Interventional vascular MRI: moving forward

Joachim Lotz*

Institute for Diagnostic and Interventional Radiology, Heart Center Göttingen, University Medical Center Göttingen Georg-August-University, DZHK (Deutsches Zentrum für Herz kreislaufforschung), Robert-Koch-Str. 40, D-37075 Göttingen, Germany

This editorial refers to ‘Real-time MRI-guided right heart catheterization in adults using passive catheters’, by K. Ratnayaka et al., doi:10.1093/eurheartj/ehs189

The article by Ratnayaka et al. is an exclamation mark for the clinical feasibility of cardiovascular interventional magnetic resonance imaging (MRI).1 The team has done a remarkable job by comparing X-ray fluoroscopy with MRI-only guidance of the right heart and pulmonary artery catheterization in 16 patients. MRI intervention has been a fascinating theme ever since interventional vascular MRI was described by Godart et al.2 and Omary et al.3 in 2000. The benefits of interventional MRI fluoroscopy are obvious: lack of ionizing radiation, freedom to choose any imaging plane at your disposal, the ability to look beyond the mere lumen of the vessel or cardiac chamber, and the instantaneous characterization of cardiac function as well as myocardial properties such as focal fibrosis, oedema,4 and temperature.5 Interventional vascular MRI has been used as guidance to close atrial or ventricular septal defects. Several groups have used MRI for atrial electrophysiological ablation therapies,6 pulmonary balloon valvuloplasty,7 interventional valve placement, or dilatation of aortic coarctation.8 Although most of these procedures have been performed in animal models, an increasing number of diagnostic and therapeutic vascular MRI interventions are performed in humans, as can be seen from the various reports published within the last 24 months. Catheter steering and visualization, patient safety, and spatial resolution of imaging remain the main issues of interventional vascular MRI. A lot has been achieved in recent years: communication in the room during noisy data acquisition has been solved by active noise cancellation techniques for the interventionalist as well as the patient. Sophisticated filter techniques and scan-algorithms allow for diagnostic electrocardiogram (ECG) monitoring and diagnostic electrophysiological mapping,9 as well as haemodynamic monitoring during MRI procedures. The concept of a virtual MRI contrast bolus—nicknamed virtual dye by the authors—has been published this year as a concept to visualize flow dynamics during real-time MRI.10 Interactive real-time manipulation of the imaging plane in MRI is by no means trivial, but there are solutions to integrate it neatly into a sensible workflow. However, the most pertinent problem remains catheter steering and visualization. There have been different approaches to visualize the tip and shaft of a catheter by active or passive markers integrated into the catheter itself. Active markers, e.g. small resonant wire loops that respond to radiofrequency pulses, seem to be the most promising approach to date. Different groups have deployed balloon-tipped catheters that can be easily tracked in real-time MRI while the balloon is inflated with either gadolinium, air, or saline.

MRI-safe guide wires are still under development. There is no MRI guide wire with clearance for use in humans. In an MRI environment, conventional guide wires cause heating and electric discharges that might lead to substantial harm to the patient. The development of new materials that are electrically safe but still flexible and sustainable is challenging. In a joint effort, the team of Kanishka Ratnayaka and Robert Lederman convinced 16 patients to be catheterized twice—once in the cath lab and another time in an interventional MRI setting. Lacking a safe guide wire, Ratnayaka used balloon-tipped catheters to probe the inferior and superior vena cava, the right ventricle, and pulmonary artery—the main trunk as well as the left and right pulmonary artery. The procedures were safe in all patients and successful in

* Corresponding author. Tel: +49 551 39 8966, Fax: +49 551 39 9606, Email: joachim.lotz@med.uni-goettingen.de

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**Video 1** Real-time magnetic resonance imaging (MRI) using radial FLASH-2D at high spatial resolution $1.5 \times 1.5 \times 6 \text{ mm}^3$, 21 ms temporal resolution, reconstructed in almost real-time. Left short axis, right three-chamber view. A video is available (courtesy of J. Frahm, Göttingen, Germany, published with his permission).

**Video 2** Image taken from a 3D real-time tracking of a hand moving in the scanner using real-time radial FLASH MRT with 23 frames/s. A video is available (courtesy of J. Frahm, Göttingen, Germany, published with his permission).
15 out of 16 patients. Twice a catheter had to be replaced due to kinking of the catheter. There was a trend towards faster probing of the left pulmonary arteries during MRI compared with X-ray fluoroscopy using the same balloon catheter. The importance of this study is that it demonstrates the safety and feasibility of vascular interventional MRI in a prospective setting of quite a number of real patients. Also it demonstrates what we expect to be one of the advantages of MRI: the unlimited choice of imaging planes helps to probe complex vascular territories more easily. The study was an ambitious project given a rather low temporal resolution of 150 ms and a spatial resolution of 1.8 mm. However, it worked.

Where are we to go from here? Temporal and spatial resolution of real-time imaging need to be improved for better visualization of vessel anatomy and catheter position in order to advance to smaller vessels. Several new techniques that might help are nearly ready for clinical use. A promising approach was published by the team of Jens Frahm, Göttingen, Germany—one of the inventors of the well known FLASH-2D sequence. Using highly undersampled MRI data processed through an iterative reconstruction algorithm, their real-time version yields temporal resolutions of up to 21 ms, an effective spatial resolution of 1.5 mm, with few artefacts (Video 1). This technique can be combined with catheter tracking (Video 2) or other imaging tools such as oedema detection, tagging, late enhancement, or temperature sensing. It will be a fascinating project to incorporate this technique into an interventional MRI setting. However, there is another message to be told based on the study of Ratnayaka et al. With all these achievements and promising developments, it is time for medical companies to rethink their strategies and engage once more in the development of guide wires suitable for MRI and MRI-visible diagnostic and therapeutic catheters. Then it will be the time to expand vascular interventional MRI to human arterial vessel territories.

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References