Comprehensive RT-Specific QA for MRI Simulation

Eric Paulson, Ph.D., DABR

Medical College of Wisconsin, Radiation Oncology, Milwaukee, WI, USA

Introduction

MRI simulation is the process of acquiring high fidelity, high contrast resolution magnetic resonance images to identify true disease extent and proximity relative to adjacent organs at risk (OAR) for the purposes of radiation treatment planning. MRI simulation can be performed using dedicated MRI scanners in radiotherapy departments [1] or using MRI scanners sited in other departments as shared resources. As more radiotherapy departments begin incorporating MRI simulation into routine treatment planning, questions often arise regarding what level of quality assurance (QA) activities are required to maintain accuracy and avoid errors. Several well-established references from the American College of Radiology (ACR) [2-3] and American Association of Physicists in Medicine (AAPM) [4-6] provide guidance regarding acceptance testing (AT), commissioning, and routine QA of MRI scanners. However, while these manuals provide procedures and tolerances for general MRI QA, no guidance documents exist that describe the unique radiotherapy-specific QA activities that need to be considered. Radiation therapy presents a new set of challenges and places additional demands on MRI compared to diagnostic radiology that, if not properly addressed, can undermine the advantages MR images offer for treatment planning. The goal of this article is to describe a comprehen-sive MRI simulation QA program to address the RT-specific QA activities required for MRI simulation.

RT-specific acceptance testing and commissioning activities for MRI simulators

Acceptance testing and commissioning of an MRI scanner often involves a series of tests from the MRI scanner vendor as well as tests recommended in ACR and AAPM guidance documents. These tests can include characterization of static magnetic field (B_0) homogeneity and drifting, radiofrequency field (B_1) gains, percent image uniformity, percent signal ghosting, slice position and thickness accuracy, and others. The majority of the latter tests are performed using the ACR MRI QA phantom [2-3]. While initial AT measurements are useful for establishing constancy benchmarks for routine MRI QA, certain tests more relevant for radiotherapy (e.g., geometrical accuracy) may not be fully characterized based on measurements of the ACR MRI QA phantom, due to the relative small size of the phantom.

Beyond the general AT and commissioning activities discussed above, RT-specific activities should also be considered. Table 1 provides a summary of the RT-specific AT and commissioning activities for MRI simulators. The fringe fields of dedicated MRI simulators sited in radiotherapy departments may affect the performance of conventional linear accelerators (LINACs) installed proximal to the MRI simulator. The strength of these fringe fields should be mapped and verified to be within the tolerance specified by the LINAC manufacturer. Residual geometric distortions that persist following three dimensional gradient nonlinearity correction should be characterized by evaluating images of a large grid phantom scanned, ideally, using a reversed gradient technique [7]. These residual distortions may affect the geometric accuracy of delineated anatomy, particularly when large field-of-view prescriptions are utilized (e.g., supine breast). In addition, optimization of RT-specific MRI simulation imaging protocols should be performed [1] utilizing thin, contiguous slices, high readout bandwidths, high order shimming, and spin echo sequences to minimize chemical shift and patient-induced distortions. The accuracy of respiratory gating and triggering windows should be assessed using dynamic motion phantoms, particularly for those institutions wishing to match the MRI acquisition to the same respiratory phases used for gated radiation therapy deliveries. For those MRI simulator suites in which external lasers are available, the longitudinal distance between the laser and MRI isocenters must be determined and configured as offsets in the MRI simulation imaging protocols. Finally,

Table 1:
RT-specific acceptance testing and commissioning activities for MRI simulators

	Acceptance Testing and Commissioning Activities
☐	Determine fringe field strength at conventional LINACs proximal to MRI simulator[1]
☐	Characterize residual distortions following 3D gradient distortion correction
☐	Optimize MRI simulation imaging protocols (FOV, slice thickness, skip, rBW, etc.)
☐	Determine the accuracy of respiratory gating windows and triggering positions
☐	Determine longitudinal offset distance between external laser and MRI isocenters[2]
☐	Perform end-to-end tests utilizing RT peripheral equipment (all orientations)[3]

[1] Required for MRI simulators sited in radiotherapy departments
[2] Required for MRI simulators equipped with external laser systems
[3] Also required following upgrades to MRI system or RT peripheral equipment

end-to-end testing utilizing ancillary RT-specific equipment, including flat table overlays, coil bridges, immobilization devices, and external lasers should be performed.

In terms of personnel, it would be most desirable if a team of MRI physicists and radiation therapy physicists performed the activities listed in Table 1. Alternatively, the activities could be performed by individuals cross-trained in both MRI and radiation therapy physics.

RT-specific daily QA activities for MRI simulators

Once AT and commissioning have been performed, a routine QA program needs to be established. Daily, monthly, and annual activities comprise our routine QA program for MRI simulators. Table 2 provides a summary of the RT-specific daily QA activities. These activities are performed during morning warm-up, similar to daily QA of other equipment in the radiotherapy department.

Minimization of geometric distortions is pivotal to the success of MRI simulation. Despite patients being screened for loose metal prior to MRI exams, it can be common to find bobby pins, earrings, and other small metal fragments lining the magnet bore. The presence of these items may affect the homogeneity of the static magnetic field and, consequently, contribute to geometric distortions. A quick daily inspection and swiping of the scanner bore for the presence of loose metal mitigates this issue. In addition, flexible phased-array receive coils are often utilized during MRI simulation exams. These coils permit the patient to be imaged in treatment position using immobilization devices. However, the repeated wrapping of the coils can lead to a higher likelihood of failure due to breakage of internal coil elements. Therefore, a short signal-to-noise ratio (SNR) and brightness check is performed daily on alternating coils used for MRI simulation exams. An alternative approach may be to extract receive coil gain information directly from log files on the MRI scanner. Finally, components involved in patient safety are also tested daily, including the intercom, panic ball, and metal detector.

Table 2: RT-specific daily QA activities for MRI simulators.

	Daily QA Activities
☐	Inspect/sweep bore for loose metal (bobby pins, earrings, fragments, etc.)
☐	Flexible RF coil inspection, SNR, brightness measurements (alternating each day)
☐	Patient safety (intercom, panic ball, metal detector)
☐	Laser alignment, isocenter agreement, couch position accuracy, end-to-end test[4]
☐	B_0 drift[4]
☐	Basic geometric accuracy[4]

[4] For sites utilizing MR-only workflows

Table 3: RT-specific monthly QA activities for MRI simulators.

	Monthly QA Activities
☐	Laser adjustment, isocenter agreement, couch position accuracy, end-to-end test[5]

[5] Required for MRI simulators equipped with external laser systems

For institutions utilizing MRI-only[6] workflows (i.e., MRI-derived images used for both delineation and dose calculation), it is essential to verify the accuracy of the laser-MRI coordinate systems on a daily basis. This includes verifying laser alignment, external laser to MRI isocenter constancy, and couch position accuracy. In addition, a quick end-to-end test should be performed to ensure the lasers used for marking patients are driven to the isocenter location prescribed on the MR images. Daily B_0 drift and basic geometric accuracy can also be evaluated using the same MR images obtained for the end-to-end test.

The RT-specific daily QA activities listed in Table 2 would ideally be performed by radiation therapists who have received additional cross-training in MRI. For sites utilizing MR-only workflows, the activities could alternatively be performed by diagnostic MRI technologists who have received cross-training in radiotherapy software used for isocenter placement.

RT-specific monthly QA activities for MRI simulators

For radiotherapy departments that utilize MRI scanners sited in other departments as shared resources, or sites that perform diagnostic MRI exams in addition to MRI simulation exams on dedicated MRI scanners sited in radiotherapy departments, weekly QA is often performed by diagnostic MRI technologists to maintain ACR accreditation. Commercial or open source [8] software is available to automate image quality analysis of the weekly QA images based on guidelines and action limits established by the ACR [2]. In these scenarios, in which the monitoring of MRI simulator performance can occur jointly across departments, reducing the workload for radiotherapy personnel.

Beyond general image quality activities recommended for MRI, the only RT-specific monthly QA activity for MRI simulators (see Table 3) involves laser adjustment for those MRI simulator suites equipped with external laser systems [9]. Ideally, these adjustments would be made by radiation therapy physicists.

RT-specific annual QA activities for MRI simulators

Annual MRI QA activities (including SNR and brightness tests of dedicated coils used for diagnostic imaging, magnetic field homogeneity, etc.) are performed by MRI physicists to maintain ACR accreditation [2]. Beyond these general QA activities recommended for MRI, no additional RT-specific QA activities are performed for MRI simulators on an annual basis.

[6] Radiotherapy Planning where MR data is the only imaging information is ongoing research. The concepts and information presented in this article are based on research and are not commercially available. Its future availability cannot be ensured.

RT-specific patient QA checklist for MRI simulation

Although conceptually, the process of virtual simulation using MRI parallels that of CT, there are several additional steps that must be performed before, during, and after an MRI simulation exam in order to maintain the high accuracy required for radiation treatment planning. To protect against human performance failures, a checklist of patient-specific QA activities (see sample checklist in Table 4) was designed similar to the safe surgery checklists [10] derived from the airline industry. The checklist items would ideally be performed during an MRI simulation exam by a radiation therapist who has received additional cross-training in MRI.

Table 4: RT-specific patient QA checklist for MRI simulation exams

Yes	N/A	Task
☐	☐	Patient orientation (Cervix brachy: FFS; otherwise use treatment orientation)
☐	☐	Abdomen/Chest/Pelvis: Large RF flexible receive coils supported by coil bridges
☐	☐	Esophagus: ECG leads placed on patient
☐	☐	Cholangiocarcinoma: Nasal cannula placed on patient with oxygen at 2-3 liter/min
☐	☐	Cholangiocarcinoma: Injector loaded with Eovist (Bayer HealthCare, Whippany, USA)
☐	☐	Cervix brachy/Abdomen: 0.5 mg glucagon IV at start, midway of exam
☐	☐	Prostate: Bladder, rectum fill check
☐	☐	High order shim volume optimized and copied to each series
☐	☐	B_0 map acquired with body coil; magnitude and phase images reconstructed successfully
☐	☐	Additional diagnostic sequences added for MR Sim with interpretation
☐	☐	High bandwidths or Advanced WARP used for metal* (hip replacements, spine hardware)
☐	☐	Cervix brachy: 3D images acquired as straight axials
☐	☐	Abdomen/Esophagus: Breath holds at end expiration
☐	☐	Coverage sufficient (check order for directives and special instructions)
☐	☐	Images screened for artifacts. Did fatsat, Dixon separation work? (re-run if necessary)
☐	☐	Spine/Sarcoma: Upper+lower groups combined in 3D viewer or composer
☐	☐	Brain: rCBF mosaic separated into individual images (Application → Mosaic → Split)
☐	☐	3D distortion correction applied to all images
☐	☐	3D distortion-corrected images (DIS3D suffix) sent to treatment planning systems

Summary

A comprehensive MRI simulation QA program consists of unique RT-specific QA activities that supplement established, general MRI QA activities. For many institutions, QA activities can be split between radiotherapy and diagnostic radiology departments. With the move toward MR-only treatment planning, comprehensive QA programs will be essential to protect against machine and human performance failures and maintain the high levels of accuracy required for radiation therapy.

*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.

Contact

Eric Paulson, Ph.D., DABR
Assistant Professor and Senior Medical Physicist
Radiation Oncology, Radiology, and Biophysics
Medical College of Wisconsin
Radiation Oncology
8701 Watertown Plank Road
Milwaukee, WI 53223
USA
epaulson@mcw.edu

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