The tests for both coils were performed using a Network Analyzer, employed in averaging mode for improving measurements sensitivity, and a dual-loop probe. Both coils are quadrature lowpass birdcage: the smaller one is a 4 cm radius and 12 cm length and is employed for ^{13}C metabolic studies in rat, while the bigger one, used for pig experiments, has 18.5 cm radius and 36 cm length.

Results:

The rat coil was tested using a 6 mm radius sphere while for the pig coil a 20 mm radius sphere was employed. The measurement results are reported in Table 1.

Coil	Sensitivity ($\mu T/\sqrt{W}$)
Rat birdcage coil	23.55
Pig birdcage coil	2.80

Table 1

Since the noise increases as the square root of the coil volume, we obtain that the ratio between the square root of the volume for the two coils, is 8.03: very similar to the ratio between the coil sensitivities measured (8.41).

Successively we verified the accuracy of perturbing sphere method by comparing the obtained data with those experimentally measured using a magnetic resonance experiment with the rat coil. We know that the rotational angle is given by:

$$\theta = \gamma B_1 \tau \tag{3}$$

where γ is the gyromagnetic ratio (10.7 MHz/T for ^{13}C nucleus) and τ is the width in seconds of the RF hardpulse of amplitude B_1.

Since we transmitted 4 W using a 504 μs length pulse, the B_1 corresponding to a 90° flip angle should be 46 μT, estimated in the rotating frame. This value is very similar to the one estimated using $B_1 = \eta\sqrt{P}$ =23.55*2=47.1 μT.

Discussion:

The use of a simple and fast coil sensitivity estimation method for low frequency coils was demonstrated, which is able to predict, with great accuracy, the coil performance in terms of sensitivity and SNR. The method has been applied for measuring the sensitivity of two ^{13}C birdcace coils and its accuracy was verified using theoretical and experimental approaches.

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