Small animal large field of view magnetic resonance imaging with metamaterial-inspired resonator

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Abstract. Large field of view magnetic resonance imaging is often required during small animal imaging to cover the entire body of an animal. Large field of view imaging should nevertheless be performed with sufficient signal to noise ratio and resolution. A combination of large signal to noise ratio and high resolution is usually achieved via using small loop coils with small field of view, which is inapplicable in case whole animal or a large portion of its body needs to be imaged. Here, a metamaterial-inspired coil based on an array of parallel wires is employed to perform large field of view imaging. A number of mice are imaged in a 7 T preclinical magnetic resonance scanner. Properties of the resulting images are compared to the ones acquired with commercial coil designated for whole-body imaging as well as a with a commercial small loop antenna designated to provide high signal to noise ratio images in a limited area. The signal to noise ratio is compared between the coils in different tissues and on different distances from the metamaterial-inspired coil plane. The coil is found to provide signal to noise ratio a few times higher than the commercial coil in the optimal reception region and comparable signal to noise ratio off the optimal observation region. The metamaterial-inspired coil is also shown to provide rivaling signal to noise ratio in small field-of-view application, when compared to a small-region loop coil.

1. Introduction

Some application in preclinical magnetic resonance imaging (MRI) require acquisition of large field of view (FoV) images of small animals (e.g., angiography [1], fat quantification [2], contrast agent or drug delivery [3-5]). In order to obtain a large FoV image an animal should either be placed in a receiver or transceiver coil covering the required area of interest (usually, a birdcage coil) or sequentially scanned with small surface loop coils. The first approach allows large FoV imaging at the cost of low signal to noise ratio (SNR), the latter leading to low image quality, longer acquisition and increased chance of image inaccuracies induced by physiological motion. The second approach provides higher SNR, but requires multiple scans to cover the entire animal body due to smaller FoV of a single scan, thus leading to multifold experiment time increase.
This work aims to show the possibility of combining both the large receptive field and high SNR in single-channel preclinical imaging by using a metamaterial-inspired coil. Such medium-sized flat coil should have both high radiofrequency field homogeneity and high sensitivity, allowing it to compete with large volume coils and small coil arrays.

2. Methods
The metamaterial-inspired coil was fabricated for a 300 MHz MR-scanner employing an array of six parallel telescopic tubes connected at both ends to copper patches on a dielectric substrate with a common ground plane at the opposite side of the substrate. A 40-mm diameter feeding loop was used to excite the lowest order eigenmode of the manufactured resonator, having the most homogeneous magnetic field distribution at the scanner transmitter frequency. The structures were held together by a 3D-printed holder. A more detailed description of the coil structure and its operation principles is presented elsewhere [6].

In-vivo large FoV imaging was performed on a 7 T Bruker BioSpec 70/30 USR (Bruker BioSpin GmbH, Germany) horizontal 200 mm bore scanner. These experiments were carried out in the Centre for Collective Usage “Biospectrometry” supported by the Faculty of Fundamental Medicine of Lomonosov Moscow State University, Moscow, Russia. Images of 2 outbred mice BALB/c of age 5-6 months and weight 35-40g were acquired. Experimental procedures were conducted in accordance with the European Community Council directives 2010/63/EU and were approved by the local institutional animal ethics committee. Animal body motion was reduced by providing isoflurane via face mask during the whole scanning procedure. Three type of coils have been used: first mouse was scanned with a RF RES 1H T6594 birdcage coil and metamaterial-inspired coil. Second mouse was scanned with the latter coil as well as with a rat-brain receive-only surface coil. Excitation in the latter case was provided by the RF RES 300 1H/13C T10334 72 mm birdcage coil.

The imaging sequence for large FoV imaging was 2D SE with the following scan parameters: FoV = 40×100 mm², matrix = 200×200, slice thickness = 1.5 mm, flip angle= 90°, refocusing flip angle = 180°, TR = 800 ms and TE = 14 ms. Additionally, small FoV kidney images were acquired with all the aforementioned coils using a similar pulse sequence with scan parameters FoV = 40×30 mm², matrix = 266×200, slice thickness = 1 mm, flip angle= 90°, refocusing flip angle = 180°, TR = 800 ms and TE = 13.64 ms. In an experiment, where small FoV image was acquired with a small surface coil TE was changed to 14.34 ms due to longer refocusing pulses required to produce a 180° rotation.

3. Results
The mouse in-vivo large FoV images obtained with all coils allowing large FoV imaging are presented in Figure 1. In order to compare the coils, SNR was measured in three sets of images presenting the whole mouse body as well as in the focused small FoV mouse kidney images. The SNR values were calculated as the ratio of the mean intensity values in muscle tissue (or kidney parenchyma in the case of targeted kidney imaging) to the standard deviation of the intensity values in the tissue-free region. Intensities from 4 muscle/kidney regions per image were averaged for mean signal calculation and variances from 4 tissue-free regions were averaged for mean noise calculation. The results for large FoV and targeted kidney imaging are presented in Table 1 and Table 2 correspondingly.
Figure 1 Large FoV images obtained in two scanning sessions with metamaterial-inspired coil and commercially available birdcage coil. Top row: mouse one, metamaterial-inspired coil. Middle row: mouse two, metamaterial-inspired coil. Bottom row: mouse two, birdcage coil.

Table 1 SNR measurements summary in muscle tissue for large FoV imaging with metamaterial-inspired coil and birdcage coil.

| Slices (ventral to dorsal) | Metamaterial-inspired coil (Mouse 1) | Metamaterial-inspired coil (Mouse 2) | 154 mm birdcage |
|---------------------------|--------------------------------------|--------------------------------------|-----------------|
|                           | 3                                    | 55 ± 5                               | 36 ± 3          |
|                           | 4                                    | 54 ± 9                               | 33 ± 4          |
|                           | 5                                    | 65 ± 6                               | 85 ± 9          | 33 ± 2          |
|                           | 6                                    | 99 ± 11                              | 84 ± 9          | 33 ± 2          |
|                           | 7                                    | 67 ± 10                              | 63 ± 7          | 35 ± 3          |
|                           | 8                                    | 65 ± 6                               | 85 ± 9          | 33 ± 2          |
|                           | 9                                    | 96 ± 9                               | 101 ± 9         | 24 ± 8          |
|                           | 10                                   | 118 ± 8                              | 112 ± 11        | 30 ± 3          |
|                           | 11                                   | 97 ± 9                               | 75 ± 19         | 30 ± 2          |
|                           |                                      | 88 ± 11                              | 73 ± 16         | 32 ± 2          |
Table 2 SNR measurements in mouse kidney tissue with different coils.

|                     | Mouse 1     | Mouse 2     |
|---------------------|-------------|-------------|
| Metamaterial-inspired coil | 19.7 ± 1.6  | 15.5 ± 2.1  |
| 154 mm birdcage      | 6.8 ± 1.6   | -           |
| Surface coil         | -           | 25.0 ± 4.1  |

As has been shown in two scanning sessions, field distribution of the metamaterial-inspired coil allows imaging the whole mouse torso with addition of either the head or the caudal portions of the mouse. The SNR measurements in the images from two sessions obtained with the metamaterial-inspired coil tend to fall within error limits of each other with some deviations resulting from different mouse positioning, physiological movement and varying slice location.

4. Summary

The SNR measurements presented in Table 1 show similar values for metamaterial-inspired and birdcage coils on the slices most distant from the metamaterial-inspired coil surface with over 300% SNR enhancement in the area of best reception. The small FoV SNR values show similar (about 290%) benefit of using the metamaterial-inspired coil, when compared to the birdcage coil. An expected superiority of the small loop antenna in small FoV imaging is also visible in SNR values in Table 2. Nevertheless, the metamaterial-inspired coil shows only 38% less SNR than a dedicated loop coil.

The measured SNR values show the metamaterial-inspired coil to be suitable for whole-body small animal imaging with SNR surpassing one of the birdcage coils. Additional small FoV experiments show the coil can also be used in multiresolution experiments, where images with different FoVs and spatial resolutions need to be acquired without mouse repositioning.

Acknowledgements

This work was supported by the Ministry of Education and Science of the Russian Federation (project No. 14.587.21.0041 with the unique identifier RFMEFI58717X0041). This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 736937

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