

MAGNETOM Flash

Issue Number 99 · 4/2026
iMRI Edition

magnetomworld.siemens-healthineers.com

Page 4

Editorial Comment
iMRI is Expanding Image-Guided Therapy Through Technology and Improved Patient Outcomes
Max Seidensticker

Page 28

Proactive Ergonomic Design for iMRI: Insights from Digital Human Modeling
Justin Davidson, Steven Fischer, et al.

Page 38

MRI-Guided High-Dose-Rate Interstitial Brachytherapy of Hepatic Malignancies
Matthias P. Fabritius, et al.

Page 8

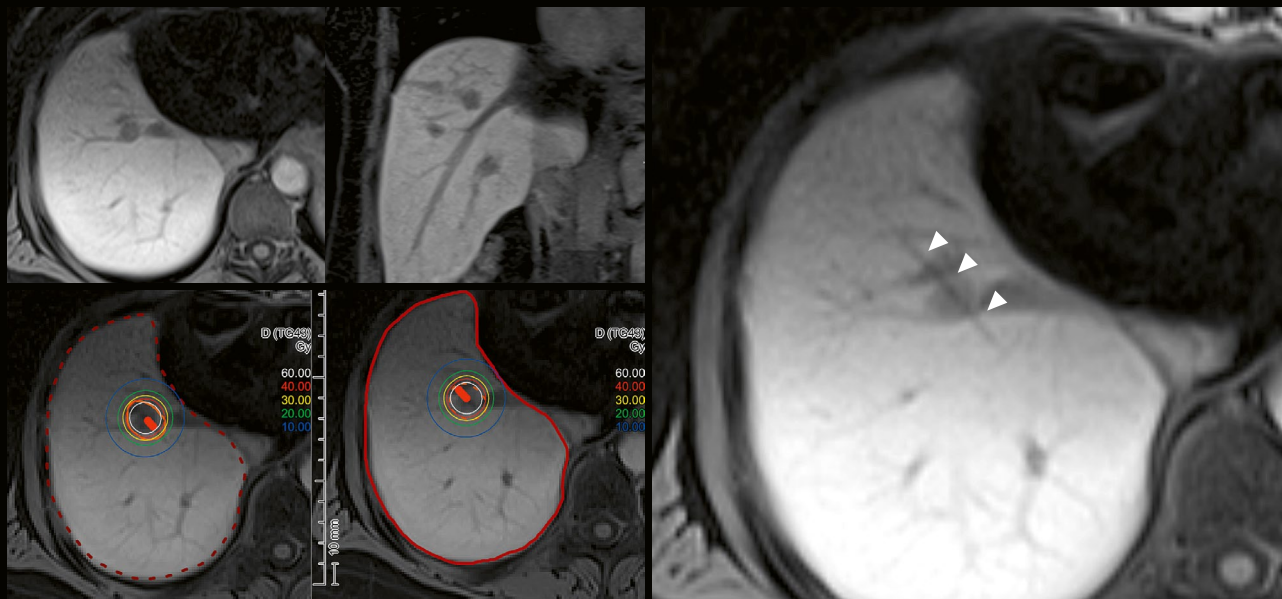
Building the iMRI Suite: An Integrated Environment for MRI-Guided Interventions
Inge M. Brinkmann, et al.

Page 34

iMRI: Current Concepts, Enabling Technologies, and Emerging Clinical Applications
Roberto Luigi Cazzato, Afshin Gangi, et al.

Page 52

Focal Therapy in the Treatment of Prostate Cancer
Jurgen Fütterer, et al.



Not for distribution in the U.S.

Strategic
Partner

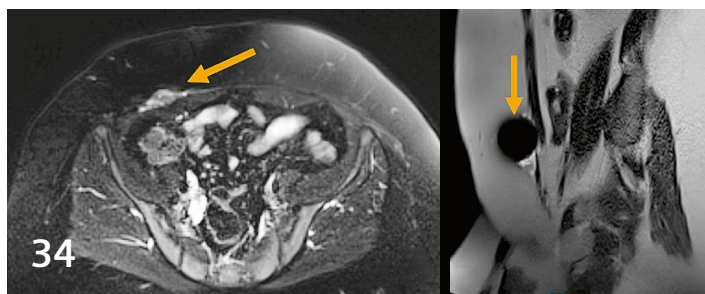
Interventional
MRI

COOK
MEDICAL

SIEMENS
Healthineers



Patience access at MAGNETOM Free.XL¹



MRI-guided cryoablation of an endometriotic implant

Editorial Comment

4 Interventional MRI is Expanding Image-Guided Therapy Through Technology and Improved Patient Outcomes

Max Seidensticker

LMU University Hospital, Munich, Germany

Education

25 A Framework for Growth in Interventional MRI: From Initial Adoption to Program Expansion

David A. Woodrum, et al.

Radiology and Vascular Centers, Mayo Clinic, Rochester, MN, USA

Product News

8 Building the iMRI Suite¹: An Integrated Environment for MRI-Guided Interventions

Joshua Krieger (Cook Medical, Bloomington, IN, USA),
Inge M. Brinkmann (Siemens Healthineers, Erlangen, Germany), et al.

16 MAGNETOM Free.XL¹ as a Strategic System for Diagnostic Imaging and MRI-Guided Interventions

Jan Brandt, Michaela Martin

Siemens Healthineers, Erlangen, Germany

Interventional MRI

28 Proactive Ergonomic Design for Interventional MRI: Insights from Digital Human Modeling

Justin Davidson, Steven Fischer, et al.

Faculty of Health, University of Waterloo, ON, Canada

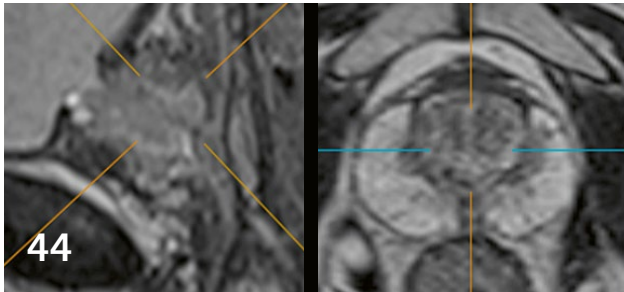
34 Interventional Magnetic Resonance Imaging: Current Concepts, Enabling Technologies, and Emerging Clinical Applications

Roberto Luigi Cazzato, Afshin Gangi, et al.

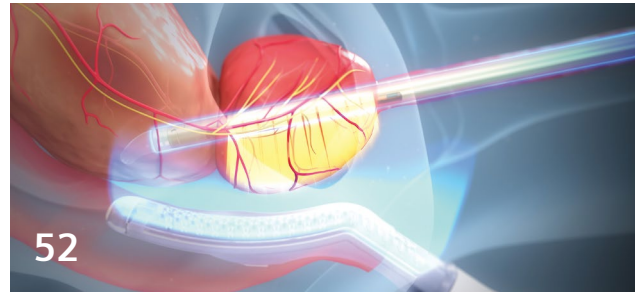
Department of Interventional Radiology, University Hospital of Strasbourg, France

¹ The products/features mentioned herein are not commercially available in all countries. Their future availability cannot be guaranteed.

² The MRI restrictions (if any) of the metal implant must be considered prior to patient undergoing MRI exam. MR imaging of patients with metallic implants brings specific risks. However, certain implants are approved by the governing regulatory bodies to be MR conditionally safe. For such implants, the previously mentioned warning may not be applicable. Please contact the implant manufacturer for the specific conditional information. The conditions for MR safety are the responsibility of the implant manufacturer, not of Siemens Healthineers.



0.55T prostate MRI



Focal therapy in prostate cancer

Hepatic iMRI

38 MRI-Guided High-Dose-Rate Interstitial Brachytherapy of Hepatic Malignancies

Matthias P. Fabritius, et al.

Department of Radiology, LMU Hospital, Munich, Germany

Meet Siemens Healthineers

59 Introducing Jan Brandt

Global Segment Manager Interventional and Intraoperative MRI

Siemens Healthineers, Erlangen, Germany

Urologic iMRI

44 Prostate Imaging and Interventions at 0.55T: Increasing Access to High-Quality Prostate Cancer Diagnosis and Treatment

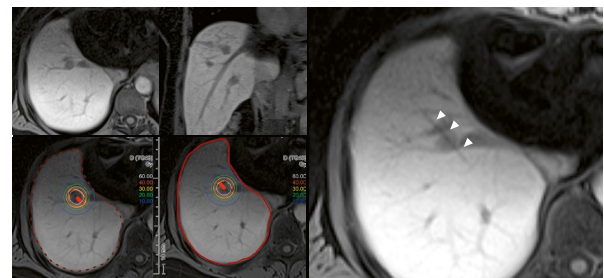
Joseph Busch, Jr.

Busch Center, Alpharetta, GA, USA

52 Focal Therapy in the Treatment of Prostate Cancer

Lauren te Molder, Jurgen J. Fütterer, et al.

Department of Medical Imaging, Radboudumc, Nijmegen, The Netherlands



Cover images from *MRI-Guided High-Dose-Rate Interstitial Brachytherapy of Hepatic Malignancies* by MP Fabritius, et al. (LMU Hospital, Munich, Germany)



Max Seidensticker is Professor of Image-Guided Minimally Invasive Oncology in the Department of Radiology at Ludwigs Maximilians University Hospital in Munich, Germany. He leads the division of Interventional Radiology/Interventional Oncology.

Professor Seidensticker has outstanding clinical expertise in the interdisciplinary management of patients with hepatic tumors, covering both diagnostic and interventional radiology. This is reflected in his role as leader of the diagnostic study part of the European multicenter SORAMIC trial, which compares hepatobiliary MRI to CT imaging in decision-making for treatment in hepatocellular carcinoma (HCC) patients. He is also the principal investigator of the multicenter ZUGSPITZE trial, which focuses on selective internal radiation therapy (SIRT) plus immuno-oncology (IO) therapy in HCC patients. Additionally, he is exploring interventional MRI for diagnostics and therapies in multiple pioneering prospective clinical trials.

He has been an invited speaker at numerous international meetings, where his lectures have focused on interventional treatment of liver tumors as well as liver imaging. His expertise in interventional radiology is further reflected in his membership of the image-guided therapy committee of the European Organisation for Research and Treatment of Cancer.

Interventional MRI is Expanding Image-Guided Therapy Through Technology and Improved Patient Outcomes

The development of interventional magnetic resonance imaging (iMRI) applications has accelerated in recent years. iMRI represents more than the evolution of an imaging modality; it reflects a broader transformation in image-guided therapy. As minimally invasive procedures become increasingly precise and personalized, imaging is no longer merely used to confirm anatomy. Instead, it has become an active partner throughout the intervention. The ability to visualize anatomy, monitor therapy, and support clinical decision-making in real time is redefining how complex procedures are planned and performed at ease. Importantly, iMRI is not primarily about improving image guidance, but rather achieving superior precision and improved patient outcomes. Ultimately, the success of every intervention is measured not by the sophistication of the technology itself, but by its ability to improve clinical decision-making, increase treatment precision, reduce complications, preserve healthy tissue, and deliver better outcomes for patients. These objectives continue to drive innovation across interventional oncology, neurosurgery, urology, musculoskeletal interventions, and many other emerging applications.

The development of iMRI is now being supported by new innovations from the medical industry that will facilitate the adoption of this technique tremendously. Attention has been directed toward systems that combine high-quality diagnostic imaging with practical interventional workflow solutions for image-guided procedures. Rather than requiring dedicated interventional scanners with limited utilization, modern concepts increasingly focus on dual-use platforms capable of supporting both routine diagnostic imaging and advanced therapeutic applications. The novel MAGNETOM Free.XL¹ MRI system facilitates access with its 100 cm wide flared opening and optionally elevated magnet. It enables more robust imaging of anatomical structures and medical devices with its 0.55T lower-field strength and XL gradients. Furthermore, the system has a small footprint and a sealed-for-life dry magnet that requires just 0.7 liters of helium, allowing installation without a quench pipe. These engineering innovations address not only image quality but also accessibility, ergonomics, installation flexibility, and sustainability, which are important considerations for hospitals seeking to integrate iMRI into existing clinical environments.

¹ The products/features mentioned herein are not commercially available in all countries. Their future availability cannot be guaranteed.

Together, the innovations help create a practical foundation for expanding MRI-guided interventions beyond highly specialized academic centers.

However, economically speaking, using an MRI system solely for interventions might not be realistic for many centers at first. The future therefore lies in flexible clinical platforms that are capable of seamlessly transitioning between diagnostic examinations and interventional procedures throughout the day. Such versatility allows institutions to maximize equipment utilization while simultaneously expanding access to advanced minimally invasive therapies. A combined use for diagnostics and interventions seems mandatory. Through strong gradients and deep learning-based image reconstruction, the MAGNETOM Free.XL delivers state-of-the-art diagnostic images of all body regions. Furthermore, the lower field strength has the potential to reduce metal-related artifacts, supporting imaging in regions of interest containing metal implants.² These advances further demonstrate that lower-field MRI should not simply be viewed as an alternative field strength, but rather as a platform with unique physical characteristics that can provide important clinical advantages in selected patient populations and procedural workflows.

To facilitate the use of the technique and provide access to all opportunities in intervention and diagnostics, the concept of the iMRI Suite was developed, which offers a turnkey solution. Beyond the scanner itself, successful implementation of a suite depends on carefully designed workflows, dedicated room concepts, appropriate medical devices, multidisciplinary collaboration, and clinical processes. The development of comprehensive concepts for an iMRI Suite is therefore an important milestone on the road to making MRI-guided interventions more reproducible, scalable, and accessible across diverse healthcare systems.

This special issue showcases the recently introduced MAGNETOM Free.XL, the iMRI Suite, and various centers' experiences with iMRI. Collectively, the contributions illustrate the technological advances that have been achieved, as well as the clinical experience, scientific evidence, and multidisciplinary collaboration that continue to shape the future of MRI-guided therapy. They demonstrate that iMRI has evolved from an emerging concept into a rapidly expanding clinical discipline with growing global momentum.

The team from Cook Medical and Siemens Healthineers report on the concept and the core of the iMRI Suite. The underlying idea is that optimal use of iMRI requires a dedicated setup with appropriate room layout and medical

devices. The article takes a nuanced look at the needs and requirements of different users. Ultimately, the structured development of an iMRI Suite significantly facilitates the introduction of iMRI into clinical routine through the use of the MAGNETOM Free.XL for both diagnostic imaging and interventions. The authors emphasize that successful implementation depends as much on optimized workflow and infrastructure as on the imaging technology itself.

In an extensive pictorial article, Jan Brandt and Michaela Martin demonstrate the high-quality diagnostic capabilities of the MAGNETOM Free.XL for routine standard-of-care imaging in various body regions, including cardiac imaging and the real-time imaging that is essential for iMRI. The clinical examples demonstrate how deep learning-based image reconstruction continues to expand the diagnostic capabilities of modern lower-field MRI.

David Woodrum, et al. outline a development and growth strategy for iMRI. The paper clearly illustrates the key pillars of sustainable and scalable development for a new interventional technique and places them in the context of the differing expectations of various healthcare providers. Beyond technology, successful implementation requires clinical evidence, workflow integration, collaboration, and sustainable adoption strategies.

The occupational biomechanics study led by Steven Fischer at the University of Waterloo explores the ergonomic challenges in iMRI. The authors present possibilities for ergonomic simulations of an iMRI workplace and outline the results of a comparative analysis of a conventional MRI system versus the MAGNETOM Free.XL, which has a flared opening, and option-ally elevated magnet. As iMRI matures, ergonomics is becoming increasingly important for procedural efficiency, physician comfort, and clinical adoption.

In a review article, Roberto Cazzato and Afshin Gangi present the breadth of iMRI procedures and the corresponding benefits. Among other topics, they cover MRI-guided biopsy, cryoablation, and prostate ablation, as well as prospects for endovascular applications.

Matthias Fabritius et al. provide insight into a relatively new form of local ablative therapy: catheter-based brachytherapy. Local ablation is achieved here via focal radioablation using the afterloading technique. To enable the temporary placement of a radiation source in the body, a catheter must be inserted under image guidance. Since all materials used for brachytherapy are available as MRI-conditional devices, and therapy mostly does not require general anesthesia, the therapy can be performed very easily. Targeting small liver lesions obviously benefits from MRI guidance. Fortunately, room times are generally

² The MRI restrictions (if any) of the metal implant must be considered prior to patient undergoing MRI exam. MR imaging of patients with metallic implants brings specific risks. However, certain implants are approved by the governing regulatory bodies to be MR conditionally safe. For such implants, the previously mentioned warning may not be applicable. Please contact the implant manufacturer for the specific conditional information. The conditions for MR safety are the responsibility of the implant manufacturer, not of Siemens Healthineers.

short for this procedure. The article describes the procedure and the clinical outcomes of MRI-guided brachytherapy for liver lesions. It demonstrates how MRI guidance can enable highly precise, minimally invasive oncologic therapies while supporting efficient clinical workflows.

Joe Busch provides excellent insights into the use of 0.55T MRI for both diagnostics and MRI-guided therapy, as well as MRI therapy monitoring in prostate cancer. The illustrations nicely demonstrate the use of the lower-field MAGNETOM Free.Max in diagnostics and therapy. The article highlights the growing role of MRI as a platform that supports diagnosis, therapy guidance, and treatment monitoring within a single clinical workflow.

Lauren Te Molder and Jurgen Fütterer provide a comprehensive overview of innovative localized prostate therapy using transurethral ultrasound ablation (TULSA). In addition to technical insights, the authors present the current state of the data and ongoing study designs. The article reflects the growing momentum for MRI-guided focal therapies that aim to preserve organ function while maintaining oncologic effectiveness.

Taken together, these contributions reflect the remarkable breadth of modern iMRI, ranging from ergonomics and workflow optimization to oncology, focal therapies, ablation, and emerging treatment concepts. They highlight a field that is rapidly moving beyond proof-of-concept studies and toward routine clinical implementation. More importantly, they demonstrate a shared vision: using MRI not simply to visualize disease, but also to actively enable safer, more precise, and more patient-centered therapy.

The future is here... and it's X-ray free!



Max Seidensticker

We appreciate your comments.

Please contact us at magnetomworld.team@siemens-healthineers.com

Editorial Board



Antje Hellwich
Editor-in-chief



André Fischer, Ph.D.
Associate Editor



Kera Westphal, Ph.D.
Global Head Collaboration
Management MR



Wellesley Were
MR Business Development
Manager Australia and
New Zealand



Katie Grant, Ph.D.
Vice President of MR
Malvern, PA, USA



Arne Hengerer, Ph.D.
Head MR-Guided Therapy

Review Board

Jan Brandt, Ph.D.
Global Marketing Segment Manager
MR in Therapy

Axel Krafft, Ph.D.
Solution Owner Interventional MRI

Florian Maier, Ph.D.
Senior Key Expert for
MRI-Guided Therapies

Tassiana Marini, Ph.D.
Head of Clinical and
Scientific Marketing

Christian Schuster, Ph.D.
Head of MR Application Product
Management

The MAGNETOM World

Your portal to protocols, articles and case studies

Siemens Healthineers' global MRI community offers peer-to-peer support and information. Radiologists, physicists, cardiologists, and technologists, have all contributed with publications, protocols, training documents, case studies, and more – all freely available to you via this unique network.

The centerpiece of the MAGNETOM World Internet platform consists of our users' clinical results. Here you will find case reports and clinical methods.

Go to

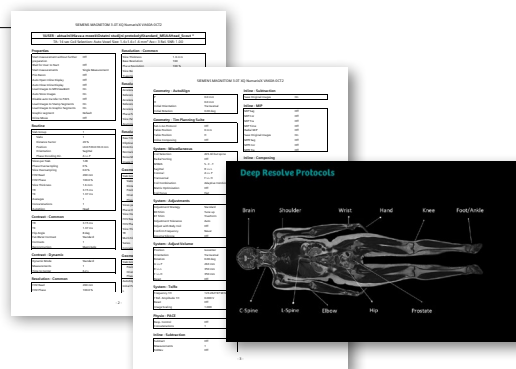
Clinical Corner > Case studies



Here you can download clinical protocols, phoenix images and application tips including videos.

Go to

Clinical Corner > Protocols



Just a mouse click away you will find application videos and useful tips allowing you to optimize your daily MR examinations.

Go to

Clinical Corner > Application Tips



Building the iMRI Suite: An Integrated Environment for MRI-Guided Interventions

Joshua Krieger¹, Peter Simpson¹, Axel J. Krafft², Jan Brandt², Inge M. Brinkmann²

¹ Cook Medical, Bloomington, IN, USA

² Siemens Healthineers, Erlangen, Germany

Physicians who want to perform MRI-guided interventions today still have to assemble the program themselves: the rooms, the devices, the imaging protocols, and the team. The iMRI Suite and surrounding services solve this problem by defining all the components as one integrated environment. This article describes that environment, what a site gets when it builds one, and what is needed to move from a finished room to a working clinical program.

1. Why interventional MRI programs have been hard to build

Interventional MRI (iMRI) has a history of individual programs solving the same challenges independently, each finding workable answers for their institution that are not fully translatable to another. Access and ergonomics constrained what the physician could physically do in the bore (see also the article by Cazzato and Gangi [1]). Room classification determined which procedures were permitted in a given space [2]. Teams converted existing diagnostic rooms successfully, but they still had to build the clinical workflow themselves through multidisciplinary planning, mock procedures, and explicit bailout protocols [3]. Assembling and operating a team proved as demanding as any technical requirement [4]. And device availability and visibility limited which procedures a program could attempt at all [5, 6].

What held iMRI back from broader adoption was not clinical imagination, but rather a coordination problem. Imaging manufacturers, device companies, and clinical teams each advanced their own piece of the puzzle. Manufacturers optimized MRI systems for diagnostic throughput. Device companies built interventional radiology and interventional cardiology portfolios around fluoroscopy and CT. Programs that succeeded did so through individual champions and extraordinary effort, not through a model that another institution could adopt.

A team at an institution reading the literature could satisfy itself that MRI-guided biopsy works and still have no reliable way to determine what its own room would cost, how large it should be, which of its existing devices could enter it, or how long the staff would take to become competent. Those are the questions that decide whether a program gets funded and ultimately succeeds.

An iMRI Suite has to satisfy a host of interdependent factors: MR siting rules, interventional room standards, and both diagnostic and interventional patient workflows at the same time. An imaging system capable of real-time guidance does little if the devices it must visualize were never designed to be seen. A device portfolio and a trained team produce nothing without a room classified to safely conduct the procedure. As Fabritius et al. state, without the multidisciplinary infrastructure in place, the procedure “cannot be implemented safely and reproducibly.” (see the article by Fabritius, et al. [7]).

2. The design thesis

An image guided interventional procedure is when a physician manipulates a medical device under medical imaging. Interventional MRI is an interventional procedure where MRI is the primary imaging modality, and the iMRI Suite is the holistic environment in which iMRI happens. It is not a scanner with accessories attached. The capability to perform the procedure comes from the rooms of the iMRI Suite, the integrated technology, and the devices as a whole. Turning that capability into clinical practice is achieved by enablement, which is layered on top of the space and the tools. Neither element works alone. A fully specified room without trained staff produces no cases, and a trained team without a suitable room has nowhere to work.

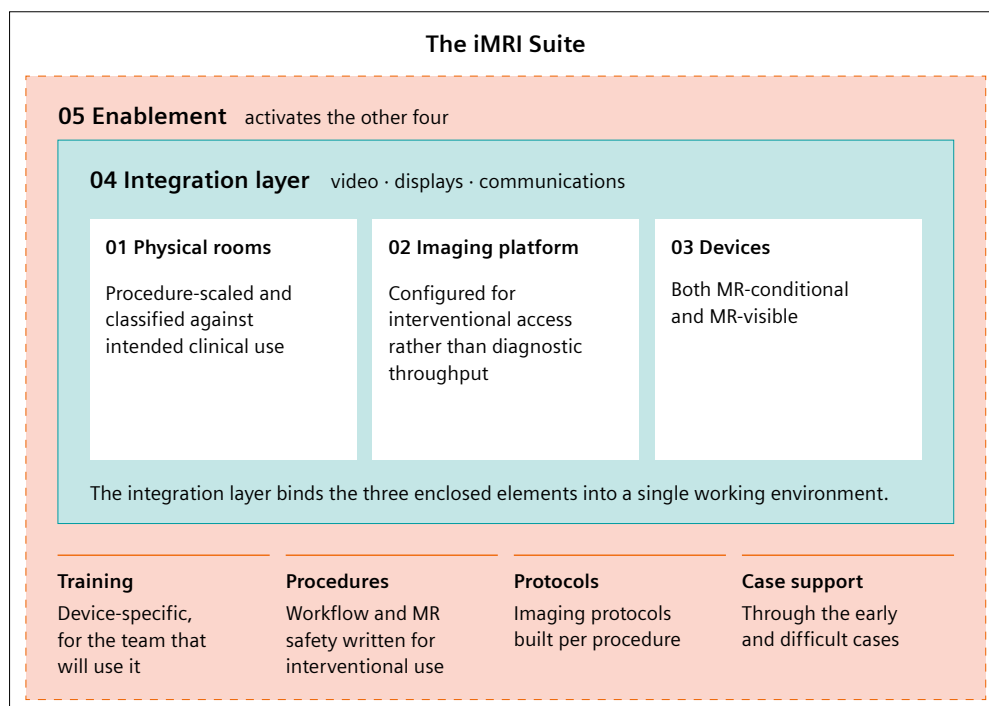
Four elements make up the physical iMRI Suite (Fig. 1):

- **The physical rooms:** procedure-scaled and classified against intended clinical use
- **The imaging platform:** configured for interventional access rather than diagnostic throughput
- **The devices:** designed to be both MR-conditional and MR-visible
- **The integration layer:** comprising video, displays, and communications.

These four elements are activated by a fifth element, **enablement**. This comprises device-specific training, workflow and MR safety procedures written for interventional use, procedure-specific imaging protocols, and case support during the early and difficult cases.

All five elements are scoped to enable and support the set of procedures a program intends to perform in year one and beyond. We call this “clinical-use-based planning.” It defines room size and class, anesthesia requirements, the device portfolio, the equipment and accessories, and the training plan.

The practical difference between an integrated environment designed around procedures, and an assembled environment shows up in the decisions that a site no longer has to make. In an assembled program, the compatibility of the table with the transfer system, the routing of video through the radiofrequency (RF) barrier, the MR-conditional status of the ablation generator, and the position of the anesthesia machine relative to the bore are all open questions that the institution resolves itself, usually in sequence and usually after something has already been ordered. An integrated environment answers the questions in advance, as interrelated parts of a full solution. We developed the integrated environment described in this paper through clinical-use-based planning for many iMRI Suites.



1 The four elements of a physical iMRI Suite, and the enablement layer.

3. What a site is buying

3a. The room

Figure 2 shows a dimensioned layout for a full-featured Class 2 iMRI Suite. The procedure room occupies 594 sq ft (55 m²) wall to wall, and the complete suite comes to 1,188 sq ft (110 m²) once the control room, induction room, and equipment room are included (Table 1). This is a reference layout and is the starting point for creating a tailored configuration for each iMRI Suite.

Three design principles organize the space: Sterile zones establish where the sterile field begins and what may cross it. Circulation zones establish how staff, patients, and equipment move without crossing each other at the wrong moment. Equipment zones establish where items park when they are not in use and where they go when they are.

The schematic highlights the elements that determine the functionality of the room during a case: the clinical work area beside the table, the anesthesia work area, the circulation path running from the control room to the head side of the magnet, storage for MR-specific consumables, equipment parking for items not in active use, and the induction, control, and equipment rooms.

Patient transfer happens in the induction area while the patient is positioned on the detachable patient table from the MR system.

The design stage simultaneously includes medical gas access, power distribution, RF shielding adaptations, and penetration panel locations. This is because each of these elements is difficult and expensive to change once construction finishes.

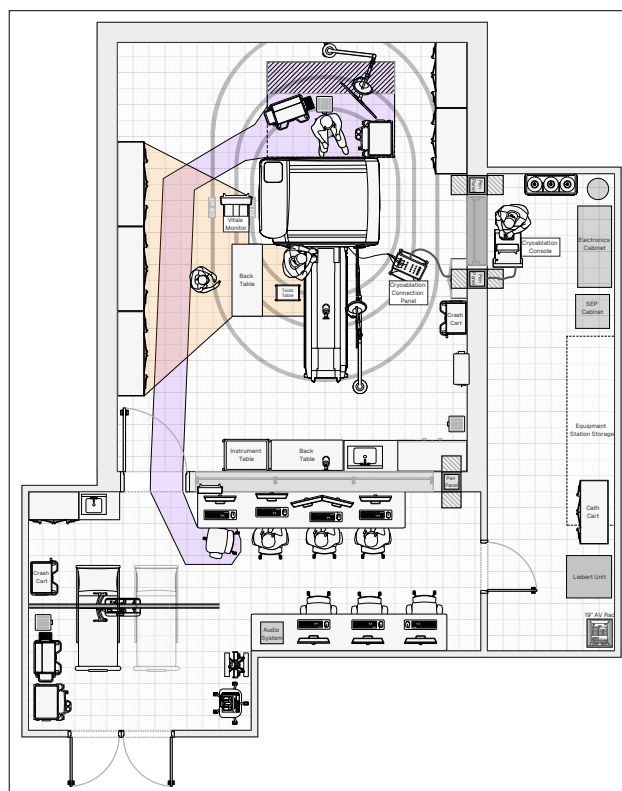
In the United States, the Facility Guidelines Institute's (FGI) *Guidelines for Design and Construction of Hospitals* provide the design baseline [8]. Three points about FGI are worth emphasizing:

First, FGI classifies imaging rooms based on safety, not on specific procedures or clinical specialty. Class 1 rooms support diagnostic procedures, Class 2 rooms support diagnostic and therapeutic procedures, and Class 3 rooms provide OR or hybrid-OR conditions for invasive surgery. Diagnostic MRI rooms are Class 1. All iMRI Suites are at least Class 2, and iCMR and advanced vascular configurations are typically Class 3. Each class carries its own

requirements for room size, layout, in-room power, gas connections, and minimum airflow.

Second, FGI does not determine which procedure a given room may host. The ultimate determination belongs to the healthcare organization and the enforcing authorities, informed by the functional planning and the site's infection control risk assessment. A program should classify the room against the most stringent procedure it plans to perform, which means planning now for a site's projected case mix, rather than for its year-one case mix.

Third, the FGI and the American College of Radiology's guidance on MRI safety are necessary but not sufficient. Neither addresses the iMRI environment specifically. Airflow rates, equipment clearances, and medical gas specifications written for fluoroscopy suites have to be applied in a context those documents did not anticipate,



2 Example of a full-featured Class 2 iMRI Suite with procedure room, control room, induction room, and equipment room.

Configuration	Procedure room	Support spaces	Total
Compact: percutaneous guidance and diagnostic imaging	408 sq ft (38 m ²)	362 sq ft (34 m ²)	770 sq ft (72 m ²)
Full-featured Class 2, (shown in Fig. 2)	594 sq ft (55 m ²)	594 sq ft (55 m ²)	1,188 sq ft (110 m ²)
Class 3, iCMR-capable	690 sq ft (64 m ²)	594 sq ft (55 m ²)	1,284 sq ft (119 m ²)

Table 1: iMRI Suite areas by configuration, wall to wall.

and most MR siting requirements look only at MRI performance requirements. In our experience, rooms built for diagnostic MRI frequently do not meet interventional room requirements and may need modification before procedural use. Retrofitting a diagnostic room to meet those requirements is often more complex and more costly than building to them from the outset.

Table 1 shows the iMRI Suite from Figure 2, along with the configurations on either side of it. Notice how both the procedure room and the support spaces scale to enable smooth clinical workflows and sufficient space for each stage of a procedure.

The Class 3 suite has a larger procedure room, but area is not the most important difference between a Class 2 and a Class 3 suite. Ventilation, power isolation, room layout, and proximity to recovery and bailout spaces carry more weight than square footage, which is why we have designed Class 3 rebuilds on nearly the same footprint as the room in Figure 2.

3b. The imaging platform

The MAGNETOM Free.XL¹ specifications, including the 100 cm flared opening, the DryCool technology, the XL gradients, Deep Resolve reconstruction, myNeedle Guide, and the Nexaris Dockable Table are described by Brandt in the article on MAGNETOM Free.XL [9]. Three properties matter procedurally:

Real-time interaction supplements step-and-shoot acquisition. The physician sees device advancement, tissue response, and anatomical landmarks continuously rather than through the pause-acquire-assess cycle of earlier iMRI approaches. This compressed feedback loop is what makes iMRI procedurally practical, and it lowers the barrier to adoption more than any single hardware specification.

The physician keeps access to the patient throughout the case. The large bore geometry, patient position, coil placement, and table design collectively determine whether the physician can hold a target trajectory, manipulate devices, preserve sterility, observe the patient, and coordinate with nursing, anesthesia, and the MR technologist [2, 3, 10, 11].

The field strength involves a deliberate and limited tradeoff. Imaging at 0.55T may reduce susceptibility-related distortion and RF deposition, and may lower heating for some conductive devices, potentially broadening the range of devices that are MR-conditional at 0.55T. The cost is a lower intrinsic signal-to-noise ratio. Gradient performance, coil design, acquisition, and reconstruction recover signal [12].

Between interventional cases, the same system performs routine diagnostic imaging. The dual use means that the number of different procedures can grow, with

no need to dedicate the scanner to intervention from day one. This materially changes the business case for institutions building their first program.

3c. The devices

MR-conditional and MR-visible are different properties, and interventional use requires both. A device can be entirely safe but still unusable for guidance.

MR-conditional describes the conditions under which a device is safe to use in a specified MR environment. It says nothing about whether the physician can see the device. MR-visible means the device produces a discernible, reliable signal artifact under imaging, one that lets the physician identify the device, track it in motion, and navigate it to the target.

Both properties are scarce in the existing interventional inventory. Many standard interventional radiology (IR) devices are not MR-conditional at 0.55T. Very few were built for MR visibility, because manufacturers built most of them for fluoroscopy, where visibility comes from radiopacity rather than from signal behavior. A program therefore cannot assemble an iMRI device portfolio by filtering its existing catalog. The iMRI device portfolio has to be built.

A device also has to offer sufficient clinical performance. It must be mechanically appropriate for the procedure, safely usable under its labeled conditions, and visible enough for controlled navigation without causing an artifact so large that it obscures the target. Those requirements all pull against each other, and resolving them is a primary design challenge rather than a materials substitution exercise.

Cook Medical's interventional needle portfolio is purpose-designed for in-bore use, is MR-conditional at the relevant field strength, and is optimized for MR visibility (Fig. 3). Each device must be used only under the conditions specified in its labeling, and MR-conditional status does not necessarily carry across field strengths, sequences, orientations, or procedures.

3d. Technology integration

For iMRI, a wide range of MR-conditional equipment must be available in the procedure room. The list is longer than new iMRI sites expect, covering patient monitors, anesthesia machines and ventilators, infusion pumps, ultrasound systems, ablation generators and effectors, procedural lighting, accessory furniture, cameras, boom arms, and display monitors. The versions of these used in fluoroscopy suites and cath labs will need to be replaced by MR-conditional versions, and each has to be sourced, evaluated, and integrated into the suite [13]. Therapy systems need the same scrutiny: Microwave, laser, and cryoablation each require MR-conditional generators, effectors, and

¹The products/features mentioned herein are not commercially available in all countries. Their future availability cannot be guaranteed.



3 Some examples from Cook Medical's MR-conditional and MR-visible interventional needle portfolio.

Some products or part numbers may not be available in all markets.

monitoring arrangements, with delivery protocols adapted to the MR environment.

In addition to MR-appropriate clinical equipment, the iMRI Suite needs communication and integration technology built for the way iMRI teams work. Getting the right information to the right person at the right moment matters as much as imaging performance.

During a case, the physician, scrub nurse, MR technologist, and anesthesiologist may stand in different parts of the procedure room or work in different rooms and focus on different tasks. Seamless communication across this team is central to effective procedures. This means each iMRI Suite must have an audio communications system with low-profile, high-fidelity headsets for in-room coordination and hearing protection, with continuous audio between the procedure room and the control room.

Visual information across the iMRI Suite should do more than duplicate the MR console to the intervention-alist. Our room integration system captures every video source in the iMRI Suite and routes images to the appropriate displays to provide task-specific information and clinical context to the full team. It also supports remote case assistance with video and audio during live procedures, and enables iMRI education as the program matures. This means designing in-room cameras, video capture from patient monitoring and treatment systems, in-room displays, control room displays, and audio integration from the start. Figure 4 shows this technology installed and operating at the Cook Medical iMRI Suite in West Lafayette, Indiana, USA.

With iMRI, it is possible to extract information that is not available under fluoroscopy or CT. These include thermometry for real-time progress monitoring during ablation, and pressure-volume assessment for cardiac hemodynamics. A robust room integration system should

capture these results and make the data visible to the whole care team.

Anesthesia requires its own iMRI adaptation. Beyond MR-conditional anesthesia machines and patient monitors, the physical relationship between the provider and the patient is different than in a standard operating room. The work splits between in-room delivery and remote monitoring and control. Equipment selection and space design inside and outside the procedure room must be adapted to this dual-location workflow.

4. Making it work clinically: The enablement layer

A fully built and equipped iMRI space is not an operational iMRI Suite. The rooms, the platform, the devices, and the integrating technology create capability. Enablement, which means establishing iMRI clinical methods and training the team to run them, converts that capability into practice.

This is the implementation point at which programs most often stall, and the reason is usually structural rather than clinical. Too often, sites treat enablement as commissioning: a week of training at handover, after which the team is expected to be competent. Our lead sites show otherwise. Enablement works as a parallel workstream that begins during design and continues past the first several months of cases. Planned that way, it has four distinct foci, each with its own deliverables, owners, and completion criteria.

Device-specific training: MR-visible disposables are the procedural foundation. They are consumed with each case and are different from their traditional IR analogs. The site-specific device portfolio follows from clinical use-based planning: A needle-based oncology program draws on



4 The Cook Medical iMRI Suite in West Lafayette, showing installed video, display, and communications technology.

MR-compatible biopsy and ablation systems, while a cardiovascular program requires MR-visible guidewires, catheters, and sheaths.

Physicians, nurses, and MR technologists each need training on those devices before first use. This is because the devices handle differently from their fluoroscopy equivalents; more importantly, they appear differently on imaging. A physician reading the device position from an MR-visible artifact rather than from a radiopaque shadow is interpreting a signal whose size and shape change with the sequence, orientation, and field strength. That interpretation is a learned skill, not a property of the device, and the way to learn it is on a phantom, not a patient.

Workflow and MR-safety procedures written for interventional use: Interventional standard operating procedures (SOPs) have to address screening under procedural conditions, patient transport and transfer, sterile setup within the magnet environment, equipment zone management, emergency response, including removing the patient from the magnet room, and conversion to another modality if the case requires it. The multidisciplinary core team writes each of those procedures, rehearses them in full-scale mock-ups, and revises them afterward. This is because mock-ups reliably surface constraints that a written procedure does not anticipate.

The MR technologist's role changes most. In diagnostic practice, the MR tech manages patient safety and imaging protocols for a scheduled examination. In the iMRI Suite, their role expands to active clinical coordination during a live procedure, real-time protocol adjustment in response to what the interventionalist needs to see next, oversight of the Zone 4 boundary as staff and items enter and leave, and oversight of a safety environment considerably more complex than for a diagnostic scan. This is a different job from the diagnostic one. Define it in a written role descrip-

tion, staff it deliberately, and name the individuals who will own it before the room is finished, so that their training runs in parallel with construction rather than after it.

Procedure-specific imaging protocols: Generic diagnostic sequences are not sufficient for interventional guidance. Diagnostic characterization, navigation, device-tip confirmation, MR-based treatment monitoring, and post-treatment assessment all require a different balance of spatial resolution, temporal resolution, soft-tissue contrast, and artifact behavior, and a program moves between those states several times within a single case. The imaging team and the clinical operators build protocols together for the anatomical area, the procedure type, and the patient habitus, then refine them as the case mix evolves.

Case support through the early cases: Historically, programs were less likely to stall because of equipment inadequacy than because of structured support being absent when the team needed it. When support extends through the early cases, including remote assistance during live procedures, it builds clinical confidence when confidence is scarcest and reduces variability as volume grows. Programs with experienced case support from the outset achieve stable, self-sustaining operation materially faster than programs without it.

The evidence showing that structured support changes clinical performance is stronger than it usually gets credit for, and none of it depends on new hardware. In prostate MRI, central review and protocol feedback in the PRIME trial raised the proportion of scanners achieving a Prostate Imaging Quality (PI-QUAL) score of 5 from 32% to 97% [14]. In focal prostate therapy, the 21.7% five-year salvage rate reported in the TACT pivotal trial of TULSA is attributed in part to early operator experience rather than to any change in the device [15]. Both findings point in the same direction: In image-guided practice, a substantial share

of the performance gap between centers comes from practical guidance rather than from equipment, which is why sustained case support belongs in the program plan.

5. What iMRI enables, procedure by procedure

iMRI is an additional interventional modality, taking its place beside CT-, ultrasound-, and fluoroscopy-guided intervention. Where iMRI merely duplicates another modality, it is not a compelling choice over mature interventional methods. For instance, MRI-guided procedures have run longer than their CT equivalents [16]. MRI-guided intervention is compelling when the information it provides changes target selection, trajectory planning, device placement, treatment control, or confirmation. The list of such applications is growing.

Biopsy of small lesions: In focal liver lesions smaller than 20 mm, MRI-guided freehand biopsy achieved 96% clinical success against 74% for CT guidance, with a complication rate of 0% against 13% [16]. For a high-volume procedure performed in most health systems, that difference is clinically and operationally significant. iMRI can guide biopsies of sub-centimeter lesions that are ambiguous or invisible under CT, enabling biopsies earlier than previously possible, particularly in the liver and the prostate, where MRI is already the diagnostic standard.

Thermometry-monitored ablation: Real-time MR thermometry gives the status of the evolving ablation zone during the case, rather than confirming a completed zone at the end [17]. The proceduralist can identify incomplete coverage early, adapt treatment during the procedure, and monitor thermal exposure of adjacent structures through quantitative temperature mapping, a capability not routinely available with conventional CT- or US-guided ablation [18].

Prostate targeting and focal therapy: MRI-guided prostate intervention uses MRI for lesion targeting, device placement, thermometry, and post-treatment assessment, while MRI-ultrasound fusion is useful when direct in-bore intervention is impractical [19]. This application area has the deepest sustained clinical experience.

Vascular malformations: MRI-guided treatment of low-flow vascular malformations with freehand targeting using a Cook MReye needle [6] demonstrates clinical efficacy using a commercially available device portfolio in routine iMRI practice.

Cardiovascular, including congenital and pediatric: MRI guidance simultaneously shows cardiac anatomy, catheter position, and hemodynamic response, without ionizing radiation. This matters most in patients facing repeated catheterization for chronic disease [4, 5]. The

limiting factors are device availability and training, rather than imaging capability.

Musculoskeletal: Soft-tissue masses with poor conspicuity under ultrasound or CT, perineural tumors, and lesions in anatomically complex regions benefit in ways that parallel the liver and prostate experience. As MRI-guided ablation portfolios expand, this application set is likely to grow.

iMRI may broaden access to image-guided procedures for patient populations for whom radiation-based guidance may be less desirable, including: pediatric patients, patients requiring repeated interventions for chronic disease management, and those for whom cumulative radiation exposure is a particular concern. For some of these patients, the question is not whether the procedure is better under iMRI. It is whether they could even access the procedure under an alternative, radiation-dependent modality.

6. Getting started

Experience shows that successful iMRI implementation occurs in steps, and the sequence is consistent across multiple examples [3, 4]:

- Select one or two procedures where MRI guidance offers a clear advantage and where the team already has volume and expertise.
- Name a clinical champion and assemble a core team spanning the procedural specialty, MR services, technologists, nursing, anesthesia, MR safety or physics, infection prevention, biomedical engineering, and facilities.
- Decide on the physical location and equipment: whether an existing diagnostic space can be adapted, or whether the program needs a new Class 2 or Class 3 environment. Design the suite and select the MR-conditional equipment that supports the planned procedures and enables the team.
- Develop procedure-specific imaging protocols that balance device visibility, temporal resolution, and image quality. Run full team mock-ups and dry runs with the actual equipment before the first patient. Define explicit go/no-go and bailout criteria, and measure safety and workflow from the first case. Where resources are constrained, sequential MRI-augmented workflows or an emphasis on lower-complexity cases will build shared experience as a lead-up to more complex real-time interventions [4].

7. Conclusion

Interventional MRI has reached a level of maturity which allows to implement a comprehensive iMRI Suite. Cook Medical's research suite in West Lafayette, Indiana, USA,

operates the configuration described in this article with a MAGNETOM Free.XL installed, and it is where we validated the design against an actual procedural workflow. Market availability will follow the regulatory approval of the imaging platform. In the European Union, where MAGNETOM Free.XL is on the market, the complete iMRI Suite is available now. In the United States, the iMRI Suite will become commercially available on release of MAGNETOM Free.XL. Regulatory status, product configuration, and availability vary by jurisdiction.

All of this begins with a conversation about which procedures a program intends to perform, for which patients, and on what timeline. Every other decision described in this article follows from those answers. Cook Medical and Siemens Healthineers support the process from that first conversation, through the first case, and beyond.

References

- Cazzato RL, Gangi A. Interventional Magnetic Resonance Imaging: Current Concepts, Enabling Technologies, and Emerging Clinical Applications. *MAGNETOM Flash*. 2026;99:34–37. Available from: https://marketing.webassets.siemens-healthineers.com/d8ba6570c89722c0/16c892592d70/siemens-healthineers_MWorld_Cazzato_Gangi_iMRI.pdf
- Azmi H, Gibbons M, DeVito MC, Schlesinger M, Kreitzer J, Freguletti T, et al. The interventional magnetic resonance imaging suite: experience in the design, development, and implementation in a pre-existing radiology space and review of concepts. *Surg Neurol Int* [Internet]. 2019;10:101. Available from: <http://dx.doi.org/10.25259/SNI-209-2019>
- Bijvoet GP, Holtackers RJ, Smink J, Lloyd T, van den Hombergh CLM, Debie LJB, et al. Transforming a pre-existing MRI environment into an interventional cardiac MRI suite. *J Cardiovasc Electrophysiol* [Internet]. 2021;32(8):2090–6. Available from: <http://dx.doi.org/10.1111/jce.15128>
- Amin EK, Campbell-Washburn A, Ratnayaka K. MRI-guided cardiac catheterization in congenital heart disease: how to get started. *Curr Cardiol Rep* [Internet]. 2022;24(4):419–29. Available from: <http://dx.doi.org/10.1007/s11886-022-01659-8>
- Rogers T, Campbell-Washburn AE, Ramasawmy R, Yildirim DK, Bruce CG, Grant LP, et al. Interventional cardiovascular magnetic resonance: state-of-the-art. *J Cardiovasc Magn Reson* [Internet]. 2023;25(1):48. Available from: <http://dx.doi.org/10.1186/s12968-023-00956-7>
- Bailey CR, Giraldo Herrera D, Neumeister N, Weiss CR. Magnetic resonance - guided treatment of low-flow vascular malformations and the technologies to potentiate adoption. *Front Med (Lausanne)* [Internet]. 2024;11:1319046. Available from: <http://dx.doi.org/10.3389/fmed.2024.1319046>
- Fabritius MP, Seidensticker M, Ricke J. MRI-Guided High-Dose-Rate Interstitial Brachytherapy of Hepatic Malignancies. *MAGNETOM Flash*. 2026;99:38–43. Available from: https://marketing.webassets.siemens-healthineers.com/e712d93de2b13077/ea55c33eace8/siemens-healthineers_DIMRI_Fabritius_iMRI_Brachy.pdf
- The Facility Guidelines Institute. Guidelines for design and construction of hospitals. The Facility Guidelines Institute; 2022.
- Brandt JM, Martin M. MAGNETOM Free.XL as a Strategic System for Diagnostic Imaging and MRI-Guided Interventions. *MAGNETOM Flash*. 2026;99:16–24. Available from: https://marketing.webassets.siemens-healthineers.com/55d37938474e3355/df21dd7581ce/Siemens-Healthineers_Magnetomworld_Martin_Brandt_MAGNETOM_Free_XL_.pdf
- Weiss CR, Nour SG, Lewin JS. MR-guided biopsy: a review of current techniques and applications. *J Magn Reson Imaging* [Internet]. 2008;27(2):311–25. Available from: <http://dx.doi.org/10.1002/jmri.21270>
- Thompson SM, Gorny KR, Knavel Koepsel EM, Welch BT, Mynderse L, Lu A, et al. Body interventional MRI for diagnostic and interventional radiologists: current practice and future prospects. *Radiographics* [Internet]. 2021;41(6):1785–801. Available from: <http://dx.doi.org/10.1148/rg.2021210040>
- Campbell-Washburn AE, Ramasawmy R, Restivo MC, Bhattacharya I, Basar B, Herzka DA, et al. Opportunities in interventional and diagnostic imaging by using high-performance low-field-strength MRI. *Radiology* [Internet]. 2019;293(2):384–93. Available from: <http://dx.doi.org/10.1148/radiol.2019190452>
- Cross NM, Hoff MN, Kanal KM. Avoiding MRI-related accidents: a practical approach to implementing MR safety. *J Am Coll Radiol* [Internet]. 2018;15(12):1738–44. Available from: <http://dx.doi.org/10.1016/j.jacr.2018.06.022>
- Giganti F, Ng A, Asif A, Chan VWS, Rossiter M, Nathan A, et al. Global variation in magnetic resonance imaging quality of the prostate. *Radiology* [Internet]. 2023;309(1):e231130. Available from: <http://dx.doi.org/10.1148/radiol.231130>
- Eggner S, Zagaja G, Oto A, Pavlovich C, Macura K, Koch M, et al. Pivotal study of MRI-guided transurethral ultrasound ablation (TULSA) of localized prostate cancer: 5-year follow up. *Urol Oncol* [Internet]. 2024;42:S83. Available from: <http://dx.doi.org/10.1016/j.urolonc.2024.01.234>
- Schmidt VF, Öcal O, Walther V, Fabritius MP, Dietrich O, Kazmierczak PM, et al. Clinical benefits of MRI-guided freehand biopsy of small focal liver lesions in comparison to CT guidance. *Eur Radiol* [Internet]. 2024;34(9):5507–16. Available from: <http://dx.doi.org/10.1007/s00330-024-10623-9>
- Öcal O, Dietrich O, Lentini S, Bour P, Faller T, Ozenne V, et al. Predicting liver ablation volumes with real-time MRI thermometry. *JHEP Rep* [Internet]. 2024;6(11):101199. Available from: <http://dx.doi.org/10.1016/j.jhepr.2024.101199>
- Zhu M, Sun Z, Ng CK. Image-guided thermal ablation with MR-based thermometry. *Quant Imaging Med Surg*. 2017;7(3):356–368. Available from: <http://dx.doi.org/10.21037/qims.2017.06.06>
- van Luijckelaar A, Futterer JJ, Bomers JGR. Minimally invasive magnetic resonance image-guided prostate interventions. *Br J Radiol* [Internet]. 2022;95(1131):20210698. Available from: <http://dx.doi.org/10.1259/bjr.20210698>



Contact

Dr. rer. nat. Inge M. Brinkmann
Siemens Healthineers
SHS DI MR NEW THP
Allee am Roethelheimpark 2
91052 Erlangen
Germany
inge.brinkmann@siemens-healthineers.com

MAGNETOM Free.XL as a Strategic System for Diagnostic Imaging and MRI-Guided Interventions

Jan-M. Brandt, Ph.D.; Michaela Martin, BSc (Medical Radiations) PGc (MRI)

Siemens Healthineers, Erlangen, Germany

Abstract

Magnetic resonance imaging (MRI) is increasingly expected to support not only diagnosis but also treatment planning, procedural guidance, therapy monitoring, and longitudinal patient follow-up. This evolution is particularly apparent in oncology, neurology, cardiovascular medicine, women's and men's health, and image-guided interventions, where diagnostic imaging has become an integral component for clinical decision making for physicians throughout the patient journey. Hence, features such as patient access, workflow integration, procedural usability, and patient experience are becoming more relevant for healthcare providers. Recent advances in gradient performance, acquisition strategies, and deep-learning-based image reconstruction have renewed interest in lower-field MRI.

Contemporary 0.55T systems have demonstrated diagnostic image quality across a broad range of neurological, musculoskeletal, abdominal, pelvic, and cardiovascular applications. At the same time, wide-bore system designs may facilitate access for image-guided procedures [2, 4–6]. In particular, the MAGNETOM Free.XL system (Siemens Healthineers, Erlangen, Germany) is a platform designed around these emerging clinical requirements. By combining modern lower-field imaging capabilities with a 100 cm flared bore and a workflow-oriented design approach, the system seeks to bridge diagnostic imaging and image-guided intervention. This article explores the clinical rationale for such a platform.

The products/features mentioned herein are not commercially available in all countries. Their future availability cannot be guaranteed.



1 The MAGNETOM Free.XL system showing the 100 cm flared bore (1A) and the importance of patient access (1B).

Introduction

For much of its history, magnetic resonance imaging (MRI) has been evaluated primarily through the lens of diagnostic performance. Technological innovation focused on improving image quality through higher magnetic field strengths, faster acquisitions, stronger gradients, and sophisticated coils. Clinical success was largely measured by signal-to-noise ratio, spatial resolution, and diagnostic confidence. Today, however, the role of MRI is changing. Across multiple clinical disciplines, imaging has become deeply integrated into treatment planning, procedural guidance, therapy assessment, and longitudinal disease monitoring. In interventional oncology, MRI provides imaging information to support clinical assessment throughout the patient pathway, from diagnosis through follow-up, when interpreted by a healthcare professional. In neurology, it supports not only disease characterization but also emerging image-guided therapies. In cardiovascular care, MRI combines structural, functional, and tissue characterization capabilities. Similarly, image-guided interventions rely on MRI to provide precise soft-tissue visualization without exposure to ionizing radiation [1–6].

For many years, MRI development was largely associated with increasing magnetic field strength. While higher-field systems continue to provide important advantages for selected applications, advances in hardware and software have fundamentally changed the capabilities of modern lower-field MRI. Recent developments in gradient technology, accelerated acquisition techniques, and deep-learning reconstruction (i.e., Deep Resolve) have enabled contemporary 0.55T systems to achieve diagnostic image quality across a broad spectrum of clinical applications. Emerging evidence demonstrates the feasibility of routine neurological imaging, body imaging, musculoskeletal imaging, and cardiovascular applications at lower-field strengths, while also highlighting unique opportunities created by the underlying physics [2, 7–17]. Lower field strengths are associated with reduced susceptibility effects and decreased image distortion around metallic implants and devices, especially in musculoskeletal imaging. These characteristics may be advantageous in clinical situations involving implants and interventional devices. Furthermore, lower field strengths can provide favorable imaging conditions in environments where procedural flexibility and device compatibility are important considerations. The renewed interest in lower-field MRI therefore reflects more than a technical discussion about image quality; it reflects a broader recognition that future MRI platforms should consider not only diagnostic imaging performance but also accessibility, workflow integration, procedural usability, and adaptability to emerging therapeutic applications [18–26].

As healthcare systems move toward integrated and outcome-oriented care, imaging technologies are expected to contribute throughout the care pathway rather than at individual diagnostic time points. Consequently, clinicians are not only evaluating MRI systems by image quality, but also by the systems' ability to support broader clinical workflows and therapeutic strategies. This article illustrates the key features and diagnostic imaging capabilities of MAGNETOM Free.XL to demonstrate how this lower-field MRI system unlocks greater workflow potential. In this context, in-bore patient access, procedural usability, and workflow integration become strategic attributes alongside state-of-the-art metrics of imaging performance.

Accessibility as a clinical enabler

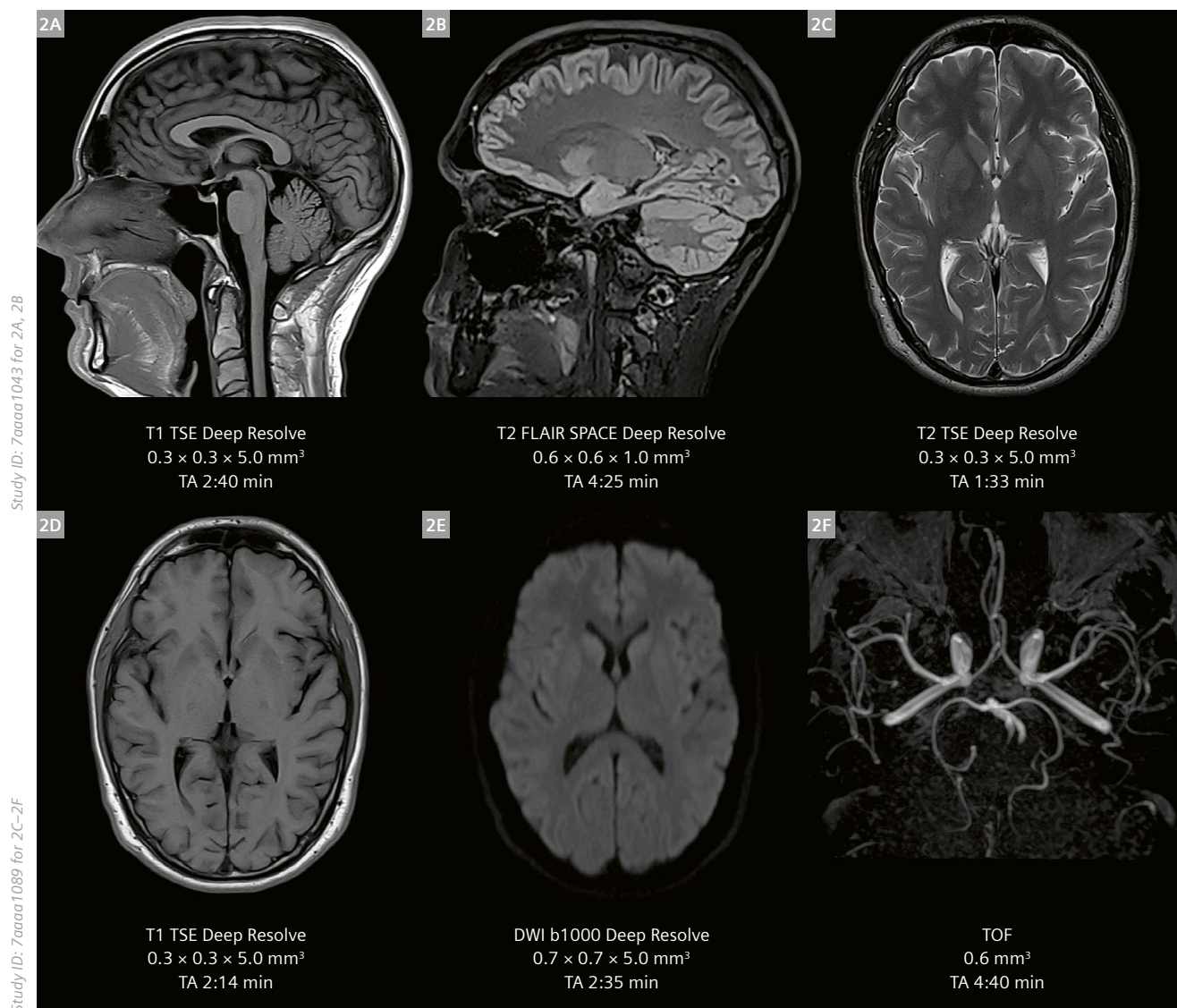
As MRI becomes more integrated into therapeutic pathways, physical access to the patient receives greater importance. Conventional MRI systems were primarily optimized for image acquisition where a 70 cm bore diameter was sufficient. Procedural interaction with the patient was therefore not necessarily a primary design consideration. However, larger MRI bores require substantially more energy because a larger magnetic field volume is needed to maintain field homogeneity across the larger bore volume. The emergence of MRI-guided therapies creates new clinical requirements: Physicians must maintain access for patient positioning, device manipulation, treatment delivery, monitoring, and anesthesia support. Procedural success may depend not only on image quality but also on the practical ability to work effectively around the patient within the imaging environment. Studies show that modern lower-field systems with 80 cm bores have reported favorable patient perceptions related to bore size, reduced acoustic burden, and overall examination tolerance when compared with conventional systems [4, 6]. These findings are clinically relevant because the patient's experience influences examination compliance, throughput, and access to MRI-based care. MAGNETOM Free.XL addresses and further advances these considerations with its 100 cm flared bore architecture that is designed to increase the usable working space around the patient (Fig. 1). While accessibility alone does not determine clinical value, it may facilitate positioning, improve procedural ergonomics, simplify integration of ancillary equipment, and potentially support future therapy-oriented workflows. Besides that, MAGNETOM Free.XL is part of the MAGNETOM Free. Platform. As such, it features a sealed-for-life, quench-pipe-free magnet design that requires only 0.7 liters of liquid helium, and it has a smaller footprint and lower weight. The system is further equipped with the

Nexaris Dockable Table to streamline patient positioning and transfer during image-guided interventions. Integrated within the multimodality Nexaris Therapy Suites, the Nexaris Dockable Table enables seamless workflows across MRI, CT, angiography, and intraoperative MRI.

Neurological imaging and beyond

Brain imaging is one of the most frequently performed MRI examinations. Accurate diagnosis and longitudinal monitoring require high-quality visualization of anatomy, pathology, treatment effects, and disease progression. MRI has therefore become indispensable throughout neurological care pathways (Fig. 2). Advances in acquisition and reconstruction techniques have enabled modern lower-field MRI to support a broad range of neurological

examinations while maintaining workflow compatibility within routine clinical environments [1]. At the same time, neurological treatment strategies are evolving. Image-guided interventions, minimally invasive therapies, focused ultrasound procedures, and thermal treatment techniques rely on imaging before, during, and after the intervention. In these settings, MRI is expected to support the treating physician in therapeutic decision-making, procedural planning, treatment delivery, and patient follow-up. The growing integration of imaging and intervention suggests that future neurological MRI systems may be evaluated not only by their ability to characterize disease but also by their ability to facilitate emerging treatment pathways, such as high-focused ultrasound and stereotactic therapy to name only a few [6–9].

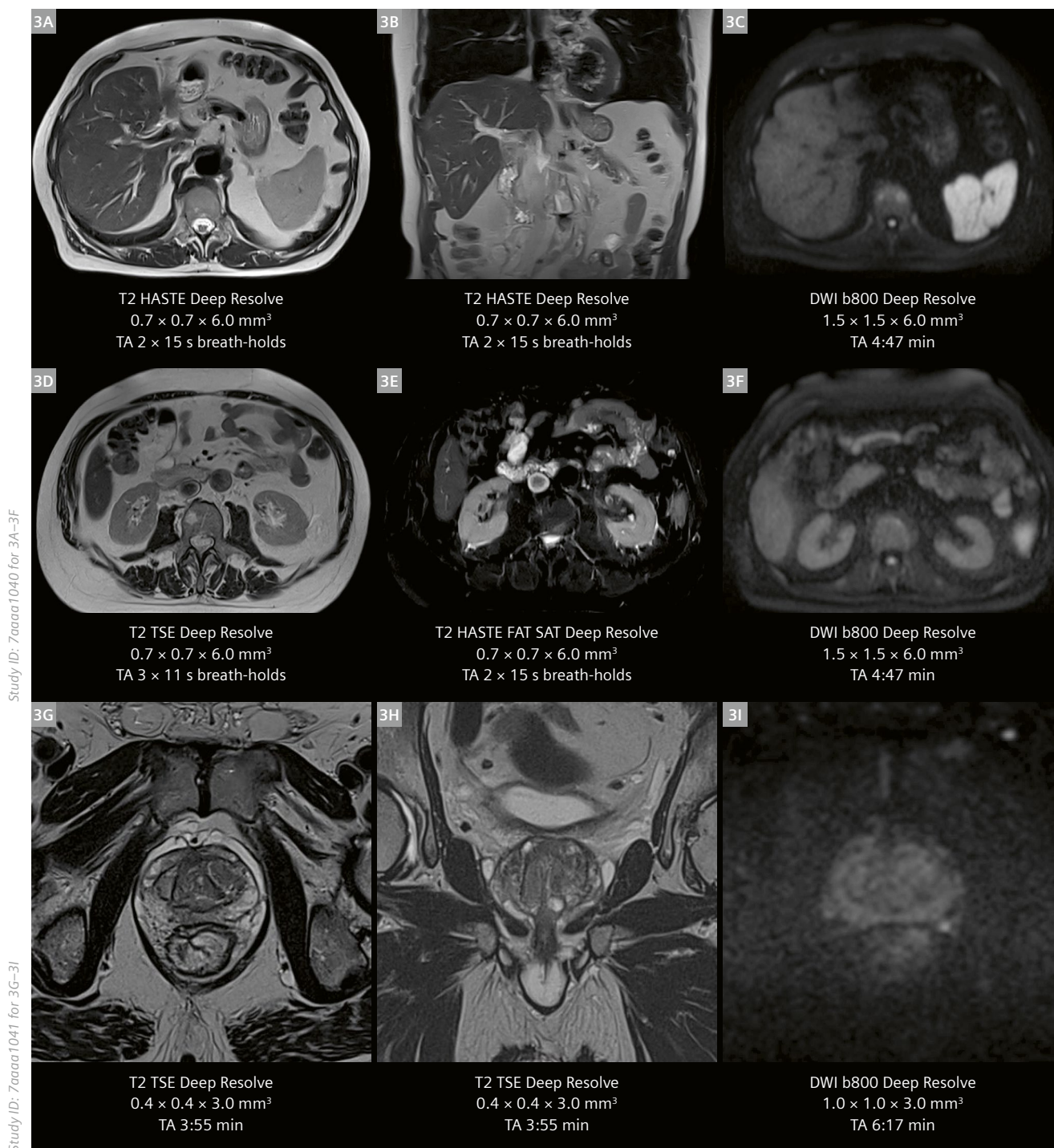


2 Routine brain imaging demonstrates that the scan times and imaging parameters meet the standard of care.

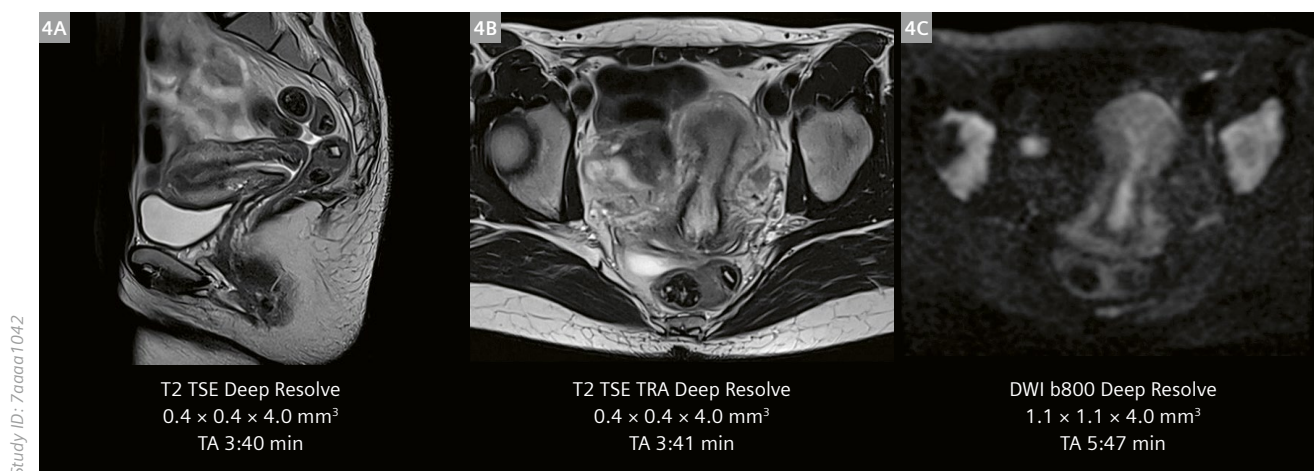
Body imaging and precision medicine

Body MRI has become an essential component of modern oncology and precision medicine. Applications in prostate cancer, liver disease, renal lesions, and pelvic disorders support treatment selection, procedural planning, and long-term patient management. The role of MRI in men's

health continues to expand, supporting prostate lesion detection, risk stratification, biopsy guidance, treatment planning, and surveillance [3, 7, 10, 11, 12]. This evolution is particularly important because prostate MRI supports diagnosis and during interventional procedures (Fig. 3).



3 MAGNETOM Free.XL supports diagnostic imaging and selected abdominal workflows.



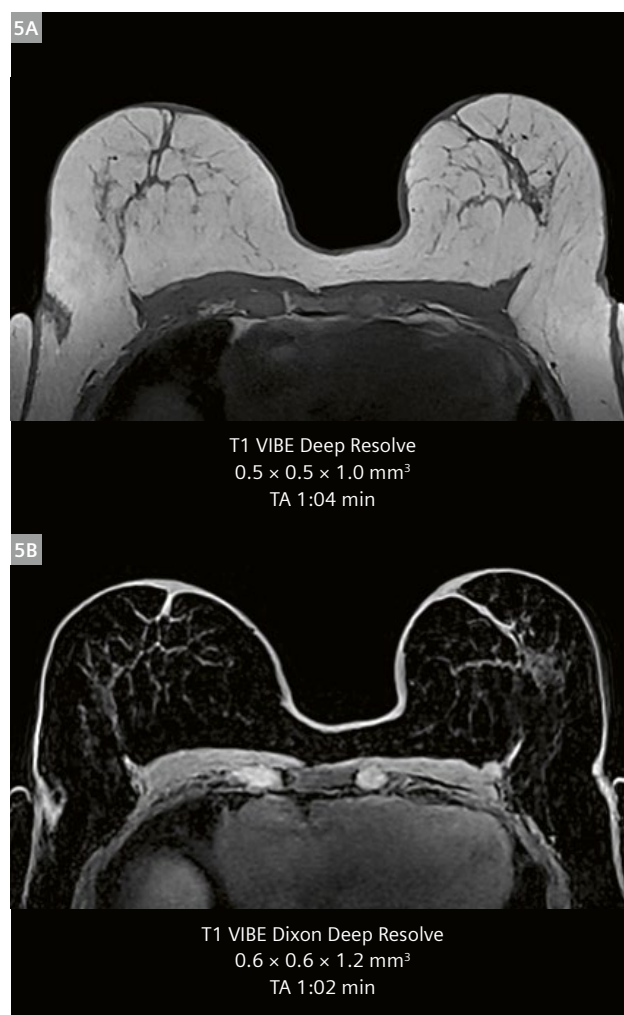
4 MRI in women's pelvic health can support disease mapping, treatment planning, and follow-up in endometriosis and uterine fibroid care.

Recent work has demonstrated the clinical feasibility of MRI-guided in-bore prostate biopsy at 0.55T, illustrating how modern lower-field MRI can contribute to image-guided interventions [4, 7, 8]. Similarly, MRI has become indispensable in liver imaging, where its ability to characterize focal lesions and diffuse disease influences therapeutic decision-making across a broad range of clinical scenarios [12]. MAGNETOM Free.XL may therefore enable new opportunities for supporting complex oncologic workflows.

Women's health and pelvic imaging

In women's health, MRI is integrated into comprehensive care pathways for conditions requiring detailed soft-tissue characterization, such as deep infiltrating endometriosis, adenomyosis, and gynecologic malignancies [19, 20] (Fig. 4). Beyond diagnosis, MRI contributes to treatment planning and assessment, particularly as minimally invasive therapeutic approaches continue to expand. Image-guided ablation techniques have already demonstrated feasibility in selected endometriosis-related applications, illustrating how advanced imaging can become integrated into therapeutic workflows [17]. These developments align with a broader trend in which imaging technologies are expected to support clinical decision-making across the entire treatment continuum rather than solely during initial diagnosis.

A similar trend is evident in breast imaging, where MRI is an established pillar of comprehensive care. Leveraging high tissue contrast, MRI enables precise lesion detection, staging, and monitoring, particularly in women with dense breast tissue or in high-risk screening cohorts [22, 23]. The American College of Radiology Appropriateness Criteria recommend breast MRI for high-risk women and selected women with dense breast tissue, reflecting established



5 Breast images of high soft-tissue contrast for lesion assessment and visualization of breast, chest wall, and axillary anatomy, using T1 VIBE and T1 VIBE Dixon, both with Deep Resolve.

evidence that MRI provides superior sensitivity for early breast cancer detection compared with mammography alone in these populations [24] (Fig. 5).

Musculoskeletal imaging

In musculoskeletal MRI, system performance is best reflected by the ability to depict both fine anatomy and clinically relevant pathology with diagnostic confidence. Representative examinations should provide clear assessment of cartilage, menisci, ligaments, tendons, muscle, and marrow, as well as abnormalities such as edema, osteochondral injury, occult fracture, and soft-tissue lesions. MAGNETOM Free.XL is of interest in this context because contemporary 0.55T MRI systems (i.e., MAGNETOM Free.Max) with deep-learning reconstruction have demon-

strated diagnostic image quality for routine knee imaging, while the lower field strength may reduce metal-related artifacts (Fig. 6) [2, 3, 4, 18]. MRI-guided interventions in musculoskeletal cases have been shown to deliver standard of care in nerve root infiltration therapy, but with higher soft-tissue contrast than CT imaging [25].

Cardiovascular imaging

Cardiovascular MRI and MRI-guided interventions are among the most technically demanding applications for diagnostic imaging. However, they are highly clinically valuable because they provide comprehensive assessment of cardiac characteristics without exposing patients to ionizing radiation [2, 15]. This radiation-free imaging is particularly important for pediatric patients and for

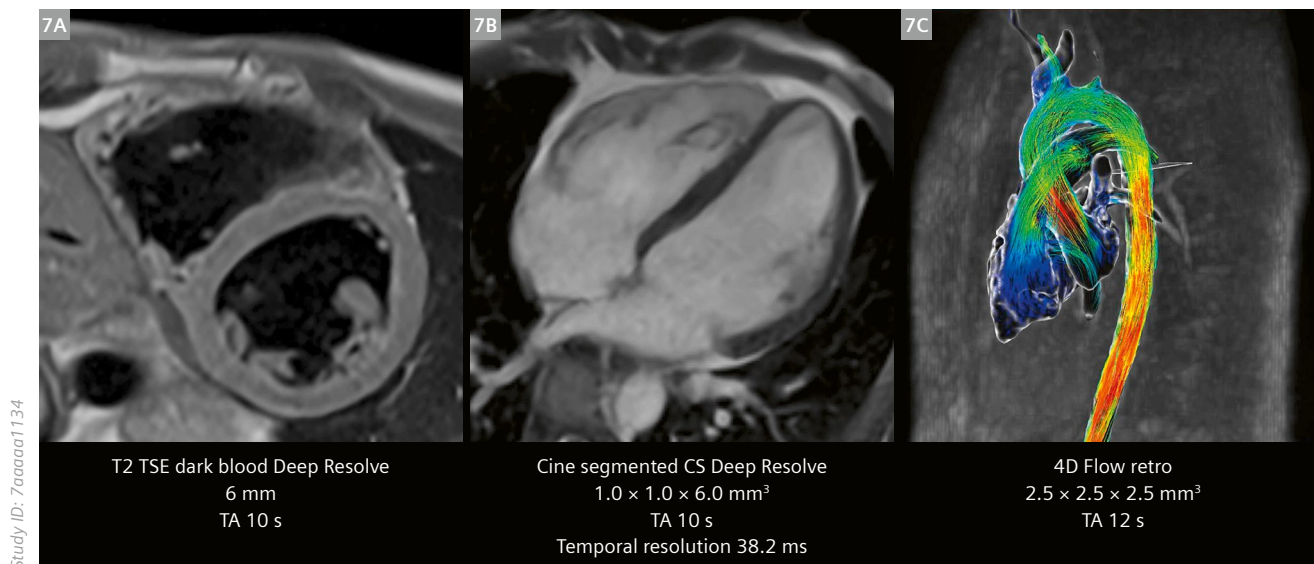


6 Images that support confident assessment of joint anatomy and potential pathology (e.g., 6D) in a patient with bilateral hip replacement.

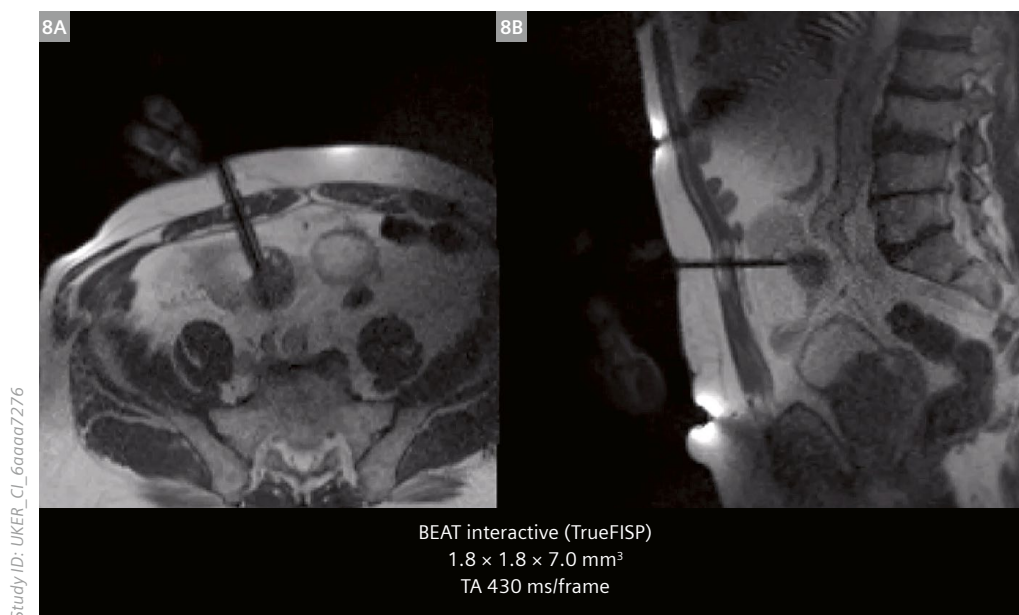
individuals who require repeated follow-up examinations, for whom cumulative radiation exposure is a significant concern. Lower-field cardiac MRI has recently attracted renewed interest because lower field strengths may offer several intrinsic advantages for cine and blood flow imaging (Fig. 7). For patients with implants, lower-field MRI can reduce artifacts. These advantages also support MRI-guided cardiac interventions, where accurate real-time imaging is critical for catheter movement and procedural success.

Interventions with real-time imaging

MAGNETOM Free.XL combines the inherent advantages of 0.55T MRI with high-performance “XL gradients” (59 mT/m at 277 T/m/s slew rate [along single axis 34 mT/m at 160 T/m/s]), Deep Resolve, and a patient-centered flared bore design, creating a system that balances image quality, patient accessibility, and workflow efficiency. Strong gradient performance plays a central role by enabling faster spatial encoding, shorter acquisition times, and



7 Various contrasts show that cardiac imaging with MAGNETOM Free.XL can be routine. **(7A)** T2 TSE dark blood with Deep Resolve, **(7B)** Cine with Compressed Sensing and Deep Resolve, **(7C)** 4D Flow velocity-encoded blood-flow information.



8 Real-time imaging guidance with BEAT interactive (TrueFISP contrast) sequence during a needle biopsy of a lymphatic lesion in the abdomen. Images courtesy of Matthias May, M.D., EBIR; Universitätsklinikum Erlangen, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany.

improved temporal resolution, which are essential for real-time imaging during percutaneous needle-guided and catheter-guided interventions. The XL gradients enhance temporal resolution by significantly compressing the acquisition time, resulting in a higher frame rate [1, 5–7, 17, 19]. This integration means that MRI can support targeting, verification, intervention, and follow-up, within a single environment (Fig. 8).

Discussion

The future of MRI will ultimately be defined less by magnetic field strength and more by its ability to integrate into patient care pathways. Healthcare systems increasingly seek technologies that support diagnosis, treatment planning, intervention, therapy monitoring, and longitudinal follow-up within a unified clinical framework [26]. This transformation is already visible across oncology, neurology, cardiovascular medicine, women's health, and interventional radiology. As imaging becomes progressively more essential for intervention, MRI systems must provide not only diagnostic performance but also accessibility, workflow flexibility, and procedural adaptability. The MAGNETOM Free.XL system reflects this evolving paradigm. Its significance lies not simply in operating at 0.55T, but also in combining excellent diagnostic imaging that meets the standard of care with a platform designed around patient access, procedural usability, workflow, and convenient institutional integration. Such characteristics are becoming more important as MRI-guided interventions continue to expand across multiple clinical disciplines.

References

- Michael AE, Heuser A, Moenninghoff C, Surov A, Borggrefe J, Kroeger JR, Niehoff JH. Does bore size matter?—A comparison of the subjective perception of patient comfort during low field (0.55 Tesla) and standard (1.5 Tesla) MRI imaging. *Medicine (Baltimore)* [Internet]. 2023;102(47):e36069. Available from: <http://dx.doi.org/10.1097/MD.00000000000036069>
- Campbell-Washburn AE, Varghese J, Nayak KS, Ramasawmy R, Simonetti OP. Cardiac MRI at Low Field Strengths. *J Magn Reson Imaging* [Internet]. 2024;59(2):412–30. Available from: <http://dx.doi.org/10.1002/jmri.28890>
- Thompson SM, Gorny KR, Koepsel EMK, Welch BT, Mynderse L, Lu A, et al. Body Interventional MRI for Diagnostic and Interventional Radiologists: Current Practice and Future Prospects. *Radiographics* [Internet]. 2021;41(6):1785–801. Available from: <http://dx.doi.org/10.1148/rg.2021210040>
- Arnold TC, Freeman CW, Litt B, Stein JM. Low-field MRI: Clinical promise and challenges. *J Magn Reson Imaging* [Internet]. 2023;57(1):25–44. Available from: <http://dx.doi.org/10.1002/jmri.28408>
- Rusche T, Vosschenrich J, Winkel DJ, Donners R, Segeroth M, Bach M, et al. More Space, Less Noise—New-generation Low-Field Magnetic Resonance Imaging Systems Can Improve Patient Comfort: A Prospective 0.55T-1.5T-Scanner Comparison. *J Clin Med* [Internet]. 2022;11(22):6705. Available from: <http://dx.doi.org/10.3390/jcm11226705>
- Kelsey LJ, Seiberlich N, Morehouse J, Richardson J, Srinivasan A, Bapuraj J, et al. Routine and Advanced Neurologic Imaging at 0.55-T MRI: Opportunities and Challenges. *Radiographics* [Internet]. 2025;45(3):e240076. Available from: <http://dx.doi.org/10.1148/rg.240076>
- MacDonell J, Patel N, Rubino S, Ghoshal G, Fischer G, Burdette EC, et al. Magnetic resonance-guided interstitial high-intensity focused ultrasound for brain tumor ablation. *Neurosurg Focus* [Internet]. 2018;44(2):E11. Available from: <http://dx.doi.org/10.3171/2017.11.FOCUS17613>
- Gupta K, Cabaniss B, Kheder A, Gedela S, Koch P, Hewitt KC, et al. Stereotactic MRI-guided laser interstitial thermal therapy for extratemporal lobe epilepsy. *Epilepsia* [Internet]. 2020;61(8):1723–34. Available from: <http://dx.doi.org/10.1111/epi.16614>
- Lavrova A, Mishra S, Richardson J, Masotti M, Kurokawa R, Kurokawa M, et al. Quality assessment of routine brain imaging at 0.55 T: initial experience in a clinical workflow. *NMR Biomed* [Internet]. 2024;37(7):e5017. Available from: <http://dx.doi.org/10.1002/nbm.5017>
- Fernandes MC, Yildirim O, Woo S, Vargas HA, Hricak H. The role of MRI in prostate cancer: current and future directions. *MAGMA* [Internet]. 2022;35(4):503–21. Available from: <http://dx.doi.org/10.1007/s10334-022-01006-6>
- Kaur T, Jiang Y, Seiberlich N, Hussain H, Wells S, Wei J, et al. Clinical feasibility of MRI-guided in-bore prostate biopsies at 0.55T. *Abdom Radiol (NY)* [Internet]. 2025;50(8):3773–83. Available from: <http://dx.doi.org/10.1007/s00261-024-04783-x>
- Ichikawa S, Goshima S. Clinical Significance of Liver MR Imaging. *Magn Reson Med Sci* [Internet]. 2023;22(2):157–75. Available from: <http://dx.doi.org/10.2463/mrms.rev.2022-0100>
- Tian Y, Nayak KS. New clinical opportunities of low-field MRI: heart, lung, body, and musculoskeletal. *MAGMA* [Internet]. 2024;37(1):1–14. Available from: <http://dx.doi.org/10.1007/s10334-023-01123-w>
- Winkelmann MT, Kübler J, Hoffmann R. Magnetic Resonance-guided Procedures: Consensus on Rationale, Techniques, and Outcomes. *Tech Vasc Interv Radiol* [Internet]. 2023;26(3):100914. Available from: <http://dx.doi.org/10.1016/j.tvir.2023.100914>
- Armstrong AK, Liu Y, Kelly JM, Krishnamurthy R, Swinning J, Liu Y, et al. Feasibility of magnetic resonance imaging-guided cardiac catheterization, angioplasty, and stenting in a commercial wide-bore 0.55T scanner. *J Cardiovasc Magn Reson* [Internet]. 2025 Summer;27(1):101858. Available from: <http://dx.doi.org/10.1016/j.jocmr.2025.101858>
- Sneag DB, Abel F, Potter HG, Fritz J, Koff MF, Chung CB, et al. MRI Advancements in Musculoskeletal Clinical and Research Practice. *Radiology* [Internet]. 2023;308(2):e230531. Available from: <http://dx.doi.org/10.1148/radiol.230531>
- Lopez Schmidt I, Haag N, Shahzadi I, Frohwein LJ, Schneider C, Niehoff JH, et al. Diagnostic Image Quality of a Low-Field (0.55T) Knee MRI Protocol Using Deep Learning Image Reconstruction Compared with a Standard (1.5T) Knee MRI Protocol. *J Clin Med* [Internet]. 2023;12(5):1916. Available from: <http://dx.doi.org/10.3390/jcm12051916>

18 Khodarahmi I, Brinkmann IM, Lin DJ, Bruno M, Johnson PM, Knoll F, et al. New-Generation Low-Field Magnetic Resonance Imaging of Hip Arthroplasty Implants Using Slice Encoding for Metal Artifact Correction: First In Vitro Experience at 0.55 T and Comparison With 1.5 T. *Invest Radiol* [Internet]. 2022;57(8):517–26. Available from: <http://dx.doi.org/10.1097/RLI.0000000000000866>

Contact

Michaela Martin, BSc (Medical Radiations)
PGC (MRI)
MR Senior Applications Specialist
Siemens Healthineers
SHS DI MR M&S CSM MAC
Allee am Röthelheimpark 2
91052 Erlangen
Germany
michaela.martin@siemens-healthineers.com



Jan-M. Brandt, Ph.D.
Global Segment Manager Interventional MRI
Siemens Healthineers
SHS DI MR M&S CSM
Allee am Röthelheimpark 2
91052 Erlangen
Germany
jan.brandt@siemens-healthineers.com



- 19 Thomassin-Naggara I, Dolcianni M, Chamie LP, Guerra A, Bharwani N, Freeman S, et al. ESUR consensus MRI for endometriosis: indications, reporting, and classifications. *Eur Radiol* [Internet]. 2025;35(11):7260–8. Available from: <http://dx.doi.org/10.1007/s00330-025-11579-0>
- 20 Jouffrieau C, Cazzato RL, Gabriele V, Faller E, Weiss J, Host A, et al. Percutaneous Imaging-guided Cryoablation of Endometriosis Scars of the Anterior Abdominal Wall. *J Minim Invasive Gynecol* [Internet]. 2023;30(11):890–6. Available from: <http://dx.doi.org/10.1016/j.jmig.2023.06.018>
- 21 Dagar N, Sarin M, Yadav P, Thidwar R. Radiologic imaging and its current importance in breast cancer management. *Front Radiol* [Internet]. 2025;5(1689635):1689635. Available from: <http://dx.doi.org/10.3389/fradi.2025.1689635>
- 22 Sardanelli F, Magni V, Rossini G, Kilburn-Toppin F, Healy NA, Gilbert FJ. The paradox of MRI for breast cancer screening: high-risk and dense breasts-available evidence and current practice. *Insights Imaging* [Internet]. 2024;15(1):96. Available from: <http://dx.doi.org/10.1186/s13244-024-01653-4>
- 23 Olthof S-C, Nickel MD, Weiland E, Leyhr D, Afat S, Nikolaou K, et al. Deep learning-enhanced T1-weighted imaging for breast MRI at 1.5T. *Diagnostics (Basel)* [Internet]. 2025;15(13):1681. Available from: <http://dx.doi.org/10.3390/diagnostics15131681>
- 24 Expert Panel on Breast Imaging, Yeh ED, Brown A, Freer PE, Bahl M, Bennett DL, et al. ACR Appropriateness Criteria® Female Breast Cancer Screening: 2025 Update. *J Am Coll Radiol* [Internet]. 2025;22(11S):S508–30. Available from: <http://dx.doi.org/10.1016/j.jacr.2025.08.044>
- 25 Guillemin PC, Salomir R, Lauper N, Lorton O, Maturana E, Stöckli A, et al. Clinical outcomes of 3T magnetic resonance imaging-guided lumbar and sacral foraminal injections. *Neuroradiology* [Internet]. 2023;65(12):1793–802. Available from: <http://dx.doi.org/10.1007/s00234-023-03234-6>
- 26 Jerjes W, Harding D (2024) Enhancing primary care through integrated care pathways: a convergence of theory and practice. *Front Health Serv* [Internet]. 2024;4:1432901. Available from: <http://dx.doi.org/10.3389/frhs.2024.1432901>

A Framework for Growth in Interventional MRI: From Initial Adoption to Program Expansion

Jan-M. Brandt, Ph.D.¹; Moises Cruz, MBA²; David A. Woodrum, M.D., Ph.D.³

¹ Clinical & Scientific Marketing, Siemens Healthineers, Erlangen, Germany

² Cook Medical, Bloomington, IN, USA

³ Radiology and Vascular Centers, Mayo Clinic, Rochester, MN, USA

Introduction

In modern healthcare, the success of new technology depends on far more than just hardware. Even highly capable systems can underperform when implementation is not supported by the clinical, operational, and organizational structures needed for routine use. This is especially true in complex environments such as interventional MRI (iMRI), which sits at the intersection of imaging, intervention, surgery, anesthesia, nursing, and hospital operations [1]. Its value is realized only when these domains are aligned. Adoption must therefore be treated as a system-level challenge, requiring coordinated workflows, embedded safety standards, clear roles, consistent case selection, protected training time, and institutional confidence to move from isolated early cases to reliable routine practice.

Traditional implementation models often emphasize installation, initial training, and application support, while broader adoption barriers such as staffing variability, fragmented protocols, weak governance, and uncertainty around long-term economic sustainability remain largely unresolved [2–5]. The result is a gap between installation and real-world utilization. The Framework for Growth (FFG) was developed to close that gap by providing a structured pathway that supports iMRI adoption beyond launch and guides programs toward long-term clinical maturity.

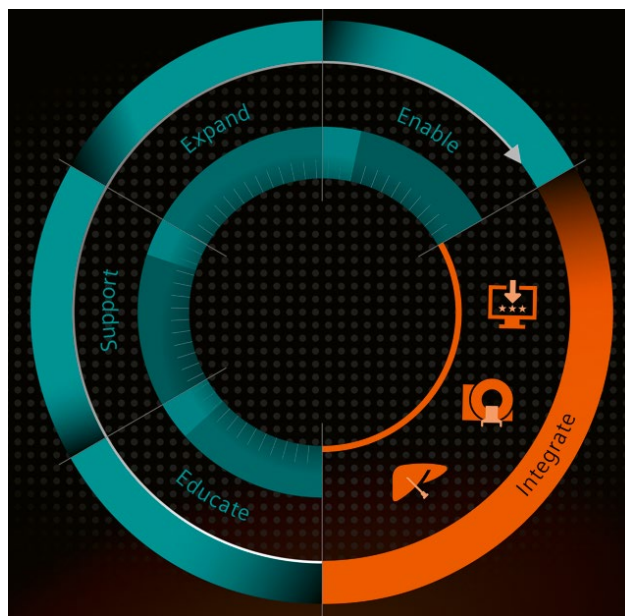
The Framework for Growth

The Framework for Growth is an end-to-end enablement approach, jointly delivered by Cook Medical and Siemens Healthineers, designed to support hospitals and clinical teams throughout the life cycle of iMRI adoption. Rather than positioning training as a one-time intervention, it treats implementation as a staged process in which capability is built, reinforced, standardized, and expanded over time.

The framework recognizes that clinical adoption relies on five interdependent dimensions: strategic readiness, technical and workflow integration, education and competency development, ongoing support, and planned expansion. These dimensions are captured in five pillars:

Enable, Integrate, Educate, Support, and Expand (Fig. 1). Together, these pillars establish the conditions necessary for a site not only to start using iMRI, but to use it consistently, safely, and with increasing confidence.

A central distinction of the framework is that it shifts the conversation from training to capability-building. Training is necessary but not sufficient; attending educational sessions does not necessarily translate into readiness for independent clinical execution. Capability-building requires tangible outputs and measurable progress: clearly defined team roles, site-specific protocols, readiness milestones, workflow maps, safety checklists, competency signoffs, escalation pathways, and criteria for progression toward more advanced case complexity. By embedding these outputs into implementation, the framework creates transparency and accountability while giving institutions practical tools for repeatable performance, particularly in environments where staff rotate, schedules are constrained, and local processes evolve over time.



1 The Framework for Growth showing the five interdependent pillars that structure iMRI adoption from readiness to expansion.

The five pillars

1. Enable

The first pillar focuses on establishing strategic and operational readiness. Before a program can succeed clinically, it must be grounded in a clear institutional vision, aligned stakeholder expectations, and a feasible operating model. This includes defining the intended clinical scope, assessing patient pathways, aligning internal decision-makers, evaluating business and reimbursement considerations, and planning the physical and organizational environment in which iMRI will be used. This stage moves sites from aspiration to preparedness.

2. Integrate

Successful iMRI programs depend on seamless integration across systems, devices, workflows, and people. Integration extends beyond the MRI scanner itself to include procedural tools, third-party equipment, room logistics, communication pathways, and interactions between departments. The objective is a coordinated clinical ecosystem rather than a technically capable but operationally fragmented environment, allowing clinical teams to move confidently through setup, imaging, intervention, and post-procedural processes without avoidable disruption or ambiguity.

3. Educate

Education within the framework is role-based, practical, and progressive. It is designed to both transfer knowledge and build applied competence across the multidisciplinary team, covering MRI safety, procedural workflow, application use, room behavior, setup expectations, and team-specific responsibilities. Education extends beyond didactic instruction to include supervised first cases, procedural observation, structured debriefing, and reinforcement over time. The goal is confident execution in real clinical settings and a reduced gap between training and independent practice.

4. Support

Clinical adoption does not end after the first successful case. Ongoing support is required to stabilize workflows, reinforce good practice, adapt to staff turnover, address emerging challenges, and maintain momentum. In this phase, sites move from initial use toward procedural routine, with repeatability, predictability, and confidence becoming the defining markers of progress. Support serves as a bridge between implementation and maturity, helping institutions consolidate gains and avoid regression during the most vulnerable stage of adoption.

5. Expand

Once a stable clinical routine has been established, programs can grow in a more deliberate way. Expansion may involve increased case volumes, onboarding of additional staff, extension into adjacent indications, broader internal referral patterns, and participation in external networks of expertise. Responsible expansion requires that growth be supported by governance, competence, and operational stability. This pillar ensures that growth is not opportunistic but structured, and transforms early adoption into sustained institutional development.

Standardization and governance

Standardization and governance are the connective tissue across the five pillars. Standardization in this context does not mean rigidity or the suppression of clinical judgment; it means a reliable foundation from which teams can operate safely and efficiently while progressing along the learning curve. It provides structured approaches to case selection, workflow sequencing, role definition, troubleshooting, safety practices, and local documentation.

Governance is equally important. Programs that define metrics, review outcomes, and formalize implementation pathways are better able to justify resource allocation, maintain internal confidence, and identify opportunities for improvement. Delivering these elements through the Framework for Growth partnership between Cook Medical and Siemens Healthineers gives institutions a credible, jointly supported path from first case to defensible program quality, and supports evidence development through registry participation, publication, and cross-site benchmarking. In the context of procedural training and site readiness, the partnership delivers a comprehensive solution, multidisciplinary training, case-based preparation, workflow simulation, safety and escalation pathways, and formal readiness criteria that go beyond the Framework for Growth infrastructure [6].

Site examples

Academic centers

Academic hospitals are often the most experienced iMRI environments, with strong clinical ambition, specialist expertise, and early procedural familiarity. The pathway to launch may be faster, but the implementation challenge remains substantial: multiple teams, overlapping responsibilities, and variable staffing models can create inconsistency despite high levels of expertise. For academic centers, the framework supports the standardization of roles, protocols, checklists, and progression criteria. Its value lies in reducing variability, improving reproducibility, and creating the structure needed to move efficiently toward more advanced and complex procedures.

Regional hospitals

Regional hospitals face a different set of constraints, such as limited protected training time, leaner staffing models, lower exposure to complex procedures, and operational pressure on room utilization. Here, success depends less on rapid expansion and more on reproducibility, simplicity, and confidence. The framework emphasizes role-based microlearning, simplified procedural pathways, structured onboarding, and supported go-live execution. Where appropriate, connections to experienced reference centers further strengthen local confidence and capability.

Network-based programs

A third model involves networked adoption across multiple institutions with different levels of maturity. Experienced academic centers may serve as hubs while smaller or less experienced hospitals act as spokes. Shared protocols, common training resources, peer exchange, and aligned quality expectations create a distributed but coherent infrastructure for adoption, which is particularly relevant when institutions aim to scale access while maintaining consistency.

Why this infrastructure matters

The history of the adoption of complex medical technology shows that hardware alone rarely determines long-term success. What differentiates high-performing programs is the presence of enabling infrastructure: structured education, clear workflows, multidisciplinary coordination, defined governance, and longitudinal support. In iMRI, this infrastructure is especially important because the barriers to adoption are often operational rather than technological.

Without a structured model, sites may struggle to move beyond pilot cases, maintain routine performance, or justify economic and clinical expansion, leaving the clinical and economic potential of the system underrealized. The Framework for Growth is intended to address precisely this challenge. It complements the installed iMRI clinical suite environment with the practical and organizational mechanisms required for sustained use, helping institutions convert technical possibilities into reliable clinical practice. For the partnership between Cook Medical and

Siemens Healthineers, the Framework For Growth transforms the offering from a product sale into a program-enablement collaboration with ongoing brand presence, helping customers reduce adoption risk, accelerate routine use, and realize the full clinical value of their iMRI investment. The outcome in iMRI is not determined only by the technology, but by the pathway to clinical success [3–5].

Conclusion

Adopting iMRI requires more than installation and initial training; it requires structured development of clinical and operational capability. The Framework For Growth addresses this need by supporting readiness, workflow integration, team education, and long-term program development. In doing so, it aims to reduce variability, improve reproducibility, and enable safe, sustainable routine use. As MRI-guided therapies continue to advance, particularly with the introduction of a commercially available iMRI suite, structured implementation models may become essential for translating technical innovation into consistent clinical practice.

References

- 1 Thompson SM, Gorny KR, Koepsel EMK, Welch BT, Mynderse L, Lu A, et al. Body Interventional MRI for Diagnostic and Interventional Radiologists: Current Practice and Future Prospects. *Radiographics*. 2021;41(6):1785–1801. doi: 10.1148/rg.2021210040.
- 2 Borges do Nascimento IJ, Abdulazeem H, Vasanthan LT, Martinez EZ, Zucoloto ML, Østengaard L, et al. Barriers and facilitators to utilizing digital health technologies by healthcare professionals. *NPJ Digit Med*. 2023;6(1):161. doi: 10.1038/s41746-023-00899-4.
- 3 Granja C, Janssen W, Johansen MA. Factors Determining the Success and Failure of eHealth Interventions: Systematic Review of the Literature. *J Med Internet Res*. 2018;20(5):e10235. doi: 10.2196/10235.
- 4 Marcus HJ, Ramirez PT, Khan DZ, Layard Horsfall H, Hanrahan JG, Williams SC, et al. The IDEAL framework for surgical robotics: development, comparative evaluation and long-term monitoring. *Nat Med*. 2024;30(1):61–75. doi: 10.1038/s41591-023-02732-7.
- 5 Greenhalgh T, Wherton J, Papoutsis C, Lynch J, Hughes G, A'Court C, et al. Beyond Adoption: A New Framework for Theorizing and Evaluating Nonadoption, Abandonment, and Challenges to the Scale-Up, Spread, and Sustainability of Health and Care Technologies. *J Med Internet Res*. 2017;19(11):e367. doi: 10.2196/jmir.8775.
- 6 Copernicus™ — Cook Medical's iMRI training and readiness program. Available from: <https://www.cookmedical.com/divisions/imri/copernicus/>



Moises Cruz, MBA
moises.cruz@cookmedical.com



Jan-M. Brandt, Ph.D.
jan.brandt@siemens-healthineers.com



David Woodrum, M.D., Ph.D.

Contact

David Woodrum, M.D., Ph.D.
Radiology and Vascular Centers
Mayo Clinic
200 First St. SW
Rochester, MN 55905
USA
woodrum.david@mayo.edu

Proactive Ergonomic Design for Interventional MRI: Insights from Digital Human Modeling

Justin Davidson, M.Sc., Ph.D.(c)¹; Joshua Krieger, B.S.²; Sean Chambers, Ph.D.²; Jan-M. Brandt, Ph.D.³; Steven Fischer, Ph.D., RKin, CCPE¹

¹ Faculty of Health, University of Waterloo, Waterloo, ON, Canada

² Cook Medical, Bloomington, Indiana, USA

³ Siemens Healthineers, Erlangen, Germany

Abstract

Interventional MRI (iMRI) is increasingly recognized as a powerful platform for image-guided procedures, offering non-ionizing imaging and superior soft-tissue contrast compared with conventional CT-guided workflows [1, 2]. While the clinical benefits of iMRI are well established, less attention has been paid to the physical and ergonomic demands placed on interventional radiologists who must work within the geometric constraints of MRI systems. Longer bore lengths, narrower access, and constrained reach conditions can require clinicians to adopt sustained, non-neutral postures that may elevate musculoskeletal loading over time.

The solution is to apply digital human modeling (DHM) techniques to quantify ergonomic exposures during simulated needle-insertion tasks performed in CT and MRI environments. By integrating live human motion-capture data with predictive biomechanical simulation, this study demonstrates how scanner geometry, specifically bore length, bore diameter, bore flaring, and table height, interact with clinician anthropometry to influence physical (ergonomic) demands on the body.

The findings show that ergonomic risk in iMRI is not inherent to MRI as a modality but rather is highly design dependent. Certain MRI configurations, particularly those incorporating flared bore entries and elevated table heights, can substantially reduce low-back loading compared with both CT-guided workflows and more conventional MRI designs. Shoulder loading, often cited as a barrier to MRI-guided intervention, was found to be comparatively modest across systems and sensitive to access geometry rather than bore length alone.

This work underscores the value of embedding ergonomics early in scanner design and service planning. Digital human modeling provides a rigorous, evidence-based approach for proactively evaluating human–system

interactions. It thereby supports the development of iMRI environments that optimize clinical performance while safeguarding the long-term occupational health of interventional radiologists.

Introduction

Interventional radiology has evolved around the principle of minimally invasive, image-guided therapy, with precision and safety as core objectives. MRI-guided interventions align strongly with these goals, offering real-time visualization without ionizing radiation exposure [3, 4]. Compared with CT guidance, MRI provides superior soft-tissue contrast, which can improve visualization of small



1 Motion-capture data were collected around the MAGNETOM Free.Max* as clinicians performed a simulated needle insertion using a torso phantom to parameterize and validate the digital human model.

* The MAGNETOM Free.Max would not normally be used for interventions. It was used here due to its greater in-bore access and availability.

The products/features mentioned herein are not commercially available in all countries. Their future availability cannot be guaranteed.

lesions (< 1 cm) and targeting accuracy, particularly in complex anatomical regions [5].

As iMRI adoption increases, clinicians are spending more time performing procedures within MRI environments. Unlike CT scanners, which typically have short gantries and open access, MRI systems are characterized by longer bores and more restrictive entry geometries. To access targets that are positioned near the scanner isocenter, which is required for optimal image quality, interventional radiologists may need to reach deep into the bore while maintaining visual attention on external displays. These constraints shape the posture, reach strategy, and loading at the shoulder and low back, which can influence the risk of developing musculoskeletal disorders.

Why ergonomics matters in image-guided interventions

Musculoskeletal disorders are prevalent among interventional clinicians, with the shoulder and low back frequently identified as regions of vulnerability [2]. Tasks involving sustained arm elevation, asymmetric reaching, and trunk flexion are known to increase joint loading and fatigue potential [6]. In CT-guided procedures, these demands are compounded by the requirement to wear protective lead aprons, which typically add 4–5 kg of mass to the torso and increase spinal loading [7].

MRI-guided interventions eliminate ionizing radiation exposure and therefore the need for lead protection, offering an immediate ergonomic advantage. However, this benefit may be partially offset by the increased reach distances and constrained access imposed by MRI bore geometry and isocenter location. The net ergonomic outcome is therefore not obvious and cannot be inferred from imaging modality alone. Instead, it emerges from the interaction between human characteristics, task demands, and system design.

Digital human modeling provides a computational framework for representing human posture, movement, and biomechanical loading across a range of anthropometries. Modern digital human models can be integrated with computer-aided design (CAD) environments to simulate realistic human–system interactions and quantify joint torques, reach feasibility, and fatigue-related metrics [8, 9]. In this study, DHM was deployed to understand how scanner design elements shape the posture, reach strategy, and loading at the shoulder and low back.

Methodology

Phase 1: From motion capture to comparative simulation

The research followed a two-stage workflow. In the first stage, six clinicians with a range of experience levels and body sizes performed representative needle-insertion tasks in an MRI environment using a torso phantom. Tasks

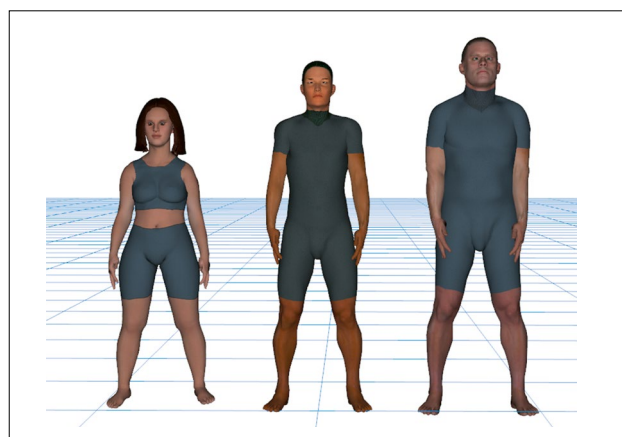
varied by reach depth (isocenter and 12 cm short of the isocenter) and needle orientation, reflecting common interventional scenarios. Whole-body kinematics were captured using an inertial measurement system (Fig. 1) and processed to define a representative “standard” posture.

The MAGNETOM Free.Max would not normally be used for interventions but was used due for greater in-bore access and availability. At the time of the study, the MAGNETOM Free.XL was not yet commercially available; therefore, clinician postures were collected using the MAGNETOM Free.Max during the first phase of the study. These experimentally captured postures were used to inform and calibrate the DHM workflow by providing representative reference postures for simulated needle insertion tasks. From these baseline postures, the DHM could then adapt the simulated clinician’s anthropometry to the surrounding MRI geometry in order to predict likely working postures in other scanner configurations, including the MAGNETOM Free.XL. This approach allowed the model to be used to investigate the potential ergonomic implications of different MRI design features within the MAGNETOM Free.XL geometry.

Motion-capture data were used to parameterize and validate the DHM. DHM predicted joint angles for key degrees of freedom fell largely within one standard deviation of the in vivo measured means, indicating that the simulated postures were realistic representations of clinician behavior.

Phase 2: Comparative simulation to inform scanner design

In the second stage, the validated model was applied to comparative simulations of three imaging systems. One was a conventional CT scanner (including simulated lead apron loading) and two were MRI designs with distinct



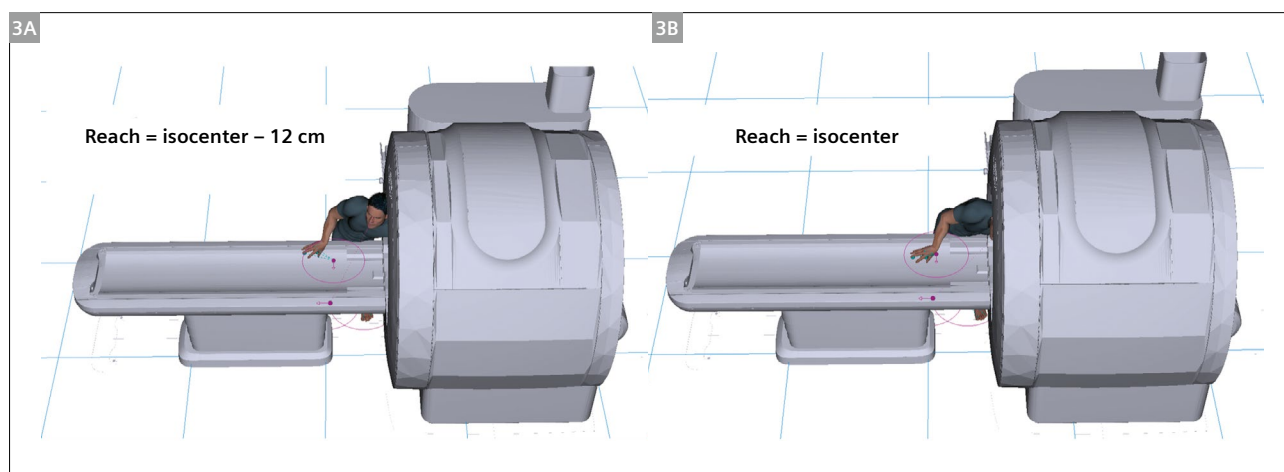
2 Avatars of a woman in the 5th percentile for height, a man in the 50th percentile, and a man in the 95th percentile were selected to understand how clinician anthropometry interacts with MR scanner design elements.

bore geometries: The 0.55T MAGNETOM Free.XL features a 100 cm flared bore design with a larger bore diameter (80 cm) and longer bore length (165 cm) than the 1.5T MAGNETOM Sola, which features no flaring, a smaller bore diameter (70 cm), and a shorter bore length (157 cm). The MAGNETOM Free.XL has a bore geometry specifically designed for interventions, whereas the MAGNETOM Sola represents a conventional MRI scanner.

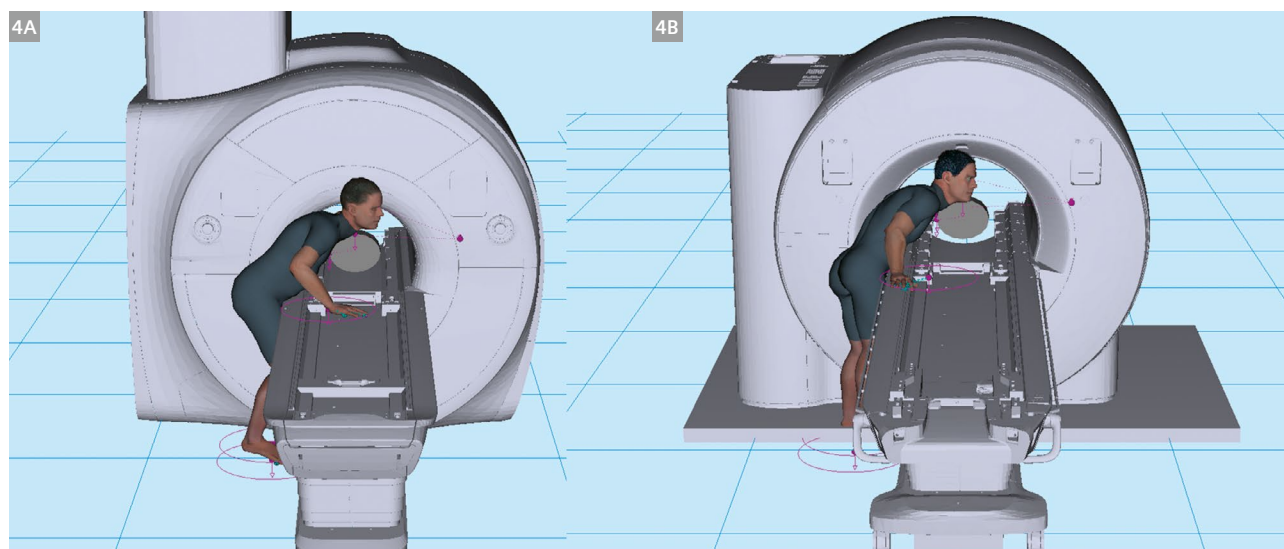
Avatars representing a woman in the 5th percentile for height, a man in the 50th percentile for height, and

a man in the 95th percentile for height (Fig. 2) were used to explicitly examine the interaction between scanner design and anthropometry (Fig. 3).

Primary outcome metrics included joint torques at the shoulder and low back, as well as endurance times estimated using joint-specific fatigue models [10]. Joint torques serve as a metric to evaluate the intensity of effort on the shoulder and low back. Endurance time serves as a proxy measure for muscular fatigue, where muscular fatigue is difficult to model directly.



3 Simulation of a male clinician in the 50th percentile for height reaching into the bore to perform a needle ablation. The left panel (3A) illustrates a reach to a location that is 12 cm short of the isocenter (the maximum distance from isocenter that can provide strong contrast). The right panel (3B) illustrates a reach to isocenter.



4 Bore height, diameter, and flare all influence the ways clinicians will move to perform needle targeting. The left panel (4A) illustrates a man in the 95th percentile for height reaching into a scanner with a lower height, narrower bore, and limited flare at bore entry. These design elements can limit the clinician's ability to lean into the bore. The right panel (4B) illustrates a man in the 95th percentile for height reaching into a scanner with a higher height, wider bore, and more pronounced flare at bore entry. This enables an easier lean into the bore and a more upright posture while monitoring the screen.

Results

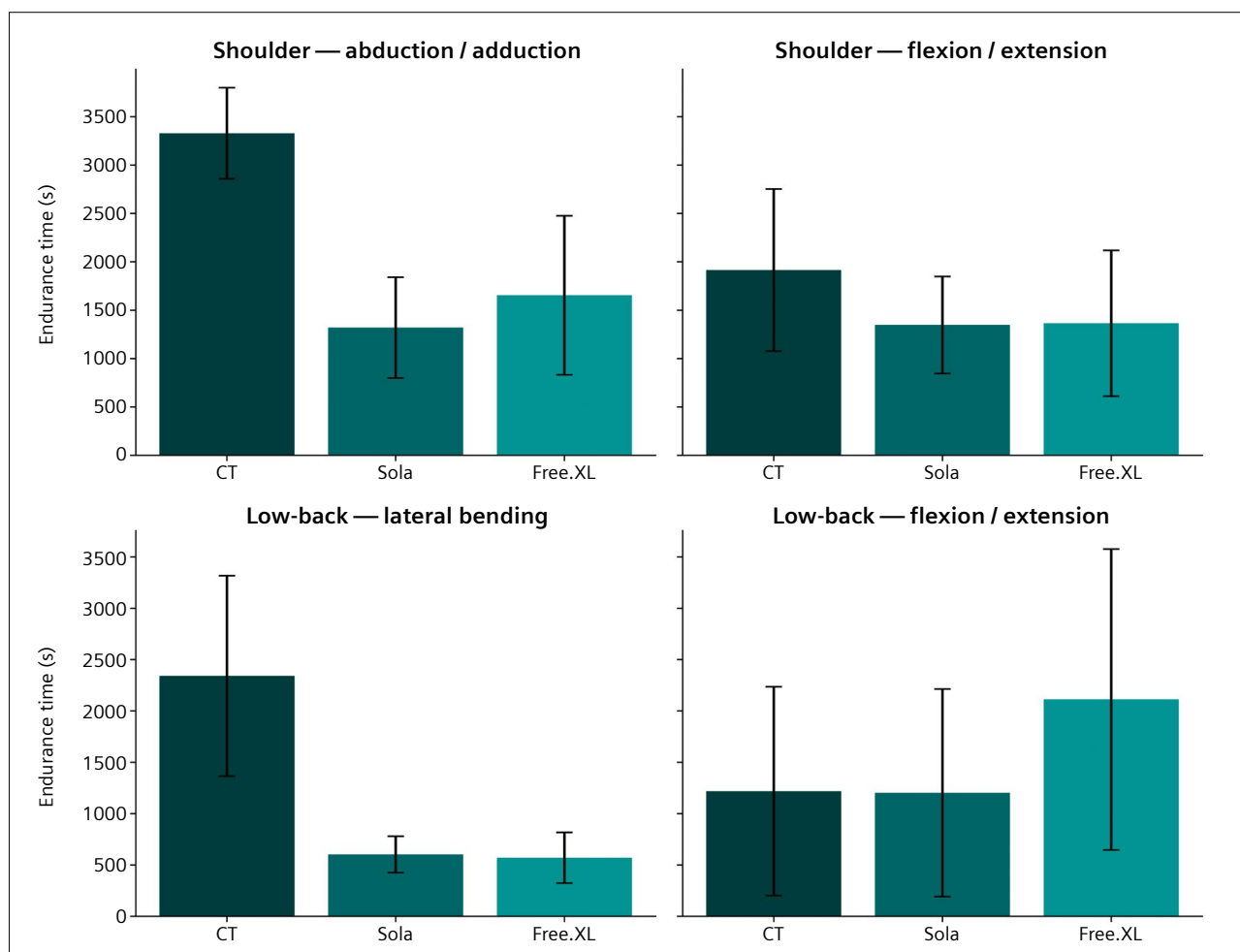
Key findings I: Shoulder loading is modest and geometry dependent

Across all simulated systems, shoulder torques during needle-insertion tasks were relatively low, remaining below levels typically associated with elevated injury risk [6]. As expected, CT-based simulations exhibited the lowest shoulder torques overall, reflecting the shorter reach distances enabled by the compact gantry geometry.

Differences between the two MRI designs revealed important trade-offs. One configuration reduced shoulder abduction/adduction torque while increasing flexion/extension torque, whereas the other demonstrated the opposite pattern. These findings indicate that shoulder loading is influenced not only by bore length, but also by bore diameter, entry flaring, and table height. The 100 cm flared bore of the MAGNETOM Free.XL allows clinicians to position the shoulder closer to the target, reducing moment arms even in longer systems (Fig. 4).

Key findings II: Low-back loading and fatigue are strongly design dependent

The most pronounced differences between imaging systems were observed at the low back. In CT-guided simulations, low-back extensor torques were consistently higher when the additional mass of a typical protective lead apron was included (4.26 kg), despite the shorter reach distances. This finding aligns with established bio-mechanical evidence showing that external torso loads substantially increase spinal extensor demand [6]. At the low-back, about the lateral bend axis, endurance time was longest when performing a needle-insertion procedure in a CT scanner (Fig. 5). However, endurance time about the flexion/extension axis was lowest when simulating a needle-insertion task using the MAGNETOM Free.XL scanner, where endurance time was 46% lower (i.e. increased rate of fatigue) when simulating needle-insertion in CT relative to the MAGNETOM Free.XL.



5 Shoulder abduction/adduction and flexion/extension endurance times and low-back lateral bending and flexion/extension endurance times across three scanner models aggregated across avatar anthropometry and needle-insertion location. Higher values are interpreted as less fatiguing (i.e., the task could be performed for a longer time without fatiguing).

The MRI design featuring a flared bore, larger diameter, and elevated table height (MAGNETOM Free.XL) demonstrated markedly lower low-back flexion/extension torques and substantially longer endurance times compared with both conventional CT and a more conventional MRI geometry. These reductions were attributed to the combined effects of eliminating the lead apron load, improving access geometry, and reducing forward trunk flexion.

Discussion

Inclusivity and anthropometry

A critical contribution of this work is its explicit consideration of anthropometric diversity. Simulations showed that certain reach tasks were not feasible for the smallest avatar under specific MRI configurations unless table height or clinician elevation was adjusted. This finding highlights the importance of adjustable system features in supporting an inclusive interventional workforce.

Rather than treating reach limitations as individual shortcomings, the results emphasize the role of design in enabling safe and effective performance across a wide range of statures (Fig. 6).

Implications for scanner design and clinical practice

The findings synthesized here reinforce that ergonomic outcomes in interventional imaging are design dependent rather than modality dependent. Bore length, bore diameter, bore flaring, and table height interact to shape musculoskeletal loading and fatigue potential.

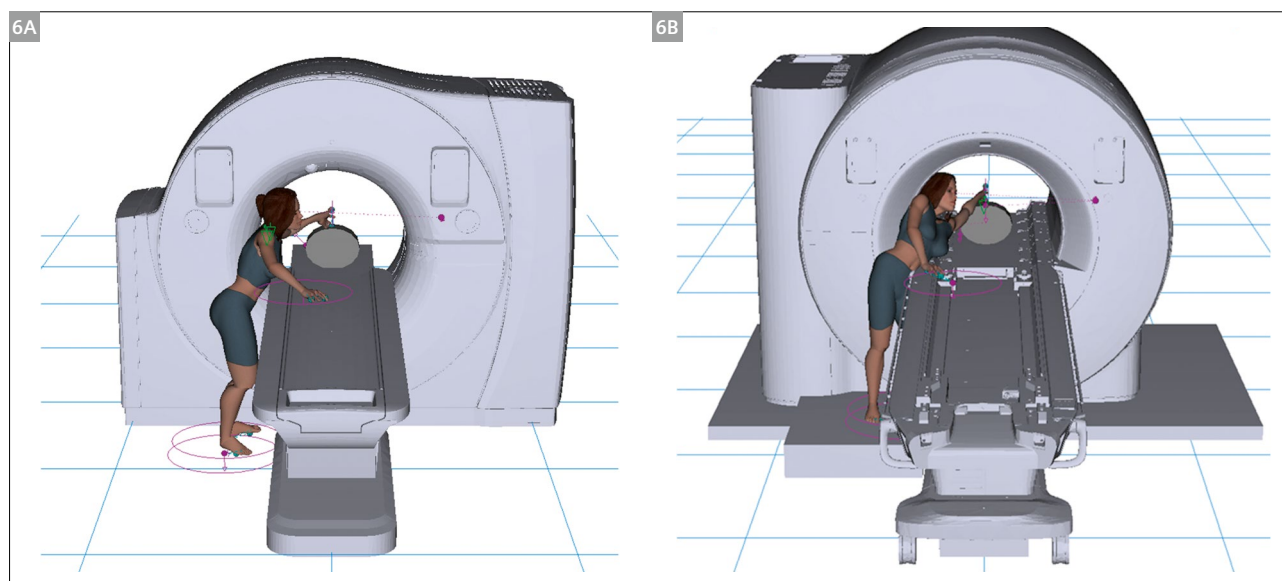
For manufacturers, DHM provides a powerful framework for evaluating ergonomic trade-offs early in the design process, complementing traditional performance metrics such as image quality and throughput [8]. For healthcare organizations, these insights support more informed procurement and service planning decisions, particularly as iMRI programs scale.

Future directions

Future work can extend DHM-based evaluation to longer procedures, dynamic task sequences, and team-based workflows. Advances in fatigue modeling and predictive simulation may further enhance realism and applicability [9]. Beyond hardware design, DHM may support training, workflow optimization, and procedure-specific setup recommendations based on clinician anthropometry.

Conclusion

Interventional MRI offers clear clinical advantages, but its long-term success depends on designing systems that support the people who use them. The work summarized here demonstrates that ergonomic risk in iMRI is neither inevitable nor uniform. Through validated digital human modeling, it is possible to identify design features that meaningfully reduce musculoskeletal loading, particularly at the low back, while maintaining clinical functionality. The 100 cm flared bore geometry of the MAGNETOM Free.XL appears to have ergonomic advantages compared with conventional CT and conventional 70 cm bore MRI geometries.



6 A lower scanner (left panel, **6A**) is more accessible for a woman in the 5th percentile for height. However, as illustrated in Figure 4, a lower scanner increases ergonomic risks for taller clinicians. However, the ability to match clinician hip height to the table height of the MAGNETOM Free.XL (right panel, **6B**), regardless of scanner height, offers an ideal solution.

By embedding ergonomics upstream in scanner design and service planning, the field can move beyond reactive mitigation and toward proactive prevention to support the sustainable, human-centered growth of interventional MRI.

References

- 1 Bock M, Wacker FK. MR-guided intravascular interventions: techniques and applications. *J Magn Reson Imaging* [Internet]. 2008;27(2):326–38. Available from: <http://dx.doi.org/10.1002/jmri.21271>
- 2 Cornelis FH, Razakamanantsoa L, Ben Ammar M, Lehrer R, Haffaf I, El-Mouhadi S, et al. Ergonomics in interventional radiology: Awareness is mandatory. *Medicina (Kaunas)* [Internet]. 2021;57(5): 500. Available from: <http://dx.doi.org/10.3390/medicina57050500>
- 3 Kos S, Huegli R, Bongartz GM, Jacob AL, Bilecen D. MR-guided endovascular interventions: a comprehensive review on techniques and applications. *Eur Radiol* [Internet]. 2008;18(4):645–57. Available from: <http://dx.doi.org/10.1007/s00330-007-0818-4>
- 4 Saeed M, Wilson M. Value of MR contrast media in image-guided body interventions. *World J Radiol* [Internet]. 2012;4(1):1–12. Available from: <http://dx.doi.org/10.4329/wjr.v4.i1.1>
- 5 Fernández-Gutiérrez F, Martínez S, Rube MA, Cox BF, Fatahi M, Scott-Brown KC, et al. Comparative ergonomic workflow and user experience analysis of MRI versus fluoroscopy-guided vascular interventions: an iliac angioplasty exemplar case study. *Int J Comput Assist Radiol Surg* [Internet]. 2015;10(10):1639–50. Available from: <http://dx.doi.org/10.1007/s11548-015-1152-y>
- 6 Chaffin, DB, Andersson GBJ. *Occupational Biomechanics*. 2nd ed. Nashville, TN: John Wiley & Sons; 1991.
- 7 Barrier Technologies. How Much Does A Lead Apron Weigh & What Are The Effects On The Body? [Internet]. Barrier Technologies. 2022 [cited 2026 June 23]. Available from: <https://barriertechnologies.com/how-much-does-a-lead-apron-weigh/>
- 8 Chaffin DB. Improving digital human modelling for proactive ergonomics in design. *Ergonomics* [Internet]. 2005;48(5):478–91. Available from: <http://dx.doi.org/10.1080/00140130400029191>.
- 9 Abdel-Malek K, Arora JS. *Human Motion Simulation: Predictive Dynamics*. San Diego, CA: Academic Press; 2013.
- 10 Frey-Law LA, Avin KG. Endurance time is joint-specific: a modelling and meta-analysis investigation. *Ergonomics* [Internet]. 2010; 53(1):109–29. Available from: <http://dx.doi.org/10.1080/00140130903389068>

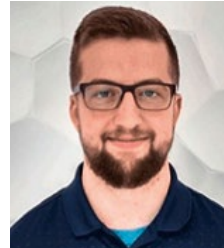
Further reading

- Davidson JB, Cashaback JGA, Fischer SL. A response surface methodology to determine the optimal objective function weightings within a multi-objective optimization digital human model used to predict postures. *Comput Methods Biomech Biomed Engin* [Internet]. 2023;26(2):187–98. Available from: <http://dx.doi.org/10.1080/10255842.2022.2052052>
- Davidson JB, Fischer DSL. Predicting preferred motorcycle riding postures to support human factors/ergonomic trade-off analyses within a multi-objective optimisation-based digital human model. *Ergonomics* [Internet]. 2025;68(3):359–73. Available from: <http://dx.doi.org/10.1080/00140139.2024.2329694>
- Davidson JB. et al. Evaluating alternative MRI designs to support interventional radiology using an in-silico simulation approach. 2026. Manuscript under review.
- National Institute for Occupational Safety and Health. Hierarchy of Controls [Internet]. CDC. 2024 April 10 [cited 2026 June 23]. Available from: https://www.cdc.gov/niosh/hierarchy-of-controls/about/index.html?CDC_AA_refVal=https%3A%2F%2Fwww.cdc.gov%2Fniosh%2Ftopics%2Fhierarchy%2Fdefault.html



Contact

Steven Fischer, Ph.D., RKin, CCPE
Associate Professor, Associate Chair,
Applied Research, Partnerships, & Outreach
Department of Kinesiology and
Health Sciences, University of Waterloo
200 University Ave W
Waterloo, Ontario, Canada N2L 3G1
steven.fischer@uwaterloo.ca



Justin Davidson, M.Sc., CSCS
Ph.D. Candidate
Department of Kinesiology and
Health Sciences, University of Waterloo
200 University Ave W
Waterloo, Ontario, Canada N2L 3G1
justin.bryce.davidson@uwaterloo.ca

Interventional Magnetic Resonance Imaging: Current Concepts, Enabling Technologies, and Emerging Clinical Applications

Roberto Luigi Cazzato^{1,2}, Afshin Gangi^{1,2,3}

¹ Department of Interventional Radiology, University Hospital of Strasbourg, France

² ICube Laboratory, University of Strasbourg, CNRS, INSA Strasbourg, France

³ School of Biomedical Engineering and Imaging Sciences, King's College London, UK

Abstract

Interventional magnetic resonance imaging (iMRI) has evolved from an experimental imaging platform into an established modality for guiding minimally invasive diagnostic and therapeutic procedures. Its unique combination of superior soft tissue contrast, multiplanar imaging, real time guidance, and absence of ionizing radiation provides decisive advantages over conventional image guidance techniques. Despite these strengths, the adoption of iMRI has historically been constrained by technical complexity, cost, and workflow challenges.

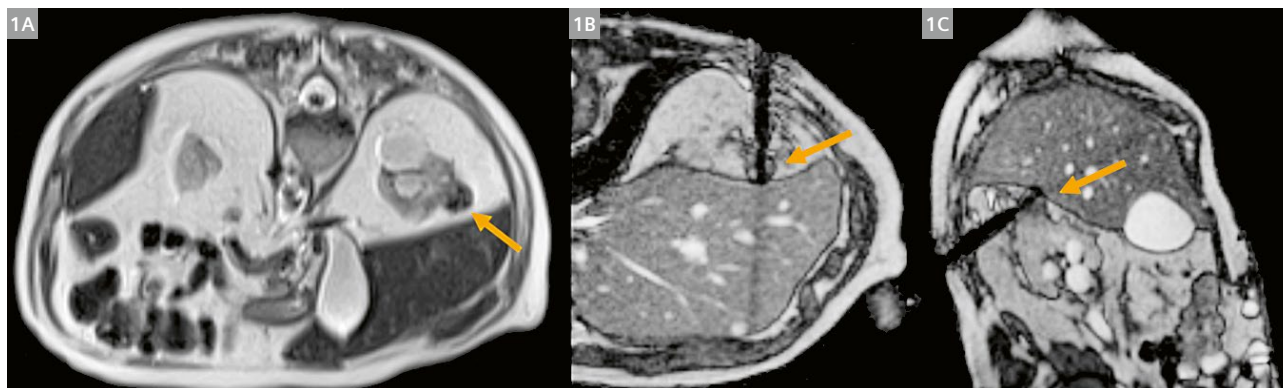
Recent advances, including renewed interest in lower field MRI systems and the maturation of MRI guided ablation techniques such as cryoablation and transurethral ultrasound ablation (TULSA) for prostate, are reshaping the field.

This narrative review summarizes the fundamental principles of iMRI, discusses how lower field MRI units may facilitate wider adoption, and reviews contemporary clinical applications with a focus on MRI guided biopsy, cryoablation, TULSA for prostate, and endovascular procedures.

Introduction

Magnetic resonance imaging (MRI) is widely regarded as the reference standard for soft tissue imaging owing to its excellent contrast resolution, multiplanar capability, and lack of ionizing radiation. Although initially limited to diagnostic use, MRI has progressively expanded into the interventional domain over the past three decades. Interventional MRI (iMRI) refers to diagnostic or therapeutic procedures performed under MRI guidance, using MRI for lesion localization, device navigation, intraprocedural monitoring, and immediate post treatment assessment.

Early iMRI procedures were performed in the 1990s using open, low field MRI systems that allowed direct access to the patient but were limited by poor image quality. The subsequent introduction of wide bore, high field MRI scanners, MRI compatible devices, and fast imaging sequences enabled more complex interventions, including biopsies and tumor ablation. Among these, MRI guided cryoablation has become a cornerstone application because of its inherent compatibility with MRI physics and the ability to directly visualize treatment effects [1]. This



1 A 79-year-old male patient presenting with an exophytic nodule arising from the upper pole of the right kidney. (1A) Axial T2-weighted MR image demonstrates the target lesion (arrow). The patient subsequently underwent percutaneous MRI-guided biopsy. (1B) Axial and (1C) sagittal BEAT MR images show the biopsy needle sampling the target renal nodule.

narrative review summarizes the fundamental principles of iMRI, discusses how lower field MRI units may facilitate wider adoption, and reviews contemporary clinical applications with a focus on MRI guided biopsy, cryoablation, TULSA for prostate, and endovascular procedures.

Rationale and advantages of interventional MRI

Compared with computed tomography (CT), fluoroscopy, and ultrasound, iMRI offers several unique advantages:

- Superior soft tissue contrast enabling precise lesion delineation
- Multiplanar imaging without patient repositioning
- Near real time guidance during device advancement
- Intraprocedural assessment of tissue response
- Absence of ionizing radiation for patients and staff
- Possibility to allow temperature monitoring during thermal ablation procedures

These characteristics are particularly valuable when lesions are not visible on other imaging modalities, when anatomy is complex, or when adjacent critical structures must be preserved [1, 2].

MRI systems for interventional use

High field closed bore MRI systems

Most contemporary iMRI procedures are performed in wide, closed bore 1.5T to 3T scanners. These units provide high signal to noise ratios, advanced pulse sequences, and robust workflow integration. However, a closed bore geometry limits operator ergonomics and physical access to the patient, and the associated costs and infrastructure requirements may restrict iMRI availability on a large scale.

Lower field MRI systems: Facilitating adoption

Lower field MRI systems ($\leq 1T$), historically regarded as obsolete, have gained renewed interest due to improvements in magnet design, radiofrequency coils, and image reconstruction. Moreover, image quality has been significantly improved thanks to artificial-intelligence-based algorithms, and now equals that obtained with high field systems. Accordingly, modern lower field MRI may be sufficient for many interventional tasks.

Importantly, lower field systems may facilitate broader adoption of iMRI by lowering costs, simplifying siting requirements, improving ergonomics, and reducing susceptibility artifacts. These advantages are particularly relevant for intraoperative and point of care interventions and may enable dissemination of iMRI beyond tertiary academic centers [3, 4].

MRI compatible devices and imaging techniques

iMRI requires the use of non ferromagnetic, MRI compatible needles, probes, and catheters. Device visualization relies primarily on susceptibility artifacts rather than direct depiction of the device shaft. Artifact size increases with magnetic field strength and varies with device orientation relative to the main magnetic field, which may complicate interpretation when multiple instruments are used simultaneously.

Commonly used imaging sequences include fast T2 weighted sequences (HASTE, BLADE) for lesion visualization, balanced steady state free precession sequences for MR fluoroscopy, and MR thermometry for heat based therapies [1].

MRI guided biopsy

MRI guided biopsy is an essential diagnostic application of iMRI for lesions that are poorly visible or inaccessible under ultrasound or CT guidance. MRI guided biopsies are performed using MRI compatible needles, often with a coaxial technique, and may be combined with ablation in the same session. MRI allows direct targeting of lesions visualized on diagnostic MRI, including diffusion restricted or contrast enhancing foci [1].

The retro orbital compartment presents a challenging biopsy environment due to confined anatomy and proximity to the optic nerve and vascular structures. MRI guided biopsy offers superior safety and accuracy in selected cases, particularly for lymphoproliferative, inflammatory, or metastatic lesions [2].

MRI guided biopsy is also often useful for renal (Fig. 1) and hepatic lesions visible only on MRI and for deep seated lymphadenopathies adjacent to critical structures. MRI guidance enables accurate needle placement while minimizing radiation exposure and improving diagnostic yield in complex cases [1, 2].

MRI guided cryoablation

MRI guided cryoablation is one of the most mature and widely applied therapeutic applications of iMRI. Cryoablation induces tissue necrosis through repeated freeze-thaw cycles, resulting in cell membrane disruption, microvascular thrombosis, and delayed ischemic injury. A defining advantage of cryoablation under MRI guidance is the direct visualization of the ice ball, which appears as a sharply demarcated signal void on all MRI sequences [1].

Small renal masses are a well established indication for MRI guided cryoablation, particularly in patients with significant comorbidities, limited renal reserve, a solitary kidney, or hereditary renal tumor syndromes. MRI guidance

is especially valuable for lesions that are isoattenuating on CT.

MRI allows precise monitoring of ice ball expansion relative to the renal collecting system, adrenal gland, bowel, pancreas, and adjacent nerves. Hydrodissection is frequently used and readily visualized under MRI. Clinical studies have demonstrated high technical success, favorable oncologic outcomes, and preservation of renal function in appropriately selected patients [1, 5–7].

Desmoid tumors are benign but locally aggressive fibroblastic neoplasms with high recurrence rates after surgery. MRI guided cryoablation has emerged as a minimally invasive alternative, allowing tailored debulking or curative ablation while avoiding surgical trauma. Large studies report high rates of symptomatic relief and functional improvement with low complication rates [8].

Abdominal wall endometriosis is another emerging clinical field for MRI-guided cryoablation (Fig. 2). Often occurring after cesarean section or laparoscopic surgery, abdominal wall endometriosis may cause chronic pain and inflammation. MRI guided cryoablation enables precise targeting of endometriotic implants while preserving surrounding musculature and fascia. Early experience suggests durable pain relief and minimal morbidity compared with surgical excision [1].

Additional soft tissue applications include Morton's neuroma, peripheral-nerve related pain syndromes, in transit melanoma metastases, and selected vascular malformations, where MRI guidance provides decisive anatomic definition and cryoablation ensures controlled tissue destruction [1, 9].

MRI guided transurethral ultrasound ablation

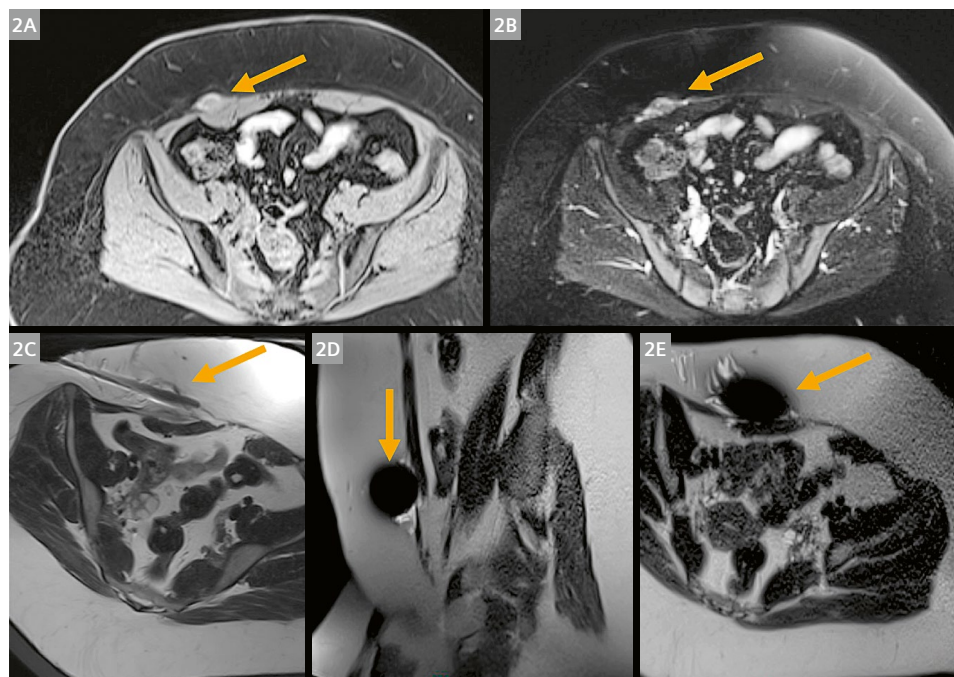
Transurethral ultrasound ablation (TULSA) is an incision free, MRI guided therapy for localized prostate cancer and benign prostatic hyperplasia. Ultrasound energy is delivered via a transurethral applicator, while MRI provides real time anatomic visualization and thermometry, enabling closed loop temperature control.

Clinical studies have demonstrated a favorable safety profile, preservation of urinary continence and erectile function, and meaningful oncologic control in selected patients. However, residual or recurrent clinically significant disease has been reported, underscoring the need for careful patient selection and follow up [6, 7, 10].

Endovascular applications of interventional MRI

Endovascular interventional MRI is one of the most technically demanding yet conceptually promising extensions of iMRI. While contemporary endovascular procedures are almost exclusively performed under X ray fluoroscopic guidance, MRI offers unique advantages, including the ability to acquire functional and flow sensitive information.

Reported applications include arterial catheter navigation, targeted embolization, and preclinical and early clinical feasibility studies involving aortic, peripheral, visceral, and neurovascular interventions. However, clinical adoption remains limited by technical challenges such as reduced temporal and spatial resolution compared with



2 A 30-year-old female patient presenting with a painful endometriotic implant in the right anterior abdominal wall.

(2A) Axial T1-weighted and (2B) axial T2-weighted MR images demonstrate the target lesion (arrows). The patient subsequently underwent percutaneous MRI-guided cryoablation. (2C) Axial T2-weighted MR image shows one of the two cryoprobes (arrow) positioned within the lesion. (2D) Sagittal and (2E) axial T2-weighted MR images demonstrate the ice ball (arrows) completely encompassing the target lesion during cryoablation.

fluoroscopy, device visualization and tracking constraints, radiofrequency induced heating, and the limited availability of dedicated MRI compatible guidewires and catheters.

Recent advances in passive and active catheter tracking, MR safe endovascular devices, and optimized real time MRI sequences have significantly advanced the field. Systematic reviews and expert analyses indicate that MRI guided endovascular interventions are feasible and safe in selected experimental and early clinical settings, although current human experience remains limited to small case studies. Continued technological development, including integration with lower field MRI platforms, may be critical for broader clinical translation of MRI guided endovascular therapies [11–13].

Future perspectives and conclusion

Interventional MRI represents a powerful convergence of imaging and minimally invasive therapy. Advances in lower field MRI technology, growing clinical evidence for MRI guided cryoablation and TULSA, and increasing experience with MRI guided biopsy are accelerating the clinical integration of iMRI. As technology and expertise evolve, iMRI is poised to become a central platform for precision guided interventions across oncologic, musculoskeletal, and functional domains.

References

- Cazzato RL, Garnon J, Shaygi B, Tsoumakidou G, Caudrelier J, Koch G, et al. How to perform a routine cryoablation under MRI guidance. *Top Magn Reson Imaging* [Internet]. 2018;27(1):33–8. Available from: <http://dx.doi.org/10.1097/RMR.0000000000000158>
- Kaye EA, Granlund KL, Morris EA, Maybody M, Solomon SB. Closed-bore interventional MRI: Percutaneous biopsies and ablations. *AJR Am J Roentgenol* [Internet]. 2015;205(4):W400–10. Available from: <http://dx.doi.org/10.2214/AJR.15.14732>
- Kravchenko D, Hagar MT, Vecsey-Nagy M, Kabat I, Groteklaes A, Luetkens JA, et al. Low-field and portable MRI technology: advancements and innovations. *Eur Radiol Exp* [Internet]. 2025; 9(1):103. Available from: <http://dx.doi.org/10.1186/s41747-025-00638-2>
- Jones DK, Alexander DC, Chetcuti K, Cercignani M, Donald KA, Griswold MA, et al. Low field, high impact: democratizing MRI for clinical and research innovation. *BJR Open* [Internet]. 2025; 7(1):tzaf022. Available from: <http://dx.doi.org/10.1093/bjro/tzaf022>
- Cazzato RL, Garnon J, Ramamurthy N, Koch G, Tsoumakidou G, Caudrelier J, et al. Percutaneous image-guided cryoablation: current applications and results in the oncologic field. *Med Oncol* [Internet]. 2016;33(12):140. Available from: <http://dx.doi.org/10.1007/s12032-016-0848-3>
- Sundaram KM, Staruch R, Burtnyk M, Lane JS, Penson DF, Arora SS. MR imaging-guided transurethral ultrasound ablation of localized prostate cancer: Preliminary experience from a single center in a prospective, multi-center, single-arm clinical trial. *J Vasc Interv Radiol* [Internet]. 2020;31(5):740–746.e4. Available from: <http://dx.doi.org/10.1016/j.jvir.2019.12.802>
- Ahrar K, Ahrar JU, Javadi S, Pan L, Milton DR, Wood CG, et al. Real-time magnetic resonance imaging-guided cryoablation of small renal tumors at 1.5 T. *Invest Radiol* [Internet]. 2013; 48(6):437–44. Available from: <http://dx.doi.org/10.1097/RLI.0b013e31828027c2>
- Schmitz JJ, Schmit GD, Atwell TD, Callstrom MR, Kurup AN, Weisbrod AJ, et al. Percutaneous cryoablation of extraabdominal desmoid tumors: A 10-year experience. *AJR Am J Roentgenol* [Internet]. 2016;207(1):190–5. Available from: <http://dx.doi.org/10.2214/AJR.15.14391>
- Cazzato RL, Garnon J, Ramamurthy N, Tsoumakidou G, Caudrelier J, Thenint MA, et al. Percutaneous MR-Guided Cryoablation of Morton's Neuroma: Rationale and Technical Details After the First 20 Patients. *Cardiovasc Intervent Radiol.* [Internet]. 2016;39(10): 1491–8. Available from: <http://dx.doi.org/10.1007/s00270-016-1365-7>
- Rajeev R. Clinical outcomes of MRI-guided transurethral US ablation (MRI-TULSA) of localized prostate cancer. *Radiol Imaging Cancer* [Internet]. 2025;7(4):e259015. Available from: <http://dx.doi.org/10.1148/rycan.259015>
- Kilbride BF, Narsinh KH, Jordan CD, Mueller K, Moore T, Martin AJ, et al. MRI-guided endovascular intervention: current methods and future potential. *Expert Rev Med Devices* [Internet]. 2022; 19(10):763–78. Available from: <http://dx.doi.org/10.1080/17434440.2022.2141110>
- Nijsink H, Overduin CG, Willems LH, Warlé MC, Fütterer JJ. Current state of MRI-guided endovascular arterial interventions: A systematic review of preclinical and clinical studies. *J Magn Reson Imaging* [Internet]. 2022;56(5):1322–42. Available from: <http://dx.doi.org/10.1002/jmri.28205>
- Kos S, Huegli R, Bongartz GM, Jacob AL, Bilecen D. MR-guided endovascular interventions: a comprehensive review on techniques and applications. *Eur Radiol* [Internet]. 2008;18(4):645–57. Available from: <http://dx.doi.org/10.1007/s00330-007-0818-4>



Contact

Roberto Luigi Cazzato, M.D., Ph.D.
Associate Professor of Radiology and
Interventional Radiology
Department of Interventional Radiology
University Hospital of Strasbourg
1 Place de l'Hôpital, BP 426,
67091 Strasbourg Cedex
France
RobertoLuigi.CAZZATO@chru-strasbourg.fr



Afshin Gangi, M.D., Ph.D.
Professor of Radiology and Chairman of
Radiology and Nuclear Medicine
Department of Interventional Radiology
University Hospital of Strasbourg
1 Place de l'Hôpital, BP 426,
67091 Strasbourg Cedex
France
Afshin.Gangi@chru-strasbourg.fr

MRI-Guided High-Dose-Rate Interstitial Brachytherapy of Hepatic Malignancies

Matthias P. Fabritius, M.D.; Max Seidensticker, M.D.; Jens Ricke, M.D.

Department of Radiology, LMU Hospital, Munich, Germany

Introduction

Primary and secondary liver malignancies remain a major clinical challenge. Primary liver cancer is among the most common cancers worldwide and one of the leading causes of cancer-related mortality [1]. At the same time, the liver is a frequent site of metastatic spread, particularly in colorectal cancer, neuroendocrine tumors, breast cancer, and other gastrointestinal malignancies. As systemic therapies continue to improve, more patients present with limited hepatic tumor burden, oligometastatic disease, oligoprogression, or residual liver-dominant disease. In this setting, local treatment has become an increasingly important part of multidisciplinary oncologic care [2, 3].

Thermal ablation, including radiofrequency ablation and microwave ablation, is well established for small primary and secondary liver tumors. In appropriately selected patients, it offers low morbidity, short recovery times, and high rates of local tumor control. However, the physical principles of heat-based ablation define its limits. Tumors larger than 3 cm are more difficult to treat completely. Lesions adjacent to large vessels may be undertreated because of heat-sink effects. Tumors near the central bile ducts, gallbladder, stomach, duodenum, colon, heart, or diaphragm carry a higher risk of thermal injury to vulnerable structures. In these situations, a technically feasible needle position does not always translate into a safe and oncologically adequate ablation [4].

Interstitial high-dose-rate (HDR) brachytherapy offers an alternative way to think about local ablation [5–7]: Instead of heat, it uses radiation delivered from within the tumor. After percutaneous placement of one or more closed-ended applicator catheters, a high-activity Iridium-192 source is advanced by a robotic afterloader to predefined dwell positions. Based on three-dimensional treatment planning, a steep and conformal dose distribution can be generated around the catheter, with rapid dose fall-off outside the target volume. In clinical practice,

single-session target doses typically range from 15 to 25 Gy, depending on tumor entity, target size, and adjacent organs at risk.

A growing body of clinical and dosimetric evidence supports the specific advantages of this approach [8–12]. First, it is not limited by heat-sink effects and can therefore be used close to major hepatic vessels. Second, because dose distribution can be calculated and adapted, it is particularly attractive for lesions adjacent to heat-sensitive structures. Third, large or irregular tumors can be treated by placing multiple catheters and shaping the dose distribution accordingly. Fourth, unlike many thermal ablations, catheter-based radiotherapy can often be performed under conscious sedation and local anesthesia rather than general anesthesia. Finally, in centers where HDR brachytherapy infrastructure is already established, the procedure can also be economically attractive, as disposable material costs are generally lower than those associated with many thermal ablation systems, and no dedicated ablation generator is required.

Patient selection remains essential. Candidates are typically discussed in an interdisciplinary tumor board that considers tumor entity, systemic disease status, liver function, coagulation parameters, previous biliary interventions, and alternative local or surgical options. Patients with impaired liver function, advanced cirrhosis, relevant coagulopathy, or biliary-enteric anastomoses require particular caution because of the increased risks of bleeding, infection, abscess formation, or hepatic decompensation [13]. A further practical limitation is organizational rather than technical: Successful liver HDR brachytherapy requires close collaboration between interventional radiology, radiation oncology, medical physics, and nursing staff. Without this infrastructure, the procedure cannot be implemented safely and reproducibly.

Advantages of MRI guidance

For many years, CT has been the workhorse modality for percutaneous catheter placement in interstitial liver brachytherapy. CT is fast, widely available, and provides reliable visualization of needles, sheaths, and catheters. However, CT guidance can be limited by poor soft-tissue contrast, particularly in small liver lesions or tumors located in complex anatomic regions such as the liver dome, caudate lobe, or central liver close to the hilum [14, 15].

MRI changes the interventional environment. Its superior soft-tissue contrast, combined with hepatocyte-specific contrast agents, can improve lesion conspicuity for a prolonged time window. This is highly relevant in the liver, where many small metastases or hepatocellular carcinomas are only faintly visible on CT or ultrasound but clearly delineated on hepatobiliary-phase MRI. In addition, MRI allows free selection of imaging planes, making it possible to align the slice orientation with the planned needle trajectory. With real-time gradient-echo MR fluoroscopy, the interventionalist can monitor needle advancement dynamically, including in oblique or double-oblique trajectories that would be difficult to appreciate with conventional axial CT fluoroscopy. Another advantage, of course, is that MRI guidance eliminates exposure to ionizing radiation for both patients and staff.

The value of MRI guidance is particularly evident when targeting small tumors or tumors at risk of geographic miss. A catheter placed slightly off-center may still allow target coverage by increasing the irradiated volume, but this comes at the cost of exposing more healthy liver parenchyma or nearby organs at risk. MRI-guided catheter placement aims to reduce this compromise: Better visualization enables more accurate central catheter positioning, which in turn may allow tighter dose distribution and better sparing of non-target tissue.

Our preliminary experience supports this concept. Between June 2023 and April 2024, a total of 27 patients with 54 liver lesions were treated in a prospective single-center trial investigating MRI-guided catheter-based radiotherapy for primary and secondary liver tumors. Procedures were performed under conscious sedation and local anesthesia on a 1.5T MRI system (MAGNETOM Sola Fit) equipped with a 15 cm loop coil.

The treated cohort included hepatocellular carcinoma, colorectal cancer metastases, gastrointestinal stromal tumor metastases, neuroendocrine tumor metastases, and metastases from other primaries. Median lesion diameter was 11 mm, highlighting the role of MRI guidance for small tumors. Compared with a propensity-score-matched CT-guided cohort from a large institutional

control population, MRI-guided procedures required longer room time, with a median of 60 minutes, versus 46 minutes for CT guidance. However, MRI guidance was associated with a significantly lower non-target liver parenchyma irradiation (V5Gy: 15% vs. 43%), and preliminary 12-month local tumor control was higher in the MRI-guided cohort than in the matched CT-guided group (95.1% vs. 79.9%). Procedural complications were rare; one patient experienced minor bleeding that required neither transfusion nor intervention.

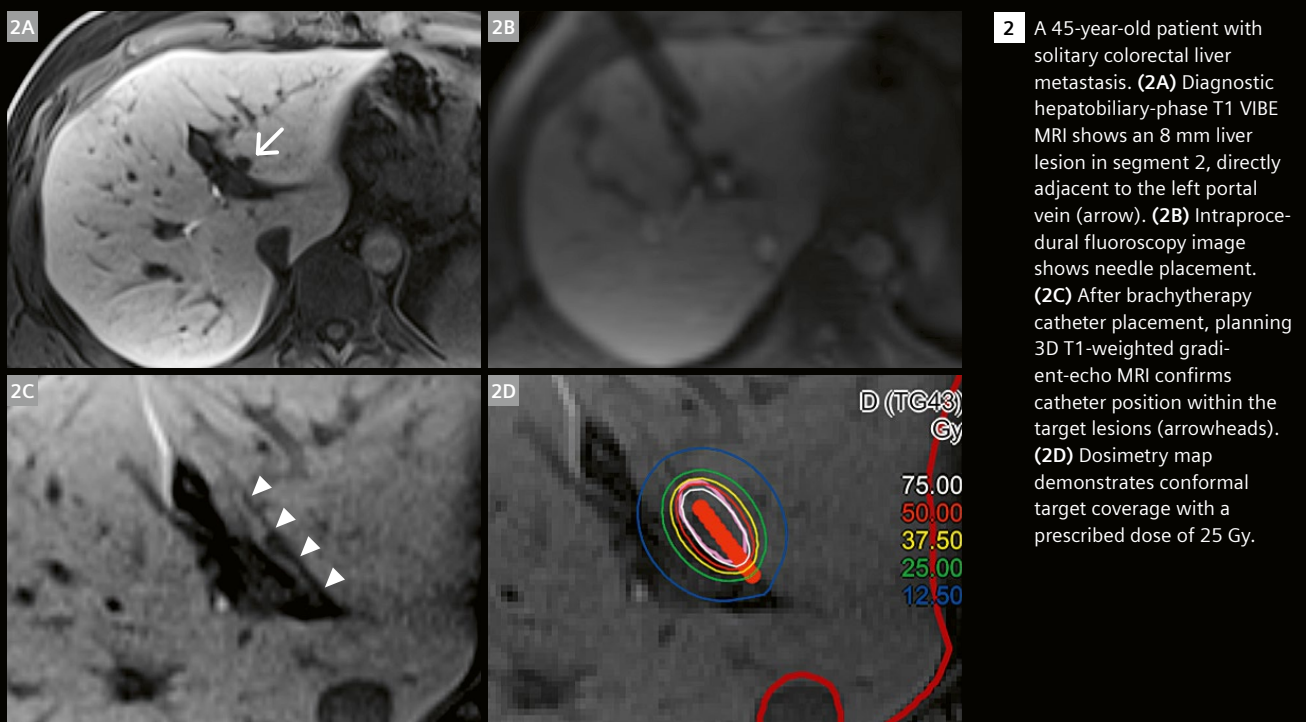
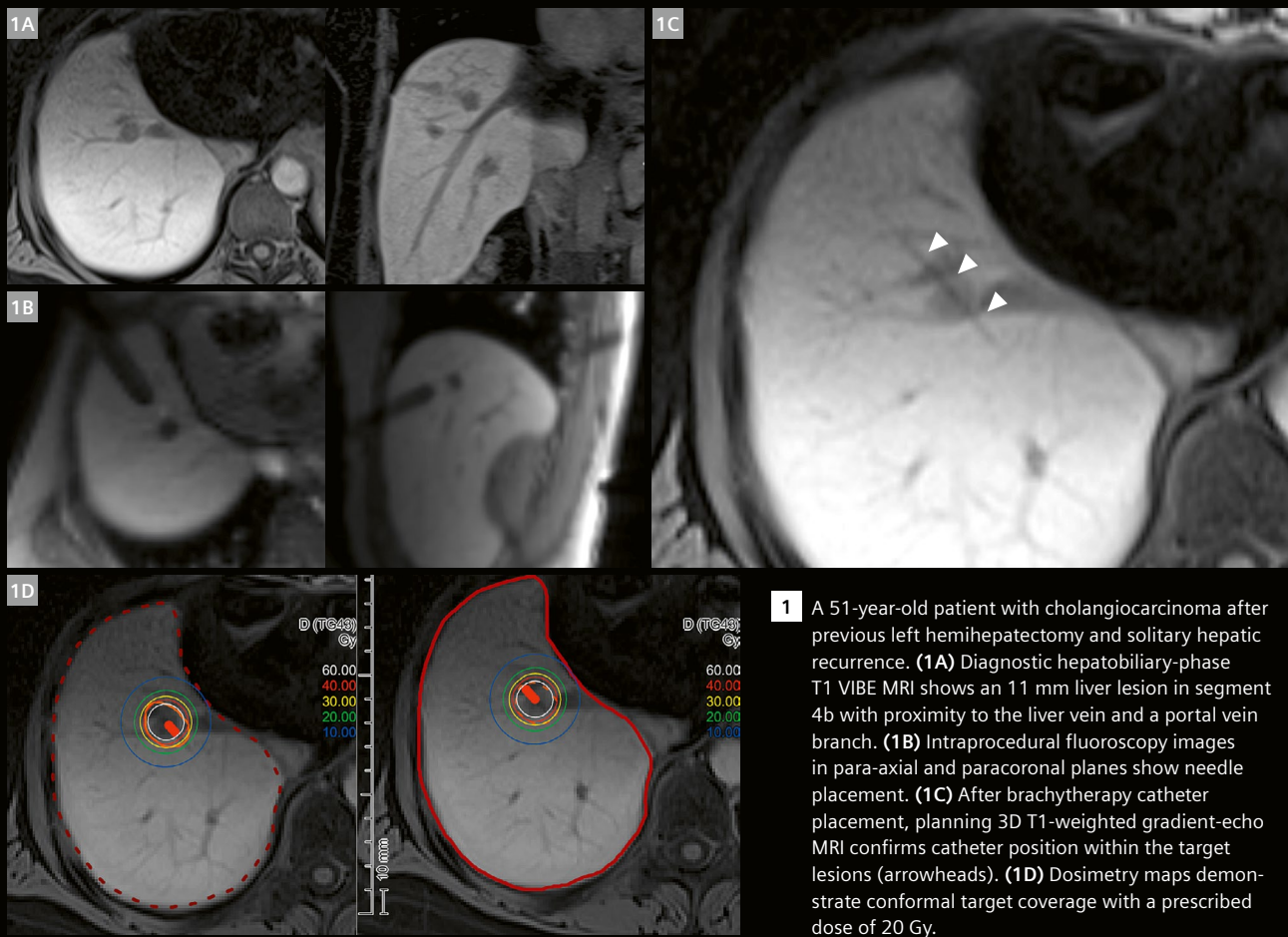
These early data suggest that the additional procedural time of MRI guidance may be offset by greater targeting confidence, reduced non-target irradiation, and potentially improved local tumor control. Further follow-up and larger cohorts will be needed, but for small or poorly CT-visible lesions, MRI-guided brachytherapy may represent a particularly promising direction.

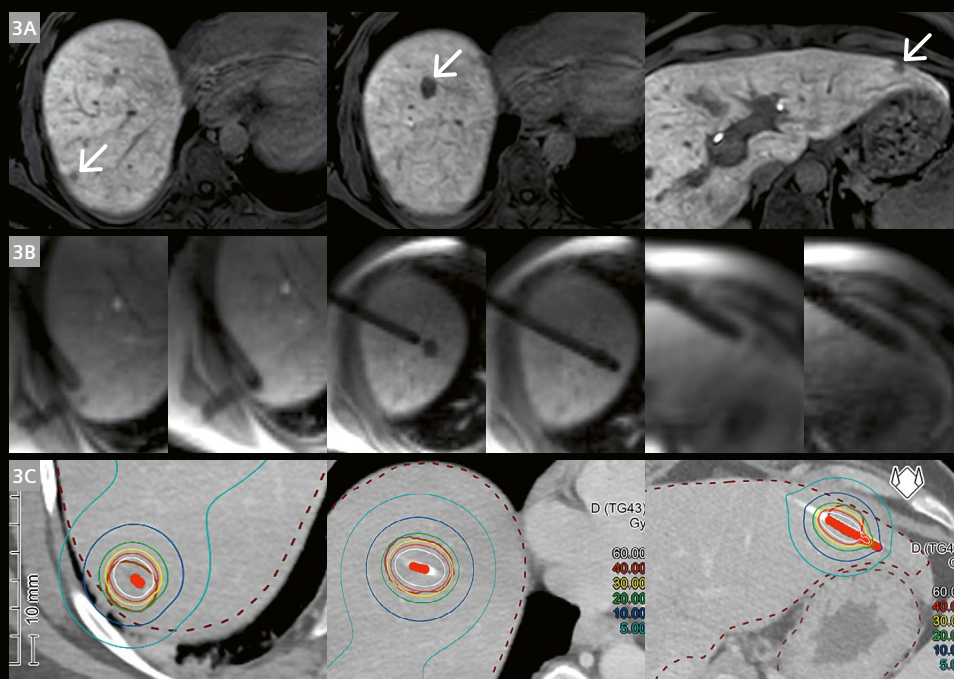
HDR brachytherapy: How to do it

The workflow begins before the patient enters the interventional suite. Pre-procedural imaging is reviewed jointly by interventional radiology and radiation oncology. The number, size, and location of target lesions are assessed, as are the proximity of vessels, bile ducts, bowel, stomach, gallbladder, diaphragm, and heart. Laboratory evaluation includes coagulation parameters, platelet count, liver function tests, and renal function. Anticoagulation and antiplatelet therapy must be managed according to institutional and society recommendations. Patients with previous sphincterotomy, biliary stents, or biliary-enteric anastomoses should receive appropriate antibiotic prophylaxis because of the increased risk of abscess formation after liver interventions.

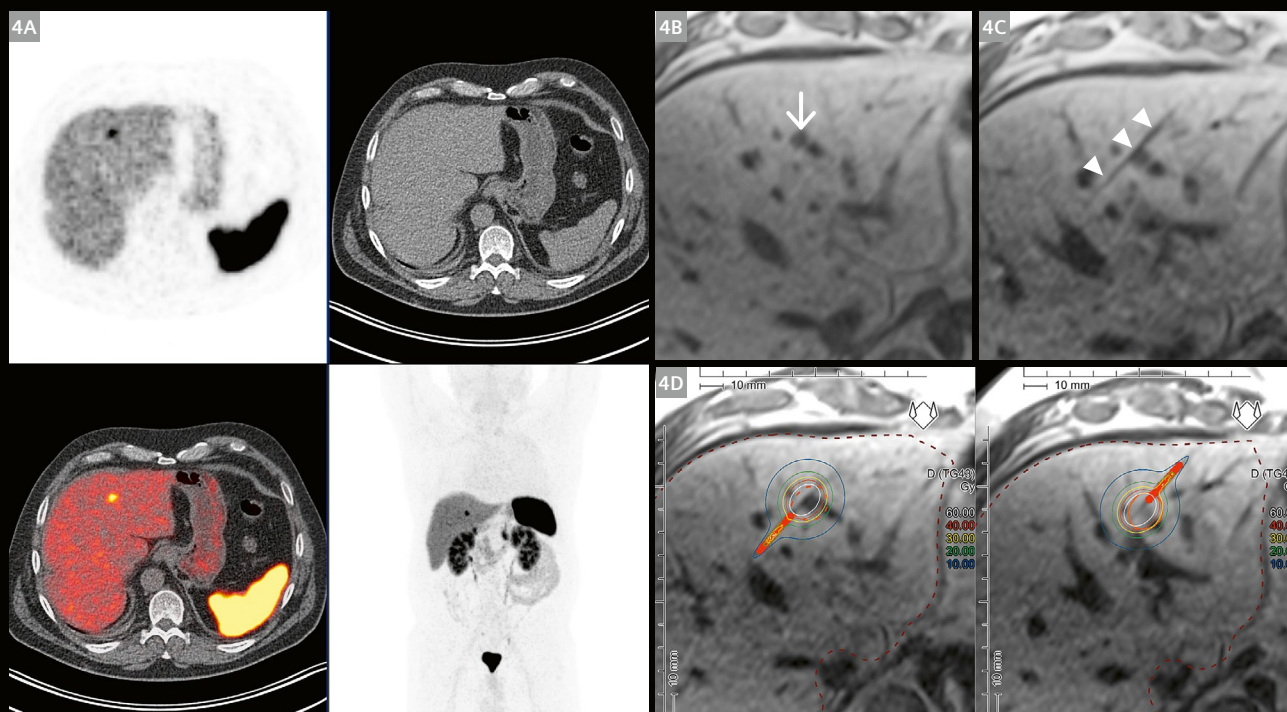
Most procedures can be performed under conscious sedation and local anesthesia. Oxygen supplementation, ECG monitoring, pulse oximetry, and repeated blood pressure measurements are mandatory. Sedation is typically achieved with titrated opioid and benzodiazepine administration, while preserving spontaneous breathing. Reversal agents and airway support must be immediately available, and the team must be familiar with sedation-related emergencies.

In MRI-guided procedures, the patient is positioned on the scanner table 15 minutes after the administration of gadoxetic acid (0.1 mmol/kg body weight). Axial and coronal hepatobiliary-phase T1-weighted images are acquired for lesion localization and access planning. After sterile preparation, local anesthetic is infiltrated into the skin, subcutaneous tissues, and liver capsule. The puncture is then performed with an 18G coaxial needle under





3 A 55-year-old patient with oligometastatic breast cancer (three liver metastases). **(3A)** Diagnostic hepatobiliary-phase T1 VIBE MRI shows three small liver lesions: one in segment 7 measuring 6 mm (left), one in segment 8 measuring 18 mm (middle), and one in segment 3 measuring 7 mm (right). **(3B)** Intraprocedural fluoroscopy images show needle placement in para-axial plane. **(3C)** After brachytherapy catheter placement, planning with contrast-enhanced CT was required for treatment planning as the catheter-tip conspicuity was insufficient in MRI. Dosimetry maps demonstrate conformal target coverage with a prescribed dose of 20 Gy.



4 A 57-year-old patient with a history of bronchial neuroendocrine tumor and hepatic recurrence following 10 years of remission. **(4A)** 68Ga-DOTATATE PET/CT shows a solitary hepatic metastasis with enhanced uptake. **(4B)** Hepatobiliary-phase T1 VIBE MRI shows a 7 mm liver lesion in segment 4a with proximity to a portal vein branch. **(4C)** After brachytherapy catheter placement, planning 3D T1-weighted gradient-echo MRI confirms decent catheter position (arrowheads). **(4D)** Dosimetry maps demonstrate conformal target coverage with a prescribed dose of 20 Gy.

real-time gradient-echo MR fluoroscopy (TE 3.4 ms, TR 7.3 ms, FA 30°). Once optimal needle positioning is confirmed, the inner stylet is withdrawn and a stiff 0.035-inch guidewire is introduced in retrograde orientation (rear-end first) to enable exchange of the needle for a 6 French/25 cm sheath with dilator using the Seldinger technique. After removal of the wire and dilator, a closed-ended 6F brachytherapy catheter is advanced through the sheath, and its extracorporeal length is measured and marked to detect potential displacement. The catheter is fixed carefully at the skin.

For larger tumors or irregular target volumes, multiple catheters may be required. Their number and geometry are determined by the expected dose distribution and the relationship of the lesion to surrounding organs at risk. After catheter placement, a three-dimensional gradient-echo MRI sequence is used for immediate position verification, although contrast-enhanced CT might be required for treatment planning and dosimetric calculations if catheter-tip conspicuity is insufficient. The target volume and organs at risk are segmented by the radiation oncology team, and the medical physicist calculates a plan based on catheter position, dwell points, and dwell times. If coverage is insufficient, an additional catheter can be placed before treatment delivery.

The patient is then connected to the HDR afterloader. The Iridium-192 source travels through the catheter to the programmed dwell positions, delivering the prescribed dose from inside the tumor. Treatment times vary according to source strength, dose prescription, tumor volume, and number of catheters, but usually remain clinically practical within a single session. Depending on tumor entity, commonly prescribed target doses are 15 Gy for hepatocellular carcinoma (HCC), 25 Gy for metastatic colorectal cancer, and 20 Gy for other tumor entities. The catheter tract is routinely irradiated with 5 Gy before removal to reduce the risk of tumor cell seeding.

After treatment, catheters are removed under careful hemostatic technique. The access tract is sealed with gelatin sponge pledgets during sheath withdrawal to reduce bleeding risk. Post-procedural monitoring includes clinical observation and ultrasound to exclude hematoma, subcapsular bleeding, or free intra-abdominal fluid. Most patients can be managed without intensive post-procedural care, although monitoring must be adapted to liver function, coagulation status, sedation depth, and comorbidities.

Complications are uncommon but must be anticipated. The most relevant are bleeding, infection or abscess, transient pain, nausea, and rare bile-duct injury or hepatic decompensation. The risk profile depends on tumor burden, access route, liver function, coagulation status, and biliary anatomy.

Follow-up imaging requires familiarity with post-radiation changes. The treatment zone may initially appear larger than the original tumor and can show edema, peripheral arterial hyperenhancement, or delayed parenchymal enhancement. These findings should not be mistaken for viable tumor unless there is new or increasing nodular enhancement suggestive of local progression. MRI is particularly valuable for follow-up after liver-directed therapy because it combines high soft-tissue contrast with multiphasic and hepatobiliary information.

Representative case examples are shown in Figures 1–4.

Conclusion

MRI-guided interstitial HDR brachytherapy brings together two strengths: the precision of modern interventional MRI and the conformal dose delivery of catheter-based radiotherapy. For hepatic malignancies that are small, poorly visible on CT, close to vessels, adjacent to heat-sensitive structures, or unsuitable for thermal ablation, this technique expands the local treatment armamentarium beyond heat.

CT guidance will remain important because of its speed, availability, and robustness. However, MRI guidance offers a compelling advantage in selected patients: improved lesion visibility, flexible imaging planes, real-time needle guidance without ionizing radiation to the operator, and the potential for more precise catheter placement. Preliminary single-center data indicate that MRI-guided catheter-based radiotherapy is feasible and safe, with low complication rates, reduced non-target liver irradiation, and encouraging early local control.

The future of liver-directed therapy will likely be increasingly individualized. Some lesions are best treated surgically, others thermally, transarterially, stereotactically, or systemically. MRI-guided HDR brachytherapy occupies a distinct and valuable niche within this spectrum. Its broader adoption will depend not only on technology, but also on interdisciplinary workflows that unite interventional radiology, radiation oncology, medical physics, and patient-centered oncologic decision-making.

References

- 1 Bray F, Laversanne M, Sung H, Ferlay J, Siegel RL, Soerjomataram I, et al. Global cancer statistics 2022: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA Cancer J Clin* [Internet]. 2024;74(3):229–63. Available from: <http://dx.doi.org/10.3322/caac.21834>
- 2 Cremolini C, Chalabi M, Elez E, Fassin M, Gelli M, Goéré D, et al. Metastatic colorectal cancer: ESMO Clinical Practice Guideline for diagnosis, treatment and follow-up. *Ann Oncol* [Internet]. 2026;37(6):759–76. Available from: <http://dx.doi.org/10.1016/j.annonc.2026.03.005>
- 3 Vogel A, Chan SL, Dawson LA, Kelley RK, Llovet JM, Meyer T, et al. Hepatocellular carcinoma: ESMO Clinical Practice Guideline for diagnosis, treatment and follow-up. *Ann Oncol* [Internet]. 2025;36(5):491–506. Available from: <http://dx.doi.org/10.1016/j.annonc.2025.02.006>
- 4 Crocetti L, de Baére T, Pereira PL, Tarantino FP. CIRSE Standards of Practice on Thermal Ablation of Liver Tumours. *Cardiovasc Intervent Radiol* [Internet]. 2020;43(7):951–62. Available from: <http://dx.doi.org/10.1007/s00270-020-02471-z>
- 5 Bretschneider T, Ricke J, Gebauer B, Streitharth F. Image-guided high-dose-rate brachytherapy of malignancies in various inner organs - technique, indications, and perspectives. *J Contemp Brachytherapy* [Internet]. 2016;8(3):251–61. Available from: <http://dx.doi.org/10.5114/jcb.2016.61068>
- 6 Ricke J, Wust P, Wieners G, Beck A, Cho CH, Seidensticker M, et al. Liver malignancies: CT-guided interstitial brachytherapy in patients with unfavorable lesions for thermal ablation. *J Vasc Interv Radiol* [Internet]. 2004;15(11):1279–86. Available from: <http://dx.doi.org/10.1097/01.RVI.0000141343.43441.06>
- 7 Ümütlü MR, Öcal O, Pühr-Westerheide D, Fabritius MP, Wildgruber M, Deniz S, et al. Efficacy and Safety of Local Liver Radioablation in Hepatocellular Carcinoma Lesions within and beyond Limits of Thermal Ablation. *Dig Dis* [Internet]. 2024;42(5):461–72. Available from: <http://dx.doi.org/10.1159/000538788>
- 8 Auer TA, Anhamm M, Böning G, Fehrenbach U, Schöning W, Lurje G, et al. Effectiveness and safety of computed tomography-guided high-dose-rate brachytherapy in treating recurrent hepatocellular carcinoma not amenable to repeated resection or radiofrequency ablation. *Eur J Surg Oncol* [Internet]. 2024;50(7):108429. Available from: <http://dx.doi.org/10.1016/j.ejso.2024.108429>
- 9 Auer TA, Müller L, Schulze D, Anhamm M, Bettinger D, Steinle V, et al. CT-guided High-Dose-Rate Brachytherapy versus Transarterial Chemoembolization in Patients with Unresectable Hepatocellular Carcinoma. *Radiology* [Internet]. 2024;310(2):e232044. Available from: <http://dx.doi.org/10.1148/radiol.232044>
- 10 Auer TA, Ranner-Hafferl MHH, Anhamm M, Böning G, Fehrenbach U, Mohr R, et al. CT-guided high-dose-rate brachytherapy ablation of HCC patients with portal vein tumor thrombosis. *Eur Radiol Exp* [Internet]. 2025;9(1):16. Available from: <http://dx.doi.org/10.1186/s41747-025-00564-3>
- 11 Ricke J, Mohnike K, Pech M, Seidensticker M, Rühl R, Wieners G, et al. Local Response and Impact on Survival After Local Ablation of Liver Metastases From Colorectal Carcinoma by Computed Tomography-Guided High-Dose-Rate Brachytherapy. *Int J Radiat Oncol Biol Phys* [Internet]. 2010;78(2):479–85. Available from: <http://dx.doi.org/10.1016/j.ijrobp.2009.09.026>
- 12 Bilski M, Kuncman Ł, Orzechowska M, Cisek P, Mastroleo F, Skrzypczak M, et al. Survival outcomes and toxicity profile after CT-guided HDR brachytherapy (interventional radiotherapy) for liver oligometastases in breast cancer patients: The BRALIBREST real world multicenter study. *Radiother Oncol* [Internet]. 2026; 214(111280):111280. Available from: <http://dx.doi.org/10.1016/j.radonc.2025.111280>
- 13 Mohnike K, Wolf S, Damm R, Seidensticker M, Seidensticker R, Fischbach F, et al. Radioablation of liver malignancies with interstitial high-dose-rate brachytherapy : Complications and risk factors. *Strahlenther Onkol* [Internet]. 2016;192(5):288–96. Available from: <http://dx.doi.org/10.1007/s00066-016-0957-0>
- 14 Schmidt VF, Öcal O, Walther V, Fabritius MP, Dietrich O, Kazmierczak PM, et al. Clinical benefits of MRI-guided freehand biopsy of small focal liver lesions in comparison to CT guidance. *Eur Radiol* [Internet]. 2024;34(9):5507–16. Available from: <http://dx.doi.org/10.1007/s00330-024-10623-9>
- 15 Pereira PL, Siemou P, Rempp HJ, Hoffmann R, Hoffmann RT, Kettenbach J, et al. CT versus MR guidance for radiofrequency ablation in patients with colorectal liver metastases: a 10-year follow-up favors MR guidance. *Eur Radiol* [Internet]. 2024;34(7): 4663–71. Available from: <http://dx.doi.org/10.1007/s00330-023-10270-6>

Contact


Matthias P. Fabritius, M.D.
 LMU Hospital
 Department of Radiology
 Campus Großhadern
 Marchioninistr. 15
 81377 Munich
 Germany
matthias.fabritius@med.uni-muenchen.de
www.lmu-klinikum.de/radiologie

Prostate Imaging and Interventions at 0.55T: Increasing Access to High-Quality Prostate Cancer Diagnosis and Treatment

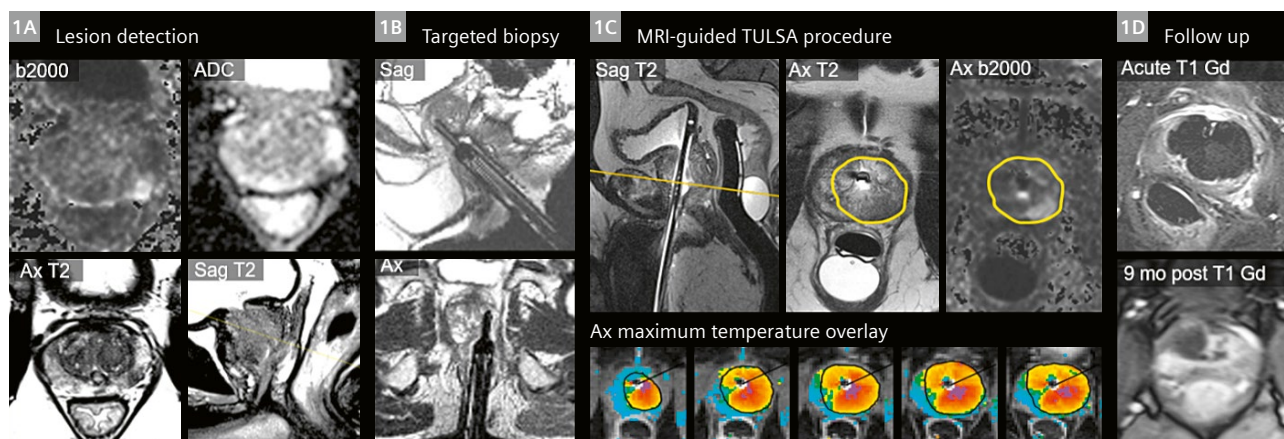
Joseph Busch, Jr., M.D.

Founder, Busch Center, Alpharetta, GA, USA

Introduction

Magnetic resonance imaging (MRI) of the prostate has become an integral part of the standard of care for prostate cancer management, supported by multiple randomized trials demonstrating superiority of MRI-targeted over systematic biopsy for clinically significant prostate cancer detection [1]. A growing body of evidence also supports the role of MRI to guide active surveillance of favorable-risk prostate cancer [2], post-treatment follow-up and recurrence evaluation [3–5], and even population-level prostate cancer screening [6]. In parallel, advances in interventional MRI (iMRI) have expanded the role of prostate MRI beyond diagnostic imaging to encompass image-guided interventions like in-bore MRI-guided biopsy as well as intraoperative treatment planning and real-time treatment monitoring [7] (Fig. 1). The increasingly central role of MRI across the prostate cancer care continuum underscores the need to achieve reproducible outcomes beyond academic centers, and to broaden access to high-quality prostate MRI and MRI-guided procedures.

Access to high-quality prostate MRI is limited due to the high prevalence of suboptimal imaging protocols even among expert sites, and due to the high cost of traditional high-field MRI, which is not available widely enough to serve the expanding population of patients for whom prostate MRI is indicated. This has stimulated initiatives to standardize prostate MRI acquisition and interpretation, and has driven interest in lower-field MRI systems, where recent advances have enabled high-quality imaging with potential advantages in accessibility and workflow integration. Moreover, the inherent characteristics of low-field MRI reduce susceptibility artifacts, enhance patient access, and lower operating costs, making it particularly well-suited for interventional applications. Here we review drivers of prostate MRI quality, which recent studies suggest are mostly practical matters that are independent of MRI field strength. We also discuss how technological developments that enable high-performance imaging on lower-field scanners could enable broader access to diagnostic and interventional MRI, and we evaluate the feasibility of prostate MRI and interventions at 0.55T.



1 The role of MRI from prostate cancer diagnosis to treatment and follow-up, currently performed and demonstrated here at 1.5T and 3T. **(1A)** Diffusion and T2-weighted images enabling lesion detection, localization, and staging. **(1B)** In-bore MRI-targeted biopsy for accurate sampling of MRI-visible lesions. **(1C)** MRI-guided ablation with TULSA including intraoperative T2- and diffusion-weighted planning, and real-time MR thermometry used for automated treatment control to achieve the intended ablation volume. **(1D)** Post-treatment contrast-enhanced MRI to evaluate the acute ablation zone and follow treatment response.

Drivers of prostate MRI quality

As Level 1 evidence on MRI-directed prostate cancer management has accumulated, MRI before prostate biopsy is now firmly established as the standard of care in international practice guidelines. With rising demand for prostate MRI, concerns have increased about the ability to reproduce clinical trial results outside specialized academic centers, and international guidelines caution that the utility of prostate MRI in the diagnosis of prostate cancer depends critically on the quality of image acquisition and interpretation [8]. This has prompted efforts to study variability in the diagnostic performance of prostate MRI, to establish standards for the assessment of prostate MRI quality, and to systematically improve the quality of prostate MRI programs.

One of the largest efforts to study the consistency of prostate MRI performance, conducted by the Society for Abdominal Radiology Prostate Cancer Disease-Focused Panel, found that even leading academic centers have difficulty achieving high-quality diagnostic prostate MRI [9]. In more than 3,000 men at 26 premier academic centers, more than half of the sites had a rate below 50% for correctly identifying clinically significant prostate cancer, with a positive predictive value of less than 0.5 for lesions with a PI-RADS (Prostate Imaging and Reporting and Data System) score of 4 or higher. Interestingly, the wide variability across centers did not appear to depend on the use of 1.5T versus 3T scanners; instead, the leading causes of poor-quality prostate MRI were typically practical concerns related to scan protocol and patient preparation, including the management of rectal gas. In the UK PRIME trial [10], which assessed and established standards for prostate MRI quality at 41 centers across 18 countries using the Prostate Imaging Quality (PI-QUAL) scoring system, only 32% of submitted test exams demonstrated optimal image quality (PI-QUAL score 5 out of 5). In that study, the leading reasons for suboptimal PI-QUAL scores included basic protocol errors such as inadequate resolution, field of view, slice thickness, diffusion b-values, temporal resolution of dynamic contrast-enhanced images, motion artifacts, and air in the rectum. With feedback from the central quality-improvement group about making simple changes to MRI protocols and patient preparation, 97% of participating centers achieved optimal PI-QUAL 5 scores upon repeat assessment. Similarly, the American College of Radiology's Prostate MR Image Quality Improvement Collaborative followed PI-QUAL scores across 2,380 exams over 9 months at 5 large hospital networks [11]. They found that the rate of diagnostic-quality exams improved from 67% to 87% through protocol adjustments, specifically the consistent application of clear patient preparation instructions (including prompts to use the bathroom before the exam, and at some centers the use of a mini enema), MRI technologist training, and periodic review

of diagnostic performance with feedback to MRI technologists and radiologists [11]. Across these and other quality-improvement studies, key drivers of improved prostate MRI quality tended to be practical interventions rather than movement to higher field strength.

At the Busch Center, which focuses entirely on prostate MRI and MRI-guided interventions, prostate MRI examinations begin with consistent patient preparation performed in-office using a mini enema immediately before the exam in a dedicated bathroom for pre-exam preparation. An essential aspect of the MRI protocol is performing the diffusion scan first, as this sequence is most sensitive to patient motion and bowel gas, both of which are more likely to arise as time goes on. If motion or rectal air artifacts do appear, the examination is paused and the patient is asked to repeat the mini enema before continuing. Finally, the overall diagnostic quality of the study depends on the quality of interpretation; radiologists are encouraged to invest in training and mentorship, specialize in reading prostate MRI examinations, and continuously review biopsy reports based on MRI targeting to improve accuracy and to understand the relationship between histologic grade and apparent diffusion coefficient (ADC) values on their machine [12].

Accordingly, technology improvements to raise the quality of prostate MRI are ideally focused on ensuring consistent application of best practices in image acquisition and diagnosis. There has been significant development in the standardization of streamlined acquisition protocols, with results from the PRIME study confirming that simplified biparametric protocols comprised only of T2 and high-b diffusion-weighted imaging (DWI) did not reduce cancer detection compared to multiparametric prostate MRI protocols including time-consuming and highly variable dynamic contrast-enhanced (DCE) T1-weighted acquisitions [13]. MRI vendors are developing AI tools that assist technologists in improving the consistency of prostate MRI acquisition with automated slice prescription, that shorten acquisition times and thus motion artifacts without reducing the signal-to-noise ratio (SNR) using AI-powered image reconstruction and post-processing techniques (Deep Resolve), and that automatically identify image artifacts and notify technologists to repeat scans while patients are still in the scanner [14]. Numerous tools are also being developed to assist radiologists in evaluating prostate MRI, with automated segmentation of the prostate gland and zonal anatomy, machine learning-based lesion detection and grading validated against biopsy or whole-mount histology to improve diagnostic yield for less experienced readers, and auto-population of imaging reports to ensure adherence to established standards such as PI-RADS, PRECISE, and PI-RR (AI-Rad Companion). Together, these improvements have the potential to not only maintain, but also improve the quality and consistency of prostate MRI as the number of programs and cases increases.

0.55T: Increasing access to high-quality prostate MRI

While demand for prostate MRI is increasing, and the combination of protocol standardization and technological improvements is raising the ability of new programs to achieve high diagnostic yield, there are also significant economic and geographic disparities in access to MRI [15]. Compared with traditional high-field magnets, helium-free scanners reduce the complexity of MRI installation, enabling deployment of imaging capabilities to previously inaccessible locations while also significantly decreasing the cost of acquisition, buildout, and operation, thereby reducing barriers to entry. Helium-free scanners with ultrawide 80 cm bores also increase access by supporting imaging of bariatric and claustrophobic patients. Furthermore, imaging at 0.55T instead of higher fields lowers barriers for patients with metal implants by decreasing SAR-induced heating and reducing susceptibility artifacts around implants, and may also improve reproducibility by decreasing the susceptibility-related effects of air in the rectum.

While there are numerous potential advantages to prostate imaging with a modern 0.55T scanner, it is not yet known whether improvements in hardware and

AI-enhanced reconstruction can overcome the lower SNR relative to higher field strengths to produce diagnostic-quality T2 and diffusion-weighted images. The current PI-RADS guidelines for reporting prostate MRI advise against prostate imaging below 1.5T because of limited experience and limited prospective assessment of diagnostic performance at lower field strengths. To date, publications on prostate MRI at 0.55T have focused on protocol development [16], technical analysis of anatomical features compared with 1.5T and 3T [17], and guidance of in-bore MRI-targeted biopsy [18]. Evaluations of diagnostic performance at 0.55T or diagnostic comparisons with higher field strengths are not yet available.

To explore the feasibility of prostate imaging using ultrawide-bore, helium-free 0.55T MRI, we ported our 3T MAGNETOM Skyra biparametric prostate MRI protocol to the MAGNETOM Free.Max system for volunteer imaging in a series of three participants at the MRI facility of Siemens Healthineers in Erlangen, Germany. Table 1 lists the technical scan parameters that have quality specifications in the PI-RADS reporting guidelines. Without optimization, this initial attempt at volunteer imaging met all PI-RADS technical specifications (except field of view on the diffusion scan, which was later updated with minimal change in

Sequence	PI-RADS technical specification	3T MAGNETOM Vida protocol	0.55T MAGNETOM Free.Max protocol
Axial T2W			
Slice thickness (mm)	3, no gap	3, no gap	3, no gap
Field of view (cm)	12–20	20	20
In-plane dimension (mm)	≤ 0.7 (phase), ≤ 0.4 (frequency)	0.3 × 0.3	0.4 × 0.4
Echo train length	Excessive ETL to be avoided	51	27
Acquisition duration (min:sec)	–	1:14	3:10
Axial DWI			
Echo time (ms)	≤ 90	63	89
Repetition time (ms)	≥ 3000	3800	4300
Slice thickness (mm)	≤ 4, no gap	3	3
Field of view (cm)	16–22	20	24
In-plane dimension (mm)	≤ 2.5 phase & frequency	0.9 × 0.9	1.3 × 1.3
Low b-value (s/mm ²)	0–100 (preferably 50–100)	50	50
Intermediate b-value (s/mm ²)	800–1000	800	800
High b-value (s/mm ²)	≥1400 (separate or calculated)	calc b2000	calc b1400
Acquisition duration (min:sec)	–	1:56	5:18

Table 1: Comparison of sequence parameters used for volunteer imaging at 0.55T.

image quality or scan time). Despite a nearly sixfold decrease in magnetic field strength, PI-RADS-compliant scans were attainable with a modest increase in scan time.

The first volunteer (Fig. 2) was a man in his 80s with a prostate volume of approximately 100 cc. In addition to axial T2-weighted and diffusion scans, the test protocol also included sagittal, coronal, and 3D T2W acquisitions. The T2-weighted images met all criteria for diagnostic quality by satisfying the PI-RADS and PI-QUAL technical specifications, including axial and orthogonal views, clear delineation of the capsule, seminal vesicles, ejaculatory ducts, neurovascular bundles, and sphincter muscle, and freedom from motion or rectal air artifacts. The DWI sequence was free of rectal air artifacts, with surprisingly high SNR, resolution, and geometric fidelity in ADC maps and calculated b2000 images. A small focus in the transition zone was clearly visible, with hypointensity on T2W, high signal intensity indicating restricted diffusion on high-b DWI, and low ADC values of 600–800 sec/mm². Given the transition-zone location, this was consistent with a PI-RADS 4 lesion and likely low histologic grade.

The second volunteer, a man in his 60s with a 40 cc gland, also demonstrated excellent depiction of the intra- and extraprostatic anatomy (Fig. 3). A focus of hyperintensity was seen in the right anterior transition zone on the calculated b1400 images, but the corresponding ADC values were above 900×10^{-6} mm²/s and the finding lacked conspicuity on T2W images. The combined T2-weighted, diffusion-weighted, and susceptibility-weighted images

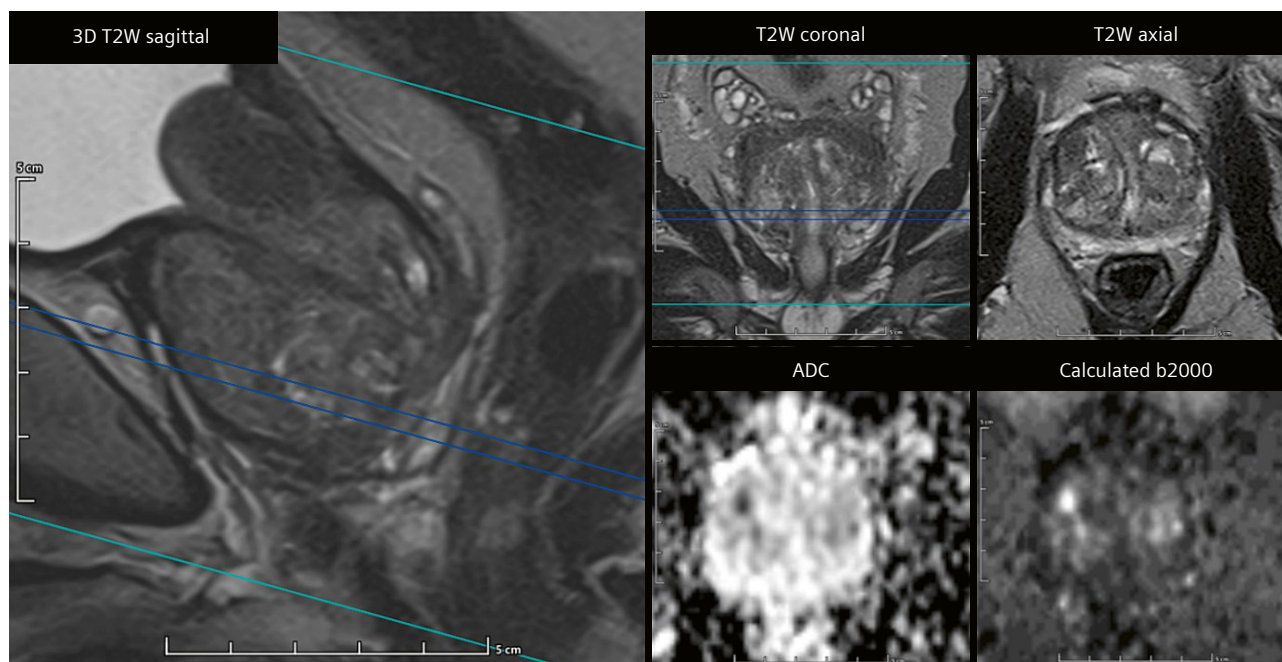
demonstrated the feasibility of acquiring high-quality anatomical and functional prostate MRI at 0.55T.

The third volunteer, a 50-year-old man with an approximately 40 cc prostate and no history of prostate cancer, was imaged at both 0.55T and 3T on the same day (Fig. 4). Anatomical contrast and resolution on T2W images were effectively equivalent for the detection of clinically significant lesions. DWI resolution and contrast were superior at 3T, but clear visualization of the transition zone and peripheral zone, together with concordant conspicuity of a focus of restricted diffusion in the right transition zone, speak to the potential for diagnostic prostate MRI at 0.55T.

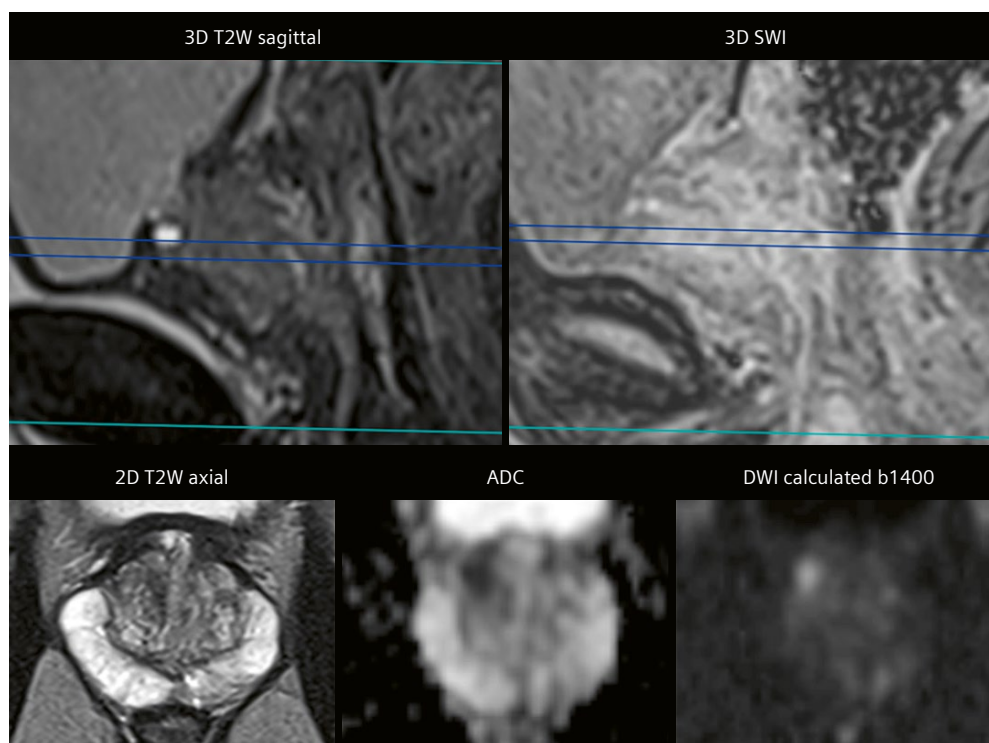
Prostate interventions at 0.55T: Transurethral ultrasound ablation (TULSA)

As described in several articles in this issue, ultra-wide-bore, 0.55T, almost helium-free magnets offer numerous technical and practical advantages for MRI-guided interventions. The wider bore facilitates interventional device insertion and manipulation, the lower field reduces device-associated image artifacts and heating concerns, and helium-free operation reduces cost, making it feasible for private-practice surgeons and interventionalists to establish their own MRI-guided interventional suites.

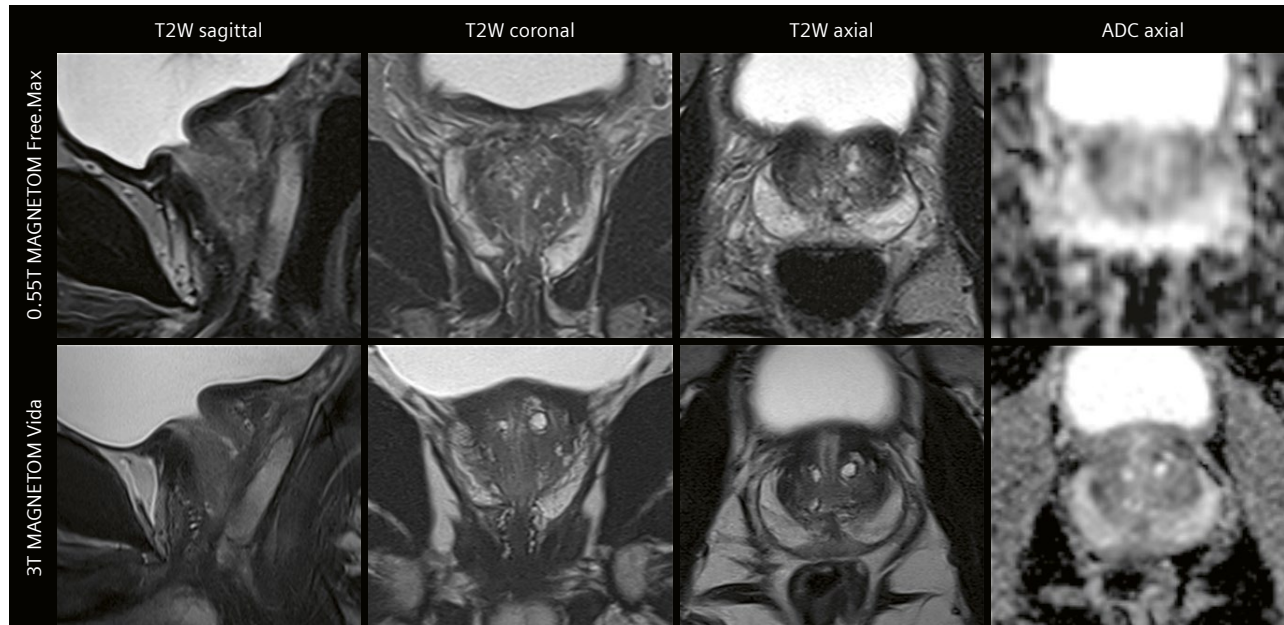
One of the most mature technologies for in-bore MRI-guided prostate ablation is transurethral ultrasound ablation (TULSA). Each single-use TULSA ultrasound applicator (UA) uses a linear array of 10 directional ultrasound



2 Prostate MRI in an 83-year-old healthy volunteer on a 0.55T MAGNETOM Free.Max system. Representative images include T2-weighted images in sagittal, coronal, and axial planes, along with axial apparent diffusion coefficient (ADC) and high calculated b-value diffusion-weighted ($b = 2000$ s/mm²) images, demonstrating prostate visualization and image quality at low field strength.



3 Prostate MRI from a 64-year-old healthy volunteer acquired using the 0.55T MAGNETOM Free.Max. The top row shows a 3D T2-weighted sagittal image (left) and a 3D sagittal susceptibility-weighted imaging (SWI) acquisition (right; in-plane resolution $0.65 \times 0.65 \text{ mm}^2$, slice thickness 2 mm). The bottom row shows the corresponding axial T2-weighted image, apparent diffusion coefficient (ADC) map, and high b-value ($b = 1400 \text{ s/mm}^2$) diffusion-weighted image (DWI). The blue reference line displayed on the sagittal images indicates the location of the axial slice shown in the bottom row.

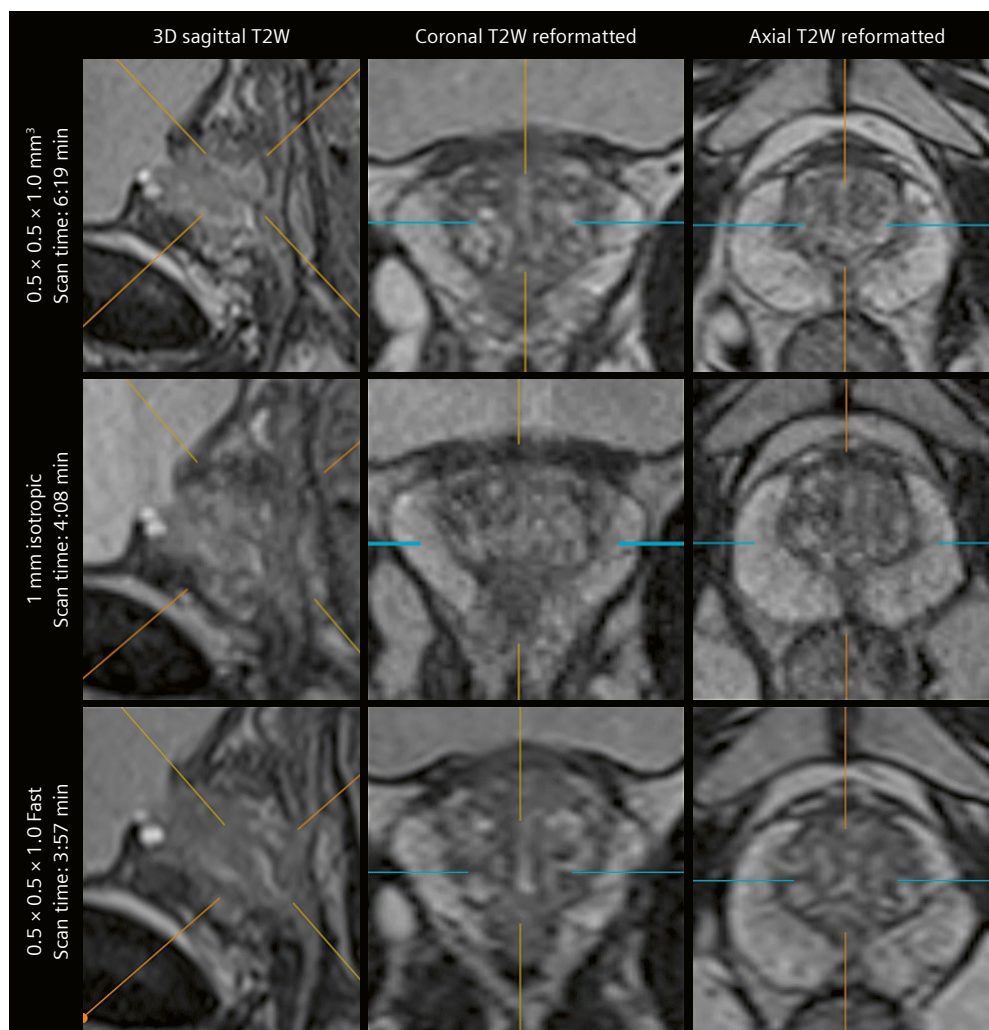


4 Multiplanar T2- and diffusion-weighted prostate MRI in a 50-year-old man at 0.55T and 3T. Sagittal, coronal, and axial images are shown for comparison between a 0.55T system (MAGNETOM Free.Max) (top row) and a 3T system (MAGNETOM Vida) (bottom row). Both scans were acquired on the same day. The 3T examination demonstrates greater bladder distension at the time of imaging. Despite differences in field strength, corresponding anatomical structures are consistently visualized across all planes, demonstrating feasibility of low-field imaging for prostate MRI.

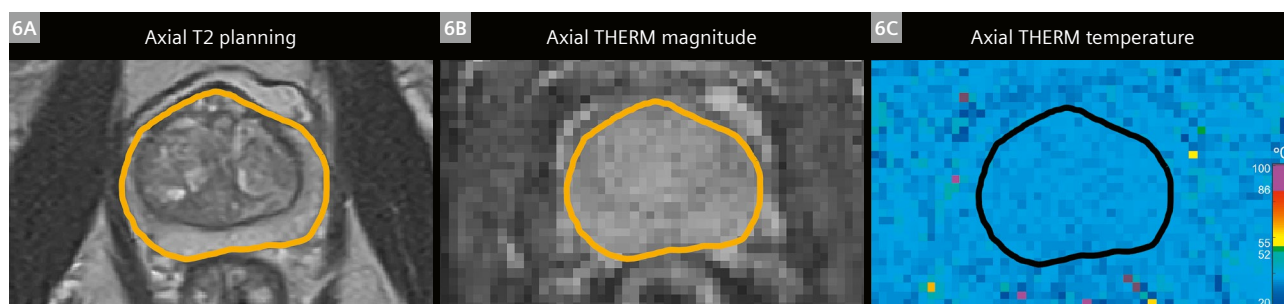
beams to form a “blade” of energy that achieves thermal coagulation of prostate tissue extending from the urethra to the prostatic capsule. An MRI-compatible robot automates precise image-guided positioning of the applicator during planning, and continuous computer-controlled rotation of the ultrasound blade during treatment. Historically performed at 1.5T and 3T, TULSA leverages the superior soft tissue contrast of MRI for accurate lesion localization and target delineation. It also harnesses MRI’s unique capability to achieve fast, high-precision, volumetric temperature mapping to monitor and provide quantitative feedback control that drives thousands of automatic adjustments of ultrasound power and penetration depth for conformal thermal ablation of targeted prostate tissue with millimeter precision while preserving surrounding healthy tissue and functional outcomes. The MRI-guided transurethral approach to thermal energy delivery has demonstrated decreased morbidity, promising efficacy, and broad treatment flexibility for focal and whole-gland ablation across the spectrum of prostate disease, including in early feasibility studies [19–21], a pivotal multicenter trial in localized

prostate cancer [22, 23], and investigator-initiated studies in radio-recurrent prostate cancer [24] as well as tissue debulking for benign prostatic hyperplasia (BPH) [25]. A multicenter randomized controlled trial comparing TULSA to robotic prostatectomy (CAPTAIN, NCT05027477) has completed enrollment, with early outcomes demonstrating superior safety and quality-of-life for TULSA [26]; oncologic outcomes will be reported at 3 and 10 years.

During TULSA treatment, standard diagnostic 3 mm axial T2-weighted and diffusion-weighted images such as those evaluated at 0.55T in the volunteers above are acquired to delineate the planned ablation volume with visualization and sparing of neurovascular bundles, urethra, sphincter complex, and adjacent critical structures. Additionally, 3D T2-weighted imaging with 1 mm isotropic voxels is particularly valuable to delineate the prostatic apex and external urinary sphincter for preservation of urinary function in patients with apical lesions [27]. Figure 5 shows high-resolution isotropic 3D T2-weighted imaging at 0.55T from the second volunteer, demonstrating clear visualization of the prostate zonal anatomy



5 Representative prostate MRI from a 64-year-old healthy volunteer acquired on a 0.55T MAGNETOM Free.Max system. Rows (top to bottom) show images from T2 SPACE sag (acquisition time 6:19 min; voxel size $0.5 \times 0.5 \times 1.0 \text{ mm}^3$), T2 SPACE sag (acquisition time 4:08 min; isotropic voxel size $1.0 \times 1.0 \times 1.0 \text{ mm}^3$), and T2 sag fast (acquisition time 3:57 min; voxel size $0.5 \times 0.5 \times 1.0 \text{ mm}^3$). Columns (left to right) display the original 3D sagittal T2-weighted acquisition, coronal reformat, and axial reformat, respectively. All acquisitions were obtained with a slice thickness of 1 mm.



6 Three-dimensional MR thermometry for MRI-guided TULSA therapy at 0.55T. **(6A)** Axial T2-weighted treatment planning image. **(6B)** Axial thermometry magnitude image acquired during treatment. **(6C)** Corresponding axial temperature map demonstrating stable real-time thermal monitoring.

and surrounding pelvic structures in sagittal, coronal, and axial reconstructions.

The most critical consideration for TULSA at lower field strengths with lower overall signal-to-noise ratio is maintaining the accuracy of MRI temperature monitoring needed for precise ablation control. To address the anticipated decrease in SNR at lower field, a 3D MR thermometry sequence was implemented at 0.55T in place of conventional 2D acquisitions, enabling equivalent temperature monitoring resolution, coverage, and speed, while improving SNR efficiency (Fig. 6). Technical validation of the MAGNETOM Free.Max TULSA-PRO platform demonstrated that the precision of 3D thermometry at 0.55T was comparable to that achieved with standard 2D thermometry at 1.5T while maintaining the same scan time, voxel size, and field-of-view. These findings suggest that the MAGNETOM Free.Max can support real-time visualization and control of thermal deposition during MRI-guided prostate ablation with TULSA, while maintaining temperature measurement precision and enabling the workflow, accessibility, and cost advantages associated with lower-field systems.

Outlook and perspective

With widespread adoption of MRI in prostate cancer diagnosis and management, it is important to be aware of the practical steps that can be taken to ensure high diagnostic performance of prostate MRI programs. High-quality prostate MRI is achieved by paying careful attention to consistent patient preparation, standardized MRI protocols, technologist training, and feedback among technologists, radiologists, and pathologists. Low-field, wider-bore, helium-free MRI scanners such as the MAGNETOM Free.Max have the potential to increase access to prostate MR imaging and interventions due to broadened patient eligibility and the lower technical and economic barriers to installation and operation. While studies of the diagnostic performance of prostate MRI at 0.55T are needed for acceptance in imaging guidelines, our initial volunteer T2 and diffusion

images at 0.55T presented here demonstrate adequate spatial and functional resolution for diagnostic use, with quality approaching that of images at 1.5T and 3T. Similarly, the isotropic 3D T2-weighted images and quantitative MRI thermometry mapping sequences specific to TULSA were demonstrated to be adequate to plan and control prostate ablation at 0.55T. For interventional radiology or urology practices with a prostate focus, MAGNETOM Free.Max presents a unique opportunity to reduce the cost and complexity of offering high-quality prostate MRI for a more efficient patient pathway that uses MRI for prostate cancer screening, detection, biopsy targeting, surveillance, in-bore interventions such as TULSA, and follow-up.

References

- 1 Drost F-JH, Osses D, Nieboer D, Bangma CH, Steyerberg EW, Roobol MJ, et al. Prostate magnetic resonance imaging, with or without magnetic resonance imaging-targeted biopsy, and systematic biopsy for detecting prostate cancer: A Cochrane systematic review and meta-analysis. *Eur Urol* [Internet]. 2020;77(1):78–94. Available from: <http://dx.doi.org/10.1016/j.eururo.2019.06.023>
- 2 Englman C, Adebosoye B, Maffei D, Stavrinides V, Bridge J, Kirkham A, et al. Magnetic resonance imaging-led risk-adapted active surveillance for prostate cancer: Updated results from a large cohort study. *Eur Urol* [Internet]. 2025;88(2):167–75. Available from: <http://dx.doi.org/10.1016/j.eururo.2025.03.019>
- 3 Giganti F, Dickinson L, Orczyk C, Haider A, Freeman A, Emberton M, et al. Prostate Imaging after Focal Ablation (PI-FAB): A proposal for a scoring system for multiparametric MRI of the prostate after focal therapy. *Eur Urol Oncol* [Internet]. 2023;6(6):629–34. Available from: <http://dx.doi.org/10.1016/j.euo.2023.04.007>
- 4 Light A, Mayor N, Cullen E, Kirkham A, Padhani AR, Arya M, et al. The Transatlantic Recommendations for Prostate Gland Evaluation with magnetic resonance imaging after Focal Therapy (TARGET): A systematic review and international consensus recommendations. *Eur Urol* [Internet]. 2024;85(5):466–82. Available from: <http://dx.doi.org/10.1016/j.eururo.2024.02.001>
- 5 Panebianco V, Villeirs G, Weinreb JC, Turkbey BI, Margolis DJ, Richenberg J, et al. Prostate magnetic resonance imaging for local Recurrence Reporting (PI-RR): International consensus -based guidelines on multiparametric magnetic resonance imaging for prostate cancer recurrence after radiation therapy and radical prostatectomy. *Eur Urol Oncol* [Internet]. 2021;4(6):868–76. Available from: <http://dx.doi.org/10.1016/j.euo.2021.01.003>

- 6 Thorley N, Parry T, Giganti F, Kopcke D, Sidhu HS, Brembilla G, et al. Diagnostic accuracy of abbreviated biparametric MRI for prostate cancer screening: a prospective feasibility study (ReIMAGINE study). *Eur Radiol* [Internet]. 2026;36(3):1959–70. Available from: <http://dx.doi.org/10.1007/s00330-025-11837-1>
- 7 Busch JJ Jr. The role for MRI-guided transurethral ultrasound ablation in the continuum of prostate cancer care. *Br J Radiol* [Internet]. 2022;95(1131):20210959. Available from: <http://dx.doi.org/10.1259/bjr.20210959>
- 8 Sprenkle PC, Seibert TM, Moses KA, Bahler C, Box G, Catalona WJ, et al. NCCN Guidelines [Internet]. NCCN Clinical Practice Guidelines in Oncology: Prostate Cancer Early Detection. 2026 [cited 2026 Sept 7]. Available from: <https://www.nccn.org/guidelines/guidelines-detail?category=2&id=1460>
- 9 Westphalen AC, McCulloch CE, Anaokar JM, Arora S, Barashi NS, Barentsz JO, et al. Variability of the positive predictive value of PI-RADS for prostate MRI across 26 centers: Experience of the Society of Abdominal Radiology Prostate Cancer Disease-focused Panel. *Radiology* [Internet]. 2020;296(1):76–84. Available from: <http://dx.doi.org/10.1148/radiol.2020190646>
- 10 Giganti F, Ng A, Asif A, Chan VW-S, Rossiter M, Nathan A, et al. Global variation in magnetic resonance imaging quality of the prostate. *Radiology* [Internet]. 2023;309(1):e231130. Available from: <http://dx.doi.org/10.1148/radiol.231130>
- 11 Puryso AS, Zacharias-Andrews K, Tomkins KG, Turkbey IB, Giganti F, Bhargavan-Chatfield M, et al. Improving prostate MR image quality in practice-initial results from the ACR prostate MR Image Quality Improvement Collaborative. *J Am Coll Radiol* [Internet]. 2024; 21(9):1464–74. Available from: <http://dx.doi.org/10.1016/j.jacr.2024.04.008>
- 12 Bird VY, Masihi K, Varela J, Busch J. Correlation of MRI-derived apparent diffusion coefficient (ADC) values with Gleason scores in prostate cancer and quantitative prostate MRI reading. *Cureus* [Internet]. 2026;18(4):e106336. Available from: <http://dx.doi.org/10.7759/cureus.106336>
- 13 Ng ABCD, Asif A, Agarwal R, Panebianco V, Girometti R, Ghai S, et al. Biparametric vs multiparametric MRI for prostate cancer diagnosis: The PRIME diagnostic clinical trial: The PRIME diagnostic clinical trial. *JAMA* [Internet]. 2025;334(13):1170–9. Available from: <http://dx.doi.org/10.1001/jama.2025.13722>
- 14 Belue MJ, Law YM, Marko J, Turkbey E, Malayeri A, Yilmaz EC, et al. Deep learning-based interpretable AI for prostate T2W MRI quality evaluation. *Acad Radiol* [Internet]. 2024;31(4):1429–37. Available from: <http://dx.doi.org/10.1016/j.acra.2023.09.030>
- 15 Leapman MS, Dinan M, Pasha S, Long J, Washington SL 3rd, Ma X, et al. Mediators of racial disparity in the use of prostate magnetic resonance imaging among patients with prostate cancer. *JAMA Oncol* [Internet]. 2022;8(5):687–96. Available from: <http://dx.doi.org/10.1001/jamaoncol.2021.8116>
- 16 Lemberskiy G, Chandarana H, Bruno M, Ginocchio LA, Huang C, Tong A, et al. Feasibility of accelerated prostate diffusion-weighted imaging on 0.55 T MRI enabled with random matrix theory denoising. *Invest Radiol* [Internet]. 2023;58(10):720–9. Available from: <http://dx.doi.org/10.1097/RLI.0000000000000979>
- 17 Segeroth M, Breit H-C, Wasserthal J, Bach M, Rentsch C, Matthias M, et al. AI-based evaluation of prostate MR imaging at a modern low-field 0.55 T scanner compared to 3 T in a screening cohort. *Acad Radiol* [Internet]. 2025;32(5):2700–6. Available from: <http://dx.doi.org/10.1016/j.acra.2024.11.024>
- 18 Kaur T, Jiang Y, Seiberlich N, Hussain H, Wells S, Wei J, et al. Clinical feasibility of MRI-guided in-bore prostate biopsies at 0.55T. *Abdom Radiol (NY)* [Internet]. 2025;50(8):3773–83. Available from: <http://dx.doi.org/10.1007/s00261-024-04783-x>
- 19 Chopra R, Colquhoun A, Burtynyk M, N'djin WA, Kobelevskiy I, Boyes A, et al. MR imaging-controlled transurethral ultrasound therapy for conformal treatment of prostate tissue: initial feasibility in humans. *Radiology* [Internet]. 2012;265(1):303–13. Available from: <http://dx.doi.org/10.1148/radiol.12112263>
- 20 Ramsay E, Mougenot C, Staruch R, Boyes A, Kazem M, Bronskill M, et al. Evaluation of focal ablation of magnetic resonance imaging defined prostate cancer using magnetic resonance imaging controlled transurethral ultrasound therapy with prostatectomy as the reference standard. *J Urol* [Internet]. 2017;197(1):255–61. Available from: <http://dx.doi.org/10.1016/j.juro.2016.06.100>
- 21 Chin JL, Billia M, Relle J, Roethke MC, Popeneciu IV, Kuru TH, et al. Magnetic resonance imaging-guided transurethral ultrasound ablation of prostate tissue in patients with localized prostate cancer: A prospective phase 1 clinical trial. *Eur Urol* [Internet]. 2016;70(3):447–55. Available from: <http://dx.doi.org/10.1016/j.eururo.2015.12.029>
- 22 Klotz L, Pavlovich CP, Chin J, Hatiboglu G, Koch M, Penson D, et al. Magnetic resonance imaging-guided transurethral ultrasound ablation of prostate cancer. *J Urol* [Internet]. 2021;205(3):769–79. Available from: <http://dx.doi.org/10.1097/JU.0000000000001362>
- 23 Eggener S, Zagaja G, Oto A, Pavlovich C, Macura K, Koch M, et al. Pivotal study of MRI-guided transurethral ultrasound ablation (Tulsa) of localized prostate cancer: 5-year follow up. *Urol Oncol* [Internet]. 2024;42:S83. Available from: <http://dx.doi.org/10.1016/j.urolonc.2024.01.234>
- 24 Anttinen M, Mäkelä P, Nurminen P, Pärssinen H, Malaspina S, Sainio T, et al. Salvage magnetic resonance imaging-guided transurethral ultrasound ablation for localized radiorecurrent prostate cancer. *Eur Urol Open Sci* [Internet]. 2025;71:69–77. Available from: <http://dx.doi.org/10.1016/j.euro.2024.11.001>
- 25 Viitala A, Anttinen M, Mäkelä P, Pärssinen H, Nurminen P, Sainio T, et al. Magnetic resonance imaging-guided transurethral ultrasound ablation for benign prostatic obstruction: 1-year clinical outcomes of a phase II study. *BJU Int* [Internet]. 2025;136(3):473–83. Available from: <http://dx.doi.org/10.1111/bju.16795>
- 26 Woodrum D, Mynderse L, Raman S, Sella D, Frey G, Ghanouni P, et al. Abstract no. 50 randomized controlled trial of MRI-guided transurethral ultrasound ablation (TULSA) versus robotic prostatectomy for intermediate-risk prostate cancer: Ablation parameters and initial perioperative outcomes. *J Vasc Interv Radiol* [Internet]. 2026;37(4):108057. Available from: <http://dx.doi.org/10.1016/j.jvir.2026.108057>
- 27 Bird V, Busch K, Rose R, Varela J, Busch J. Prostate cancer treatment in the extreme apex: Preservation of continence with robotic-assisted MRI-guided transurethral ultrasound ablation. *Cureus* [Internet]. 2026;18(5):e108671. Available from: <http://dx.doi.org/10.7759/cureus.108671>



Contact

Joseph J. Busch, Jr., M.D.
 Oncological Radiologist
 Busch Center
 Brookside Concourse 100
 3650 Brookside Pkwy, Suite 175
 Alpharetta, GA 30022
 USA
 Tel.: +1 770-424-6270
contacts@buschcenter.com
<https://buschcenter.com>

Focal Therapy in the Treatment of Prostate Cancer

Lauren te Molder¹; Pouya Doerwald²; Gina Clarke²; Robert Staruch²; Jurgen Fütterer¹

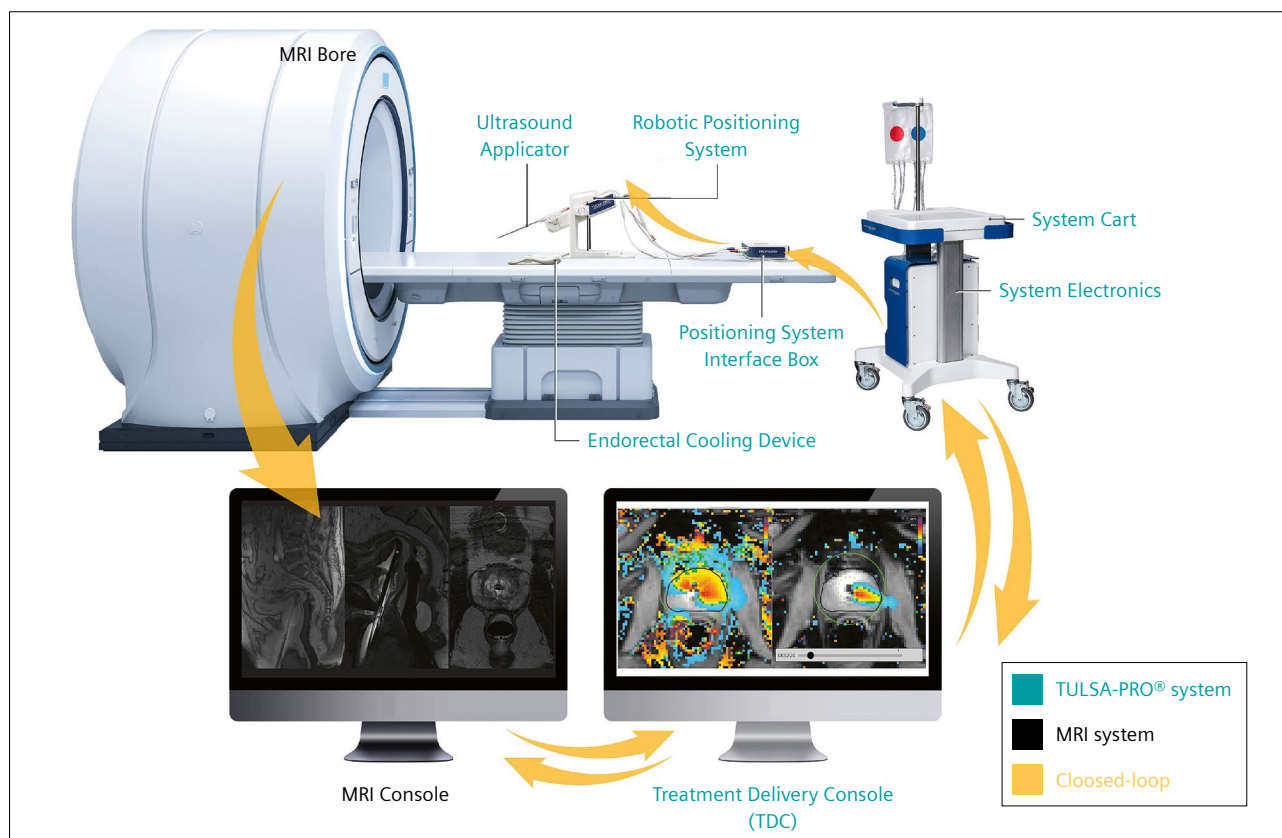
¹Department of Medical Imaging, Radboud University Medical Center, Nijmegen, the Netherlands

²Profound Medical Inc., Mississauga, Canada

Clinical need for focal therapy

Prostate cancer is the most prevalent malignancy affecting men globally. Its morbidity and mortality are associated with its progression. The standard of care is radical treatment, consisting of radical prostatectomy and radiation therapy. These therapies are effective but are associated with significant complications including urinary incontinence and erectile dysfunction [1]. Such complications can immensely impact the quality of life, motivating the development of less invasive yet effective therapeutic alternatives. In current clinical practice patients and clinicians have a growing awareness of the impact of treatment side effects on quality of life and seeking options.

Focal therapy promises to meet this demand, by treating cancer while preserving key anatomy responsible for urinary and sexual function. Focal therapy targets the lesion plus a margin of normal tissue, while sparing the rest of the prostate gland. By minimizing the treatment volume, the risk of adverse events and the chance of functional preservation may be optimized [2]. Currently, clinical research on focal therapy is being carried out with different energy sources: ultrasound ablation, either transrectal high-intensity focused ultrasound (HIFU) or MRI-guided transurethral ultrasound ablation (TULSA), cryoablation, laser ablation and irreversible electroporation (IRE). All



1 TULSA-PRO system. The device integrates electronics to power the ultrasound applicator, a robot for fine positioning, and a computer console that interfaces with the MRI to provide real-time feedback to the system and automatically control heating.

modalities leverage different mechanisms to eradicate localized prostate cancer [3]. TULSA uses transurethral high-intensity, planar ultrasound, performed in-bore and automatically guided in real-time by MRI thermometry feedback. HIFU, on the other hand, uses transrectal delivery of focused ultrasound under ultrasound guidance. Other focal therapies rely on different energy sources. For example, focal laser ablation uses laser light may also be performed under MRI or ultrasound guidance. In a recent systematic review, no differences in terms of oncological outcomes and quality of life were shown between the various energy modalities [4].

The rationale for focal therapy and partial gland ablation rooted in the index lesion theory [5]. Prostate cancer is frequently multifocal. According to the index lesion theory, the largest and most aggressive lesion within the gland drives the clinical behavior and progression of disease, while the secondary foci have less potential to do so. Several studies have demonstrated favorable oncological control when the index lesion is effectively targeted [3, 6], demonstrating the potential to achieve adequate oncological treatment while preserving genitourinary function and reducing the risk of complications.

The body of evidence in support of focal therapy is growing, and demonstrating oncological outcomes comparable to radical treatment, especially in low- and intermediate-risk prostate cancer. The comparative effectiveness is also shown in systematic reviews and meta-analyses [4, 6]. There is a need for a multicenter randomized trial (RCT), due to a lack of high-quality, level 1 evidence.

Benefits of focal therapy

Focal therapy offers several advantages over radical treatments. Focal therapy has been shown to reduce the burden of complications and decrease in quality of life after treatment. While urinary incontinence and impotence frequently occur after radical therapy for prostate cancer, the rate of such complications is reduced in patients treated with focal therapy owing to tissue sparing. Erectile function may be preserved sparing the nerve bundles, responsible for erections. Even if both nerve bundles cannot be spared, focal therapy is frequently unilateral. Radical prostatectomy and radiotherapy treat the whole gland, placing both nerve bundles at risk. With these lesser occurring adverse events, quality of life is being preserved. Quality of life can also be improved with a minimally invasive approach [7].

The goal of focal therapies is oncological control, which may compare favourably to radical treatments in literature estimates [3, 8, 9]. By targeting the lesion, oncological efficacy is achieved in carefully selected patients with low- or intermediate-risk prostate cancer.

By virtue of minimal invasiveness, focal therapies are associated with shorter recovery times, less pain, and fewer complications [4, 10]. Some focal therapies, like HIFU, TULSA, and laser ablation, can even be provided in an outpatient care setting.

After performing focal therapy, the possibility of radical- or re-treatment with focal therapy is still available [11]. The need for re-treatment may arise due to in-field recurrence, or if a new lesion is present in the untreated area of the prostate.

Focal therapy may also be cost-effective in the treatment of prostate cancer, owing to reduced hospital stay, reduced need for extensive postoperative care, and less complication management. The patient may directly benefit from reduced cost of supplies to manage complications (e.g., incontinence pads).

Challenges in focal therapy

Patient selection

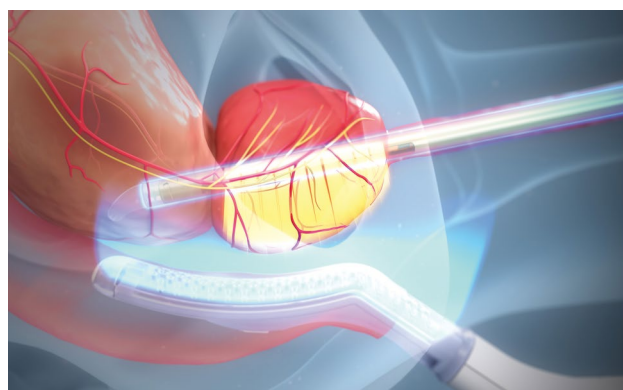
Even though the benefits of focal therapy are promising, there are challenges to adoption into the standard of care. It is known that prostate MRI may underestimate tumor size, underlining the importance of treating a margin of tissue around the tumor in focal therapy [12, 13]. Conversely, there is a risk of undertreatment if the safety margin is not sufficient. Accurate pre-treatment biopsy is crucial to ensure effective focal therapy. Biopsy may suffer from undersampling and underestimate the aggressiveness of the tumor. Such risk is mitigated with more accurate, image-guided biopsy techniques [14, 15]. Targeted biopsies are often used, but are still prone to sampling errors. MRI-guided biopsies show a high diagnostic sensitivity for detecting prostate cancer. MRI guidance enhances detection and sampling of anterior lesions compared with transrectal ultrasound (TRUS)-guided biopsy [16]. One study showed that using MRI guidance reduced the rate of biopsy upgrading on radical prostatectomy, compared with TRUS [17].

As discussed before, the index lesion theory is based on the rationale that one lesion is the most aggressive and most clinically important lesion. However, it is known that prostate cancer is often multifocal. There may be secondary lesions, even if not yet visible on MRI. Patients with multifocal disease are often excluded from focal therapy. Evidence to guide patient selection for focal therapy is lacking. There is no consensus whether patients with multifocal disease are eligible for focal therapy. Such patients create a niche that TULSA aims to fill, since TULSA can be performed as a focal to whole gland treatment.

Currently, a considerable learning curve is observed in treating prostate cancer using focal therapy. Since this approach is not a standard practice yet, limited experience is available in the field. Undertreatment in prostate cancer



- 2** Real-time feedback through MRI thermometry in the TULSA procedure. The heating parameters are controlled through a closed-loop system which automatically adjusts the power and rotation rate of the ultrasound applicator.



- 3** The ultrasound applicator delivers heating to the prostate with 10 independently-controlled transducer elements. The ultrasound and endorectal cooling device are actively cooled to protect the urethra and the rectum.

has been associated with a poor prognosis even after salvage radical prostatectomy if the recurrence occurs in-field [18]. Residual malignancy after focal therapy may indicate a phenotypically worse disease associated with poor oncologic outcomes.

Follow-up

PSA is not a validated biomarker for surveillance after focal therapy. Consequently, different protocols for following patients after focal therapy are necessitated which may increase cost. Currently, follow-up includes MRI, plus targeted and systematic biopsies. Given the slow progression of prostate cancer, investment into long-term follow up is required for all patients treated with focal therapy, regardless of risk group. And recurrence may occur only during long-term follow-up.

Overall there are crucial considerations for patient selection, tumor staging, treatment planning and intensive follow-up for patients receiving focal therapy. Due to a lack of long-term follow-up, it is difficult to establish evidence-based guidelines for focal therapy. Therefore, the need for randomized controlled trials (RCTs) comparing safety and efficacy of focal therapy with the standard of care is growing.

TULSA: Customizable therapy for prostate cancer

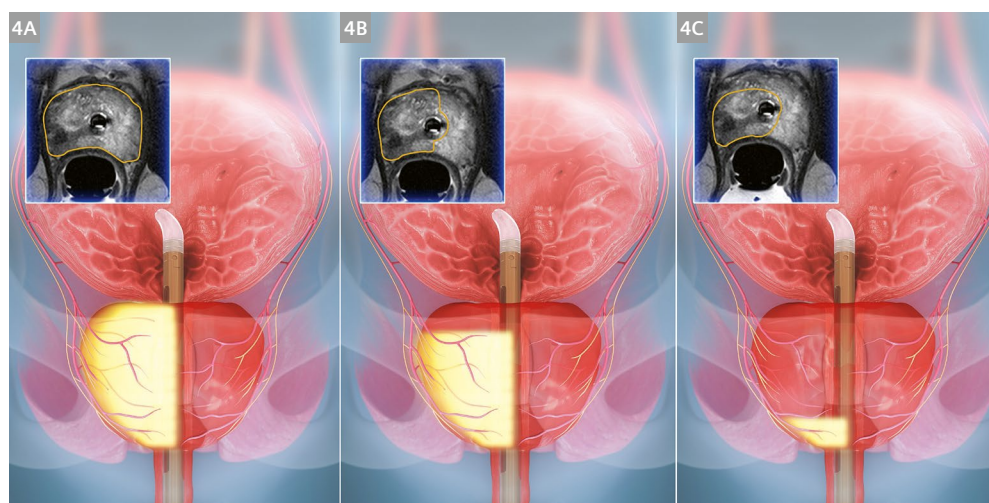
The TULSA Procedure combines transurethral, robotically-driven therapeutic ultrasound with real-time visualization of temperature and automated control of heating from magnetic resonance thermometry. The high spatial, thermal, and anatomic resolution of the target volume enables precise ablation of prostate tissue while sparing functionally important structures, potentially reducing the risk of side effects relative to RP.

TULSA: Previous research

The largest, prospective study of TULSA is the TULSA-PRO Ablation Clinical Trial. This is a prospective, multi-center, single-arm pivotal study in patients with localized prostate cancer (NCT02766543). The protocol was designed in conjunction with the U.S. Food and Drug Administration towards 510(k) clearance as a prostate ablation device and received IRB approval at 13 centers in the U.S.A., Europe, and Canada. Informed consent was obtained from all participants. Inclusion criteria were age 45 to 80 years old, Gleason Grade Group 1 to 2 prostate cancer, clinical stage T2b or less, PSA 15 ng/ml or less, minimum 10-core biopsy, no previous treatment, and could undergo MRI. Exclusion criteria were prostate greater than 90 cc, width greater than 6 cm or length greater than 5 cm; non-MRI compatible implants, active infection, suspected tumor within 3 mm of the prostate apical plane on MRI, intraprostatic cysts or calcifications greater than 1 cm.

The primary objectives were safety and efficacy. The primary safety endpoint was the frequency and severity of adverse events, documented at each visit according to the Common Terminology Criteria for Adverse Events. The primary efficacy endpoint for prostate tissue ablation was the proportion of men achieving a PSA reduction 75% of baseline, defined to meet regulatory requirements rather than oncological control. Secondary endpoints were early oncological efficacy, defined as the proportion of patients with no cancer or reduced grade and extent of cancer on 12-month 10-core biopsy, prostate volume reduction assessed by central radiology, patient reported changes in quality-of-life, and evaluation of post-treatment multi-parametric MRI.

The 5-year follow-up from the TACT pivotal study was recently reported [19]. Median (IQR) age at baseline was 65 (59–69). PSA decreased from 6.3 (4.6–7.9) ng/mL at base-



4 The user creates treatment plans by contouring the target volume on axial T2-weighted images (insets). Treatment plans range from whole-gland therapy (**4A**), to hemi (**4B**), and focal therapy (**4C**).

line to 0.5 (0.3–1.2) at 1y, stable to 0.6 (0.18–1.9) ng/mL ($n = 68$) at 5y. At baseline, 72/115 (63%) had $\geq$ GG2 disease, decreasing to 17/111 (15%) by 1y. By 3y, 15 men (13%) received salvage treatment, increasing to 25 (21.7%) by 5y (10 prostatectomy, 11 radiotherapy, 3 ADT, 1 surgery and radiation) with no unexpected complications. On review of the 25 cases, identified failure modes included undertreatment due to targeting error and patient selection, and misalignment due to intraprocedural swelling/motion. Early (1y) predictors of treatment failure by 5y included PSA (OR = 3; CI [1.7, 5.4]) and visible lesion on mpMRI (OR = 12; CI [4.4, 34]), both $p \leq 0.001$. By 5y, 80/92 (87%) preserved erections sufficient for penetration, and 61/66 (92%) preserved pad-free continence. 12 men (10%) incurred Grade 3 adverse events, none had a Grade ≥ 4 event or rectal injury. Intraprocedural imaging parameters, positive MRI and rising PSA at 1y year predicted the risk of salvage therapy by 5y. As TACT represents early experience with the technology, results reflect the learning curve, and historical protocols which have since been refined to mitigate failures due to screening and intraprocedural factors. Modern protocols include refined patient selection (e.g., screening for intraprostatic calcifications that can lead to undertreatment), alternative strategies for device positioning, and thermal dose escalation to mitigate undertreatment visible on intraprocedural imaging. Effective disease control was achieved in 78% of men at 5 years after a single TULSA procedure. Favorable safety and functional outcomes were durable to 5y.

Current research

The safety and efficacy of TULSA is being compared in a head-to-head fashion in the CAPTAIN study (NCT05027477, A Comparison of TULSA Procedure vs. Radical Prostatectomy in Participants with Localized Prostate Cancer). CAPTAIN is a prospective, multi-centre randomized controlled trial

which will enroll of 201 patients with organ-confined, Gleason Score 7 cancer. 67 patients will receive radical prostatectomy (RP) and 134 patients will receive one or two TULSA Procedures. The trial is currently open at 16 sites in the United States, two in Canada, and one in Finland comprising a mix of academic centers and private clinics. Enrollment began in January 2022, and interim results are expected in 2025.

The goal of CAPTAIN is to demonstrate that the efficacy of the TULSA Procedure is not inferior to RP for efficacy while demonstrating superior safety. The primary safety endpoint is the proportion of patients who preserve both erectile potency and urinary continence one year after treatment. The primary efficacy endpoint is the proportion of patients who are free from any additional treatment for prostate cancer by three years after treatment. Secondary endpoints include a comparison of rates of complications, cost-effectiveness, and timing of the return to baseline activity. Long-term follow-up will be gathered for up to ten years after treatment.

Primary Endpoints

- 1-year safety: % patients maintaining EPIC Q5 pad-free continence and IIEF Q2 erections sufficient for penetration
- 3-year efficacy: % patients with no additional interventions for prostate cancer, no metastases or prostate cancer death (1 repeat TULSA at 12 months allowed)

Secondary Endpoints and extended 10-year follow-up

- Survival, histologic failure, biochemical failure, mpMRI
- Complications, penile rehabilitation and length, blood loss, hospitalization
- Patient-reported pain, 30-day diary, return to normal activities, QOL questionnaires: IPSS, IIEF-15, EPIC-26, EQ-5D-5L
- Cost-effectiveness

The other, multi-centre RCT comparing TULSA with the standard of care is the ENFORCE Focal trial (Effectiveness of focal therapy in men with prostate cancer, NCT06223295). ENFORCE is a prospective, Dutch multi-center randomized controlled trial gathering evidence for focal therapy in patients with intermediate-risk, unilateral clinically localized prostate cancer compared to usual care. In this study, 356 patients will be included and randomized 1:1 between focal therapy and standard of care. Standard of care consists of robot-assisted radical prostatectomy (RARP) or radiotherapy (RT), while focal therapy consists of 3 different modalities: transurethral ultrasound ablation (TULSA), irreversible electroporation (IRE) and high-intensity focused ultrasound (HIFU). Five participating centers will perform one of the focal therapies as well as standard of care. Patients will receive one-time focal therapy or standard-of-care intervention within the study. Recruitment opened in January 2024 and is ongoing.

The aim of ENFORCE focal is to study efficacy and cost-effectiveness, and quality of life of focal therapy versus standard of care in patients with intermediate-risk, unilateral clinically localized prostate cancer. The primary endpoints are: oncological effectiveness at 36 months after treatment, and quality of life at 12 months. ENFORCE tests a hypothesis of non-inferiority of focal therapy to usual care for efficacy, and superiority for quality of life. Oncological effectiveness is defined as treatment failure, i.e., the need for retreatment with salvage treatment (radical prostatectomy, radiotherapy, or systemic therapy) in the focal therapy group, and as biochemical recurrence followed by salvage local or systemic treatment in the usual care group. Secondary endpoints include oncologic safety, cost-effectiveness, and disease-free survival.

Technical aspects and clinical workflow TULSA

The preparation phase starts a day before the treatment, when the patient is instructed to consume a liquid diet. Before anesthesia, the patient empties both the bowel and bladder.

On the day of the treatment, the dedicated MRI technician prepares the TULSA system, a 20 to 40-minute process that includes testing the components and ensuring all systems are operational before the anesthesia.

At our institution, the patient is positioned supine on the MRI table in the MRI room. Anesthesia is administered, and subsequent steps involve disinfecting the surgical area, applying sterile draping, lubricating the urethra, and inserting a transurethral catheter, followed by emptying the bladder. The patient is then transferred and docked to the MRI machine, with legs secured to facilitate better access for the endorectal cooling device (ECD).

The urologist introduces the ECD, stabilizing it with sterile water to prevent unintended rotation. A guidewire is then inserted through the transurethral catheter, facilitating the careful insertion of the ultrasound applicator, which is then securely attached to the robot. Once the devices are properly positioned, the patient is transferred into the MRI bore, and the remaining steps are carried out in the control room.

The radiologist and urologist work together to prescribe and deliver the ablation. In the MRI workflow, initial imaging is conducted by the technicians on the MRI console. The resulting scans are critically reviewed by the radiologist to confirm proper device placement and to ensure the absence of air bubbles in the treatment area, which is crucial for accurate thermometry and effective tissue ablation using ultrasound energy. Subsequent adjustments are made by the urologist as needed to optimize device alignment. The radiologist then registers the position of the ultrasound applicator in the TULSA software using 3D T2-weighted images.

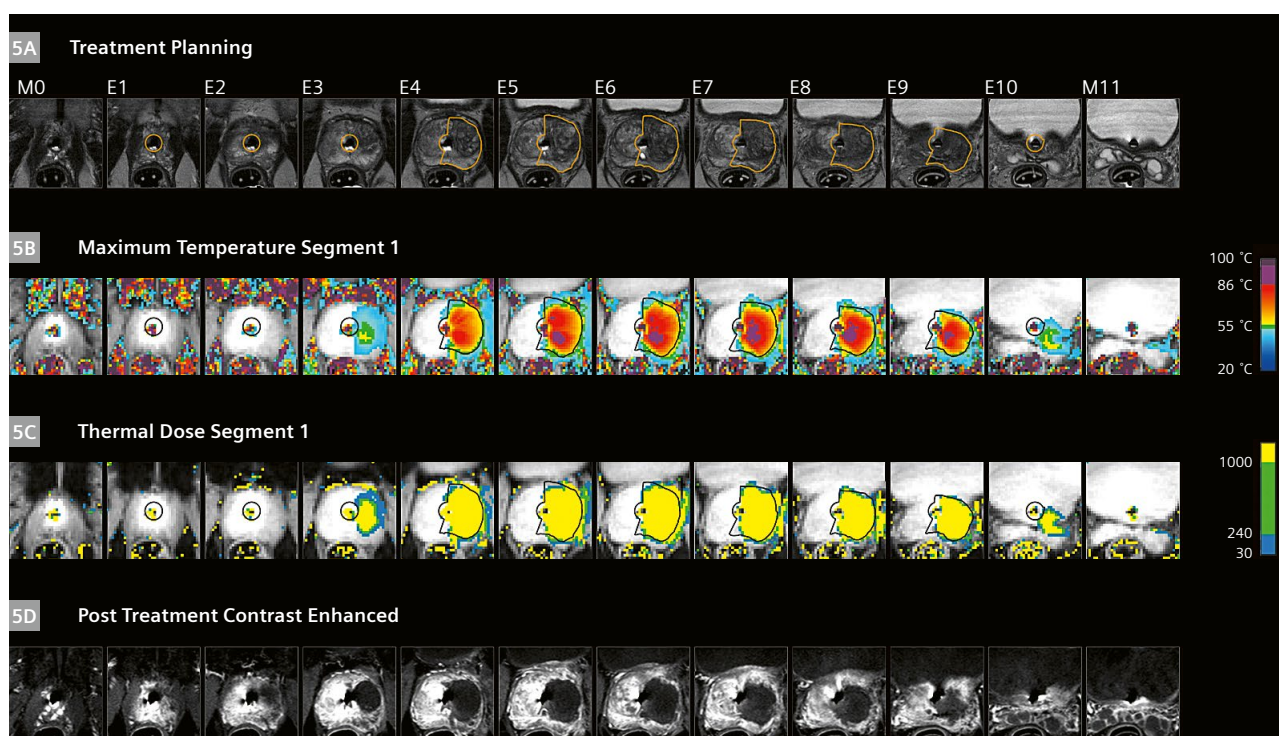
The radiologist further adjusts the position of the ultrasound applicator using the TULSA robot and confirms correct placement with additional 3D T2-weighted images. Using transverse T2-weighted images and a test THERM scan, the radiologist precisely defines the boundaries of the desired ablation volume for each of the 10 independently-controlled treatment elements on the ultrasound applicator, and the boundary is subsequently confirmed by the urologist.

Following these preparations, the radiologist sets the starting angle and prepares for treatment. The system then automatically executes the prescribed treatment plan, controlling the device's rotation speed and power output based on real-time temperature images. The radiologist monitors these real-time images and adjusts or pauses the treatment as necessary.

Finally, the radiologist uses contrast-enhanced T1-weighted images to confirm the treatment effect and assess the non-perfused volume. After treatment completion, the urologist removes the devices and inserts a Foley catheter. The anesthetist oversees the patient's recovery from sedation.

The cost-effectiveness of focal therapy

With fewer expected adverse events, TULSA and other focal therapies are expected to be more cost efficient in managing complications after focal therapy relative to conventional treatments. Reduction in cost associated with shorter hospital stays and surgical suite are also expected for focal therapy, which can be performed in outpatient settings, or may require at most admission for one-night observation.



5 (5A) Treatment plan outlined for a partial gland ablation on a T2w image. (5B) Heatmap with maximum temperatures as obtained at the end of the treatment. (5C) Thermal dose. (5D) Post treatment contrast enhanced T1w images showing the non-perfused volume.

On the other hand, there are costs associated with focal therapy which are not incurred in conventional treatments. Image-guided therapies require ultrasound or MRI. Closer follow-up using MRI and biopsy may also increase cost, due to the lack of a validated PSA threshold for recurrence. Focal therapy therefore increases reliance on MRI and therefore cost. Cost may also be increased through the extended follow-up duration, for the focally treated patient who still has prostate tissue in which (multifocal) disease can recur.

In conclusion, focal therapy is expected to be more cost-effective compared to radical treatments. Level one evidence to support this hypothesis is being generated by the CAPTAIN and ENFORCE trial.

Future perspectives

MAGNETOM Free.Max from Siemens Healthineers is an innovative MRI scanner that combines a 0.55 Tesla field strength with advanced hardware design and deep learning technologies. By doing so, the scanner broadens the range of MR clinical applications and provides users with the inherent clinical benefits of a lower-field MR scanner. The first and only 80 cm wide-bore system available on the market, MAGNETOM Free.Max also facilitates MR scanning for larger and/or claustrophobic patients, enhancing

the patient experience. At less than 7,700 Lbs and 80 inches high, MAGNETOM Free.Max is the most lightweight, compact whole-body scanner ever offered by Siemens Healthineers. Its reduced size permits installation with only minimal structural modifications. Furthermore, where MR scanners typically require several hundred liters of helium and a quench pipe for cooling purposes, the new DryCool technology uses less than 1 liter of liquid helium, reducing lifecycle and infrastructure costs. For these reasons, MAGNETOM Free.Max has simplified MRI integration in locations previously not suitable for MR imaging.

The Transurethral Ultrasound Ablation ("TULSA") procedure, performed using Profound's TULSA-PRO® system, employs real-time MR guidance for precision to save patients' vital functions while killing the targeted prostate tissue via a precise sound absorption technology that gently heats it to kill temperature (55°C). TULSA-PRO® enables surgeons to ablate whole- or partial-gland prostate tissue in patients with low-, intermediate, or high-risk prostate cancer; with benign prostatic hyperplasia ("BPH"); as well as those prostate cancer patients on active surveillance seeking treatment of their cancer and relief from their symptoms of BPH. TULSA is a "one-and-done" procedure, performed in a single session that takes a few hours, and no hospital stay is required. Most TULSA patients report quick recovery to their normal routine.

With the recent introduction of TULSA-PRO®, MR imaging now not only has the power to fundamentally change how prostate cancer is diagnosed, but also how it is treated.

The collaboration between Siemens Healthineers and Profound on developing a complete therapeutics solution, combining its TULSA-PRO® system with the MAGNETOM Free.Max MR scanner¹ has the potential to improve oncological and functional outcomes for a very significant number of prostate cancer patients.

¹Work in progress. The combination is currently under development and is not for sale in the U.S. and in other countries. Its future availability cannot be ensured.

References

- Haglund E, Carlsson S, Stranne J, Wallerstedt A, Wilderäng U, Thorsteinsdottir T, et al. Urinary Incontinence and Erectile Dysfunction After Robotic Versus Open Radical Prostatectomy: A Prospective, Controlled, Nonrandomised Trial. *Eur Urol.* 2015;68(2):216–25.
- Ahmed HU, Akin O, Coleman JA, Crane S, Emberton M, Goldenberg L, et al. Transatlantic Consensus Group on active surveillance and focal therapy for prostate cancer. *BJU Int.* 2012;109(11):1636–47.
- Guillaumier S, Peters M, Arya M, Afzal N, Charman S, Dudderidge T, et al. A Multicentre Study of 5-year Outcomes Following Focal Therapy in Treating Clinically Significant Nonmetastatic Prostate Cancer. *Eur Urol.* 2018;74(4):422–429.
- Hopstaken JS, Bomers JGR, Sedelaar MJ, Valerio M, Fütterer JJ, Rovers MM. An Updated Systematic Review on Focal Therapy in Localized Prostate Cancer: What Has Changed over the Past 5 Years? *Eur Urol.* 2022;81(1):5–33.
- McClure TD, Margolis DJ, Hu JC. Partial gland ablation in the management of prostate cancer: a review. *Curr Opin Urol.* 2017;27(2):156–160.
- Valerio M, Ahmed HU, Emberton M, Lawrentschuk N, Lazzari M, Montironi R, et al. The role of focal therapy in the management of localised prostate cancer: a systematic review. *Eur Urol.* 2014;66(4):732–51.
- Malcolm JB, Fabrizio MD, Barone BB, Given RW, Lance RS, Lynch DF, et al. Quality of life after open or robotic prostatectomy, cryoablation or brachytherapy for localized prostate cancer. *J Urol.* 2010;183(5):1822–8.
- Blazevski A, Scheltema MJ, Yuen B, Masand N, Nguyen TV, Delprado W, et al. Oncological and Quality-of-life Outcomes Following Focal Irreversible Electroporation as Primary Treatment for Localised Prostate Cancer: A Biopsy-monitored Prospective Cohort. *Eur Urol Oncol.* 2020;3(3):283–290.
- Klotz L, Pavlovich CP, Chin J, Hatiboglu G, Koch M, Penson D, et al. Magnetic Resonance Imaging-Guided Transurethral Ultrasound Ablation of Prostate Cancer. *J Urol.* 2021;205(3):769–779.
- Chin JL, Billia M, Relle J, Roethke MC, Popeneciu IV, Kuru TH, et al. Magnetic Resonance Imaging-Guided Transurethral Ultrasound Ablation of Prostate Tissue in Patients with Localized Prostate Cancer: A Prospective Phase 1 Clinical Trial. *Eur Urol.* 2016;70(3):447–55.
- Marra G, Valerio M, Emberton M, Heidenreich A, Crook JM, Bossi A, et al. Salvage Local Treatments After Focal Therapy for Prostate Cancer. *Eur Urol Oncol.* 2019;2(5):526–538.
- Le Nobin J, Rosenkrantz AB, Villers A, Orczyk C, Deng FM, Melamed J, et al. Image Guided Focal Therapy for Magnetic Resonance Imaging Visible Prostate Cancer: Defining a 3-Dimensional Treatment Margin Based on Magnetic Resonance Imaging Histology Co-Registration Analysis. *J Urol.* 2015;194(2):364–70.
- Priester A, Natarajan S, Khoshnoodi P, Margolis DJ, Raman SS, Reiter RE, et al. Magnetic Resonance Imaging Underestimation of Prostate Cancer Geometry: Use of Patient Specific Molds to Correlate Images with Whole Mount Pathology. *J Urol.* 2017;197(2):320–326.
- Elkhoury FF, Felker ER, Kwan L, Sisk AE, Delfin M, Natarajan S, et al. Comparison of Targeted vs Systematic Prostate Biopsy in Men Who Are Biopsy Naive: The Prospective Assessment of Image Registration in the Diagnosis of Prostate Cancer (PAIREDCAP) Study. *JAMA Surg.* 2019;154(9):811–818.
- Brown AM, Elbuluk O, Mertan F, Sankineni S, Margolis DJ, Wood BJ, et al. Recent advances in image-guided targeted prostate biopsy. *Abdom Imaging.* 2015;40(6):1788–99.
- Overduin CG, Fütterer JJ, Barentsz JO. MRI-guided biopsy for prostate cancer detection: a systematic review of current clinical results. *Curr Urol Rep.* 2013;14(3):209–13.
- Hambrock T, Hoeks C, Hulsbergen-van de Kaa C, Scheenen T, Fütterer J, Bouwense S, et al. Prospective assessment of prostate cancer aggressiveness using 3-T diffusion-weighted magnetic resonance imaging-guided biopsies versus a systematic 10-core transrectal ultrasound prostate biopsy cohort. *Eur Urol.* 2012;61(1):177–84.
- Marconi L, Stonier T, Tourinho-Barbosa R, Moore C, Ahmed HU, Cathelineau X, et al. Robot-assisted Radical Prostatectomy After Focal Therapy: Oncological, Functional Outcomes and Predictors of Recurrence. *Eur Urol.* 2019;76(1):27–30.
- Society of Urologic Oncology (<https://suo-abstracts.secure-platform.com/gallery/rounds/18/details/3269>)

Contact

Professor Jurgen Fütterer, M.D., Ph.D.
Department of Imaging
Radboud University Medical Centre
Geert Grooteplein Zuid 10
6525 GA Nijmegen
The Netherlands
Tel. +31 (0)24 361 40 11
jurgen.futterer@radboudumc.nl



Jurgen Fütterer



Lauren te Molder

Meet Siemens Healthineers

Siemens Healthineers: Our brand name embodies the pioneering spirit and engineering expertise that is unique in the healthcare industry. The people working for Siemens Healthineers are totally committed to the company they work for, and are passionate about their technology. In this section we introduce you to colleagues from all over the world — people who put their hearts into what they do.

Jan Brandt, Ph.D.

Jan Brandt is a biomedical engineer with expertise in materials science and tribology, the science of friction and wear. He began his career with an apprenticeship as an industrial mechanic for turbines at ABB in Mannheim, Germany, before studying Mechanical Engineering at University of Duisburg-Essen, Germany.

During his studies, Jan spent time at the National Research Council in Vancouver, Canada, and at the University of Western Australia in Perth, where he worked in the mining industry and was later introduced to the tribology of orthopedic implants and medical devices. Through various scholarships, he returned to Canada to conduct his Ph.D. in Biomedical Engineering at the University of Waterloo, while conducting his research at the Orthopaedic Division of the London Health Sciences Centre in London, Ontario. After graduating, he moved to Winnipeg, Manitoba, where he directed the implant research capabilities at the Orthopaedic Innovation Centre. In this role, he focused on developing implant test methods, evaluating hip and knee replacement technologies, and conducting clinical trials and extensive outcome research.

After 15 years abroad, Jan returned to Germany with his wife and two sons. Before joining Siemens Healthineers in 2022, he worked at Schaeffler in Herzogenaurach and later founded a proactive analytics company, applying data-driven approaches to engineering and healthcare challenges. Today, Jan is the Clinical Marketing Manager for MR Therapy in the Clinical Scientific Marketing Team. He leads the global clinical and scientific marketing strategy for MRI-guided therapy across the 0.55T, 1.5T, and 3T MRI portfolios, helping translate innovative imaging technologies into improved therapeutic workflows and better patient care.



Erlangen,
Germany

How did you first come into contact with MRI?

During my time in orthopedic research, I worked on a study that compared X-ray, CT, and MRI scans of freshly frozen cadaveric lower limbs to evaluate bone and some biomechanical characteristics. Seeing MRI for the first time was a defining moment. I was amazed by the level of anatomical detail it revealed: not only the bone itself, but also the surrounding soft tissues, ligaments, and structures. X-ray and CT simply cannot visualize those things. That experience sparked a lasting interest in MRI and ultimately led me back to imaging, where I now work to help bring its clinical value into therapeutic applications.

What do you find most motivating about your job, and what do you think is the most exciting development in MRI-guided therapy?

What motivates me is knowing that our work can have a real impact on patient care. While I can't treat patients myself, I can help physicians access imaging technologies that support diagnosis and guide interventions. Through clinical evidence, scientific collaboration, and education, we can accelerate the adoption of innovations that may help to improve patient outcomes. Being able to contribute

to that process is incredibly rewarding. On a personal level, losing a close friend to cancer changed the way I look at my professional career. Accompanying him throughout his clinical journey made me realize that engineering is much more than developing innovative technologies. To me, it is about giving physicians better tools to help patients. That sense of purpose has stayed with me ever since I switched from the mining industry to orthopedic research more than 20 years ago.

What excites me is that MRI is evolving beyond a purely diagnostic imaging modality into an integral part of the interventional pathway. With innovations such as the MAGNETOM Free.XL and the Nexaris platform, and together with our partners, we are enabling physicians to image, plan, treat, and monitor interventional outcomes within a single ecosystem. This may open up new opportunities for entirely new MRI-guided procedures and intervention pathways that were previously difficult or simply not feasible. This is a genuine paradigm shift. We are no longer just building better MRI scanners; we are helping redefine how therapy is delivered. The opportunity to support physicians with imaging technologies that aid

precision medicine, guide minimally invasive interventions, and may ultimately enhance patients' quality of life is what makes the future of MRI-guided interventions so exciting.

What would you do if you could spend a month doing whatever you wanted?

Although I would try to keep the month free from work, I have always enjoyed spending time in the clinic, observing physicians, and understanding their workflows. Being close to the point of care has always been a very rewarding part of working in the healthcare environment. If I could spend one month doing whatever I wanted, I would probably split it between two very different but equally

satisfying things: Part of me would escape into the Canadian backcountry to go fishing, camping, and enjoy the peace and solitude with my family away from everyday responsibilities. Canada was my home for many years, and I was able to explore much of the country. I find the vastness of the Canadian wilderness incredibly grounding and inspiring. The other part of me would spend long days in my garage with my sons, restoring classic mopeds from the 1960s and 1970s by taking them apart, fixing them, and making them look beautiful again. Since I was a teenager, I have been captivated by the ingenious engineering of that era — a time when these small, remarkably reliable machines were built to last.

Get to know us



Axel Krafft, Ph.D.

Erlangen,
Germany



Silvia Arroyo Camejo, Ph.D.

Erlangen,
Germany



Florian Maier, Ph.D.

Erlangen,
Germany



Mariappan S. Nadar, Ph.D.

Princeton,
USA



Tim Viebahn

Erlangen,
Germany



Find more portraits
of our colleagues
around the world!

www.magnetomworld.siemens-healthineers.com/meet-siemens-healthineers

The entire editorial staff at LMU University Hospital, Munich, Germany and at Siemens Healthineers extends their appreciation to all the radiologists, technologists, physicists, experts, and scholars who donate their time and energy — without payment — in order to share their expertise with the readers of MAGNETOM Flash.

MAGNETOM Flash — Imprint

© 2026 by Siemens Healthineers AG,
All Rights Reserved

Publisher:

Siemens Healthineers AG

Magnetic Resonance,
Karl-Schall-Str. 6, D-91052 Erlangen, Germany

Editor-in-chief:

Antje Hellwich
(antje.hellwich@siemens-healthineers.com)

Guest Editor:

Max Seidensticker, M.D.
Professor of Radiological Image Guidance
in Minimal-invasive Oncology
Deputy Director, Department of Radiology
Head of Interventional Radiology
LMU University Hospital
Marchioninistr. 15
81377 Munich, Germany
max.seidensticker@med.uni-muenchen.de

Editorial Board:

André Fischer, Ph.D.; Kera Westphal, Ph.D.;
Wellesley Were; Katie Grant, Ph.D.; Arne Hengerer, Ph.D.

Review Board:

Jan Brandt, Ph.D.; Axel Krafft, Ph.D.; Florian Maier, Ph.D.;
Tassiana Marini, Ph.D.; Christian Schuster, Ph.D.

Copy Editing:

Sheila Regan, Jen Metcalf, UNIWORKS,
www.uni-works.org
(with special thanks to Kylie Martin)

Layout:

Agentur Baumgärtner,
Friedrichstr. 4, D-90762 Fürth, Germany,
www.agentur-baumgaertner.com

PrePress and Image Editing, Production:

Sandra Birner, Andrea tom Felde, Jennifer Klancar,
Paul Linssen, Siemens Healthineers AG

Printer:

Schmidl & Rotaplan Druck GmbH,
Hofer Str. 1, D-93057 Regensburg, Germany

Details about the processing of your personal data can be found on the Siemens Healthineers Website (www.siemens-healthineers.com) under "Privacy Policy" and "Marketing Privacy Policy".

MAGNETOM Flash includes reports in the English language on magnetic resonance: diagnostic and therapeutic methods and their application as well as results and experience gained with corresponding systems and solutions. It introduces from case to case new principles and procedures and discusses their clinical potential. The statements and views of the authors in the individual contributions do not necessarily reflect the opinion of the publisher.

The information presented in these articles and case reports is for illustration only and is not intended to be relied upon by the reader for instruction as to the practice of medicine. Any health care practitioner reading this information is reminded that they must use their own learning, training and expertise in dealing with their individual patients. This material does not substitute for that duty and is not intended by Siemens Healthcare to be used for any purpose in that regard. The drugs and doses mentioned herein are consistent with the approval labeling for uses and/or indications of the drug. The treating physician bears the sole responsibility for the diagnosis and treatment of patients, including drugs and doses prescribed in connection with such use. The Operating Instructions must always be strictly followed when operating the MR system. The sources for the technical data are the corresponding data sheets. Results may vary.

Partial reproduction in printed form of individual contributions is permitted, provided the customary bibliographical data such as author's name and title of the contribution as well as year, issue number and pages of MAGNETOM Flash are named, but the editors request that two copies be sent to them. The written consent of the authors and publisher is required for the complete reprinting of an article.

We welcome your questions and comments about the editorial content of MAGNETOM Flash. Please contact us at magnetomworld.team@siemens-healthineers.com

Manuscripts as well as suggestions, proposals and information are always welcome; they are carefully examined and submitted to the editorial board for attention. MAGNETOM Flash is not responsible for loss, damage, or any other injury to unsolicited manuscripts or other materials. We reserve the right to edit for clarity, accuracy, and space. Include your name, address, and phone number and send to the editors, address above.

MAGNETOM Flash is also available online:

www.magnetomworld.siemens-healthineers.com

Not for distribution in the US

On account of certain regional limitations of sales rights and service availability, we cannot guarantee that all products included in this brochure are available through the Siemens Healthineers sales organization worldwide. Availability and packaging may vary by country and is subject to change without prior notice. Some/All of the features and products described herein may not be available in the USA.

The information in this document contains general technical descriptions of specifications and options as well as standard and optional features which do not always have to be present in individual cases, and which

may not be commercially available in all countries. Due to regulatory reasons their future availability cannot be guaranteed. Please contact your local Siemens Healthineers organization for further details.

Siemens Healthineers reserves the right to modify the design, packaging, specifications, and options described herein without prior notice. Please contact your local Siemens Healthineers sales representative for the most current information.

Note: Any technical data contained in this document may vary within defined tolerances. Original images always lose a certain amount of detail when reproduced.

Siemens Healthineers Headquarters

Siemens Healthineers AG
Siemensstr. 3
91301 Forchheim, Germany
Phone: +49 9191 180
siemens-healthineers.com

