3D hybrid Phantom Measurement: Validation of a fully integrated Preclinical 12 Channel Hybrid MPI-MRI Magnet System

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TARGET AUDIENCE This abstract is addressed to an audience interested in integrated hybrid imaging systems - especially the realization of hardware approaches as well as the data handling and fusion.

PURPOSE Magnetic Particle Imaging (MPI) is a novel tracer-based imaging modality allowing electro-magnetic detection of the spatial distribution of superparamagnetic iron oxide (SPIO) nanoparticles *in vivo* in three dimensions and in real time [1]. However, MPI lacks the detection of morphological information which makes it difficult to unambiguously assign spatial SPIO distributions to actual organ structures. Merging the quantitative spatial SPIO distribution from MPI with the corresponding morphological image, e.g. acquired with an MRI scanner, has been shown to be a promising approach in *in vivo* examinations [2]. Hybrid systems comprising MPI and MRI have been proposed in [3-5]. This work reports about the system design and first MPI-MRI images acquired with a fully integrated hybrid system [3] that allows subsequent preclinical MPI and MRI without the need of any intermediate object repositioning .

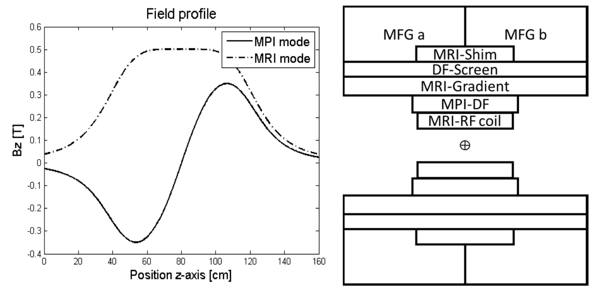

Fig. 1: a) Magnetic profiles generated by the MFG in the MRI and MPI operation modes. **b)** Sketch of the MFG cross section depicting the concentric and symmetric 12-channel coil topology.

METHODS **Hybrid Magnetic Field Generator (MFG):** The substantially different magnetic field properties required for MRI and MPI can be generated sequentially by a dedicated 12 channel MPI-MRI hybrid magnet system that allows switching the MFG between two magnet coil operation modes. The main MFG was constructed as split solenoid-like coil. Operation in a Helmholtz-like coil configuration generates a homogeneous B_0 field of approx. 0.5 T, while the Maxwell-like operation mode allows generation of the so-called Selection Field (SF) which features a high magnetic field gradient of G_z=2.2 T/m generating the so called Field Free Point (FFP) (c.f. Fig. 1a). Additionally, the MFG is equipped with a 2^{nd}-order MRI shim coil set, a 3D MRI gradient coil, a 3D MPI Tx/Rx Drive Field (DF) coil and a MRI radio frequency Tx/Rx coil (c.f. Fig. 1b). All coordinate defining coils are arranged in a symmetric and concentric setup, featuring the same Field of View (FoV) center for both modalities. This MPI-MRI hybrid scanner was used to image the phantom shown in Fig. 2a sequentially with both modalities. **Phantom:** To prove the FoV center and size conformance of both modalities, a tubular spiral phantom (c.f. Fig. 2 a) has been prepared ($tube_{ID}$=3mm, $spiral_{ID}$=18mm, $spiral_{OD}$ 21mm, winding distance≈2-4mm). **MPI measurement:** The described phantom was filled with RESOVIST® diluted to 4.8$\%_{vol}$ (23.8 µmol(Fe)/l) and placed in the iso-center of the MFG. The MFG was adjusted to a SF gradient of G_z=2.2 T/m and DF amplitudes regulated to 10/10/8 mT (x/y/z). 20 repetitions without initial averaging (AVG) were executed for MPI data acquisition. **MPI image reconstruction:** Using ParaVison6® (Bruker BioSpin MRI), a system function based MPI image reconstruction (Kaczmarz [6], $\lambda=10^{-9}$, 11 iterations, Signal-to-Noise frequency component selection ($SNR_{threshold}$=3), AVG=20, total acquisition time of 420 ms) resulted in a 3D image (FoV: 40x40x20 mm³, Matrix size: 25x25x20 voxel). **MRI measurement:** Firstly, T1 standard sample fluid (CuSO4+2H2O (1g/l)) was flushed *in situ* into the spiral tube phantom. The modality transition was achieved within less than 2 minutes and comprised minor recabling as well as MFG mode switching including field ramping up to B_0=0.5 T. A 3D Multi Slice Multi Echo (MSME) sequence (TE/TR=4.5/400 ms, Matrix size=32³, FoV=32³mm³, AVG= 4, total acquisition time of 27 min) was used right after automatic iterative B_0 shimming (1^{st} and 2^{nd} order), frequency adjustment and RF pulse reference power adjustment.

RESULTS The reconstructed MPI and MRI data can be seen in Fig. 2b and 2c, respectively, using volume rendering (VR) for 3D data visualization via PMOD 3.5 (PMOD Technologies Ltd). Fig 2d depicts the VR of the fused MPI-MRI hybrid data.

Discussion With this initial phantom study it has been proven that a fully integrated hybrid MPI-MRI scanner design allows sequential subject measurement with MPI and MRI. The concentration of RESOVIST is not detectable in MRI, but clearly shows up in MPI indicating the usefulness of this hybrid combination. Neither subject repositioning, linear data translation nor elastic registration was necessary for image data fusion.

CONCLUSION With this positive outcome, the feasibility study will pave the way for clinical MPI-MRI hybrid scanners, allowing enhanced diagnostics with the new imaging technology MPI combined with the complementary and well known capabilities of MRI generating morphological and functional data. Streamlining the modality transition phase will allow higher scan efficiency.

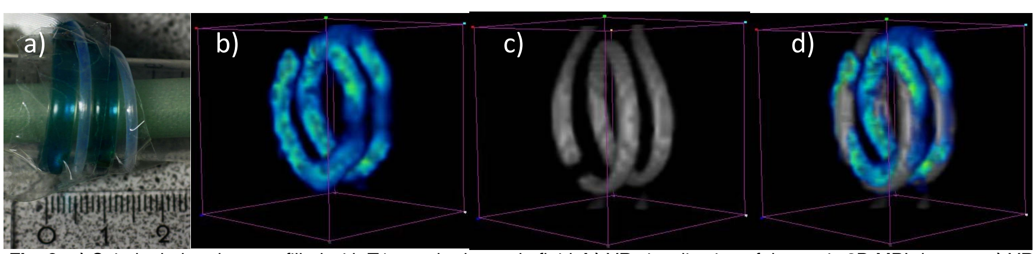

Fig. 2: a) Spiral tubular phantom filled with T1 standard sample fluid; **b)** VR visualization of the static 3D MPI dataset; **c)** VR visualization of the static 3D MSME MRI dataset; **d)** fused MPI and MRI VR data.

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