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iMPI-guided angiography in a human cadaveric perfusion model

P. Vogel[a,d,*] · M. A. Rückert[a] · J. Günther[a] · T. Reichl[a] · T. Kampf[a,b] · P. Gruschwitz[c] · A. M. Augustin[c] · J.-P. Grunz[c] · F. Kleefeldt[f] · D. Peter[g] · S. Ergün[f] · T. A. Bley[c] · V. C. Behr[a] · S. Herz[c,e] · V. Hartung[c]

[a]Department of Experimental Physics 5 (Biophysics), Julius-Maximilians University, Würzburg, Germany
[b]Department of Diagnostic and Interventional Neuroradiology, University Hospital, Würzburg, Germany
[c]Department of Diagnostic and Interventional Radiology, University Hospital, Würzburg, Germany
[d]Pure Devices GmbH, Rimpar, Germany
[e]Radiologie Augsburg Friedberg, Augsburg, Germany
[f]Institute of Anatomy and Cell Biology, Julius-Maximilians University, Würzburg, Germany
[g]Department of General, Visceral, Transplant, Vascular and Pediatric Surgery, Center of Operative Medicine, University Hospital Würzburg, Würzburg, Germany
*Corresponding author, email: Patrick.Vogel@physik.uni-wuerzburg.de

Abstract

This study investigates the use of a portable, human-sized Magnetic Particle Imaging (MPI) scanner in a human cadaveric perfusion model for real-time vascular imaging. Combined with X-ray Digital Subtraction Angiography (DSA), MPI demonstrated high temporal resolution, enabling continuous monitoring of blood flow. MPI's radiation-free nature offers advantages for certain clinical applications, positioning it as a promising tool for interventional radiology.

I. Introduction

Magnetic Particle Imaging (MPI) is an emerging tomographic technique that utilizes magnetic nanoparticles (MNPs) as tracers [1]. As background-free technology, MPI holds great potential for applications in vascular imaging, oncology, cell tracking, and localized hyperthermia [2]. Its rapid imaging capability makes it particularly well-suited for real-time endovascular procedures [3]. Recent developments, including the clinical approval of the contrast agent Resotran® and the introduction of human-sized MPI scanners, have set the stage for initial human applications [4,5,6,7]. This study evaluates the performance of a portable, human-sized MPI scanner in a human cadaveric perfusion model [8], simulating real-world vascular imaging scenarios and assessing MPI's potential for clinical use.

II. Methods and materials

II.I. Cadaveric perfusion model

To simulate clinical conditions, human cadaveric specimens with extracorporeal perfusion were used [8]. Arterial access was established through the femoral and popliteal arteries, creating a flow circuit that enabled manual injections of contrast and tracer agents. An artificial blood flow was realized using a pump.

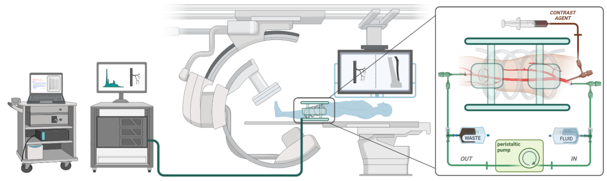

Figure 1: Schematic of the angiography lab setup, showing the I/O periphery and AMP cabinet positioned on trays, the ceiling-mounted C-arm X-ray unit, and the patient table with the body donor. The perfusion circuit and MPI scanner are illustrated on the right.

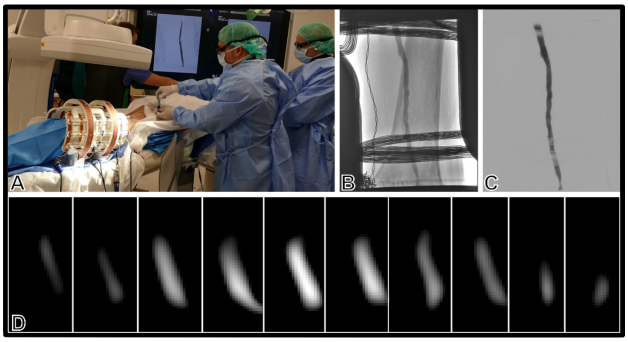

Figure 2: **A:** Operators administering a tracer-contrast agent mixture for simultaneous acquisition of DSA and MPI images. **B:** Non-subtracted angiogram showing the shared 12 cm x 8 cm field of view for both DSA and MPI, with the X-ray window limited by the scanner and overlaid receive coils. **C:** **D**igital **S**ubtraction **A**ngiography illustrating the realistically perfused superficial femoral artery at 1 fps. **D:** Series of MPI frames captured over 2 seconds at 5 fps after injecting 1.6 ml of Resotran® with 2 ml of iodine contrast. The contrast bolus's entry and clearance are clearly visualized.

II.II. iMPI scanner

The MPI scanner used in this study is a portable, human-sized scanner based on the traveling wave concept, utilizing field-free line (FFL) encoding [6]. The FFL is dynamically moved through the field of view (FOV), allowing for rapid projection imaging. Designed for vascular interventions at human extremities, the scanner features a 25 cm bore size. The scanner was positioned around the cadaver's thigh to visualize the femoral artery.

II.III. X-ray meets MPI

The hybrid setup also includes simultaneous operation with X-ray Digital Subtraction Angiography (DSA) for enhanced imaging in a clinical environment (Fig. 1). MPI utilized Resotran®, an MRI-approved contrast agent, and Perimag®, a well-established MPI tracer, while iodine-based contrast agents were used for the DSA images, creating a unique hybrid imaging system.

III. Results

The iMPI scanner was successfully operated on the human cadaveric model, demonstrating its feasibility for real-time vascular imaging (Fig. 2). The system produced high-temporal resolution images of the femoral arteries, enabling continuous monitoring of tracer flow. With an estimated spatial resolution of 5 mm, MPI was effective in detecting high-grade stenoses but had limitations in identifying smaller vascular branches or minor stenoses that were visible with DSA. The temporal resolution, reaching up to 10 frames per second, allowed precise tracking of tracer dynamics, which is crucial for real-time intervention procedures [9].

Importantly, the hybrid approach combining MPI and DSA highlighted their complementary strengths: DSA's spatial resolution provided detailed images of vascular structures, while MPI's real-time, radiation-free imaging enhanced the temporal visualization of blood flow. The signal-to-noise ratio (SNR) for Resotran® was 10.5, and for the optimized MPI tracer Perimag®, it was 23.7, indicating reliable image quality under clinical tracer conditions.

IV. Conclusion and discussion

Using a human cadaveric perfusion model provided a realistic test environment, highlighting MPI's reliability for vascular assessments. However, MPI's current spatial resolution limits its ability to detect small vascular irregularities, making it suitable only for identifying significant stenoses. Acoustic noise and minor interference with the X-ray detector suggest areas for technical improvement, including better electromagnetic and acoustic shielding.

The study also underscores the need for improved tracers. Resotran® has regulatory restrictions on dose volume, limiting its use in longer procedures. More sensitive tracers with lower injection volumes and higher SNR are needed, making further development of MPI-specific tracers a necessity. MPI's radiation-free nature is particularly advantageous for pediatric, pregnant, or radiation-sensitive populations.

This study establishes the feasibility of using a human-sized MPI scanner for real-time vascular imaging in a cadaveric perfusion model, highlighting MPI's clinical potential. It shows that MPI can complement DSA by offering enhanced temporal resolution without additional radiation, making it safer and more efficient. Future research should focus on improving MPI's spatial resolution, tracer properties, and scanner design to aid clinical integration. With these advancements, MPI could become a crucial tool in interventional radiology, offering safer, high-resolution imaging for various procedures.

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Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: N/A Ethical approval: The use of the cadaver model has been approved by the ethics committee of the University of Würzburg.

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