Magnetic Resonance–Guided Passive Catheter Tracking for Endovascular Therapy

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KEYWORDS

• Endovascular intervention • MR imaging • Passive tracking • Device tracking • MR angiography
• Real-time MR imaging

KEY POINTS

- Steady-state free precession (SSFP) sequences have become the preferred sequences for endovascular interventional MR imaging.
- Passive tracking using negative contrast uses marker materials in device construction that cause localized magnetic field inhomogeneities resulting in dephasing of adjacent proton spins and a local signal void or susceptibility artifact on MR imaging without the use of active radiofrequency (RF) components.
- Passive tracking can also be achieved with positive contrast using paramagnetic materials that cause focal T1 shortening (bright spot), such as gadolinium, within the lumen or on the surface of a catheter. Additional passive tracking methods include nonproton multispectral, and direct current techniques.
- The main advantage of passive catheter tracking over active tracking is simplicity and absence of radiofrequency (RF) heating, as no additional MR imaging scanner software, wires or electronics are required for most passive tracking techniques.
- Because device coordinates are not registered with passive tracking methods and imaging plane is not automatically updated, automatic visualization and correct imaging plane selection is difficult.

Videos on the XMR suite at UCSF Medical Center and magnetic resonance imaging–guided electrophysiological ablation accompanies this article at http://www.mri.theclinics.com/

Disclosures: Dr S.W. Hetts: Chief Medical Officer: ChemoFilter; Scientific advisory: Medina Medical; Consulting: Stryker, Silk Road Medical, Penumbra; Data Safety and Monitoring Committee: DAWN trial; Core Imaging Lab: MAPS trial, FRED trial; Grant support: NIBIB 1R01EB012031, NCI 1R01CA194533, ASNR Foundation. Dr F. Settecase, Dr A.J. Martin, Dr P. Lillaney, and Dr A. Losey have nothing to disclose.
The authors were funded by NIH R01 grant EB012031-01A1.
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Magn Reson Imaging Clin N Am 23 (2015) 591–605
http://dx.doi.org/10.1016/j.mric.2015.05.003

INTRODUCTION

The use of MR imaging for guidance of endovascular interventions has emerged as a feasible alternative or adjunctive imaging modality to digital subtraction angiography (DSA). MR imaging guidance offers several potential advantages. The absence of ionizing radiation during MR imaging is particularly attractive, as there may be substantial radiation exposures to both the patient and the interventionalist during DSA.[1,2] In addition, although DSA is limited to luminal information, MR imaging can also provide high-contrast visualization of the vessel wall and adjacent soft tissues with moderately high spatial resolution, allowing for the identification of vulnerable atherosclerotic plaques, the ability to monitor the effect of endovascular therapy on adjacent tissues, and to recognize possible complications, such as vascular perforation, hemorrhage, and infarction, all in real time. MR imaging also offers unrestricted multiplanar imaging capabilities and the opportunity to obtain physiologic and functional information such as flow velocity, 4D flow imaging and computational fluid dynamics, temperature, diffusion, and perfusion.

Concurrent advances in the design of real-time MR fluoroscopy and MR angiography pulse sequences and the development of MR safe and compatible endovascular devices have facilitated progress from in vitro and animal feasibility studies of MR guidance for endovascular interventions to their translation into clinical care. This review highlights state-of-the-art imaging techniques and hardware used for passive tracking of devices in endovascular interventional MR imaging.

THE VASCULAR INTERVENTIONAL MR IMAGING SUITE

The use of MR imaging guidance for endovascular intervention requires balancing multiple trade-offs involving image quality, spatial and temporal resolution, patient accessibility, field of view, and cost. Higher-field-strength cylindrical bore scanners are capable of better image quality; however, they require small diameter bores compared with open MR imaging scanners and therefore limit patient accessibility. At present, open bore MR imaging scanners do not provide adequate field strength, gradient strength, or field uniformity for endovascular intervention.[3] Clamshell and double-doughnut–shaped bores were initially introduced to improve patient accessibility during intraoperative MR imaging. Fortunately, arterial access at the groin for most endovascular procedures permits longer distances (40–80 cm) between the interventionist standing at the opening of the magnet bore and the target tissue of interest in the head, neck, chest, or abdomen, making commonly available cylindrical (or closed) bore clinical MR scanners suitable. Cylindrical bore magnets with shorter bore lengths (125 cm instead of 160 cm) and/or with larger bore diameters (70 cm instead of 60 cm) have been developed, allowing easier patient access and are commercially available. Most research sites now have hybrid systems consisting of a short-bore cylindrical MR imaging and DSA unit connected by a single floating table, also known as XMR systems (**Fig. 1**, Video 1). This system allows for use of either imaging modality for different parts of a procedure and permits the use of DSA backup in case of difficulties during MR guidance.

REAL-TIME MR IMAGING AND MR ANGIOGRAPHY TECHNIQUES FOR ENDOVASCULAR INTERVENTIONAL MR IMAGING

Image acquisition during MR-guided endovascular procedures must be rapid enough to allow the interventionist to visualize changes within the patient as devices are externally manipulated in real time. Several pulse sequence approaches to achieve higher-temporal-resolution MR imaging for MR-guided interventions, also known as real-time MR imaging or MR fluoroscopy, have been explored. Higher temporal resolution usually comes at the expense of spatial resolution. Nevertheless, MR fluoroscopy sequences used today allow sufficient spatial and temporal resolution to track endovascular devices. Because each pulse sequence offers unique contrast characteristics, the ideal sequence depends on the properties of the device being tracked and the passive tracking method being used for device tracking (see passive tracking section), the contrast properties of the tissue of interest, and the need for intravascular contrast. Commonly used MR fluoroscopy sequences are summarized in **Table 1**.

SSFP sequences have become the preferred sequences for endovascular interventional MR imaging. SSFP provides excellent bright blood contrast and visualization of devices using passive tracking because of the high temporal resolution (short repetition time [TR]), high signal-to-noise ratio (SNR), and greater sensitivity to magnetic field inhomogeneities[4–13] (**Fig. 2**).

T2-weighted turbo spin echo, rapid acquisition with relaxation enhancement (RARE, HASTE) sequences, may also be used for verification of device location because of the flexibility in image contrast and fast acquisition of the pulse