First in vivo imaging of the mouse brain at 4.7 T using a subcentimeter HTS surface coil

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Introduction

The use of a small surface coil is a way to increase the MR signal due to stronger magnetic coupling between the coil and the sample. Additionally, it filters out the RF noise from the rest of the body, leading to a large potential increase of the local signal-to-noise ratio (SNR). However the noise arising from the RF coil itself sets a limit to the gain available from the coil miniaturization [1]. Designing a 12-mm high-temperature superconducting (HTS) surface coil that features extremely low intrinsic noise have been shown to dramatically improve the SNR for in vivo mouse brain at 1.5 T, by more than an order of magnitude as compared to a room-temperature copper coil of similar geometry, which allowed to reach spatial resolutions of 60 μm in a clinical MRI unit [2]. For field strengths of 4.7 T and above, cryocooled probes based on normal coil conductors at 30 K have been commercially developed and afford SNR gain factors of 2-4 [3]. Only few studies relate sensitivity improvement using superconducting coil at high fields and concern only non conductive and small samples, for which SNR gain are highly significant due to the absence of sample noise [4-8]. A particularly challenging issue with HTS coils for in vivo applications at high field is the design of sub-centimeter coils in order to achieve SNR gains overcoming the limits of normal conducting cryocooled probes. In this work the design and implementation of a HTS surface coil of 6 mm mean diameter, dedicated to in vivo imaging of the mouse at 4.7 T, is proposed, and the first in vivo mouse brain images are demonstrated.

Materiel and Method

According to [1] as B0 increases sample losses increase more rapidly than coil losses. In order to benefit from the high sensitivity of HTS coil at 4.7 T the coil diameter has to be decreased less than 12 mm which is the optimized coil size used at 1.5 T. To determine the optimal size of the coil for in vivo application at 4.7 T we evaluated the different noise sources. The expected SNR gain is then calculated, for a HTS coil operated at 80 K, compared to a room temperature (RT) copper coil with the same geometry and using a semi infinite phantom with 0.66 S.m conductivity. This evaluation shows that the use of a 6 mm diameter HTS coil may yield the same SNR gain (of about 6) than the one obtained with a 12 mm diameter HTS coil at 1.5 T. The SNR of an MR image can be expressed for a given RF coil geometry as a function of Ql and Qc, the loaded and unloaded quality factors of the RF coil, respectively, and Tl, Tr, the RF coil and sample temperatures, respectively and Fc, the receiver channel noise factor [2,9] (eq. 1). Matching was adjusted to 50 Ω at an RF source level of ~30 dBm, low enough to observe a linear response with the HTS coil. The quality factors Ql and Qc were extracted during this step using swept-frequency analysis of the RF coil impedance. The equivalent noise temperature of the receiver coil was evaluated using a spectrum analyser (Agilent-AS-N9000A). The identical HTS and copper surface coils were operated at 80 K and 298 K, respectively. Their design was a five-turn transmission line resonator with 6 mm diameter. Both HTS and copper coils were used in transmit/receive mode inductively coupled to the RF preamplifier. The HTS coil was mounted in a dedicated nitrogen cryostat cooled to 80 K as demonstrated in [11].

Results

The measured SNR gain in imaging the non-conductive, and the conductive phantoms using the HTS coil and the copper coil are of about 4.7±0.97, and 3.8±0.92 in good agreement with the ones expected from eq. 2 and Q measurements (table 1) of 4.6, and 3.1 accounting for a Fc of 12.6 (11 dB). Typical in vivo data acquired with the HTS coil are displayed in figure 1 for different anatomical mouse sites.

Conclusion, discussion and perspectives

This is the first report of in vivo imaging using a subcentimeter cryocooled surface coil at 4.7 T. Complete RF characterization of the coil (Ql, Qc) and the receiver channel (Fc,ω) combined with a theoretical model [2,9] allowed the validation of SNR gains. The SNRgain for the mouse brain was about 4, so according to [10] the images shown in the present work are equivalent to those that could be obtained with a RT copper coil at 18 T. Moreover the image SNR is mainly limited here by the poor noise figure of the receiver channel, due to a problem encountered with our T/R switch device in these first experiments. Assuming a better device with a total noise figure of 1 dB, the SNR gain is expected to be as high as 5.4 and the image SNR will improved by a factor of 10 compared to the preliminary images presented here. Finally, an additional gain of 1.5 in SNR might be obtained by decreasing temperature of the HTS coil by 14 K from 80 K as demonstrated in [11].

Table 1: Quality factors of the HTS coil and the copper coil as a function of the load. The expected SNR gain of the HTS coil compared to the copper Table 1: Quality factors of the HTS coil and the copper coil as a function of the load. The expected SNR gain of the HTS coil compared to the copper


Acknowledgement: We thank Bruker Biospin for granting a PhD application related to this work.

Figure 1: In vivo Axial (A) and Sagital (B) MR-images of the mouse brain made with the HTS coil.