Canadian Partnership for Quality Radiotherapy

Technical Quality Control Guidelines

for Magnetic Resonance Imaging for Radiation Treatment Planning

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A guidance document on behalf of:

Canadian Association of Radiation Oncology

Canadian Organization of Medical Physicists

Canadian Association of Medical Radiation Technologists

Canadian Partnership Against Cancer

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Introduction

The Canadian Partnership for Quality Radiotherapy (CPQR) is an alliance amongst the three key national professional organizations involved in the delivery of radiation treatment in Canada: the Canadian Association of Radiation Oncology (CARO), the Canadian Organization of Medical Physicists (COMP), and the Canadian Association of Medical Radiation Technologists (CAMRT). Financial and strategic backing is provided by the Canadian Partnership Against Cancer (CPAC), which works with Canada's cancer community to reduce the burden of cancer on Canadians. The vision and mandate of the CPQR is to support the universal availability of high quality and safe radiotherapy for all Canadians through system performance improvement and the development of consensus-based guidelines and indicators to aid in radiation treatment program development and evaluation.

This document contains detailed performance objectives and safety criteria for *Magnetic Resonance Imaging for Radiation Treatment Planning (MRI for RTP).* Please refer to the overarching document,

Technical Quality Control Guidelines for Canadian Radiation Treatment Centres,[1] for a programmatic overview of technical quality control, and a description of how the performance objectives and criteria listed in this document should be interpreted.

System Description

The current scope of this report focuses on the use of MRI for RTP purposes. The use of magnetic resonance (MR) for image guidance at the time of treatment (e.g., in-room MR guidance, MR-linear accelerator (linac) systems) is currently out of the scope for this report.

The performance tests applicable to an MR system used for RTP applications are different for an MR simulator (MR-sim) dedicated to a radiation oncology department and a MR scanner available in a radiology department. General considerations and guidance on image acquisition specifications are provided in this document.

MR image data sets are used for RTP applications in two different ways:

- MR images are registered with the corresponding planning computed tomography (CT) images to assist in the target and normal soft-tissue delineation, as well as for the assessment of anatomical motion and treatment margins;
- MR images are used alone for treatment planning in the case of prescribed scenarios. The current version of the document will describe the tests for the first situation, as the MR-only planning technology is not widely available, yet. It is intended, however, that this document will be updated with standard tests for MR-only planning when that is more commonly used and a consensus on tests can be reached.

The safety system tests of an MR system are more specific compared to the other commonly used systems in the RTP process (e.g., CT-Sim, linac). As a result, the safety system tests are included in this document instead of the Safety Systems CPQR Technical Quality Control guidelines (TQC).

Glossary

The following glossary of terms is included to clarify specialized terminology used in this guideline.

Deformable Image Registration (DIR)

When a source image set is aligned to a target image set via a transformation that can be spatially variant where the distances between points are stretched or warped.

Electron Density Assignment

The assignment of electron density information (or equivalently, CT numbers) to voxels of an image set based on pixel intensity and/or regional distribution.

Geometric Distortion

Any shift in the apparent position of image features from their true physical representation.

Image Fusion

The creation of an image set that combines the anatomic information from two or more different image sets, often from different imaging modalities. Prior to fusion, the data sets are generally registered (rigid or deformable) against each other to ensure anatomic locations coincide.

MR Conditional

Items with demonstrated safety in the MR environment within defined conditions.[2] Conditions will at least include maximum tolerances for aspects of the static magnetic field (such as magnitude and spatial gradient), the switched gradient magnetic field, and the radiofrequency fields. Other conditions for use may be included.

MR Safe

Items for which there are no known hazards resulting from exposure to any MR environment.[2] Consequently, these items will be electrically non-conductive and non-magnetic.

MR Simulator or MR-Sim

An MR scanner that is dedicated for the use of RTP. It typically has a flat couch and an external laser system similar to CT-sim and different from a diagnostic MR scanner.

MR Unsafe

Items that pose unacceptable risks to the patient, medical staff, or other persons within the MR environment.[2]

Rigid Image Registration

When a source image set (2D/3D) is aligned to a target image set (2D/3D) via translations and/or rotations applied uniformly to all points in the image. In MR-CT registration for RTP, the MR image is typically the source image and the planning CT is typically the target image, and the transformation is typically performed in 3D rather than 2D.

Related Technical Quality Control Guidelines

In order to comprehensively assess the use of MR for RTP performance, additional tests, as outlined in related CPQR TQC guidelines must also be completed and documented, as applicable. Related TQC guidelines, available at cpqr.ca, include:

- Treatment Planning Systems
- Computed Tomography Simulators
- Data Management Systems

Test Tables

Various soft-tissue disease sites currently treated with radiation treatment could benefit from MR-Sim; however, the technology is not available at all radiation oncology departments. In addition, due to the smaller bore size of MR scanners compared to a typical CT-Sim and the use of surface coils, patient setups may not be easily reproduced at MR-Sim for all treatment sites.

MR images obtained from MR-Sim or diagnostic MR can be used in the process of RTP subject to the following considerations:

1. For MR/CT workflow, the MR Image acquisition should be performed on a date/time reasonably close to the acquisition of planning CT (before or after). This decision should be made in consultation with the treating physician depending on the nature of disease progression and expected added value of the MR.

2. MR image in-plane resolution, slice thickness, and field of view (FOV) should be sufficient to allow accurate lesion detection and segmentation of adjacent organs at risk and, if required, image registration to planning CT. Image resolution should typically be higher for RT applications than for diagnostic imaging (DI). Typical requirements on MR images used for RTP are listed below:

    a. In-plane resolution of 1 mm is desirable for most anatomical sites.
    b. Slice thickness of 1-2 mm in brain and 3 mm in the rest of the body/extremities is desirable for the primary MR image set (e.g., It is usually not possible to obtain the conventional 2D multi-slice T2-weighted images that satisfy the above criteria for the same amount of scan time as the T1-weighted images, they usually have thicker slices and cover a shorter axial range).
    c. Slice gaps for MR image acquisition are discouraged for its use in RTP, as information between slices could be crucial to the RTP process and may be lost. A drawback of eliminating the slice gap is slice cross-talk, which can modify the image contrast.

d. More than one MR sequence (i.e. multiple contrasts) may be needed to define the RT target.
e. The MR image acquisition volume is usually designed to be as small as possible to maximize image resolution and reduce scan time, while avoiding aliasing. However, in order for the MR image to be useful for RTP, at least one image acquisition must encompass the entire axial range of the targeted anatomy. When MR is used in conjunction with planning CT FOV can be smaller to provide optimal imaging (e.g., high resolution, acquisition time) on target and critical structures of interest, provided there is sufficient anatomical information related to the treatment site to ensure successful registration For example, when planning treatment for brain lesions, the skull is needed to perform accurate rigid registration between MR and CT.

3. It is common to perform 2D acquisitions in DI due to good signal-to-noise ratio (SNR) and limited coverage requirements. However, 2D imaging suffers from imperfections in the slice excitation profile as well as through-plane distortion. The SNR is linearly dependent on the slice thickness, which means that thin slices (e.g., 3 mm) are difficult to achieve with 2D imaging. 3D imaging overcomes these limitations and can provide isotropic high-resolution with improved SNR, imaging requirements more suitable for RTP. It should be noted that contrast can be affected. 3D T1-weighted imaging produces conventional-looking T1-weighted images, while the contrast in 3D T2-weighted imaging can differ from conventional 2D multi-slice T2-weighted images.

4. To minimize scanner-specific geometric distortions, when available, the vendor 2D/3D corrections should be enabled for each sequence. Furthermore, to mitigate patient-induced distortions due to susceptibility and chemical shift effects, the sequences may be optimized by increasing the readout bandwidth. Minimum values should be 220 Hz/mm and 440 Hz/mm for 1.5 T and 3 T field strengths, respectively. Vendors may have different units when it comes to calculating bandwidth. The value in Hz/pixel is typically easier to obtain; however, this value should be converted to Hz/mm to ensure consistency (e.g., 1 pixel may have a dimension of 1 mm). Please note that these are minimum values − some sources recommend values twice this large to ensure all susceptibility variation results in a distortion less than 1 mm.[4] These larger bandwidths should be used if SNR permits.

5. In the case of MR-Sim, the site-specific MR imaging protocols need to be set up prior to clinical implementation. The common diagnostic MR protocols do not meet all of the above criteria; hence, it is critical to work with the DI department of the hospital to establish a process and imaging protocols/sequences that satisfy both the RTP requirements and the scan time limits per sequence and per session, if the diagnostic MR images are to be used in the RTP process. One particular example is that most RTP systems require axial images, whereas DI commonly acquires slightly oblique scans even in the axial orientation.

6. The geometric uncertainty of a system should be accounted for in the RTP process. For MR-Sim, the recommended tests are listed in the tables below. If it is feasible to perform the geometric uncertainty tests specified in the tables below on the diagnostic MR scanner, then the test results can be used to inform the RTP process.

7. In hospitals where the radiation department does not have access to quality control (QC) time at the DI department, the geometric uncertainty needs to be accounted for if the DI MR images are to be used in the RTP process (e.g., as a contributing factor to PTV margin). The appropriate value for geometric uncertainty for the RTP process is beyond the scope of this document, as it depends on many factors including site, geometric uncertainty of the scanner/sequence/FOV, image registration accuracy, delineation uncertainty, immobilization, and image-guidance strategies.

Test tables 1, 2 and 3 are generally applicable to both dedicated MR-sims and diagnostic MR systems.

The tests in the following tables and descriptions assume familiarity with basic test procedures. Further detail for methodologies associated with generic tests can be found in works such as the NEMA MS documents,[3-5] ACR MRI Quality Control Manual,[6] and AAPM Report No. 100.[7]

Table 1: Daily/Weekly Quality Control Tests

Designator	Test	Performance	
		Tolerance	**Action**
Daily			
D1	Check MR bore for presence of loose metallic objects	No loose metallic objects	
D2	Patient safety tests	functional	
D3	SNR	Consistent with baseline	
D4	MR-Sim external lasers and table positioning	1 mm	2 mm
D5	Geometric uncertainty	1 mm	2 mm
D6	Protocol parameters verification	Consistent with baseline	
D7	Image quality: resolution	Consistent with baseline	
D8	Image quality: low-contrast detectability	Consistent with baseline	
D9	Central frequency stability	Consistent with baseline	
D10	Transmitted gain/attenuation stability	Consistent with baseline	
D11	Image artifacts assessment	functional	

Notes on Daily/Weekly Tests

Daily/Weekly QC Tests	This refers to daily incidence of MR in Radiation Oncology and weekly incidence of MR in Diagnostic Image/Radiology.
D1	Ensure that no loose metal (e.g., metal filings, earrings, bobby pins) is present in the MR bore. The loose objects may originate from previously scanned patients or after servicing done in the room or adjacent space. Removal of all loose metal is important to prevent imaging artifacts, which can cause difficulty in interpreting the anatomical information and/or delays in the scanning procedures (e.g., need for troubleshooting of issues and patient rescans).
D2	Patient-related safety tests include the A/V and intercom (similar to a linac), correct signage, unobstructed pressure release panel if present, patient call bell and survey as per local practice (i.e., written patient screening, verbal patient screening, metal detector), lighting, table docking/undocking if present (especially for brachytherapy procedures), and cooling (chiller and helium level).
D3	This test can be done with a uniformity phantom (or a uniform region within a standard phantom), in conjunction with the MR system body coil and/or a volume coil used routinely in the RT program. The signal should be measured using a consistent imaging sequence in the same geometric location, without parallel imaging. The noise should be measured outside the phantom, after windowing to view the noise floor (structured noise such as ghosting from the phantom should be avoided in the noise measurement). This process can be repeated, time and resources permitting, for other coils used for RT-related imaging on a rotating daily or weekly basis. Please note that surface coils will generate high levels of signal variation across the phantom, so special care is required to ensure the signal is measured in a consistently placed ROI.[8]
D4	This test serves the same purpose as the test D1 in the Computed Tomography Simulators TQC guideline with the tolerance consistent with those in the treatment delivery rooms. The test assesses the accuracy of the external laser position with respect to the imaging plane at magnet isocentre for the purpose of patient localization.
D5	The tolerance and action levels are applicable to the entire image FOV and include contributions from both gradient and main magnetic field non-linearities. This test requires a dedicated phantom and QC procedure for MR-sims. In designing the QC protocol, one needs to ensure that the same distortion profile is captured in the QC procedure as is present in the sequence(s) to be used in the RTP process. Although it is ideal to repeat the daily QC test with each sequence and post-processing (particularly distortion correction) that may be implemented for patient scans, it is practically

difficult to implement given that a range of possible sequence types or variants may be used at the time of patient imaging.

An acceptable approach is to group sequences with a similar distortion profile and implement QC scans that are representative of the worst-case scenario of the group. For a distortion profile to be representative, there are two basic requirements: Firstly, the read-encode trajectory must be the same, both in orientation and direction, and whether it is implemented in a 3D scan or a 2D multi-slice approach. This applies to traditional spin-warp readouts and complex radial/spiral readouts alike. Secondly, the identical distortion correction algorithm must be implemented (if any) in post-processing. If these criteria are met, the imaging sequence with the lowest bandwidth readout (worst-case distortion scenario) should be identified and implemented in the QC scan.

The daily QC phantom should also allow for quick assessment of geometric uncertainty, either through a limited set of manual measurements against known dimensions, or automated assessment. The measurements should check accuracy in all three dimensions (A/P, L/R, and S/I). Ideally the measurements should be made across the widest part of the phantom to reduce the impact of measurement bias A log of these daily measurements should be kept for each unit to identify any trends or measurements that are repeatedly close to tolerance.

For departments without dedicated MR-sims, the access to perform geometric uncertainty tests to the level of accuracy required for RTP may be limited. If this cannot be overcome, then the geometric uncertainty introduced must be accounted for in the design of PTV margins in the RTP process.

D6 This test is not designed to require an onerous effort, rather a verification that the relevant protocol setting has not been inadvertently changed. The items to be verified include but are not limited to: FOV, appropriate geometric distortion correction is applied (3D when available), bandwidth fat/water shift within local protocol (e.g., 1 voxel or 1 mm), no obliquity in image orientation and no gaps in image set, and whether the external is required to be encompassed in the image acquisition.

D7 Using a phantom with a resolution insert and a consistent imaging sequence and coil arrangement, observe the lowest resolution feature that can be successfully resolved. To note, the test interpretation is often subjective, and the recommendation is to have a consistent approach in assessing the resolution features (visually or image processing). An example of this type of feature can be seen in the American College of Radiology accreditation phantom. [6]

D8 Using a phantom with a variable low-contrast feature insert and a consistent imaging sequence and coil arrangement, observe and record the lowest contrast objects that can be successfully resolved. An example of this type of feature can be seen in the ACR accreditation phantom. [6]

D9 Record the resonant frequency as calibrated by the scanner on a consistent phantom setup and sequence implementation.

D10 Observe the transmitter settings calibrated to achieve the same nominal flip angle on a consistent phantom setup. This test is to ensure power performance, rather than an academic effort in measuring the flip angle.

D11 Test for artifacts to ensure that no deleterious effects are present (e.g., RF noise, loose metal). This refers to reviewing the daily test images to spot obvious issues.

Table 2: Monthly/Quarterly Quality Control Tests

Designator	Test	Performance	
		Tolerance	**Action**
Monthly			
M1	Geometric uncertainty 3D (large FOV, larger phantom)	1 mm	2 mm
M2	PSG (Percent signal ghosting)	Consistent with baseline	
M3	Uniformity assessment	Consistent with baseline	
M4	Slice thickness	Consistent with baseline	
M5	Slice position	Consistent with baseline	
M6	B_0 homogeneity	Consistent with baseline	
M7	RF coils check	functional	
M8	Records	complete	

Notes on Monthly/Quarterly Tests

Depending on the frequency of utilization and resource availability, these tests can be performed monthly or quarterly. While these tests are less imperative to repeat on a daily frequency, the less cumbersome tests such as PSG, slice thickness, and slice position may be incorporated into the daily/weekly regimen if time and resources permit.

M1 The monthly QC procedure should be designed to characterize the geometric performance of the unit as a whole and monitor for any medium and long-term changes, as opposed to the daily QC regimen, which considers sequence-specific differences. Although it is nominally termed as "monthly," representing the minimum acceptable frequency, it should be repeated after any upgrade or maintenance event by third-party personnel. For this, a large and consistent 3D FOV should be evaluated, with a consistent sequence and the most complete distortion correction post-processing available. The phantom itself should allow for distortion to be measured over the full 3D FOV. Distortion statistics such as RMS error and maximum offset should be calculated and recorded to monitor any performance changes. Time permitting, two scans of this phantom may be repeated, with the second scan having a reversed read-encode direction. Although only one is required for the monthly QC assessment, having data for the reversed gradient direction will allow the influences of gradient non-linearity and background field inhomogeneity to be separated, and will allow troubleshooting of distortion values over tolerance. If a large distortion phantom is not available, a smaller geometric phantom can be used as alternative by moving it to different locations and stitching the images afterwards.

M2 This test measures how much signal is misplaced outside the phantom area due to ghosting in the phase-encode direction. The test is accomplished through an image of a uniform phantom (obtained using a consistent sequence and coil arrangement) with an FOV sufficiently large to measure bands of noise on all four sides of the phantom. The mean background signal from the left and right is subtracted from the mean background signal from above and below. The absolute value of this difference is then divided by the mean signal inside the phantom and expressed as a percentage, i.e.:

$$PSG = 100 \times \frac{\left|(Sig_{Above} + Sig_{Below}) - (Sig_{Left} + Sig_{Right})\right|}{2 \times Sig_{Inside}}.$$

Please note that images are often reconstructed by the console in manner such that noise does not extend all the way to the edge of the field of view. As such, it is important to window the image so that the noise floor can be seen before selecting ROIs with which to measure background signal - only regions within the visible noise floor should be selected or biased results will occur. Also note that phantom motion can result in signal ghosting, so care should be taken to make sure the phantom is secure in its position. As a guideline, the ACR recommends a maximum value of 2.5%,[(6)] but any significant change from baseline is cause for investigating the source.

M3 This test measures the uniformity of image signal produced from a uniform phantom. The basic objective is to quantify the span of signal (normalized to the mean) in the absence of noise. Noise would artificially decrease the measured uniformity if it could affect the measurement of the signal span. The acquisition of multiple averages is a good

means of improving the measurement. Beyond this, agencies have published recommendations on measurement methods to reduce the impact of the noise on the assessment of uniformity,[5-7] including the use of ROIs to determine minimum and maximum values (rather than depending on a single pixel),[3,10] or a statistical measurement of pixel deviations from the mean.[3] Regardless of the method, it is always critical to be consistent to be able to accurately detect changes from baseline. A sudden change in image uniformity can be indicative of a coil fault or a change in B_0 homogeneity, among others. This test should be repeated on all RT-relevant coils.

M4 This test identifies any deviations between the slice thickness prescribed by the pulse sequence and the actual thickness of the excited material. The most common type of phantom feature for this test is either a wedge or a thin slab of MR-visible material that cuts through an imaging slice at a known shallow angle. In this way, one can measure the width of the wedge or slab as seen in the image and translate this measurement to the slice thickness, i.e.:

$$Slice\ Thickness = Width_{Measured} \times \tan \alpha,$$

where α is the known shallow angle at which the structure intersects the prescribed slice. The shallow angle expands the visible width on the slice far beyond the actual slice thickness and in so doing reduces the impact of measurement error. Note that the above equation will only be valid if the slice or phantom is not mispositioned in a way that would alter the intersecting angle of the slice and feature. To compensate for this source of error, most phantom features have two slabs or wedges intersecting the slice from opposite directions. The two measured widths can then be combined algebraically to compensate for orientation error. More details can be found in published standards and manuals.[6,5]

M5 This test determines whether the position of a slice as prescribed by the console is positioned at its intended place. A convenient location for a slice-positioning test is at the intersection point of a pair of crossed wedges (cutting through the plane of the slice). The slice is placed on this intersection point on the basis of a scout image. If the terminations of the wedge slopes coincide on the resulting image, then the slice was positioned correctly. Alternatively, by measuring the separation between these termination points, one can calculate the slice misplacement (assuming the slope of the wedges across the image plane is known), i.e.:

$$Slice\ Mispositioning = \frac{Wedge1_{Termination} - Wedge2_{Termination}}{2} \times \tan \beta,$$

where β is the rise angle of the wedges. The ACR accreditation phantom is an example of a phantom with these test wedges.[6]

M6 Check the overall main magnetic field homogeneity using metrics such as the full-width half-maximum value (FWHM) of the resonance peak (from a spherical uniform phantom). Detailed descriptions of this and other methods for measuring field homogeneity can be found in references 6 and 7.

M7 The coil connections, cables, and plugs should be inspected to ensure no indications of damage. The coil should be loaded with a phantom or phantoms with sufficient span so that all elements can be tested for functionality. Depending on the coil, several separate scans and phantom placements may be required to test all elements. Unlike test D3, which measured SNR as a global indication of coil stability, these tests confirm functionality of all coil components. An SNR measurement (as in D3) should be included here on RT-relevant peripheral coils that have not been tested on a regular basis in the daily/weekly regimen.

M8 Documentation relating to the daily quality control checks, preventive maintenance, service calls, and subsequent checks must be complete, legible, and the operator identified.

Table 3: Annual Quality Control Tests – MR

Designator	Test	Performance	
		Tolerance	**Action**
Annual			
A1	Patient set-up (coil, MR-compatible immobilization device, etc.)	functional	
A2	MR scanner distortion correction (2D/3D) process	functional	
A3	Spot check MR fringe field distribution	Consistent with baseline	
A4	MR ventilation	functional	
A5	Patient monitoring, gating systems, MR-compatible injectors, anesthesiology systems.	functional	
A6	Review of long-term trends for quantitative Daily and Monthly tests	complete	
A7	RF coils check	functional	
A8	Independent quality control review	complete	

Notes on Annual Tests

These tests are to be performed annually, for new implementation, or after a service event, whenever applicable.

A1 This only needs to be performed any time a new site/set-up is introduced in MR-Sim, or any changes happen to the configuration and process. Limitation of MR bore size and availability of MR-compatible immobilization devices need to be considered.

A2 A phantom should be scanned with a range of pulse sequences with and without 2D/3D distortion correction enabled. A comparison of images with and without the correction should reveal if the correction is being applied as requested. In the case of 3D imaging, a reformatted image perpendicular to the original stack may need to be generated to check distortion correction in the third dimension. On certain consoles, the implementation of distortion correction in all three dimensions can be FOV dependent. Testing of sequences with both large and smaller FOV is recommended.

A3 While adhering to proper safety practices, spot-check several locations just outside the marked 5 gauss (5 G) line to ensure the field is below this threshold. A spot check in rooms immediately neighbouring the magnet suite is recommended to ensure 5 G is not extending into public areas.

A4 With appropriate coordination with building staff, the quench vent should be inspected on the outside of the building, if possible, to look for a visible material that may block airflow.

A5 Peripheral devices such as patient monitoring, gating systems, communication, anesthesiology systems, injectors should be checked for functionality and/or inspection/calibration by qualified service personnel.

A6 While checks against baseline are expected for a number of the daily and monthly tests listed above, an annual review of the long-term data to check for trends and reproducibility is recommended. Unusual trends on monthly geometric distortion tests should be reviewed for any negative trends or regions of concern.

A7 The coil connections, cables, and plugs should be inspected to ensure no indications of damage. The coil should be loaded with a phantom or phantoms with sufficient span so that all elements can be tested for functionality. Depending on the coil, several separate scans and phantom placements may be required to test all elements.

A8 To ensure redundancy and adequate monitoring, a second qualified medical physicist (QMP) must independently verify the implementation, analysis, and interpretation of the quality control tests at least annually. There are clear definitions for QMP from both AAPM and COMP in terms of subfields and certifying bodies; however, the certification specialty requirement on the QMP for this test item is beyond the scope of this document.

Special consideration should be given in the case of an MR system servicing and upgrades. Acceptance or preventive maintenance tests provided by the MR manufacturer under an institutional service contract agreement should ensure that the MR system is at optimal functionality. However, monthly tests should be performed after any hardware upgrade and monthly/annual QA should be done after MR console software upgrade.

Additionally, in case of setup changes in the MR room as required by certain procedures or repairs/maintenance, RF-noise related tests are recommended to rule out deleterious RF noise sources.

Table 4: RTP-related Quality Control Tests

Designator	Test	Performance	
		Tolerance	**Action**
Annual			
ARTP1	Connectivity and DICOM data integrity	functional	
ARTP2	MR/CT registration – registered image quality	1 mm	2 mm
ARTP3	MR/CT registration – registration accuracy	1 mm	2 mm
ARTP4	MR/CT fusion – contour propagation	1 mm	2 mm
ARTP5	MR/CT registration – Image orientation	reproducible	
ARTP6	MR/CT registration – Registration repeatability	reproducible	
ARTP7	MR/CT registration – End-to-end image registration test	reproducible	
ARTP8	Independent quality control review	complete	

Notes on Annual Tests

ARTP1 The connectivity and data integrity tests are similar to tests C2 and C4 in the Data Management Systems TQC. In addition to the common features including image orientation, for MR images, the record of distortion correction and the type of correction should be verified as well.

ARTP2 Based on tests outlined in AAPM TG 132.[9] Registered images (both rigid and deformable) should be qualitatively reviewed to verify registered image quality and ensure there have not been visible misalignments and/or significant image manipulation/resampling errors as a result of the registration. Typical tools to perform this evaluation include split or flickering screens and image or contour overlays, etc. Performance should be measured as per specifications in the table or appropriately baselined/characterized and documented.

ARTP3 Based on tests outlined in AAPM TG 132[9] and related clinical experiences.[10] The accuracy of the image registration should be evaluated/characterized in a quantitative manner to ensure the uncertainty is within tolerance for the intended purpose and/or observed deviations are appropriately accounted for via other means (e.g., incorporated into planning margins. Suitable metrics will depend on the purpose and type (rigid or deformable) of registration and action levels may need to be adjusted appropriately. Common approaches include landmark-based distance measurements and/or volume-based comparisons methods such as Dice similarity coefficient, Hausdorff distance, Jacobian determinants. It is recommended that both geometric and anthropomorphic phantoms be evaluated over a range of transformations relevant to intended clinical applications. Refer to AAPM TG 132 for a more detailed description of common evaluation methods. Performance should be measured as per specifications in the table or appropriately baselined/characterized and documented.

ARTP4 Based on tests outlined in AAPM TG 132.[9] If applicable, verify that contours drawn on one image set are accurately propagated to a registered image set. Note this evaluation is intended to ensure a contour accurately delineates the structure of interest. Further validation of contour propagation accuracy for other purposes (e.g., deformable contour propagation for dose accumulation within that structure) is beyond the scope of this test.

ARTP5 Images with a variety of clearly marked patient orientations (head first supine/prone, feet first supine/prone, decubitus) should be imported and the appropriate scale/size and orientation/labels verified.

ARTP6 Based on AAPM TG 132.[9] The image registration algorithm should yield repeatable results and give acceptable image quality and registration accuracy. It is recommended that registration of phantom images (geometric and anthropomorphic) and phantom images with known errors (translations, rotations and/or deformations, if applicable) be tested to ensure accurate, repeatable and reproducible behaviour of registration method. Clinics should also ensure the transformation is well behaved/interchangeable.

ARTP7 Based on AAPM TG 132.[9] It is encouraged to acquire images and perform MR/CT fusion with a phantom to verify entire clinical process.

ARTP8 To ensure redundancy and adequate monitoring, a second qualified medical physicist must independently verify the implementation, analysis, and interpretation of the quality control tests at least annually.

Table 5: Patient-Specific Quality Control Tests

Designator	Test	Performance	
		Tolerance	**Action**
Case-by-Case			
PS1	MR/CT registration– verify image orientation	complete	
PS2	MR/CT registration – registered image quality	1 mm	2 mm
PS3	MR/CT registration – registration repeatability	1 mm	2 mm
PS4	MR/CT fusion – contour propagation	1 mm	2 mm
PS5	MR/CT registration – registration documentation	complete	

Notes on Patient-Specific Tests

PS1 Correct image orientation/scale of imported patient images should be verified during registration.

PS2 As per ARTP2; performance should be measured as per specifications in the table or appropriately baselined/characterized and documented for intended purpose.

PS3 As per ARTP3; performance should be measured as per specifications in the table or appropriately baselined/characterized and documented for intended purpose.

PS4 For patient images. As per ARTP4.

PS5 An assessment of registration quality and acceptability/suitability of results for intended purposes should be documented for each patient.

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