Rapid 3D *in vivo* Magnetic Particle Imaging with a Large Field of View

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Introduction

Magnetic particle imaging (MPI) is a new tomographic imaging approach that quantitatively maps concentrations of iron oxide nanoparticle distributions [1]. It combines high sensitivity [2,3] with the ability of fast volumetric imaging. *In vivo* 3D real-time MPI of a bolus of particles flowing through the heart and lung of mice has been demonstrated [4], but with an imaging approach that is limited to small fields of view (FoVs). A new scanner type with a bore diameter of 12 cm allowing rapid imaging with larger FoVs has been developed [5]. This contribution presents initial *in vivo* rat measurements on the new system.
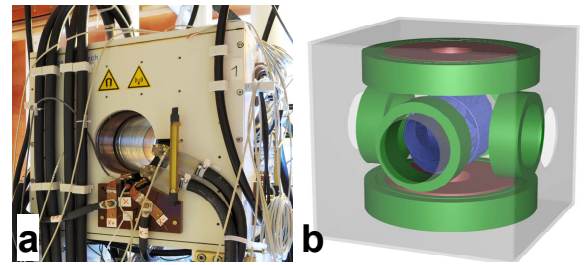

Figure 2: Fast MPI demonstrator with enlarged FoV. Photograph (a) and sketch (b) of field-generating unit, showing selection field magnets (red), focus field coils (green), and drive coils (blue).

Methods

MPI detects the non-linear response of iron-oxide nanoparticles to applied oscillating fields over a broad frequency range. Spatial encoding is achieved using a *selection field* that confines the signal to a small region, called the *field-free point* (FFP). The FFP is rapidly moved over a small volume using *drive fields*, allowing 3D spatial encoding. With this approach, a first MPI prototype was capable of 3D imaging at a rate of 46 volumes per second for a FoV of $16.8 \times 20.4 \times 12.0$ mm [4]. Larger imaging volumes would require higher drive fields, which could lead to patient heating in a clinical scenario. To overcome this problem, additional *focus field* (FF) coils have been integrated in a new preclinical demonstrator (PCD), cf. Fig. 1 [5]. The focus fields move the rapidly encoded small volume continuously or step-wise through space to increase spatial coverage up to $(10 \text{ cm})^3$. The selection field magnets generate constant gradients $dB_z/dz = 2.5$ T/m and $dB_x/dx = dB_y/dy = 1.25$ T/m and the drive coils apply sinusoidal fields with amplitudes $B_{Dx} = B_{Dy} = B_{Dz} = 11$ mT at frequencies 25.3, 26.0, and 24.5 kHz for the x, y, and z channel, respectively. These fields move the FFP in a dense pattern over a box-shaped imaging volume of $17.6 \times 17.6 \times 8.8$ mm³ with repetition time TR = 21.5 ms. Two *in vivo* scans have been performed on a rat, one with maximal temporal resolution and no FF and one with $3 \times 2 \times 2$ FF stations in the *x*, *y*, and *z* direction with shifts leading to a FFP volume coverage of $34.5 \times 24.3 \times 17.0$ mm³. At each FF station, two 3D trajectory cycles with duration 21.54 ms were performed, but only the 2nd one was used to allow for changing the FF during the 1st cycle. Thus, the 12 station sequence has a TR of 517 ms. In each TR, a full 3D image is encoded. During 5-minute scans, 4D data with several hundred volumes were acquired. Signal was received by a 3-channel insert coil with a length of 80 mm and a diameter of 65 mm. Iron oxide particles (Resovist, Bayer Schering Pharma AG, Germany) [6] were injected into the tail vein of an anaesthetized rat in two steps, each corresponding to a dosage of 280 µmol(Fe)/kg. After the MPI experiment, a T1-weighted TSE MRI scan was performed with a rat coil insert in a clinical scanner (Achieva 3.0T, Philips Healthcare, The Netherlands).
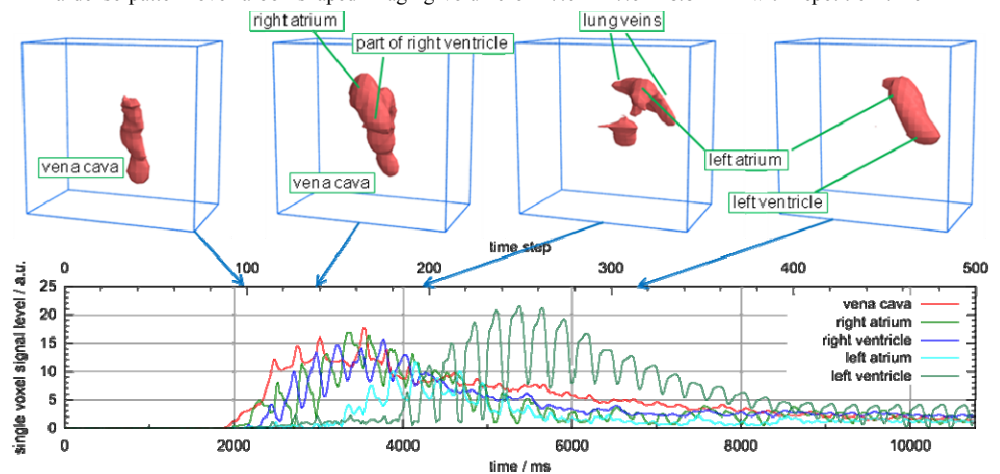

Figure 1: Single-station MPI of the iron-particle bolus passage through the rat heart. The upper row shows surface rendered views of selected MPI volumes at different points in time. The lower graph shows the signal evolution in selected voxels. The acquisition rate was 46 volumes per second.

Results and Discussion

Figure 2 shows surface rendered views of 4 selected volumes from a single station scan during the bolus passage through the heart. The compartments of the heart are visible, although the front part of the ventricles is missing, since it extends beyond the FoV. The lower graph shows the evolution of the signal level at selected voxels. The broad signal peaks, which are due to the bolus passage, are modulated with a frequency of 225 bpm, corresponding to the heart rate of the rat. Figure 3 shows overlays of the 12-station MPI images before and after the 2nd bolus injection on anatomical information obtained from MRI. Before injection (upper two images), signal from particles which accumulated in the liver after the bolus injection of the previous scan is visible. Shortly after the 2nd bolus injection (lower two images), the MPI signal shows the bolus flowing along the vena cava and entering the right atrium. Compared with the single-station sequence shown in Fig. 2, the FoV of this 12-station scan is large enough for covering the complete heart and a large part of the liver, however, at reduced temporal resolution.

Conclusion

3D MPI of large FoVs with a multi-station approach using focus fields has been demonstrated *in vivo*. While single-station scanning allows real-time imaging, a 12-station scan does not yet deliver the high temporal resolution required for cardiac imaging in a rat, but it allows particle localization over a large region of the body. Improvements on the scanner hardware are expected to increase sensitivity and speed, so that fast MPI using clinical dosages of Resovist (< 40 µmol(Fe)/l) should be feasible in the future.
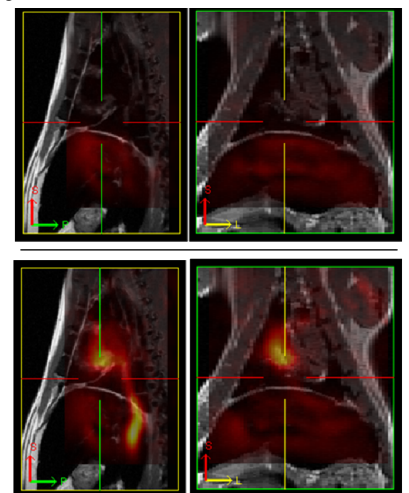
Acknowledgement

Figure 3: Overlay of 12-station MPI image on anatomical reference from MRI. Upper row: sagittal and coronal views showing liver signal from previous injection. Lower row: views showing signal from vena cava and right atrium after bolus injection.

References

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