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Proceedings Article

In Vitro Detection of Gastrointestinal Bleeding using Single- and Multi-Contrast MPI

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Abstract

Gastrointestinal (GI) bleeding is a potentially life-threatening condition that is typically diagnosed using radiation-based imaging modalities such as computed tomography (CT) or catheter-based angiography. Magnetic Particle Imaging (MPI) could provide non-invasive, real-time volumetric imaging without ionizing radiation in future human-sized scanners that covers the entire GI tract. We have developed a human-sized (3D printed) phantom that represents both the bowel lumen and the vascular compartment of the bowel wall. One version has a perforation between the two compartments and a control phantom does not. For single contrast MPI, we evaluate the fluid exchange between the two lumen by observing an administered blood pool tracer. For multi-contrast MPI, the intestinal lumen was filled with an intestinal tracer, which represents an orally administered tracer, to allow co-registration of both tracers at the same location. Both single- and multi-contrast MPI are feasible to visualize GI bleeding and MPI may prove to be a useful tool for radiation-free detection of bleeding throughout the GI tract.

I. Introduction

Gastrointestinal (GI) bleeding is associated with several diseases and clinical conditions that may require urgent medical intervention, typically by endoscopy [1]. However, if endoscopic evaluation is not feasible or is inconclusive, further imaging techniques such as computed tomography (CT) may be required [1]. Magnetic Particle Imaging (MPI) is a radiation-free technique for volumetric imaging at a high spatiotemporal resolution based on magnetic tracers [2] and has already demonstrated potential for MPI-derived angiography [3] and MPI-guided vascular interventions [4]. Furthermore, MPI enabled the detection of an induced acute GI bleeding in a murine model at low temporal resolution [5]. Compared to other imaging modalities such as CT, MPI offers the advantage of multi-contrast imaging [6]: Different tracers or different physical properties (like temperature or viscosity) can be visualized separately. Here, we exploit the different magnetization behavior of two tracers, to

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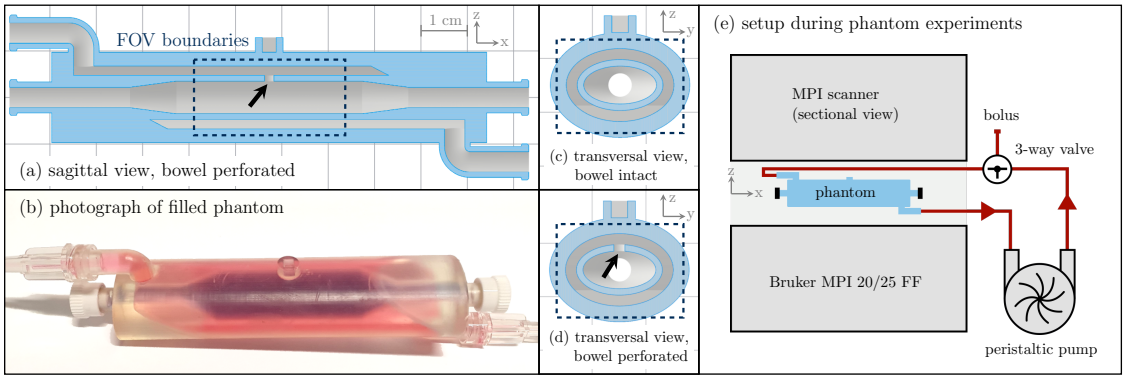

Figure 1: Phantom experiment setup. (a) Sagittal view of the phantom that represents a segment of a human small bowel. The vascular compartment encloses the bowel lumen and the arrow indicates the perforation (GI bleeding). Both compartments are accessible via an inlet and outlet. (b) Photograph of control phantom with dyed compartments. (c) Transversal cross section of the control phantom without perforation. (d) Same view as before, but with perforation that represents GI bleeding. (e) Experimental setup within MPI scanner. The vascular compartment is connected to a circulatory setup.

demonstrate the feasibility of non-invasive single- and multi-contrast MPI. Multi-contrast has the advantage of co-registration of two tracers within the same voxel to indicate hemorrhage, and we record raw data with a high temporal resolution of 21.54 ms. We visualize real-time tracer enhancement of a bowel wall and detect GI bleeding in human-sized bowel phantoms.

II. Methods and materials

Prior to phantom experiments, a mixed dilution series of the two tracers is performed to verify their separability in multi-contrast MPI. To this end, a 3x3x3 region of interest (ROI) of a reconstruction is averaged and the normalized signal intensity of 10 repetitions is plotted as a box plot. We use the tracer perimag (micromod GmbH, Rostock, Germany) as the blood-pool tracer and LS-008 (Lodespin Labs, Seattle, United States) as intestinal tracer. The focus of this study lies on the following 4 experiments that were conducted:

- single-contrast control, bowel intact
- single-contrast bleeding, perforated bowel
- multi-contrast control, bowel intact
- multi-contrast bleeding, perforated bowel

Single-contrast experiments use the blood-pool tracer only. The purpose of control measurements is to ascertain the absence of a bleeding, so that any recorded bleeding in a perforated bowel experiment can be attributed to the intended perforation in the phantom.

Experimental Setup. The setup is shown in Figure 1 and consists of a peristaltic pump that circulates the simulated blood-pool (15 mL volume) passing through the vascular compartment with a flow rate of 93 mLmin^{-1}. Cylinder shaped phantoms ($94 \times 26 \times 29$ mm^3) were 3D printed using a clear resin and coated for liquid impermeability. The inner bowel lumen is filled with either distilled water or the intestinal tracer (LS-008, 321 µg$_{Fe}$ mL^{-1}), for single- or multi-contrast experiments respectively. Inlet and outlet of the inner lumen remain sealed during the experiments. The blood tracer is administered by injection via a three-way valve for all experiments and consisted out of a 1 mL bolus of perimag (850 µg$_{Fe}$ mL^{-1}). The perforation in the phantom that represents GI bleeding is 2.0 mm in diameter.

Reconstruction. Images were reconstructed using the system matrix approach implemented by a Kaczmarz-solver. Prior to experiments, a system matrix for each tracer was acquired within a custom 1D-gradiometric receive coil (72 mm bore diameter), on the pre-clinical Bruker MPI 25/20 FF. Reconstruction parameters and frequency selection were chosen to obtain best images. We used 12 mT excitation with a gradient of 0.75 T m^{-1} ($32 \times 32 \times 16$ mm^3 field of view) and 80 averages (1.72 s temporal resolution) to reduce noise.

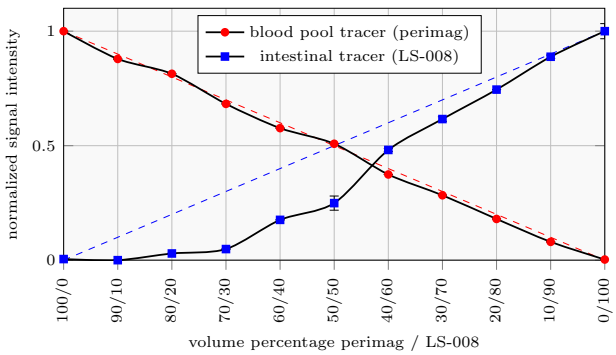

Figure 2: Box-plot of tracer separability. Normalized average signal intensities of a 3x3x3 voxel region for volume ratios of perimag/LS-008 in 10 % steps (100 µL samples). Dashed lines indicate the linear trend that is expected by ideal particles.

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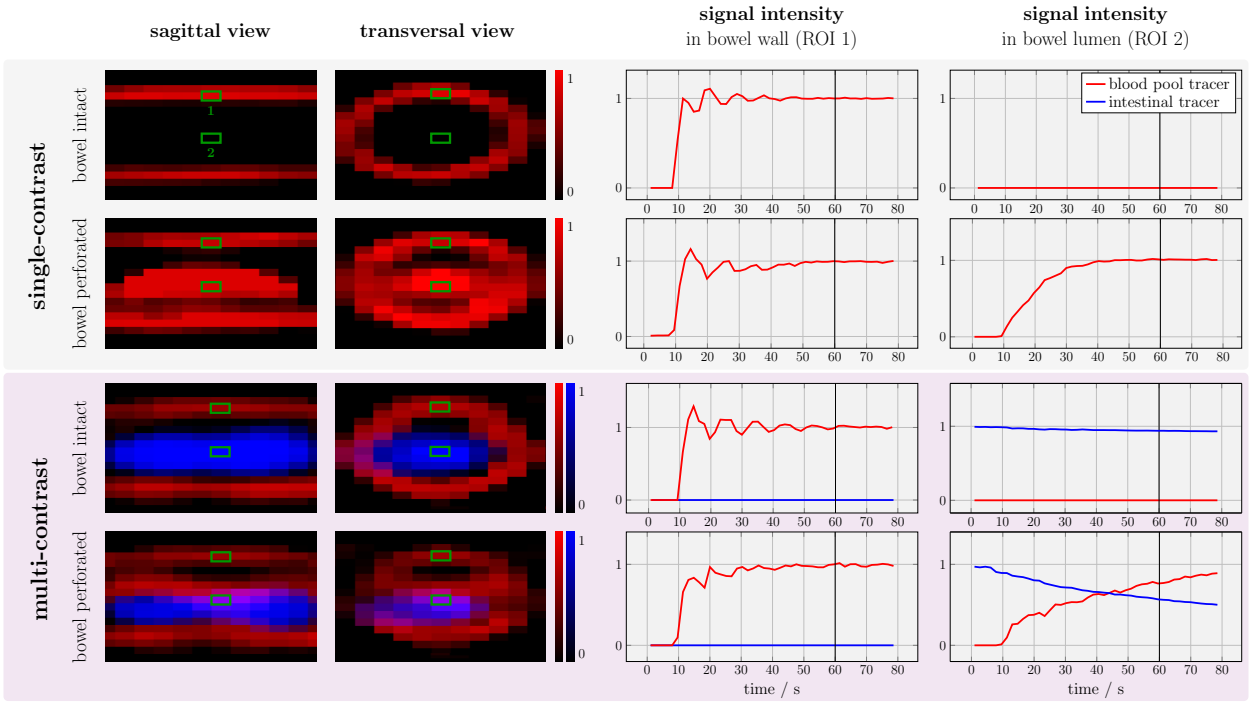

Figure 3: Phantom MPI results. Single- and multi-contrast experiments enable the detection of GI bleeding (bowel perforated) by leakage or co-registration of blood-pool tracer inside the bowel lumen. Reconstructed MPI images on the left are shown at 60 s. The injection of the blood tracer arrives at 10 s (first passing, circulatory setup) for the selected voxel (green ROI).

III. Results

Tracer separability for multi-contrast MPI is shown in Figure 2. LS-008 deviates from the linear model at low ratios, but is detectable at ratios of at least 20 %. Using MPI, we were able to visualize a bolus passing through the vascular compartment of our intestinal phantom in 3D real time. Shown in Figure 3 are images for all 4 experiments with one sagittal and one transverse slice each. The signal intensities on the right represent a single voxel chosen to be located in the bowel wall or within in the bowel lumen. In the control phantom (rows 1 and 3), no blood pool tracer was registered in the bowel lumen. In the case of GI bleeding, the blood pool tracer slowly leaked into the bowel lumen. We use multi-contrast to allow co-registration of both tracers at the same site to indicate bleeding. The blue tracer (LS-008) tends to slowly sink to the bottom of the inner compartment during the experiment.

IV. Discussion

The fast and non-ionizing imaging modality MPI could emerge as an alternative to clinically established methods such as CT for the real-time detection of gastrointestinal bleeding, with the advantage of multi-contrast imaging allowing the identification of two different tracers at the same location. In our experiments, the vascular compartment of the phantom was visualized by a blood-pool tracer bolus and an acute bleeding was detected when this tracer accumulated within the lumen. Due to the lack of anatomical background information in MPI, the correct identification of the bowel wall and the luminal compartment is a challenge for single-contrast MPI. A first MPI scan could provide the anatomical reference, once a steady-state blood-pool concentration of the tracer has been reached (single-contrast). Repeated MPI scans allow visualization of tracer accumulation in the bowel lumen, e.g. using subtraction images, which are prone to motion artifacts such as blurring. In our setup, motion was not taken into account because experiments were performed on phantoms. Movements might impair single-contrast, however, multi-contrast images that only show the co-registration of both tracers, i.e. by threshold, have an advantage against motion related artifacts and could prove more robust.

We conclude that single- and multi-contrast MPI are capable of detecting GI bleeding in human-sized bowel phantoms. The expected signal-to-noise ratio (SNR) for a human-sized imager is reduced by the value of the safe field parameters, coil dimensions, and bolus concentration, among other factors. MPI may evolve as an alternative to radiation-based techniques that covers the entire GI tract, if successfully scaled to human size.

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Author's statement

Conflict of interest: Authors state no conflict of interest.

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