Benefits, Limitations, and Improving the Future of MRI-Guided Endovascular Catheter Tracking

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Purpose: Heart disease has been the leading cause of death in the United States for nearly a century, with recent annual death tolls of approximately 600,000 people and direct and indirect costs exceeding $100 billion per year. Cardiovascular diagnostic and interventional methodologies require the use of endovascular catheterization for procedures such as angiography, angioplasty, ablation, stent placement, and valve repair. Critical tracking of these catheters is typically accomplished using x-ray fluoroscopy; this cardiovascular guidance approach allows for real-time feedback, high spatiotemporal resolution, and the ability to distinguish the position of the catheter relative to anatomical structures. However, x-ray fluoroscopy-guided catheter tracking suffers from limitations in soft tissue contrast, as well as difficulty in three-dimensional navigation. In the clinic, this technique typically requires refresh rates of 1-10 frames per second (FPS); these refresh rates, combined with procedure-related activities, can expose both the patient (direct exposure in the short term) and attending physician and team (scatter exposure over the long term) to ionizing radiation in a relatively short period of time (minutes to tens of minutes for each procedure). This can be especially problematic for pediatric patients, who not only have a much longer anticipated lifetime but also a greater potential for multiple procedures.

Magnetic resonance imaging (MRI)-guided catheter tracking is attractive due to its many potential benefits, including three-dimensional imaging of the interactions between soft tissues and the vasculature without using ionizing radiation. The use of MRI-based catheter guidance also allows clinicians to simultaneously monitor other physiologically-relevant criteria, including metabolism, temperature, blood flow velocity, and tissue perfusion. To date, typical MR-guided catheter guidance approaches fall into one of two categories: active or passive tracking. Each method carries different benefits and drawbacks; benefits include offering real-time contrast between the otherwise MR-invisible catheter and patient anatomy. Potential drawbacks include the need for specialized catheters, risk of localized tissue heating, catheter inflexibility/steering problems, negative contrast that is susceptible to distortion artefacts, competition with background signal, loss of magnetization with time and rf pulses (when using hyperpolarized tracers). For this educational session, I plan to discuss the various approaches of MRI-guided catheter tracking with the hope of initiating a dialogue that will contribute to new ideas that will advance the clinical application of this field.

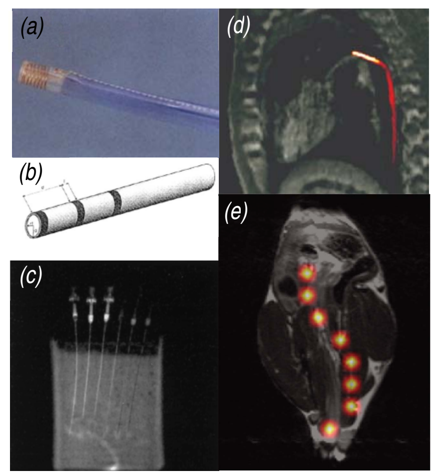

Fig. 1. Examples of MRI-guided catheter tracking. ***(a)*** Mini rf coil (Leung, *et al.* AJR—1995); ***(b)*** Dysprosium rings (Duerk, *et al.* MAGMA—2001); ***(c)*** Gadolinium (Omary, *et al.* JVIR—2000); ***(d)*** Hyperpolarized ^{13}C-tracer (Magnusson, *et. al.* Mag. Res. Med.—2007); ***(e)*** Hyperpolarized ^{29}Si particles (Whiting, Hu, *et al.*—2014).

Outline of Content:

I. Need for catheter visualization during diagnostic and interventional procedures

II. Current clinical methods (x-ray fluoroscopy): Pros and Cons

III. Potential benefits of MRI-guided catheter tracking

IV. Current techniques in MRI-guided catheter tracking (Pros and Cons)

- A). Active tracking of miniature rf coil (Fig. 1a)
- B). Passive tracking
  - 1). Susceptibility differences in catheter implants (Fig. 1b)
  - 2). T_1 imaging of catheters filled with gadolinium (Fig. 1c)
  - 3). ^{19}F imaging of catheters filled with perfluorooctylbromide
  - 4). Hyperpolarized ^{13}C imaging of catheters filled with ^{13}C-tracers (Fig. 1d)
  - 5). Hyperpolarized ^{29}Si imaging of catheters with silicon particles (Fig. 1e)

V. Main limitations of MRI-guided catheter tracking

VI. Suggestions for future directions

VII. Discussion

Summary: I plan to present a comprehensive overview of different MRI-guided catheter tracking techniques, as well as engage in a collective discussion that will encourage new ideas to apply these methods to the clinic. Large-scale adoption of MRI-guided catheter tracking will allow clinicians to perform concurrent diagnostic and interventional MRI studies without the need to shuttle patients from one imaging suite to another, decreasing patient residence time and increasing safety. Additional benefits include the absence of ionizing radiation received by the patient and clinician team, as well as removing concerns regarding potential allergies to iodinated contrast agents used in x-ray fluoroscopy (particularly in patients suffering from chronic kidney disease).