Tactile Training in Lower-Field Interventional MRI

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Introduction

When the topic of real-time imaging and image-guided procedures is discussed, we rarely think of magnetic resonance imaging (MRI). Ultrasound, X-ray fluoroscopy, and computed tomography (CT) are the modalities most often associated with image-guided interventions, and for good reason. This begs the question: Why hasn't MRI, one of the safest imaging modalities and the gold standard for soft tissue visualization, been more widely adopted for real-time interventions?

Interventional MRI (iMRI) has continuously evolved throughout the history of MRI as a whole [1]. MRI-guided breast biopsies have increasingly become part of the clinical pathway [2, 3]. In the 1990s, interventional procedures in MRI gained momentum, notably through contributions from those such as Ferenc A. Jolesz, M.D., at Brigham and Women's Hospital. Early systems operating at field strength < 1.0T aimed at enhancing neurosurgical procedures and could already demonstrate improved precision and patient outcomes [4, 5]. Subsequent advancements have included specialized system configurations, e.g., ceiling-mounted high field magnets wich can be moved into the operating suite (IMRIS, Deerfield Imaging, Chaska, MN,USA), and dedicated accessory/workflow solutions, e.g., stereotactic frames (ClearPoint Neuro Inc., Solana Beach, CA, USA), to further enhanced MRI-guided neurosurgery.

However, iMRI remains an underutilized modality, and this might be partly attributed to workflow complexity and to a learning/adoption process associated with the transition from a traditional to a new procedural environment. Any interventional procedure requires a group of skilled professionals who each play pivotal and foundational roles in the intervention. The anesthesiologists, the nursing staff, the radiological technologists, and the interventionalists themselves all work toward a successful medical intervention, regardless of modality. Over time, these people and departments have developed, and knowledge has spread so that such procedures are now carried out via consistent, safe, and effective workflows in clinical routine. The goal is to transition these routine workflows to a new environment.

As MRI-guided interventions become more viable with advances in real-time imaging and in low- and mid-field systems, there is a growing need for accessible, tactile training tools that build operator confidence and procedural accuracy. Several groups are concurrently investigating and working with iMRI for a variety of cases and procedures. Our group has investigated and is pursuing a hands-on training approach using low-cost phantoms and real-time MRI guidance on the 0.55T MAGNETOM Free.Max scanner (Siemens Healthineers, Erlangen, Germany).

1 MRI technologist showing a radiography student how to align the target and entry points within the UI.

Developing tools and language

In an effort to democratize and standardize workflows for iMRI, Cook Advanced Technologies and Siemens Healthineers have been partnering to provide a preclinical environment to foster collaboration and interactive learning. Located in West Lafayette, Indiana, a 0.55T MAGNETOM Free.Max system has been fitted to meet the needs of a preclinical, investigational setting. Four MRI display monitors (NordicNeuroLab, Bergen, Norway) on MR-conditional boom arms allow for visualization of images. Prior work also highlighted the need for an MR-conditional wireless headset system to enable continuous communication between the MRI technologist at the helm and the interventionalist and staff in the MR room even during imaging [6]. Bringing all of these components and accessories together is an important aspect toward realization of a true turn-key solution for iMRI to reduce the entry barrier because of potential complex technical integration.

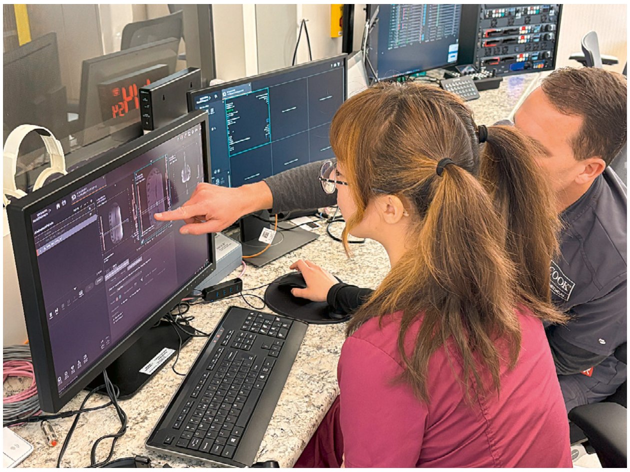
One of the main components of any successful venture is communication. In traditional X-ray-based imaging, users warn others about "X-ray!" When a CT scanner is operating, the warning lights state: "CT is in use". When live X-ray imaging is required, interventionalists call for "fluoro".

The iMRI language is a work in progress, but it should be clear to the users and distinct from X-ray-based procedures. While not industry standard, our collaborative efforts have birthed a unique, agreed-upon language that assists in successful communication. On our dual-monitor setup, the main display unit that the MRI technologist manipulates is referred to as the "Operator", and the second unit that displays imaging and live imaging is known as the "Image". Procedures being performed from the tableside are referred to as "patient side," and those from the back side of the bore are "service side".

In any procedure, the technologist is responsible for the safety of the patient and the personnel in the magnet room. It can be a daunting task, and iMRI language helps to streamline procedures while maintaining safety for all involved. At any time when the patient table might move after sequence commencement, a "table may move" announcement is given. Pinch points on the table are recognized, and staff are alerted to watch hands and fingers. It is imperative that technologists have excellent 3D spatial cognition. If an interventionalist needs to move "up" or "down", good rapport should translate that to anterior vs. posterior or superior vs. inferior. There is some language that technologists and interventional staff will develop naturally in this 3D realm. The most important, universal phrase for any iMRI procedure is "going live".

As the language of iMRI continues to develop, the tools we use are also rapidly evolving to make these procedures possible. The interactive real-time (IRT) imaging user interface (UI)[1] from Siemens Healthineers is a powerful research software tool that facilitates workflow precision and control during iMRI procedures. The extended UI allows the selection of entry and target point, dynamic imaging plane manipulation, and trajectory line overlays. If multiple targets or trajectories are needed, the iMRI UI Extension allows users to set up and save multiple target

[1] *Work in progress. The product is still under development and not commercially available. Its future availability cannot be ensured.*



2 MRI technologist demonstrating the iMRI UI Extension to a radiography student.

3 MRI technologist (blue scrubs) demonstrating the target on the Turducken phantom. The student has now had the experience of both the MRI technologist and the interventionalist.

trajectories and planes. Saved imaging planes and reformats from View&Go can be integrated into the cardiac and vascular UI for quick selection and structured flow through a procedure that follows the interventional devices.

With an intuitive display, users are able to quickly adjust slice position, switch between planes or trajectories, and manipulate certain parameters such as slice thickness and phase encoding direction. The iMRI UI Extension is designed for efficient workflows with minimal delays. It aims to enhance procedural accuracy, reduce learning curves for new users, and support a wide range of applications – from biopsies and ablations to vascular interventions. We decided to put this to the test by inviting untrained radiography students to attempt a simple needle procedure on a phantom and then comparing the times and success rates to those of experienced users. This training has become part of the Indiana University School of Medicine's visit experience for radiography students.

Education for radiography students at Indiana University School of Medicine

Now an annual event, Cook Advanced Technologies welcomes students from the IUSM radiography program to observe, assist, and learn about iMRI. The training principle of "see one, do one, teach one" is easily performed in this preclinical setting. In this vein, we aimed to evaluate a tactile learning model for training both novice and experienced MRI technologists in fine needle biopsy and aspiration techniques. The training model integrated the interactive UI with real-time MRI guidance to assess users' ability to accurately target a phantom lesion within a fixed time frame.

Participants typically include students with zero or limited MRI experience. The needle guidance procedure involves targeting a 2 × 2 × 1.5 cm phantom structure embedded in a multi-layered construct made from discounted grocery store meat – a setup humorously dubbed the "Turducken."

Two roles are assigned and assessed: interface operators (iMRI technologists) at the console, and needle drivers (interventionalists) performing the procedure. The system provided real-time image updates and trajectory feedback. We retroactively collected time-to-target data for the needle drivers. All participants successfully placed the needle into the phantom target, typically within the 5-minute window. In fact, an analysis of nine students and four experienced users demonstrated that all users, regardless of experience level, can accomplish this simple needle task within five minutes.

- **Experienced users** averaged 122 seconds (SD ± 49).
- **Novice users** averaged 230 seconds (SD ± 28).

While experienced technologists required fewer adjustments and completed the task more quickly, novice users also consistently met the success criteria. Feedback highlighted the intuitive design of the UI and its value in helping first-time users conceptualize needle trajectory.

Clinical implications

The results support the ease of using the MAGNETOM Free.Max with a real-time interactive sequence to teach interventional needle guidance. Real-time tactile feedback and image guidance enable rapid learning even for

4 iMRI UI Extension: Technologist interface (left) and iMRI live display (right). With the multiple display option, the technologist can select target and entry points for needle interventions and can manipulate the slice positions in real time. The IUSM radiography students experience both the technologist and interventionalist side of the UI, encouraging a better understanding of their role in the procedures.

inexperienced users. This low-cost, reproducible training method may help broaden the base of MRI professionals familiar with iMRI workflows – potentially catalyzing wider clinical adoption.

The use of this tactile training model using real-time iMRI and the iMRI UI Extension carries important clinical implications. The ability for novice users to quickly develop proficiency in needle guidance suggests that iMRI workflows may be more broadly accessible, aiding the democratization of iMRI. By lowering the barriers to entry, this training approach may facilitate the adoption of iMRI in new clinical environments, potentially expanding the range of MRI-guided procedures beyond highly specialized centers.

Furthermore, as healthcare systems prioritize patient safety and radiation reduction, the inherent advantages of MRI – no ionizing radiation, excellent soft tissue contrast, and real-time feedback – position it as an increasingly attractive option. Incorporating this training model into clinical practice could accelerate the integration of iMRI for biopsies, aspirations, and ablations, ultimately improving patient outcomes through more precise targeting and reduced procedural risk.

Invited physicians

Prior to extending the invitation to the IUSM radiography students, physician feedback on the system was sought. In addition to student training sessions, Cook Advanced Technologies and the iMRI Division at Cook Medical invited several interventional radiologists, surgeons, physicists, and technologists to participate in system demonstrations and hands-on trials. Overall, these physician visits provided critical, real-world feedback on the usability, workflow integration, and clinical potential of lower-field iMRI. Many of the physicians emphasized the importance of an intuitive UI, streamlined setup, and real-time feedback for procedural success. The unique iMRI lab at Cook Advanced Technologies has allowed experts to join the procedure remotely, from across the world. To increase collaboration and communication, experts in Erlangen, Germany can remotely join our training days, being provided with real-time feedback of their system and offering advice of their own to our staff and visitors.

Feedback was optimistic about the system's ability to reduce radiation exposure while maintaining high targeting accuracy, especially for procedures in sensitive anatomical areas. These early physician engagements not only validated the system's clinical relevance, but also helped refine the language, workflow, and UI for broader adoption. Ongoing collaborations with these physicians continue to inform the development of practical clinical protocols and training pathways.

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We would like to sincerely thank all participating physicians, physicists, technologists, students, engineers, and staff whose time, expertise, and enthusiasm made this project possible. Their collective contributions were essential in refining the workflow, developing effective training models, and advancing the language and practices of iMRI. We extend special gratitude to Siemens Healthineers for their invaluable partnership and support. Their commitment to innovation and to pushing the boundaries of real-time MRI workflows has been instrumental in creating accessible, practical solutions for interventional imaging.

This collaboration has not only fostered technological advancement, but has also helped cultivate a community of learners and practitioners dedicated to improving patient care through safer, more precise imaging techniques. We look forward to continuing this work together as iMRI moves toward broader clinical adoption.

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