Safety Evaluation for ^{1}H Decoupled ^{13}C Spectroscopy at 3T in Human Frontal Lobe: SAR Analysis Using Numerical Simulations

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INTRODUCTION

Past human brain ^{13}C spectroscopy studies have been limited to the occipital lobe partially because strong RF power is required to decouple large ^{1}H-^{13}C scalar coupling for methylene carbons. Recently, a new approach using [2-^{13}C]glucose and detecting carboxylic/amide carbons has demonstrated that the decoupling power can be significantly reduced with pseudo noise waveform (1, 2). As such, it is possible to acquire proton decoupled ^{13}C spectrum from human's frontal lobe using either a surface coil or a short birdcage coil. To evaluate the safety of frontal lobe decoupling, we have performed B_1 field and SAR analysis for two coil designs using computer simulations with a human head model.

METHODS

The Finite Difference in Time Domain (FDTD) and the Time-Domain Finite-Difference/Finite-Element (TD-FD/FE) hybrid method were used to calculate B_1^+ (circularly-polarized component of B_1) field and electric field inside the human head. Two coil models were created. The quadrature proton surface coil (Fig. 1a) consists of two overlapping loops formed on a cylindrical tube (dia. = 20.3 cm). Conductor width is 1.27 cm. Each loop is octagonal with nominal length = 13.3 cm and width = 12.7 cm. The 12-element unshielded, high-pass, short quadrature birdcage coil (Fig. 1b) has conductor width = 2.54 cm, coil diameter = 20.3 cm and coil length = 14.0 cm (between inner edges of end-rings). The human head model was created based on the National Library of Medicine's Visual Man Project. Each Yee cell was 2x2x2 mm^3. The model contains 18 different bone and tissues and electrical properties were assigned to each tissue (3). The surface coil was modeled by pure FDTD method and the short birdcage coil was modeled with TD-FD/FE hybrid method, in which only the curved coil structure was modeled by the Finite Element method while the rest was modeled by finite-difference method. For the birdcage coil, coil "tuning" was done by using 24 equally spaced 24.2 pF capacitors. Both coils were driven in quadrature mode. Local SAR value was then calculated by averaging RF power within 1 cc volume around each cell. Average SAR value was calculated by summing SAR values from all cells in the head region above the neck and dividing the result by the total mass of the selected region. B_1^+ and local SAR distributions were normalized to 1 W of absorbed RF power inside the human head model. Therefore, B_1^+ intensity and SAR level at different power level can be calculated from the normalized results. A mass of 5.6 kg was used to calculate the average SAR of the whole head above the neck.

RESULTS

The normalized B_1^+ field distribution of the surface and the birdcage coil in the mid-sagittal plane is shown in Fig 2a and 2b, respectively. The white dot (reference point) indicates the center of the spectroscopy voxel. B_1^+ intensity at this point was 2.5 µT for the surface coil and 1.3 µT for the birdcage coil. Fig 3a and 3b show normalized local SAR distribution for the surface coil and the birdcage coil, respectively. Each axial plane contains the maximum local SAR in the head model which is represented by small red color area next to the medial level of nasal bridge. For the surface coil, the maximum local SAR in the whole head is 3.38 W/kg and in the eye (vitreous humor) is 1.2 W/kg. For the birdcage coil, the maximum local SAR in the head is 1.02 W/kg and in the eye is 0.3 W/kg. The average SAR is 0.17 W/kg for both situations. A duty cycle of 100% is assumed for all of these results.

DISCUSSION

Based on our preliminary human studies using [2-^{13}C]glucose infusion and the surface coil, when the parameters of the noise waveforms were optimized for the surface coil, 20W forward power produced sufficient proton decoupling. With a loading factor of 0.75, only 15 W decoupling power was deposited into the human head. For 5% duty cycle (TR = 4 s and acquisition time = 200 ms), the maximum local SAR was 2.54 W/kg for the surface coil. Since the birdcage coil is ~50% less efficient than the surface coil (Fig 2), it may need four times power (60 W) to produce the same decoupling B_1 field at the same reference point. Using its normalized local SAR value (1.03 W/kg) and 5% duty cycle, the maximum local SAR was 3.06 W/kg for the birdcage coil. However, with homogeneous field, the required decoupling B_1 field for the birdcage coil may be substantially weaker. At the condition of 5% duty cycle, average SAR was 0.13 W/kg for the surface coil with 15 W absorption. With the hypothetical 60 W absorption for the volume coil, the average SAR was 0.52 W/kg. All local and average SAR values were well under the limits of FDA and IEC safety guidelines.

In our results, the location of maximum local SAR is near the nasal bridge. This is mainly due to the proximity to the coil conductor in our modeling as shown in Fig 1. The large anatomical curvature in this region may also contribute to the relatively high local SAR. Earlier simulation work using the same head model at the same frequency has shown that the location of maximum local SAR is in the masticator space using a longer birdcage coil (3).

Temperature change in the same human head model due to RF radiation has been studied previously at several different frequencies (4, 5). For an average SAR of 3.0 W/kg at 100% duty cycle, the temperature increase in the eye region is less than 0.6 °C at 200MHz (4). Since our average SAR with 5% duty cycle is only 0.13 W/kg for the surface coil and 0.52 W/kg for the birdcage coil, it is very unlikely that the subject's eye will experience excessive RF heating.

The result from this study is a conservative estimation because (a) the coil conductor can be positioned further away from subject face by using more ergonomically designed coils; (b) the fact that 15 W was used for surface coil was partially because of the B_1 inhomogeneity; and (c) volume coils may use less power than what we predicted because the decoupling sequence is expected to be more effective when B_1 field is homogeneous.

Therefore, by taking the advantage of weak coupling for carboxylic/amide carbons, one can safely acquire proton decoupled ^{13}C spectroscopy in the human frontal lobe.

REFERENCES

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Fig 1a

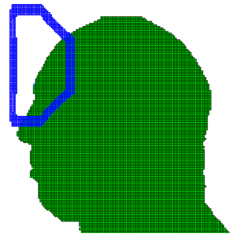
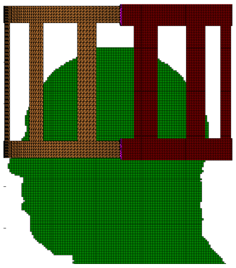


Fig 1b



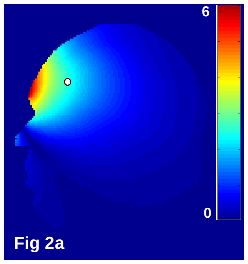


Fig 2a

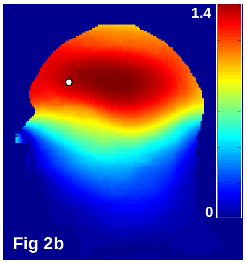


Fig 2b

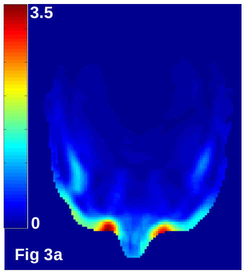


Fig 3a

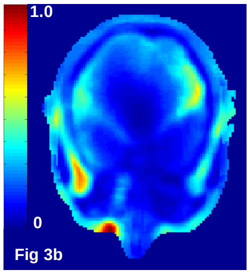


Fig 3b