PHILIPS

Radiation Oncology

MRI

How do you commission and implement an MRI system for radiation therapy planning?

Experience from St. Jude Children's Research Hospital, Memphis, Tennessee, USA

During the last decade, new applications of magnetic resonance imaging (MRI) for radiation therapy (RT), and the number of MRI system installations in radiation oncology departments, have significantly increased. While installation and commissioning of MRI for radiotherapy services are similar to these processes for MRI departments, there are key differences that you should examine.

To help you understand these differences, Drs. Chia-ho Hua, Jinsoo Uh and Thomas Merchant from St. Jude Children's Research hospital describe their 8-step process to commission and implement 1.5T and 3.0T MRI systems. These units are dedicated for RT planning and response monitoring in the center's Radiation Oncology Department.

If you are considering bringing an MRI system into your radiation oncology department or you need to adapt your diagnostic radiology MRI systems for RT planning, the information in this report could serve as a valuable resource.

In 2016, the Radiation Oncology Department at St. Jude Children's Research Hospital (Memphis, Tennessee, USA) installed two Philips Ingenia MR-RT wide-bore (70 cm) MRI systems. These scanners are dedicated for RT planning and therapy response monitoring (i.e., on-treatment monitoring). The 1.5T system is located in the photon therapy area and the 3.0T system is in the proton therapy center. Medical physicist Dr. Chia-ho Hua led the commissioning project.

Chia-ho Hua, PhD is a board-certified medical physicist and faculty member of the Department of Radiation Oncology at St. Jude Children's Research Hospital, since 2005. His research areas include integrating advanced medical imaging into radiation therapy and optimizing proton therapy to minimize normal tissue toxicity while improving tumor control for pediatric malignancy.

Jinsoo Uh, PhD is a medical imaging scientist of the Department of Radiation Oncology at St. Jude Children's Research Hospital. His research areas include development and applications of novel MRI techniques for improving radiation delivery and assessing late effects of radiation therapy.

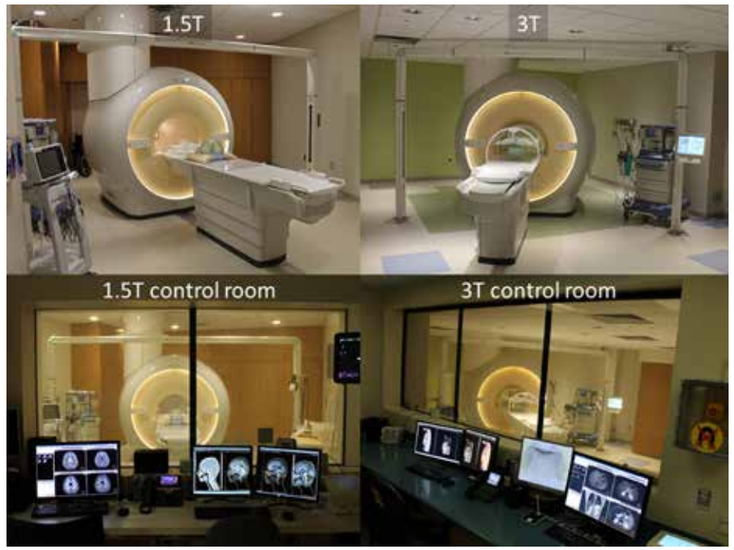

Figure 1. 1.5T and 3.0T MRI simulation rooms at St. Jude's Children's Research Hospital.

Commissioning an MRI system for radiotherapy

The St. Jude team describes 8 key steps in the commissioning of the MR-RT scanners in the RT department (see Figure 2).

1	System acceptance testing
2	Patient and staff safety preparation
3	Calibrating the external laser bridge
4	Establishing MRI system baseline performance – geometric accuracy
5	Establishing MRI quality assurance
6	RF coil testing and image quality in the treatment position
7	Imaging patients in the treatment position
8	Scan protocol (ExamCard) optimization

Figure 2. 8 key steps in commissioning an MRI system for radiotherapy

1. System acceptance testing

According to our hospital's system handover requirements, Philips engineers included specific acceptance tests and produced an installation acceptance test document (IATD) on completion of system installation.

Table 1 lists the customized acceptance tests performed at St. Jude. We defined the performance criteria based on American College of Radiology (ACR) MRI Quality Control Manual[1] guidelines, the American Association of Physicists in Medicine (AAPM) report No. 100[2] and on vendor technical specifications. Standard head coils (dStream Head coils) were used whenever applicable.

Both systems met the defined performance criteria before initiation of clinical use.

For ACR-specified tests, we used the ACR MRI accreditation phantom and the standard head coil (dStream Head coil), along with ACR specified sequences, as the performance criteria are established in the MRI community for head coils.

Test Name	Institution-Defined Performance Criteria and Source (AAPM/ACR/Philips)	Measured Performance Method
B0 magnetic field homogeneity	Inhomogeneity ≤ 0.45 ppm rms for 40-cm DSV, ≤ 0.08 ppm rms for 30-cm DSV, ≤ 0.022 ppm rms for 20-cm DSV (Philips)	24-plane homogeneity plot after final shimming during installation by Philips
Magnetic field drift	Drift ≤ 1 ppm/day (AAPM)	Record the center frequency determined by morning Periodic Image Quality Test (PIQT) quality assurance for a period of 14 days
Transmitter gain calibration	Maximum signal intensity is demonstrated with 90° spin nutation (AAPM)	Measure SNR on spin echo or gradient echo images of 100 mm bottle phantom at the isocenter with different nutation angles
Geometric accuracy	Typical inaccuracy ≤ 1 mm for 32-cm DSV (Philips)	ACR geometric accuracy method and Philips MR-RT geometric distortion phantom analysis
High-contrast spatial resolution	1-mm hole size should be resolved (ACR)	ACR phantom and method
Slice thickness accuracy	Thickness deviation should be < 0.7 mm (ACR)	ACR phantom and method
Slice position accuracy	Position offset < 4 mm (ACR)	ACR phantom and method
Image intensity uniformity	Percent integral uniformity ≥ 87.5% for 1.5T and ≥ 82% for 3.0T (ACR)	ACR phantom and method
Percent signal ghosting	Ghosting ≤ 1% (AAPM)	ACR phantom and method
Low-contrast object detectability	≥ 9 spokes detectable for 1.5T and ≥ 37 spokes for 3.0T (ACR)	ACR phantom and method
Signal-to-noise ratio (SNR)	Vendor internal criteria (Philips)	SNR from flood field uniformity test in Philips PIQT using standard head coil
EPI ghosting	Coefficient of variation of the signal intensity < 0.25% and ghosting ratio ≤ 3% (AAPM)	AAPM report 100 method
Spectral quality of spectroscopy	Percent difference between two runs in area ratio and amplitude ratio of NAA/Cr and NAA/Cho < ±5%	Single-voxel (20 × 20 × 20 mm) spectral data of metabolites were evaluated with point-resolved spectroscopy (PRESS) of a tissue-mimicking MRI spectroscopy phantom (GE Healthcare, Milwaukee, WI, USA)
Spike noise	Track down source of spike noise if detected per AAPM report 100	Philips' method of spike noise test by Philips
Eddy current compensation	Vendor internal criteria	Philips' internal Eddy current analysis by Philips
Table position accuracy	Longitudinal travel deviation (forward and backward) ≤ ±0.5 mm (Philips)	LAP lasers and rulers

Table 1. St. Jude-defined acceptance tests

Abbreviations: ACR, American College of Radiology; B0, main magnetic field; DSV, diameter spherical volume; EPI, echo-planar imaging; GE, GE Healthcare, Milwaukee, WI; NAA/Cho, N-acetylaspartate-to-choline ratio; NAA/Cr, N-acetylaspartate-to-creatine ratio; ppm, parts per million; PIQT, periodic image quality test; rms, root mean square; SNR, signal-to-noise ratio.

2. Patient and staff safety preparation

Staff training

Your center may have its own requirements for qualifying MRI system operators, and the learning curve could be steep for therapists and therapy physicists who have had no prior MRI training. For our department, we created a staff training plan with the Philips education project manager six months before clinical use. The team included an MRI registry certified therapist, a department MRI physicist, radiation therapists and Philips clinical experts. Our aim was to train the staff on the safe use of the MRI scanners and to build competence among the radiation therapists in performing MRI examinations.

To provide staff with ample learning opportunities and to optimize St. Jude's MRI ExamCards, we scheduled numerous on-site visits by Philips MRI specialists during and after go-live. Policies, procedures and competency tests for MRI system operators were developed.

MRI safety

We established the 1.5 T and 3.0 T MRI suites in safety zone facilities, with badge access required for zones II (MRI suite pre-screening zone) to IV (the magnet room). Before installing the magnet, the wall magnetic field shielding was designed to contain the 5-Gauss line inside the magnet room.

After magnet ramp-up, we measured the magnetic field in zone IV and in all adjacent rooms. Ferromagnetic detectors (FerrAlert Solo prescreener and HALO II detector, KOPP Development Inc., Jensen Beach, FL) were installed to locate ferrous hazards on patients before imaging and prevent patients with those from entering zone III or IV areas. Staff who operate MRI systems studied Philips online education courses and received training from Philips MRI specialists.

Prior to clinical use in our department, the St. Jude MRI safety officer inspected the facility. Before we approved badge access to the MRI rooms for radiation oncology and anesthesiology staff members, they were required to take institutional online MRI safety courses and receive walkthrough training. Annual refresher training also is mandatory. Numerous online resources are available for MRI safety education, including American College of Radiology, International Society for Magnetic Resonance in Medicine, and the virtual library on the AAPM website[3,4,5,6].

MRI-compatible devices

We placed several electronic patient monitoring devices in the magnet rooms. An MRI-conditional anesthesia system (Fabius MRI, Drager Medical Inc., Telford, PA) – certified for field strengths of up to 400 Gauss – is equipped with visual and audio alarms that activate in areas of high magnetic fields. Wireless MRI-conditional patient monitors (Expression, Invivo Corporation, Orlando, FL) were installed inside the magnet rooms to enable anesthesia staff to remotely monitor patients from the console area. There also is an MRI-conditional contrast injector (Spectris Solaris EP, MEDRAD Inc., Warrendale, PA) in the room. We installed a room oxygen monitor to check for the presence of inert gases, such as helium and nitrogen, which can displace oxygen in the magnet room. In addition, we visually inspected the RF shielding – where medical gas lines enter the rooms – to ensure the shielding's completeness and integrity. MRI-safe aluminum oxygen tanks are provided as backups in case of patient emergencies.

3. Calibrating the external laser bridge

We calibrated the LAP DORADOnova laser system for patient positioning accuracy by measuring the table travel distance from the external laser isocenter to the magnet imaging isocenter. This was done using imaging of the internal crosshairs of the LAP AQUARIUS phantom, and confirming that the LAP lasers project onto the phantom external markings when the table is retracted by that distance. We then entered the final distance in the longitudinal axis into the scanner calibration file for one-click travel-to-scan.

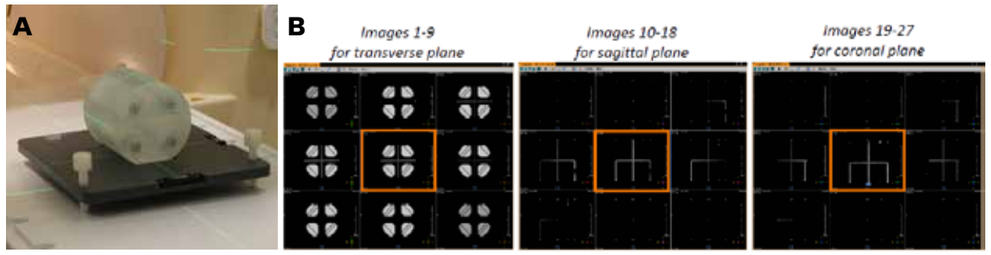

Figure 3. Imaging test with LAP AQUARIUS phantom. (A) The phantom was placed on a leveling platform and aligned with external laser projections. (B) Nine consecutive slice images were acquired and displayed for each of the axial, sagittal and coronal planes. The slice locations of the brightest crosshairs revealed the displacement of the phantom center relative to the magnet isocenter.

4. Establishing MRI baseline performance – geometric accuracy

The geometric accuracy test is among the most important tests for characterizing the distortions caused mainly by gradient field nonlinearity. The test's primary purpose is to confirm hardware integrity, which does not depend on the imaging subject and sequences. Before imaging, the system performs active shimming over the imaging volume to further correct the additional perturbation introduced by bringing a patient or object into the magnet.

We conducted the geometric accuracy test during acceptance testing and therapists repeat it daily with the Philips PIQT phantom, covering a head-size volume. In addition, our physicists perform a monthly evaluation of geometric accuracy with the large Philips geometric distortion phantom. Figure 4 shows setup of the Philips QA phantom, which has an embedded grid of 9 mm markers – each 25 mm apart – that generate a high MRI signal. A 3D T1-weighted gradient echo sequence was used for each scan with 3D distortion correction applied.

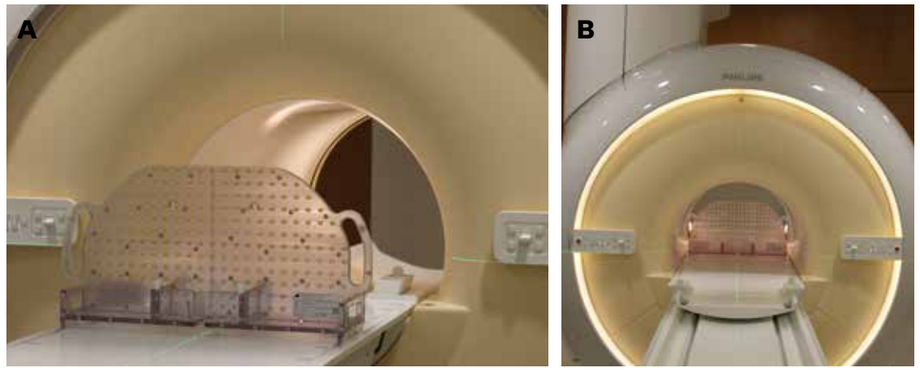

Figure 4. Photographs of (A) the Philips geometric distortion slab phantom on the indexed flat table top and (B) the measurement setup with the phantom positioned in the magnet isocenter.

Figure 5 shows the typical results of the geometric distortion measurements. The distortions within the ellipses (color-coded iso-distortion lines) were within vendor tolerances (<2 mm distortion at ±6 cm, <3 mm at ±13 cm, and < 5 mm at ±20 cm). Philips also specified a typical distortion of ≤1 mm over a 32-cm diameter spherical volume (DSV) for Ingenia MRI systems.

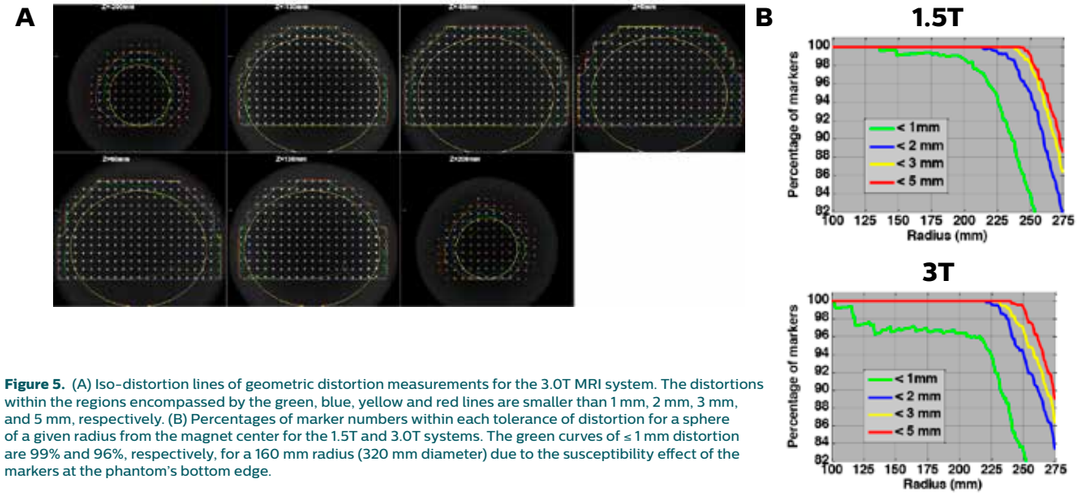

Figure 5. (A) Iso-distortion lines of geometric distortion measurements for the 3.0T MRI system. The distortions within the regions encompassed by the green, blue, yellow and red lines are smaller than 1 mm, 2 mm, 3 mm, and 5 mm, respectively. (B) Percentages of marker numbers within each tolerance of distortion for a sphere of a given radius from the magnet center for the 1.5T and 3.0T systems. The green curves of ≤ 1 mm distortion are 99% and 96%, respectively, for a 160 mm radius (320 mm diameter) due to the susceptibility effect of the markers at the phantom's bottom edge.

5.Establishing MRI quality assurance

We have established a periodic MRI system quality assurance (QA) program (Table 2) based on the ACR MRI Quality Control Manual, AAPM Report 100, on manufacturers' recommendations, and on previous reports on QA of MRI simulators. We assigned testing frequencies (daily, monthly, or annually) appropriate to the scope of the QA protocols in each category.

Daily QA confirms the basic facility integrity, the auxiliary equipment and the external laser system. In addition, as part of daily QA, we perform a manufacturer-provided batch procedure (PIQT). This test measures the center frequency, SNR, spatial resolution, slice thickness, image uniformity and spatial linearity. These measurements are somewhat extensive for daily monitoring, but the fully automated procedure makes PIQT suitable for daily QA and has replaced weekly image quality testing.

We check the facility's more general features on a monthly basis. For example, we quantitatively evaluate the laser system alignment against the magnet isocenter, and thoroughly test image quality using the ACR phantom and the 32-channel head coil. The aforementioned geometric distortion test (using a slab phantom and external laser accuracy verification) are included in the monthly QA. And, because they are most frequently used, we also test the anterior and flexible loop coils monthly.

The annual QA repeats most of the acceptance tests. Besides those included in the daily and monthly QA, the annual QA evaluates the advanced functionalities of the static magnetic field, RF transmission, and gradient field.

Test Items		Description	Methods
Daily			
Facility and equipment	Safety signage	Safety zone signs, caution and warning signs, "Magnet On" sign and ASTM labels (MRI safe/conditional/unsafe)	Visual inspection
	Metal detectors	Hand-held metal detectors and ferromagnetic detectors mounted in Zone II and at the entrance to Zone IV	Place a metal object near the detector to ensure correct operation
	Oxygen monitor	To ensure the oxygen level inside the MRI room is sufficient (> 20%)	Visual inspection
	Patient observation system	Monitoring camera and screen, operator-patient intercom, and nurse call pinch ball	Visual inspection and test operation
	Laser alignment	To ensure all laser lines converge and each laser line is sharp and continuous	Hold a piece of paper in the path of the beam
Image quality	SNR, spatial resolution, slice thickness, image uniformity and spatial linearity	Monitor the system performance	Periodic image quality test (PIQT), manufacturer-provided batch process using a 200 mm diameter head phantom and head coil
Monthly			
Facility and equipment	RF shielding	Integrity of the copper mesh on windows and the copper fingers around the door to the magnet room	Visual inspection
	Cryogen level and compressor	Checking the level of liquid helium in the magnet cryostat (> 30%) and normal sound from the cryogen compressor	Using software tool on the console and manual inspection
	External laser positioning system (ELPS)	Check of consistency between laser alignment and scanner isocenter	ELPS QA test: ExamCard and LAP AQUARIUS phantom are used.
Image quality	Geometric distortion	To determine extent of distortions inside the magnet bore by evaluating lattice-structured landmark positions in the phantom images	Manufacturer-provided batch procedure with a slab phantom
	See daily QA	The methods described in the ACR MRI Quality Control Manual[5] and the AAPM report No. 100[6]) are followed	The 32-channel head coil is used for monthly QA while the 15-channel head coil is used for daily and annual QA. Only ACR T1-weighted spin echo images are evaluated
	Receiver coil integrity	SNR and ghosting test for selected receiver coils of most frequent use	ACR phantom images with flexible loop or anterior/posterior coils are evaluated (Fig. 6)
Annual			
Facility and equipment	Table positioning accuracy	In addition to the ELPS QA, the table movements by specific distances (+100 mm, -100 mm) are confirmed	Using a scanner system's batch interpreter
Image quality	B0 homogeneity	Real and imaginary components of the phantom images in axial, sagittal, and coronal positions are evaluated	Manufacturer-provided batch procedure with a 400-mm diameter body phantom
	Magnetic field stability	Resonant frequency variation is retrospectively tracked by analyzing recorded central frequency	Retrospective review of daily PIQT reports
	Transmitter gain calibration	To check the proper calibration of RF transmitter gain by evaluating the relation between signal intensity and nutation angle	A 100-mm diameter spherical phantom and the 15-channel head coil are used
	Ultrafast imaging	Test of the temporal stability, ghosting and geometric distortion of an EPI sequence.	
	Spike noise	To determine existence of unusual noise originated from surrounding room components	Manufacturer-provided batch procedures with designated receiver coils and phantoms
	Eddy current compensation	To ensure optimal compensation of eddy current effects arising from fast switching of gradient coil	
	ACR image quality	Image quality tests with ACR phantom	See above

Table 2. Periodic MR system quality assurance protocols established in our department

Abbreviation: AAPM, American Association of Physicists in Medicine; ACR, American College of Radiology; ASTM, American Society for Testing and Materials; B0, static magnetic field; ELPS, external laser positioning system; EPI, echo planar imaging; MR, magnetic resonance; NEMA, National Electrical Manufacturers Association; PIQT, periodic image-quality test; QA, quality assurance; RF, radiofrequency; SNR, signal-to-noise ratio.

6. RF coil testing and image quality in the treatment position

We often use unconventional receiver coil configurations to accommodate immobilization devices for imaging patients in RT positions. For example, we use a pair of flexible loop coils for cranial imaging instead of standard diagnostic phased-array head coils. We were concerned that these coil configurations might result in inferior image quality due to fewer coil elements compared to standard configurations. In addition, patients are positioned somewhat further away from the posterior coil elements due to the use of a flat table top, which could also impact image quality.

We therefore repeated the ACR tests with the flexible loop and anterior coil configurations. We also estimated SNR using background noise[7], the NEMA publication). Figure 6 shows the coil setup for the performance test. A pair of loop coils was fastened to both sides of the phantom to simulate cranial imaging (Figure 6A). Extracranial scans on various body sites were represented by the phantom at various locations (center, laterally shifted by ±10 cm, and longitudinally shifted by ±20 cm) between the flat table top and the anterior coil (Figure 6B).

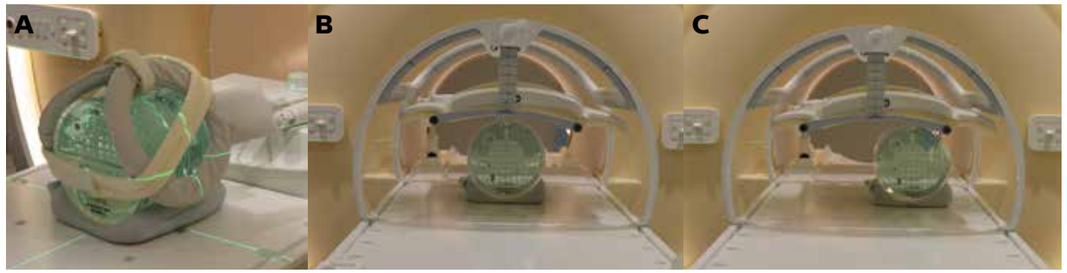

Figure 6. The setup of ACR phantom for measuring image quality with RT coil configurations that emulate (A) head imaging with a pair of large flexible loop coils and (B-C) extracranial imaging with anterior and posterior coils. The latter was performed with the phantom at several locations, including (B) the magnet isocenter, (C) 10 cm to the left, 10 cm to the right, 20 cm superiorly, and 20 cm inferiorly.

Figure 7 shows the ACR and SNR test results relevant to receiver coil selection. The performance of RT coils is compared to that of the dStream diagnostic head coils. The image-intensity uniformity was lower with coils in RT configurations: 63%-87% for RT coils vs. 95%-96% for the standard head coil for the 1.5T system; and 75%-89% for RT coils vs. 87%-91% for the standard and 32-channel head coils for the 3.0T system. Although the signal ghosting percentage and low-contrast object detectability also were lower with RT coils, they still met ACR criteria that apply to standard head coils.

The SNR was always higher with 3.0T than 1.5T by 15-64% for the same coil configuration. The SNR with the loop coils was 70-78% lower than that of the standard head coil with the same imaging parameters. Despite the lower SNR with coils in the RT configuration, we found that by adjusting imaging parameters – such as voxel size, SENSE factor and number of signal averages – the clinical ExamCards for brain imaging with loop coils compensate for the effect of reduced coil elements on SNR.

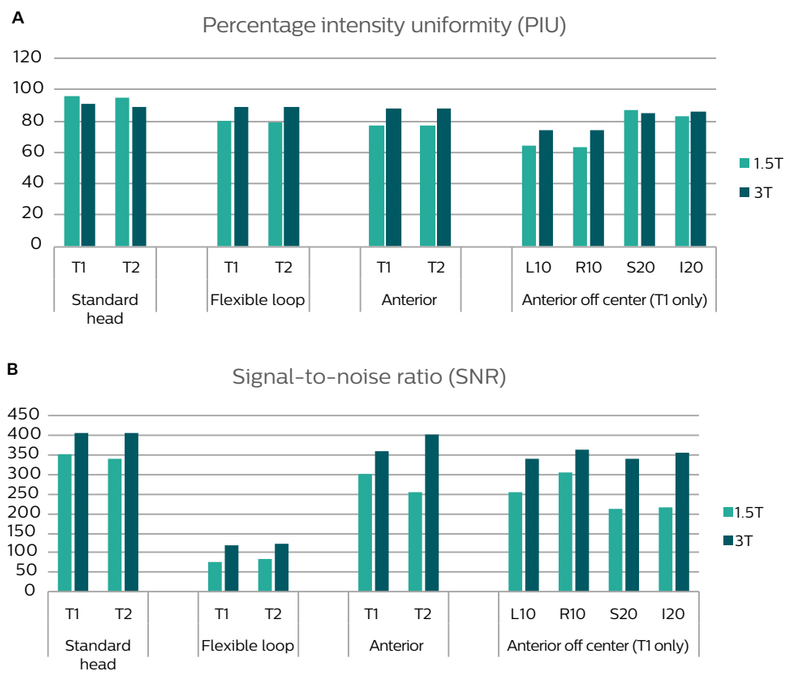

Figure 7. Image quality test results relevant to receiver coil selection. Percentage intensity uniformity (A) and signal-to-noise ratio (B) of RT coils are compared to those of the diagnostic head coil with the ACR-specified T1 and T2 imaging sequences. Uniformity correction CLEAR was applied for PIU of head coil. PIU of the other coils and SNR of all coils were measured using CLASSIC correction.

Abbreviations: I20, 20 cm inferiorly; L10, 10 cm left; R10, 10 cm right; S20, 20 cm superiorly.

7. Imaging patients in the treatment position

At St. Jude, we believed it was imperative to duplicate the patient positioning strategy used in our existing CT/linac/proton therapy workflow and apply it to MRI scanning. Essential to this was to test and confirm in advance that all patient immobilization and positioning devices were MRI-compatible.

For torso (thorax, abdomen, pelvis, spine) imaging, patients lay directly on the flat MR-RT table top. We often use knee sponges to flatten the lower spine against the table. The anterior and posterior coils integrated into the patient table are used together. We place the anterior coil on the coil support bridge instead of directly on the patient to prevent the deformation of the patient's body.

Although the Ingenia MR-RT system's indexed flat table top accommodates a variety of immobilization accessories from major vendors, we use a 5 mm thick, custom-made polycarbonate overlay board for brain tumor and head-and-neck cases and employ thermoplastic face masks to immobilize the patient's head. Figure 8 demonstrates that the head support (AccuCushions, Klarity Medical Products USA, Newark, OH) and the face mask frame (U-frame, Klarity Medical Products USA, Newark, OH) can be fastened to the overlay board with pins and clamps.

Not shown are MRI headsets, which we provide to patients during imaging to communicate with them and to protect their hearing. We can also use the ComforTone technique to further reduce acoustic noise if necessary. We also can combine flexible loop coils and the anterior coil to boost local signals, which is useful for head-and-neck imaging and other body sites.

Our current workflow entails following the CT simulation with an MRI scan. Because patients were already tattooed during the CT simulation, therapists adjust the patient's body on the MR table so existing tattoos or setup marks align with external laser beams. Because of differences in external laser coordinates, LAP laser beams in the MRI room are driven to "meet" the tattoos versus entering the isocenter coordinates determined at the CT room. For on-treatment MRI, we set up patients on the MR table following the same procedure.

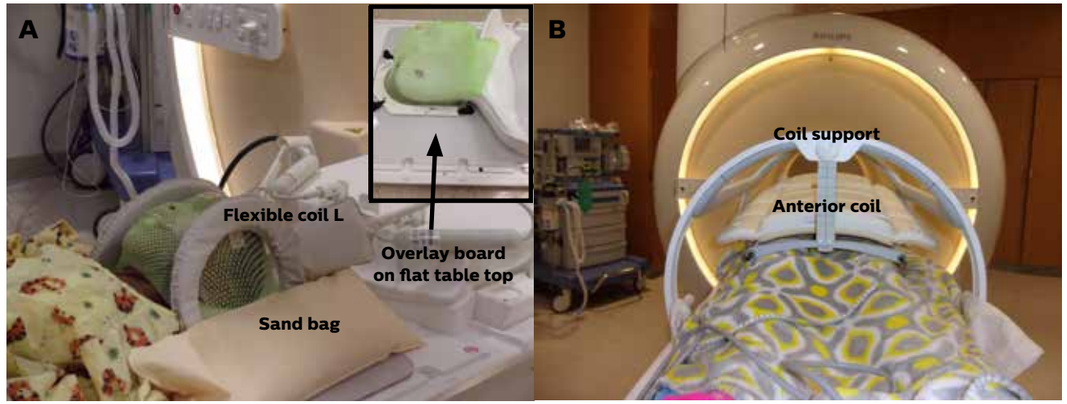

Figure 8. Patient setup for (A) head and (B) body imaging for patients receiving radiation therapy. The patient headset for reducing gradient noise was temporarily removed in the image on the left.

8. Scan protocol (ExamCard) optimization

Philips provides site-specific ExamCards in the MRI sequence library accessible at the console. Because of the unique requirements of pediatric cancer patients and treatment planning needs, we built and optimized new ExamCards with the support of Philips clinical MRI specialists. Because we anticipated this special need, an adequate number of on-site visits were included in our purchase agreement. We also purchased several on- and off-site courses for therapist training.

There are special requirements for MRI sequences used in RT planning. These include:

- Thin slices without gaps
- 3D isotropic acquisition for multiplanar reformatting
- High resolution and large field-of-view for easy registration with CT images
- Larger receiver bandwidths (water-fat shift close to 1) for reducing image distortion
- Lower SENSE factors to account for RT coil configurations with fewer coil elements

For anatomic imaging, we routinely acquire three-dimensional (3D) T1 turbo-field-echo (TFE) and 3D T2 turbo-spin-echo (TSE) sequences. To accommodate various pediatric body sizes, we optimized two sets of ExamCards with large and small field-of-views and further adjusted imaging parameters as needed for individual patients. Sequences for on-treatment imaging use a subset of those for treatment planning and we frequently use these sequences without administering contrast.

The ExamCards include options for such functional imaging techniques as perfusion or diffusion-weighted imaging (DWI), susceptibility-weighted imaging, angiography and magnetic resonance spectroscopy. These images provide additional information for determining target or organs-at-risk volumes in treatment planning and for monitoring responses during the treatment course. Note that geometric accuracy and spatial resolution in functional images could be inferior to optimized anatomic images.

Thoracic and abdominal imaging of pediatric patients present unique challenges in terms of patient respiratory motion. To suppress this motion, having patients hold their breath during imaging is often not feasible with younger patients. Therefore, our ExamCards apply respiratory triggering that utilizes signals from the external pneumatic sensor (bellows) or internal navigator. While the internal navigator detects diaphragm motion using an extra RF pulse and does not deform the body contour, it may be less robust in some situations.

The “trigger and track” option is available with the navigator to dynamically adapt the imaging stack. In addition to 3D triggered imaging, 2D imaging with a single-shot acquisition is an option because it is less sensitive to through-plane motion despite the compromised through-plane resolution. Additionally, 2D imaging allows you to use MultiVane, a technique that rotationally samples k-space to further reduce the effects of motion. Such 2D imaging is particularly useful for older children whose amplitude of respiratory motion is typically larger and the breathing pattern may be irregular.

A challenge we observed in pelvic imaging of larger patients is uniform fat suppression. Our current ExamCards use spectral attenuated inversion recovery (SPAIR) or the dual-echo modified-Dixon (mDIXON) to minimize the effect of inhomogeneous RF or static magnetic field at peripheral regions. DWI is also included in the ExamCard for pelvic imaging to monitor tumor response to radiation during the treatment course.

The ExamCards for orbit, spine and extremities include the option for 2D and 3D imaging to achieve a higher in-plane resolution and SNR as needed, despite the compromised through-plane resolution. Fat suppression with SPAIR or mDIXON is also acquired.

Our department has recently published its imaging protocols and clinical implementation experience, which may be of interest for other Ingenia MR-RT users[8].

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The advantages and challenges of dedicated MR systems in radiation oncology departments

Based on our experience, having dedicated MRIs in the radiation oncology department presents clear advantages for patients:

- Proximity to other imaging suites for CT and PET-CT simulation and treatment rooms simplifies workflow and patient scheduling for staff and alleviates the need for time-consuming patient transport between radiation oncology and diagnostic radiology departments.
- MR images acquired in the treatment position facilitates registration to CT images. It was more challenging to reproduce patient treatment positions on the diagnostic MRI systems.
- The isotropic 3D images acquired with our scan protocols provided high resolution in all orthogonal planes.
- Surface coils in RT configurations make it possible to image patients when immobilization devices are used and provide good image quality for treatment planning purposes. We can also monitor geometric accuracy frequently using automatic batch acquisition and analysis.
- Having dedicated MRI systems within the department also reduced the patient wait time and allowed us to schedule on-treatment imaging with increased flexibility. This flexibility is helpful in detecting tumor volume changes early, which may enable adaptive replanning.

There are a few challenges you should consider:

- The learning curve could be steep for therapists and therapy physicists who have no prior MRI training. For patient safety and optimal use of the MRI equipment, an MRI technologist or an MRI physicist is desirable. Each state or country may have its own requirements for qualifying MRI system operators. Our department trained therapists extensively to perform MRI scans under the guidance of Philips clinical specialists, a MRI registry certified therapist, and a department MRI physicist. At least six months before going live, we collaborated with the Philips education project manager to create a staff training plan. We scheduled numerous on-site visits by Philips MRI specialists during and after go live to provide staff ample learning opportunities and to optimize institutional MRI ExamCards. We also developed policies and procedures as well as competency evaluation for MRI system operators.
- The demand for advanced functional imaging (e.g., DSC/DCE, DTI, DWI, MRS, SWI, angiography) beyond routine anatomic imaging is increasing for radiation therapy patients. It is often challenging to obtain functional images with current surface coils in RT configurations.
- Continuous optimization is needed for scan protocols for pediatric radiation therapy patients. This may be a less serious issue for adult departments for which accumulated experience from multiple institutions is available. We hope institutions with similar needs can collaborate to build a more complete sequence library for radiation therapy purposes and share their experience.

Conclusion

We successfully installed, commissioned and optimized two wide-bore MRI simulators in a radiation oncology department dedicated to treating pediatric cancer patients. The ability to generate high quality MRI for patients in treatment positions and immobilization devices at the time of simulation and during the RT course greatly facilitate patient care.

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