Diffusion Tensor MRI Using High-Temperature Superconducting Tape RF coil

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Abstract

High-temperature superconducting (HTS) coil is one of the best ways to increase the signal-to-noise ratio (SNR). Bi2Sr2Ca2C3Ox (Bi-2223) tapes were suitable to use because of the easier fabrications and lower cost. In this study, we built the HTS Bi-2223 tape coil and showed that the SNR of using the HTS tape coil was 3 or 4 folds higher than the the copper coil. The accuracy of diffusion tensor imaging (DTI) highly depends on the noise level. Using HTS coil, we also demonstrated the capacity to save the accuracy of DTI in a reduced scan time significantly.

Introduction

With the property of the non-resistive conduction, high-temperature superconducting (HTS) coil is one of the best ways to increase the image signal-to-noise ratio (SNR) [1]. Most of the HTS RF coils were fabricated into films by YCBO materials, but the procedure was much complicated and cost much [2]. Different with the conventional HTS RF coil construction, Bi2Sr2Ca2C3Ox (Bi-2223) tapes showed the potential to MRI applications due to the easier fabrications and lower cost than HTS films [3]. In this study, we built the HTS RF tape coil in the small animal system and demonstrated the capacity by using the HTS tape coil in the diffusion tensor imaging (DTI), which needs enough SNR to maintain the orientation accuracy.

Materials and Methods

In order to test the capability of the HTS RF tape coils, both copper and Bi-2223 were used to be the surface coil with the same size. The Bi-2223 tape was bent into a simple circle loop. A non-magnetic capacitor with high Q (>2000) is soldered directly at both ends of the tape to form a LC resonant loop. Differ from the capacitor tuning and matching circuit used in the copper surface coil, mutually inductive coupling between the HTS receiver and the pick-up coil was used [5]. In figure 1a, L1 is the matching coil inductance and L2 is the surface coil inductance, the input impedance (1), where $Zin \cong j\omega L1+(\omega k L1 Q/(1+2jQ(\delta\omega/\omega_c)))$ k is the coupling constant. In order to create the pure resistive impedance $\omega_c = 1/\sqrt{L2C2}$ of 50 ohm at Larmor frequency, the coupling constant k must be set as the appropriate value and has to be offset from the Larmor frequency to compensate the reactance created by the inductive loop. A trimmer capacitor was used in the signal pick-up loop (figure 1a) and tuned to the value $C1 = 1/\omega_0^2 L1$, so that the imaginary part in Zin from equation (1) was cancelled out of the resonant frequency. Thus pure resistive impedance $Zin = Qk^2\omega_0 L1$ could be generated at the coil resonance. We use the above method to design our experiment setup (figure 1b).

MR experiments were performed on the Bruker Biospec 3T system (Bruker, Germany). The HTS tape coil and copper surface coil were made in 4 cm diameter. All images were acquired by using the fast spin echo sequence with TR/TE = 1000/0 ms. The in-plane resolution was 234 um and the slice thickness was 2 mm. SNR between the cortical regions and the background noise of both images were calculated to compare the performance of HTS and copper coil. In diffusion tensor imaging (DTI) acquisition, diffusion sensitizing gradients were applied along six directions: {{1, 1, 0}, {1, 0, 1}, {0, 1, 1}, {-1, 1, 0}, {0, -1, 1}, {1, 0, -1}} with the maximal diffusion-encoding sensitivity b = 2350 s/mm2. TR and TE of the diffusion-weighted images were 1000 and 34.7 ms. the diffusion gradient duration and the diffusion time were 10 and 17 ms. DTI reconstruction was based on the method proposed by Basser [7].

Results

The comparison of rat brain images from HTS tape and copper coils were shown in figure 2, where a represents the image acquired from HTS tape coil in 77k and b represents the image acquired from the copper coil in the room temperature. The SNR of using the HTS tape coil was 120, 4 folds higher than that of using the copper coil, which is 30. We could find more detailed structures revealed in the image of using the HTS tape coil. DTI reconstruction was shown in figure 3. With the same SNR as conventional used diffusion-weighted image sequence, organized cerebral cortex structures, corpus callosum and the hippocampus regions were revealed in a reduced scan time significantly.

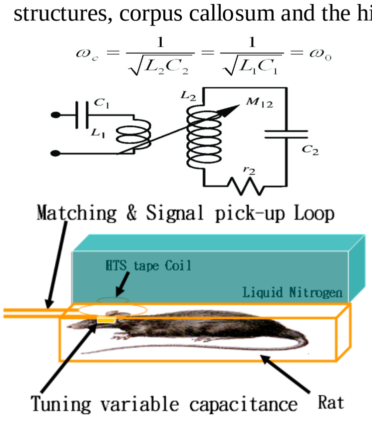

Figure 1 a) addition of the trimmer capacitor and b) the system setup of the rat experiment, where the tuning capacitor loop and pick-up coil were put in the middle of the HTS tape coil and

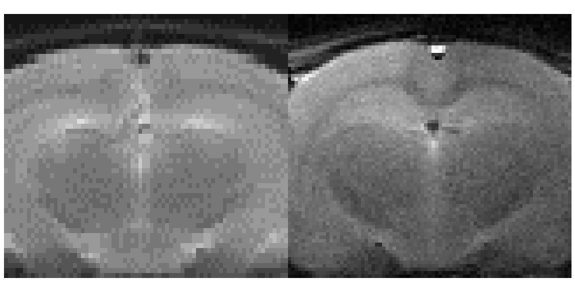

Figure 2 images acquired from HTS tape coil and the copper coil were shown in a and b, respectively. SNR of a was 120, and SNR of b was 30. The SNR using HTS tape coil was 4 folds higher than using copper surface coil.

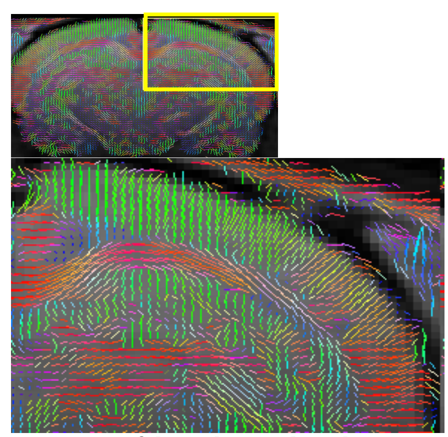

Figure 3 DTI of the rat brain, where the organized cerebral cortex structures, corpus callosum and the hippocampus were shown in the enlarged image.

Conclusions

In our results, we showed that the HTS tape coil could improve the image quality significantly. The advantages of the Bi-2223 tape were easy to fabricate and with less cost. The implementation of HTS tape coil in the DTI study was also demonstrated and the reasonable results could be obtained in a significantly reduced scan time. In the future, one dedicated holder of the HTS tape coil will be built to provide more stable performance and functional MRI studies will also be applied to test the capability of the HTS tape coil.

References

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