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Approved [insert date]*

COMMISSIONING AND QUALITY ASSURANCE OF X-RAY BASED IMAGE GUIDED RADIOThERAPY SYSTEMS

1. Introduction

Image-guided radiation therapy (IGRT), in its many forms, is an important tool in improving the effectiveness of clinical radiation oncology. IGRT involves the use of patient images to localize and reposition the patient or delivery system prior to treatment to ensure that the therapeutic beam is correctly directed toward the tumor. IGRT imaging strategies have utilized x-rays, ultrasound, and other means. In particular, IGRT has been most commonly facilitated using x-rays, beginning with use of megavoltage (MV) portal and/or orthogonal setup images some decades ago. These images provide a means of evaluating the position of the treatment isocenter and field edges relative to the patient position. Because of the poor low-contrast resolution of MV images, bony anatomy may be taken as a surrogate of the target volume, which is frequently soft-tissue-equivalent and not clearly visible within the image. However, as many studies have shown, the target volume can exhibit different patterns of motion relative to bony anatomy; therefore, daily localization using bony anatomy alone may lead to increased uncertainty in target positioning. One solution to clinical scenarios in which improved soft-tissue targeting was desired was the introduction of in-room kilovoltage (kV) imaging systems. Such systems have included computed tomography (CT) scanners located within the treatment room (e.g., “CT-on-rails”) and kV imaging systems affixed to the floor/ceiling or to the linear
accelerator gantry itself. These systems have provided improved low-contrast localization of soft tissue targets and – in the case of in-room CT scanners and gantry-mounted imaging systems – allowed for acquisition of pre-treatment volumetric images.

The specific choice and application of IGRT strategy depends on the complexity and requirements of the treatment in question. It may serve as an enhancement to an established technique (as in the case of three-dimensional conformal radiation therapy or intensity modulated radiation therapy) or as a necessary and critical component of the treatment process (as in the case of stereotactic body radiation therapy). Whatever its application, it is undoubtedly true that (1) IGRT strategies are being used more now than ever before, and (2) various forms of IGRT have been, are, and will continue to be important tools in radiation therapy.

As the clinical treatment process continues to rely more heavily on IGRT strategies, the Qualified Medical Physicist (QMP) is under increasing pressure to maintain patient safety and treatment quality through quality assurance programs that are in step with the rapid pace of technological development. Many clinical practice environments now utilize treatment delivery systems with one or more IGRT systems that fall under the responsibility of the QMP. A variety of guidance documents and task groups reports have been issued that include additional recommendations for commissioning and quality assurance of IGRT systems [1-8]. However, these reports do not clearly delineate best practice from minimum practice standards.

a. Goals and rationale

This document is part of a series of medical physics practice guidelines commissioned by the American Association of Physicists in Medicine (AAPM) intended to succinctly state the minimum acceptable standards for various aspects of clinical medical physics. While implementation of robust and comprehensive quality assurance programs recommended in other reports from the AAPM is encouraged, the purpose of this particular report is to describe the minimum acceptable practice standards for the commissioning and quality assurance of x-ray based image-guidance systems utilized in radiotherapy. This document is not intended to replace or revise previous AAPM Task Group Reports, but to assist the QMP in establishing and maintaining a safe and effective IGRT program by providing an overview of the minimum requirements and needs of x-ray based IGRT systems. Indeed, the reader is referred to the appropriate technical reference documents or task group reports in instances when additional recommendations beyond minimum practice guidelines are desired [1-8]. Finally, the standards and procedures described in this document are applicable to the imaging guidance system insofar as its resulting images are used to position the patient and/or localize the target volume. Use of IGRT system hardware and software for other purposes, such as dose calculation, are beyond the scope of this report. Technologies covered by these guidelines include:
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70  •  Gantry-mounted two dimensional MV imaging systems
71  •  Gantry-mounted three dimensional MV imaging systems
72  •  Gantry-mounted two dimensional kV imaging systems
73  •  Gantry-mounted three dimensional kV imaging systems
74  •  Room-mounted two dimensional kV imaging systems
75  •  Room-mounted three dimensional kV imaging systems

In this context, “gantry-mounted” imaging systems are those in which the mechanical movement of the imaging hardware is coupled with mechanical movement of the treatment delivery device (e.g., Varian/Elekta/Siemens on-board kV imaging systems, electronic portal MV imaging systems, TomoTherapy megavoltage CT, etc.). “Room-mounted” systems include all imaging systems not coupled with the treatment delivery device (e.g., ExacTrac, CyberKnife, in-room CT, etc.). For room-mounted and gantry-mounted two-dimensional kV imaging systems, fluoroscopy modes are also within the scope of this report.

b. Intended users

The intended users of this report are QMPs who seek to understand the technical requirements of clinical implementation and quality assurance of a safe IGRT practice, and administrators interested in the resources required for IGRT.

2. Definitions and Abbreviations

• CBCT - cone beam computed tomography
• IGRT - image guided radiotherapy
• kV - kilovoltage
• MV - megavoltage
• OIS - oncology information system
• QA - quality assurance
• TPS - treatment planning system

3. Staff qualifications and responsibilities

Implementation of a successful IGRT program requires contributions from each member of the treatment team. Recommendations for staff qualifications and responsibilities are consistent with those described by the ACR-ASTRO practice guideline for clinical use of IGRT [9].

a. Radiation Oncologist - the radiation oncologist should meet qualifications outlined in the ACR-ASTRO practice guideline for clinical use of IGRT [9]. In short, the responsibilities of the radiation oncologist in an IGRT program include:

• Managing patient positioning procedures
• Specifying imaging modalities and frequencies
• Identifying registration targets and re-positioning thresholds
• Timely review of clinical IGRT images
• Conducting regular reviews of the IGRT program

b. Medical Physicist - the QMP must be competent to practice independently in the subfield of therapeutic radiological physics. The individual must be certified either by the American Board of Radiology, American Board of Medical Physicists, or the Canadian College of Medical Physicists. Responsibilities of the QMP in an IGRT program include:
  • Acceptance testing and commissioning
  • Implementing and managing of a quality assurance program
  • Developing and implementing standard operating procedures (including imaging protocols and repositioning thresholds)

c. Medical Dosimetrist - responsibilities of the medical dosimetrist or treatment planner in an IGRT program include:
  • Creating and transferring to the OIS all patient-specific data necessary for IGRT implementation

d. Radiation Therapist - responsibilities of the radiation therapist in an IGRT program include:
  • Understanding the use of positioning devices in IGRT
  • Preparing the IGRT system for acquisition of patient-specific positioning verification images
  • Implementing the IGRT treatment protocol under the supervision of the radiation oncologist and medical physicist
  • Acquiring positioning verification images for review by the radiation oncologist
  • Assisting in periodic review of the stability of the IGRT system (e.g., daily QA)

e. Information Technologist - It is important that each facility identify an individual that is responsible for providing and maintaining resources necessary for storing, archiving and retrieving images generated during IGRT. This may be accomplished by a dedicated Information Specialist or duties assigned to another team member.

4. Implementation Guidelines

a. Minimum required resources and equipment

   i. Staffing
Approximate time requirements needed for implementation, maintenance and quality assurance of each IGRT program type (per each IGRT system) are provided below. Estimates are provided as general reference values only, and are not intended to justify site-specific staffing models or physics time for specific billing codes. "Acceptance/commissioning" includes all activities needed for IGRT program implementation, including documentation (e.g., drafting of a commissioning report and creation of policies and procedures describing the routine IGRT QA program). "Documentation" refers to creation of a formal commissioning report and drafting of policies and procedures specific to clinical use and routine quality assurance of IGRT (including creating QA forms and templates). "Ongoing support" includes all activities needed for maintenance of an established IGRT program (e.g., routine quality assurance, troubleshooting, upgrades, service/repairs).

1. Two dimensional MV imaging systems
   - Acceptance/Commissioning/Documentation: 18-36 hours
   - Ongoing support: 25-50 hours annually

2. Two dimensional kV imaging systems
   - Acceptance/Commissioning/Documentation: 18-36 hours
   - Ongoing support: 25-50 hours annually

3. Three dimensional MV imaging systems
   - Acceptance/Commissioning/Documentation: 18-36 hours
   - Ongoing support: 100-125 hours annually

4. Three dimensional kV imaging systems
   - Acceptance/Commissioning/Documentation: 18-36 hours
   - Ongoing support: 100-125 hours annually

ii. Equipment

Quality assurance phantoms and tools must provide reliable values of the measured parameters and can be used to judge whether tolerance criteria have been achieved. In many cases, manufacturers of IGRT systems provide quality assurance phantoms which can be used for quality assurance purposes. In-house and commercial phantoms specifically designed for IGRT are also available and, when coupled with automated image analysis tools, may improve efficiency. At a minimum, quality assurance tools must be capable of assessing the following IGRT characteristics:

- Image quality
- Spatial accuracy (scaling)
- Congruence of imaging and treatment isocenters
- Accuracy of registration/couch movements
- Imaging dose
b. **Staff training**

Training for the operation of the IGRT system must be provided. The IGRT system vendor typically provides onsite training to the physicist and therapists for use of the equipment. Prior to initial use of IGRT, the treatment team should meet to discuss staff responsibilities, clinical goals and process workflows. The physicist should also review the image acquisition procedures with the therapists and radiation oncologists.

c. **Process descriptions**

Example procedures for each of the tests recommended in Table 1 are described below. The approximate time needed to complete each procedure is noted in parenthesis following the process description. In some cases, customer acceptance procedures provided by the equipment vendor satisfactorily meet the stated practice standards; however, it is the responsibility of the QMP to judge the adequacy and completeness of all measurements needed for use of a particular IGRT system. It is important to note that these are only example procedures, and a variety of methods may be used to complete the recommended tests.

i. **Customer acceptance procedures (all systems)**

The QMP must be present during acceptance testing. Customer acceptance tests procedures are intended to ensure that the imaging equipment satisfies the performance requirements stated in the purchase agreement. In some cases, measurements completed as part of the acceptance procedures may also serve as components in establishing the routine quality assurance program. The vendor must demonstrate acceptable system performance. (Time: 8-16 hours).

ii. **TPS configuration and connectivity (2D systems)**

Digitally reconstructed radiographs (DRR) of test objects in various orientations are created with the treatment planning system and transferred (typically via DICOM interface) to the image guidance system. Proper display of the DRR image within the image guidance software must be ensured. (Time: 3-4 hours)

iii. **TPS configuration and connectivity (3D systems)**

Reference CT image sets of test objects in various orientations are imported into the treatment planning system. Contours are added and the images and structures are transferred (typically via DICOM interface) to the image
guidance system. Proper display of the reference CT images and structures within the image guidance software must be ensured. (Time: 3-4 hours)

iv. OIS integration and connectivity (2D systems)

Setup fields created for a test patient within the oncology information system are properly recognized by the imaging hardware and software when loaded. Acquired images are then assigned to the correct patient, if applicable. (Time: 2-3 hours)

v. OIS integration and connectivity (3D systems)

Volumetric IGRT image fields (CBCT, MVCT, CT-on-rails) created for a test patient within the oncology information system are properly loaded and recognized by the imaging hardware and software. Acquired images are assigned to the correct patient, if applicable. (Time: 2-3 hours)

vi. Routine QA baselines (all systems)

Measurements taken at the time of IGRT system commissioning which characterize IGRT system performance will serve as reference values for the routine QA program. See Table I for recommended QA tests requiring reference measurements. (Time: 2-3 hours).

vii. Documentation (all systems)

All acceptance and commissioning procedures and results must be contained within a formal report. Furthermore, a formal policy for routine IGRT QA program and procedures for performing routine QA measurements must be developed. (Time: 4-8 hours)

viii. Safety/interlocks (all systems)

With image acquisition initiated, ensure beam termination occurs when the treatment room door is opened and when any termination keys are depressed. Also ensure that gantry rotation is terminated when touch guards are depressed. Verify that indicator lamps are illuminated during image acquisition (Time: 5 minutes)

ix. Contrast (2D kV systems)

A phantom with low contrast objects (such as the Leeds phantom) is placed on the treatment couch at isocenter, typically with a 1 mm copper plate on
top of phantom. A planar kV image is acquired using a reference technique determined at the time of acceptance testing. The window and level are adjusted to reference values determined at the time of acceptance testing. The number of visible disks is recorded, with more indicating better low contrast visibility. (Time: 15 minutes).

x. **Contrast (2D MV systems)**

A phantom with low contrast targets (such as the Las Vegas phantom) is placed on the treatment couch. A planar MV image is acquired using a reference technique determined at the time of acceptance testing. The window and level are adjusted to a reference value determined at the time of acceptance testing. The number of visible disks of largest diameter or frequency groups is recorded, with more indicating better low contrast visibility. (Time: 15 minutes).

xi. **Contrast (3D systems)**

An appropriate volumetric image quality phantom (such as a CT phantom) is positioned on the treatment table using the room lasers. A volumetric image is acquired using a reference technique determined at the time of acceptance testing. Either the difference in CT number of different materials within the phantom, or the number of visible low contrast objects is recorded. (Time: 15 minutes)

xii. **Spatial resolution (2D kV systems)**

A phantom with high contrast objects (such as the Leeds phantom) is placed on the treatment couch, typically with 1 mm copper plate on top of phantom. A planar kV image is acquired using a reference technique determined at the time of acceptance testing. The number of frequency groups that are clearly distinguished is recorded; with more frequency groups indicating better spatial resolution. (Time: 15 minutes)

xiii. **Spatial resolution (2D MV systems)**

A high contrast phantom (such as the Las Vegas phantom) is placed on the treatment couch. A planar MV image is acquired using a reference technique determined at the time of acceptance testing. The number of visible disks of greatest contrast is recorded, with more disks indicating better spatial resolution. (Time: 15 minutes)

xiv. **Spatial resolution (3D systems)**
An appropriate volumetric image quality phantom (such as the Catphan) is positioned on the treatment table using the room lasers. A volumetric image is acquired using a reference technique determined at the time of acceptance testing. The number of frequency groups that are clearly distinguished is recorded; with more frequency groups indicating better spatial resolution.

(Time: 15 minutes)

xv. Scaling (all systems)

A phantom of known dimensions is placed on the treatment table using the room lasers. A planar or volumetric image is acquired. Window and level are adjusted such that phantom is clearly visible. The distance between two objects of known separation in the horizontal and vertical axes is recorded and compared with the known distance. For 3D imaging systems, scaling must be measured in all 3 dimensions. (Time: 10 minutes)

xvi. Uniformity (3D systems)

An appropriate volumetric image quality phantom (such as the Catphan) is positioned on the treatment table using the room lasers. A volumetric image is recorded. The average pixel value over a region of interest at multiple locations (e.g., center, 12 o’clock, and 3 o’clock) is recorded and compared. (Time: 15 minutes)

xvii. Imaging-treatment isocenter coincidence (2D systems)

A variety of methods may be used to verify congruence of imaging and treatment isocenters. Most of these techniques require alignment of a radiopaque marker (e.g., ball bearing, fiducial, or commercial device) to treatment isocenter via room lasers. Orthogonal or oblique images are then acquired. Congruence of imaging and treatment isocenters is verified by comparing the position of the markers with the center of the orthogonal/oblique images. (Time: 10-15 minutes)

xviii. Imaging-treatment isocenter coincidence (3D systems)

A variety of methods may be used to verify congruence of imaging and treatment isocenters. Most of these techniques are usually coupled with the “positioning/repositioning” test and begin with positioning of a radiopaque marker (ballbearing, fiducial, or commercial device) on the treatment table with known offsets from isocenter. Volumetric IGRT images are then acquired and registered with reference images. The recommended couch
shifts from the image registration software are recorded and applied, and
coincidence of the imaging and treatment isocenters is assessed by (1)
comparing the position of the marker with the room lasers or (2) comparing
the coincidence of the marker with the center position of an acquired MV
portal image, if available. (Time: 10-15 minutes)

xix. Positioning/Repositioning (all systems)

A radiopaque marker is positioned on the treatment table with known offsets
from isocenter. Images are acquired and registered with reference images.
The recommended couch shifts from the image registration software are
recorded and applied. Proper functioning of the image registration software is
verified by comparing the recommended couch shifts with the known offsets,
while correct application of the shifts is assessed by comparing the position
of the marker with the room lasers. (Time: 10-15 minutes)

xx. Imaging dose (3D systems)

Several different methods are currently used to characterize the dose from 3D
IGRT systems. The traditional metric for dose from CT imaging, the
computed tomography dose index (CTDI), has been applied to IGRT
imaging. More recently, the AAPM Task Group 111 [8] report has
introduced a new metric, the cumulative dose. These two different metrics
use different measurement equipment and irradiation geometries to
c caracterize the dose.

Measurement equipment used to measure CTDI includes a calibrated 100
mm long pencil ionization chamber and acrylic CTDI phantoms, one
resembling a head and the other a pelvis. For each imaging mode, the
phantom that matches the mode’s target anatomy is used. The phantom is
centered at isocenter and the pencil chamber is centered in the phantom. The
radiation field length is constrained to be less than the active length of the
pencil ionization chamber. For each imaging mode, measurements are
repeated for the central and peripheral phantom locations.

Measurement equipment used to measure the cumulative dose includes a
farmer chamber calibrated in the appropriate energy range and several acrylic
CTDI phantoms. For each imaging mode, the phantoms that match the
modes’ target anatomy are used. The CTDI phantoms are abutted until their
length exceeds the length of the radiation field. The phantom is centered at
isocenter and the farmer chamber is centered in the phantom. For each
imaging mode, measurements are repeated for the central and peripheral
phantom locations.
Measured imaging dose must be documented and its management should be approached with the goal of keeping it as low as necessary to achieve clinically useful images. (Time: 15-60 minutes, depending on the number of techniques measured.)

**xxi. Imaging dose (2D systems)**

Imaging dose from 2D kV systems is most typically characterized using entrance skin exposure. Measurement equipment used to measure the entrance exposure includes a calibrated ionization chamber and a phantom. The ionization chamber is placed in the phantom at a shallow depth on the tube side of the x-ray beam. The field size is set to cover the detector. A clinically relevant beam is delivered, and the exposure rate is calculated.

Measured imaging dose should be documented and its management should be approached with the goal of keeping it as low as necessary to achieve clinically useful images. (Time: 15-60 minutes, depending on the number of techniques measured)

d. Continuing quality improvement

Ongoing review and audit of the IGRT program should occur at regular intervals. In particular, use of appropriate imaging techniques/frequencies, adherence to stated QA programs, and revision of IGRT strategies based on pertinent changes in clinical practices should be assessed.

**5. Recommendations**

Recommended minimum practices for commissioning and QA of an IGRT system are shown in Table I. Test frequencies and tolerance values were developed based on relevant AAPM Task Group reports and the experience of the MPPG members in relation to the stability and importance of each parameter to the IGRT process. Sample process descriptions are included in Section 5.c. The “acceptance value” shown in the table refers to the IGRT system manufacturer’s minimum performance standard stated in the customer acceptance procedure documentation. If unavailable or not specified, then “acceptance value” can be taken as the value measured at the time of commissioning. For example, most IGRT system manufacturers have stated performance specifications for image quality and, in such cases; those may serve as the tolerance values for routine QA measurements of image quality. However, most IGRT system manufacturers do not have stated performance specifications for imaging dose and, in such cases, the imaging dose measured at the time of commissioning may serve as the baseline value to which future measurements are compared.
Table I. Recommended minimum practices for commissioning and QA of an IGRT system.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acceptance/Commissioning</strong></td>
<td></td>
</tr>
<tr>
<td>Customer acceptance procedures</td>
<td>-</td>
</tr>
<tr>
<td>TPS integration</td>
<td>-</td>
</tr>
<tr>
<td>OIS integration</td>
<td>-</td>
</tr>
<tr>
<td>Establish routine QA baselines</td>
<td>-</td>
</tr>
<tr>
<td>Documentation</td>
<td>-</td>
</tr>
<tr>
<td><strong>Daily</strong></td>
<td></td>
</tr>
<tr>
<td>Safety/interlocks</td>
<td>Functional</td>
</tr>
<tr>
<td>Imaging-treatment isocenter coincidence (SRS only)</td>
<td>1 mm</td>
</tr>
<tr>
<td>Positioning/repositioning (SRS only)</td>
<td>1 mm</td>
</tr>
<tr>
<td>Imaging-treatment isocenter coincidence (SBRT only)</td>
<td>2 mm</td>
</tr>
<tr>
<td>Positioning/repositioning (SBRT only)</td>
<td>2 mm</td>
</tr>
<tr>
<td><strong>Weekly</strong></td>
<td></td>
</tr>
<tr>
<td>Imaging-treatment isocenter coincidence (non-SRS/SBRT)</td>
<td>2 mm</td>
</tr>
<tr>
<td>Positioning/repositioning (non-SRS/SBRT)</td>
<td>2 mm</td>
</tr>
<tr>
<td><strong>Semi-Annually</strong></td>
<td></td>
</tr>
<tr>
<td>Image scaling</td>
<td>2 mm</td>
</tr>
<tr>
<td><strong>Annually</strong></td>
<td></td>
</tr>
<tr>
<td>Imaging dose</td>
<td></td>
</tr>
<tr>
<td>2D MV and all 3D imaging modes</td>
<td>± 1 cGy of acceptance value</td>
</tr>
<tr>
<td>2D kV (static imaging mode)</td>
<td>± 25 mR of acceptance value</td>
</tr>
<tr>
<td>2D kV (fluoroscopy mode)</td>
<td>± 1 R/min of acceptance value</td>
</tr>
<tr>
<td>Image quality</td>
<td>Acceptance value</td>
</tr>
<tr>
<td>2D (spatial resolution, contrast)</td>
<td></td>
</tr>
<tr>
<td>3D (uniformity, spatial resolution, contrast)</td>
<td></td>
</tr>
<tr>
<td><strong>Upgrade/Repair/Service</strong></td>
<td></td>
</tr>
<tr>
<td>Verify / Re-establish QA baselines (as appropriate)</td>
<td>-</td>
</tr>
</tbody>
</table>

Abbreviations: SRS = stereotactic radiosurgery, SBRT = stereotactic body radiation therapy
In general, the frequency of routine QA tests is proportional to the importance of their performance for the purpose of patient alignment. As such, evaluation of imaging-treatment isocenter coincidence and positioning/repositioning is considered critical. While daily checks of these parameters are preferred, weekly checks are considered acceptable for IGRT systems used with standard fractionation schemes. For IGRT systems used for SRS/SBRT, daily QA testing frequency is required on days when procedures are scheduled.

The imaging dose from an IGRT system must be measured for at least one acquisition technique of each mode of clinical operation. For example, a gantry-mounted kV system used to acquire both 2D and 3D clinical images must have documented imaging doses for both 2D and 3D modes. If imaging dose is only measured for one acquisition technique, then the chosen technique should serve to provide the most conservative value (e.g., choose the acquisition technique that results in the greatest imaging dose). For 2D kV systems operated in fluoroscopy mode, the entrance exposure rate should be measured for the technique expected to produce the highest value.

These recommendations must be also augmented with procedures required by state regulations (such as measurement of x-ray tube voltage accuracy, where applicable). Furthermore, IGRT systems with known recurring problems should be subjected to more frequent QA at the discretion of the QMP.

6. Conclusions

IGRT is a powerful and increasingly essential component of clinical radiation oncology practice. Proper use and quality assurance of clinical IGRT systems are of critical importance to maximizing the benefits and minimizing the risks of the technology. The minimum technical requirements for managing a clinical IGRT program stated in this document will help to achieve a more uniform standard of practice that improves the safety and quality of care of patients for whom IGRT is needed.

Acknowledgements

This guideline was developed according to the process described under the heading The Process for Developing AAPM Medical Practice Guidelines AAPM web site [insert link] by the Medical Physics Practice Guideline Task Group-225 of the Professional Council of the AAPM.

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