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# Organ specific mouse head coil for improved image quality in magnetic particle imaging

M. Graeser<sup>1,2,\*</sup>. T. Liebing<sup>1,2</sup>. P. Szwargulski<sup>1,2</sup>. F. Förger<sup>1,2</sup>. F. Thieben<sup>1,2</sup>. P. Ludewig<sup>3</sup>.  
T. Knopp<sup>1,2</sup>

<sup>1</sup>Section for Biomedical Imaging, University Medical Center Hamburg-Eppendorf, Hamburg, Germany

<sup>2</sup>Institute for Biomedical Imaging, Hamburg University of Technology, Hamburg, Germany

<sup>3</sup>Department of Neurology, University Medical Center Hamburg-Eppendorf, Hamburg, Germany

\*Corresponding author, email: [ma.graeser@uke.de](mailto:ma.graeser@uke.de)

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## Abstract

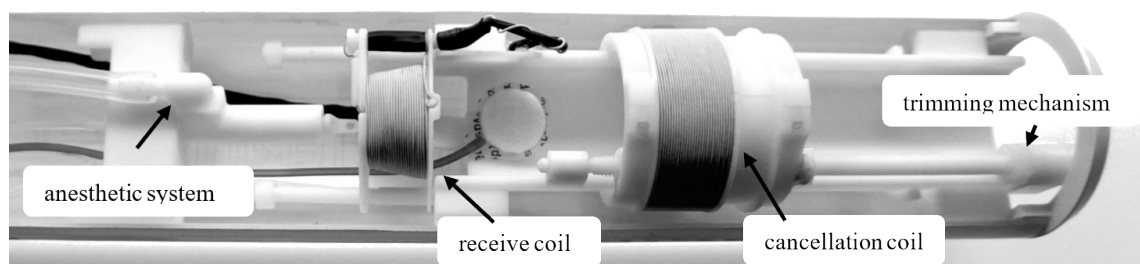
Magnetic particle imaging is a very useful tool in the detection of stroke. To study the ability of stroke in a mouse model the data acquisition is challenging as a mouse brain contains only a very small ratio of blood compared to large animals or humans. The effective concentration within the whole organ is therefore very small, especially compared to the heart or the liver. Typical MPI receiver coils however cover a sensitive region of around 30 mm to 50 mm and have a bore size of above 40 mm. This leads on the one hand to non-optimal signal coupling due to the distance to the particles and on the other hand strong signals from the heart can cause artifacts in the low signal regions. In this work we present a coil optimized for mouse brain imaging, which due to its small size, also dampens signal from regions outside of the coil.

## I Introduction

In Magnetic Particle Imaging (MPI) the received signal is broadband in nature [1]. This leads to a completely different coil design compared to Magnetic Resonance Imaging (MRI). On the other hand, in MRI many receiver coils designs have already been optimized in geometry and structure to improve signal coupling in the receiver. To match the corresponding resonance frequency, the coils are either trimmed in case of a flexible coil or are pre-tuned in case of rigid coils. In MPI, due to the broadband nature, no matching is performed. Nevertheless, the geometry optimization is advantageous as it improves the coil coupling with the contrast agent and reduces the coupling with the transmission path, thus improves the signal to background ratio. This becomes especially important in application scenarios, where very low perfused organs are imaged, e.g. a mouse brain. Although

successful experiments were performed, the image quality is not optimal as the low blood volume in a mouse brain leads to a very low effective concentration [2].

In this paper, a coil optimized to the head shape of a mouse is presented. It is built on a ridged coil support. As it should be as close to the head as possible, the coil is integrated within the animal support unit. However, the setup is too small to record a system matrix. Thus, the calibration data was recorded with a 40mm coil [3] and was corrected by the transfer function of the full receiver system. The same method was applied for the mouse head coil.



**Figure 1:** Implementation of the mouse head coil mounted within the animal support unit. The coil has a cone-like shape and is optimized for the size and shape of a mouse head. To decouple the system from the drive field, a second, solenoid shaped coil is added, which can be shifted while mounted in the scanner to find the optimal position.

## II Methods

### II.I Hardware

To acquire the optimal shape of the receiver coil, a digital mouse atlas was used (Digimouse: 3D Mouse Atlas) [4,5]. The dataset offers pre-segmented data files, which were used to generate a mesh model of a mouse in the construction software (SolidWorks, Dassault Systems). To match the average size of our mouse model, the dataset was scaled according to the body weight.

The mesh model was used to design the receiver coil shape and length. In the design two aspects were in the main focus. First, the closeness of the coil turns to the organ of interest and second limiting the sensitivity to this region of interest to avoid coupling with strong particle concentrations within hollow organs like the heart or large vessels. To study the animal handling the mouse mesh model was also printed using an FDM printer (Ultimaker 3, Ultimaker Ltd.).

To decouple the receive coil from the drive fields a second, solenoid-shaped coil was added in series which is located outside the field of view (FOV) (see figure 1). To ensure the reproducibility of the coil position within the scanner, the mouse head coil center was centered within the FOV with the help of a delta sample in the coil center. By image reconstruction of this sample using a 72 mm rat coil we center the coil position within the FOV. This position was marked via a limit stop for the rat support unit. Thus, whenever the system is inserted into the scanner the same relative position of the receive coil and the drive field coil is found.

### II.II Experiments

To evaluate the new coil two experiments were performed: First the sensitivity of the system was measured following the protocol presented in [3]. Here a dilution series was measured starting at 450 ng<sub>Fe</sub> and going down to 890 pg<sub>Fe</sub> using Perimag (micromod GmbH, Rostock) as tracer material. As a control, a measurement with only water was added to the dilution series. As gradient 2 T/m was used with 12 mT drive field in all spatial directions.

The data was averaged to resemble the same imaging speed as in [3] (2 s per frame).

Second, the brain perfusion of a healthy mouse (C57BL/6) was measured. Here, a bolus of 170 μg<sub>Fe</sub> (20 μl) was injected via the tail vein. The acquired image series were reconstructed using no averaging, a SNR threshold of 2, a regularization parameter of 0.02 and 10 iterations. After reconstruction the images were postprocessed to determine the perfusion parameter maps analog to [2].

## III Results

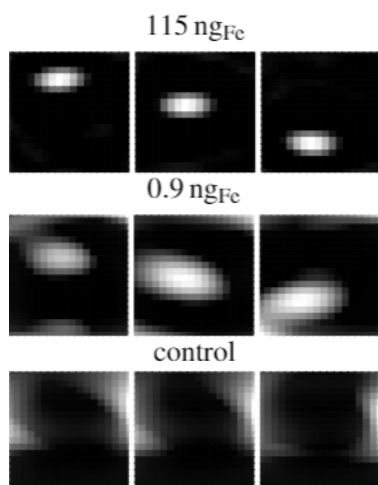
In figure 2 the results of the sensitivity experiment are shown.

Until a total iron content of 890 pg<sub>Fe</sub> the movement of the sample can be identified in the image. Thus, the sensitivity of the receiver system is in the picogram range. The total SNR improvement compared to our 40 mm bore coil is ~5.

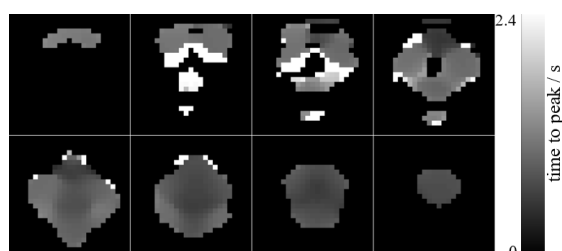
In figure 3 and 4 the results of the in vivo experiment as coronal sliced perfusion maps are shown. One can distinguish between the very short TTP values in the brain tissue and the long TTP values in the venous structure. In the relative cerebral blood volume (rCBV) values one can also see the lower blood volume for the brain tissue compared to the surrounding venous structure. Compared to former experiments the improved image quality and resolution allow a better interpretation of the data.

## IV Discussion and Conclusion

This work presented a first organ specific coil for magnetic particle imaging. Due to the vicinity of the coil to the region of interest three things have been accomplished. First the signal coupling with the region of interest is improved, second, the coupling with regions out of this area is damped and third, the coupling with the drive field is reduced. In this work, the coil body was rigid. For other organ types it might be optimal that the coil shape is adapted to the surface of the body. This however leads to a change of the receive coil inductance and in turn to

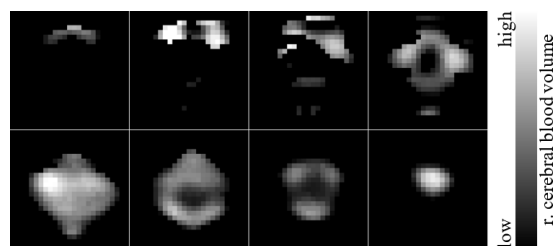


**Figure 2:** Sensitivity study. To test the systems sensitivity a sample was moved through the scanner to different positions and the corresponding image was compared to the sample position. As control an empty robot movement was recorded. The sensitivity of the system was measured to be in the picogram range.



**Figure 3:** Calculated time to peak (TTP) values for different coronal slices of the mouse brain. One can distinguish between the very short TTP values in the brain tissue and the long TTP values in the venous structure.

a non-static transfer function. In conclusion, it has been shown that surface coils have the potential to optimize the SNR leading to better image quality and resolution or lower iron dose for iron sensitive patients.



**Figure 4:** Calculated relative cerebral blood volume (rCBV) values for different coronal slices of the mouse brain. One can see the low blood volume for the brain tissue as a dark spot in the center of the images. In contrast the venous structure surrounding the brain provides capacitive accumulation of the blood resulting in a brighter spot in CBV values.

## Author's Statement

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## References

- [1] B. Gleich et al., Tomographic imaging using the nonlinear response of magnetic particles, *Nature*, 435, 1214-1217, 2005
- [2] Ludwig et al., Magnetic Particle Imaging for Real-Time Perfusion Imaging in Acute Stroke, *ACS Nano*, 11,10, 10480-10488, 2017
- [3] Graeser, M. et al. Towards Picogram Detection of Superparamagnetic Iron-Oxide Particles Using a Gradiometric Receive Coil. *Sci. Rep.* vol. 7 6872, 2017.
- [4] B. Dogdas et al., Digimouse: A 3D Whole Body Mouse Atlas from CT and Cryosection Data, *Phys. Med. Bio*, 52: 577-587, 2007.
- [5] D. Stout et al., Creating a whole body digital mouse atlas with PET, CT and cryosection images, *Molecular Imaging and Biology*.2002; 4(4): S27