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Realtime iMPI-guided PTA with a lightweight human-sized MPI scanner

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Abstract

Based on a novel open design implementing the so-called traveling wave MPI approach, the open interventional MPI (iMPI) system provides imaging of tracers based on superparamagnetic iron oxide nanoparticles (SPIONs) with high sensitivity, optimal patient handling and would even allow hybrid imaging of magnetic tracers within gold standard x-ray based interventional angiography systems. In initial experiments, the feasibility of a human-sized interventional MPI scanner with real-time data reconstruction and image visualization is demonstrated with a percutaneous transluminal angioplasty (PTA) in a realistic human-sized phantom.

I. Introduction

Magnetic Particle Imaging (MPI) has become a promising tomographic method for multiple applications in biology, chemistry, medicine and physics [1]. Especially for cardiovascular medicine MPI has grown to an applicable radiation-free option for endovascular interventions supporting the common x-ray standard (digital subtraction angiography – DSA). Since MPI could demonstrate its potential in multiple studies using pre-clinical scanners [2, 3, 4], in a next step, this technique has to be scaled up to human sizes [5, 6, 7].

In this abstract, initial results of an MPI-guided PTA (percutaneous transluminal angioplasty) using a dedicated human-sized MPI scanner for human leg is presented. The novel scanner setup is based on the Traveling Wave approach utilizing a field free line (FFL) providing real-time projection imaging of a large FOV.

II. Material and methods

The aim of the interventional MPI scanner (iMPI) is to provide a radiation-free system comparable to the clinical gold-standard DSA [7]. This requires spatial resolution in the range of millimeters, high temporal resolution, near real-time visualization, and an open design that provides a comfortable and flexible environment for patients and medical staff, as well as sufficient space for interventional instrumentation and its operation.

II.I. iMPI scanner hardware

To provide a sufficient magnetic field gradient, which is required for a high spatial resolution in MPI, a novel hardware approach is used to generate and move dynamically a field-free line (FFL) within a specific region along specific trajectories. The result is projection display comparable to DSA, e.g., of vascular structures and

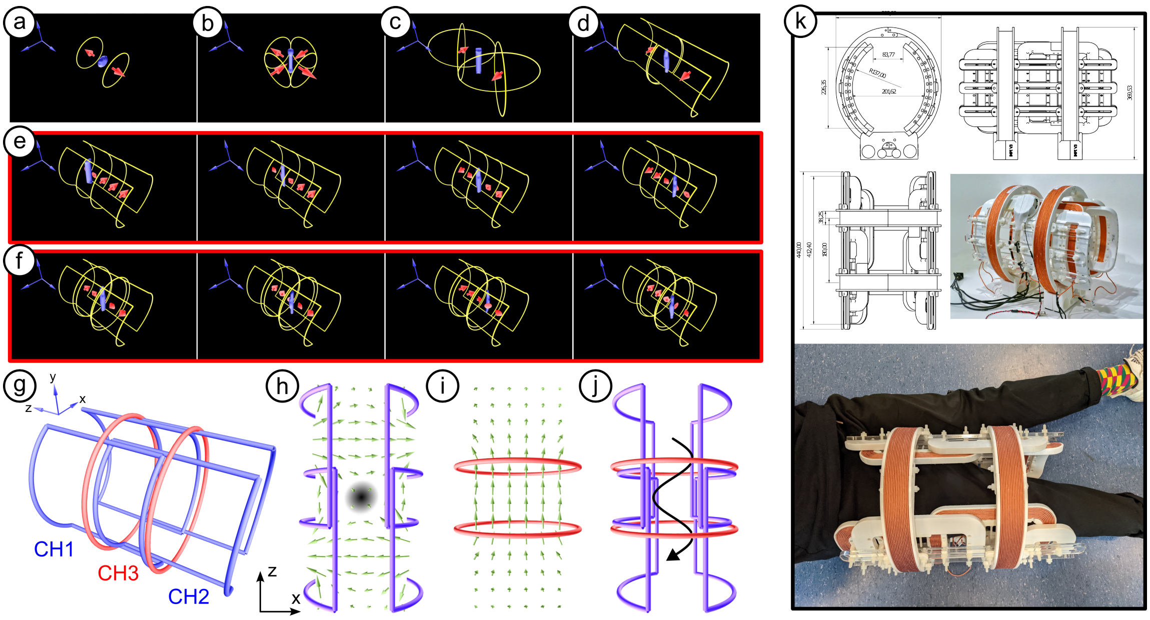

Figure 1: (a)-(f)From FFP to FFL: iMPI scanner evolution. (g)-(j): The final setup provides two saddle-coils for generating the main gradient field (FFL) traveling along the symmetry axis (traveling Wave approach). Additional solenoids (CH3) are used to deflection of the FFL to cover the entire FOV. (k) Dimensioning of the iMPI scanner and images from the real setup.

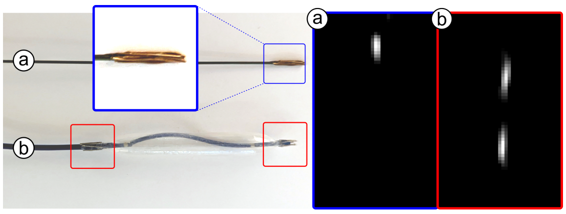

Figure 2: MPI visible instruments: (a) show the guide-wire and (b) the marked balloon. The size of the FOV is 10×25 cm².

stent positioning. Figure 1 indicates the concept behind the iMPI scanner.

II.II. MPI visible instruments

For percutaneous transluminal angioplasty (PTA), multiple instruments are required for treatment. Figure 2 shows two important instruments, which have been marked with a MPI visible material to be visible within an MPI scanner.

II.III. Flow phantom preparation

The basic structure of phantom used for this study is a tube with inner diameter of about 10 mm. The meshed 3D model has been 3D printed using a highly flexible material (Elastic 50A resin, Formlabs, USA) with an SLA printer (Form3, Formlabs, USA). With this technique, the watertight phantom can be directly used within a pumped-flow setup emulating pulsatile blood flow [11].

For emulating a removable stenosis, a clip is attached around the vessel structure, which can be removed by inflating the balloon inside the vessel during PTA.

II.IV. Image reconstruction

The interventional human-sized MPI scanner (iMPI) provides rapid projection imaging with a field of view (FOV) of about 20×25 cm² [7]. The generated field-free line (FFL) with a gradient strength of about 0.4 T/m is steered on a sinusoidal trajectory through the FOV with frequencies f_1=60 Hz and f_2=2,480 Hz. Each image has been acquired within 50 ms and reconstructed using image-based system matrix approach [8, 9].

III. Results and discussion

For demonstration, an MPI-guided PTA has been performed under realistic conditions within the catheter lab with real-time imaging up to 8 frames per second. Figure 3 indicates each step of the treatment.

The spatial resolution in this system working at 0.4 T/m is in the range of 5 to 10 mm [7]. As mentioned, a spatial resolution of 1 mm is desired. Since the power consumption of human-sized MPI scanners is the major limiting factor (here about 40 kW), there are more sophisticated approaches for figuring out desired information, e.g., using the signal intensity method for stenosis grading [10].

The MPI visible material used for the instruments

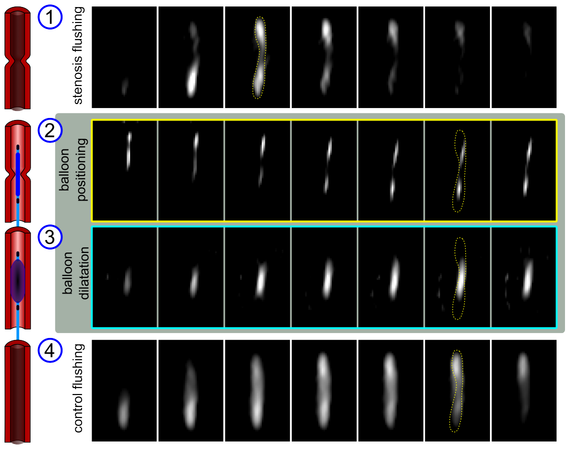

Figure 3: iMPI real-time visualization of an MPI guided PTA. First row: In a first step, the location of the experimental stenosis (grade of stenosis 70%) was determined by injecting a 1 ml Perimag bolus in the pumped-flow setup (Magnetic Particle Angiography – MPA). Second row: Balloon positioning was visualized by MPI-visible markers attached before and after the catheter-mounted balloon. Third row: Balloon dilation of the stenosis was performed by inflating the balloon catheter with Perimag. Forth row: A second MPA visualized the successful treatment of the stenosis. The size of the FOV is 10×25 cm².

is based on a magnetic wire, which is attached at the instrument tips.

IV. Conclusions

A first human-sized projection MPI scanner for interventional treatment of human-sized legs has been designed and built. Using a novel approach, this human-sized TWMPI design is portable and provides the possibility of further up-scaling.

In initial experiments, the feasibility of an MPI-guided PTA under realistic conditions within a human-sized sample could be shown. This shows promising results to pave the way to clinical routine.

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Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study.

References

[1] B. Gleich, & J. Weizenecker, *Tomographic imaging using the nonlinear response of magnetic particles*, Nature, vol. 435(7046), pp. 1217–1217, 2005

[2] S. Herz & P. Vogel et al., *Magnetic Particle Imaging guided real-time Percutaneous Vascular Angioplasty: A phantom study*, Cardiovasc Intervent Radiol, vol.41(7), pp. 1100-5, 2018

[3] S. Herz et al., *Magnetic Particle Imaging-Guided Stenting*, J Endovasc Ther, vol. 26(4), pp.512-9, 2019

[4] A. Neumann et al., *Recent developments in magnetic particle imaging*, JMMM, vol. 550:169037, 2022

[5] E. E. Mason, et al., *Design analysis of an MPI human functional brain scanner*, Int. J. Magn. Part. Imaging, vol. 3(1):1703008, 2017

[6] M. Graeser et al., *Human-sized magnetic particle imaging for brain applications*, Nature Comm, vol. 10:1936, 2019.

[7] P. Vogel et al., *iMPI – portable human-sized Magnetic Particle Imaging Scanner for real-time endovascular Interventions*, PREPRINT (Version 1) available at Research Square doi:10.21203/rs.3.rs-2294644/v1, 2022.

[8] P. Vogel et al., *Flexible and Dynamic Patch Reconstruction for Traveling Wave Magnetic Particle Imaging*, Int J Magn Part Imag,, vol. 2(2):1611001, 2016

[9] P. Vogel et al., *Low Latency Real-time Reconstruction for MPI Systems*, Int J Magn Part Imag, vol. 3(2):1707002, 2017

[10] S. Herz et al., Magnetic Particle Imaging for quantification of vascular stenoses: a phantom study, *IEEE Trans Med Imaging*, vol. 37(1), pp. 61-67, 2018.

[11] T. Reichl et al., *Highly Flexible Human Aneurysm Models for Realistic Flow Experiments with MPI and MRI*, Int J Mag Part Imag, vol. 8(1): 2203035, 2022.

