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The American College of Radiology will periodically define new practice guidelines and technical standards for radiologic practice to help advance the science of radiology and to improve the quality of service to patients throughout the United States. Existing practice guidelines and technical standards will be reviewed for revision or renewal, as appropriate, on their fifth anniversary or sooner, if indicated.

Each practice guideline and technical standard, representing a policy statement by the College, has undergone a thorough consensus process in which it has been subjected to extensive review, requiring the approval of the Commission on Quality and Safety as well as the ACR Board of Chancellors, the ACR Council Steering Committee, and the ACR Council. The practice guidelines and technical standards recognize that the safe and effective use of diagnostic and therapeutic radiology requires specific training, skills, and techniques, as described in each document. Reproduction or modification of the published practice guideline and technical standard by those entities not providing these services is not authorized.

2009 (Resolution 5)

ACR TECHNICAL STANDARD FOR MEDICAL PHYSICS PERFORMANCE MONITORING OF IMAGE-GUIDED EXTERNAL BEAM RADIATION THERAPY (IGRT)

PREAMBLE

These guidelines are an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. They are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care. For these reasons and those set forth below, the American College of Radiology cautions against the use of these guidelines in litigation in which the clinical decisions of a practitioner are called into question.

The ultimate judgment regarding the propriety of any specific procedure or course of action must be made by the physician or medical physicist in light of all the circumstances presented. Thus, an approach that differs from the guidelines, standing alone, does not necessarily imply that the approach was below the standard of care. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in the guidelines when, in the reasonable judgment of the practitioner, such course of action is indicated by the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of the guidelines. However, a practitioner who employs an approach substantially different from these guidelines is advised to document in the patient record information sufficient to explain the approach taken.

The practice of medicine involves not only the science, but also the art of dealing with the prevention, diagnosis, alleviation, and treatment of disease. The variety and complexity of human conditions make it impossible to always reach the most appropriate diagnosis or to predict

with certainty a particular response to treatment. Therefore, it should be recognized that adherence to these guidelines will not assure an accurate diagnosis or a successful outcome. All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The sole purpose of these guidelines is to assist practitioners in achieving this objective.

I. INTRODUCTION

The goal of all radiation therapy treatment is that radiation be delivered to the target volumes as planned and as precisely and accurately as possible. External beam image-guided radiation therapy (IGRT) is a process of using various imaging techniques to locate the target volume just before or during the delivery of radiotherapy, coupled with the use of calculational schemes to adjust the position of the treatment beams based on quantitative image data. This process is aimed at improving the treatment accuracy by verifying the exact location of the target volume so that the amount of healthy tissue exposed to radiation is reduced and the incidence of side effects minimized.

This standard is intended to provide guidance for quality assurance of systems used for external beam IGRT and adaptive radiation therapy.

II. QUALIFICATIONS AND RESPONSIBILITIES OF A QUALIFIED MEDICAL PHYSICIST

A Qualified Medical Physicist is an individual who is competent to practice independently one or more of the subfields in medical physics. The American College of Radiology (ACR) considers certification and continuing education and experience in the appropriate subfield(s) to demonstrate that an individual is competent to practice one or more of the subfields in medical physics and to be a Qualified Medical Physicist. The ACR recommends that the individual be certified in the appropriate subfield(s) by the American Board of Radiology (ABR), the Canadian College of Physics in Medicine, or for MRI, by the American Board of Medical Physics (ABMP) in magnetic resonance imaging physics.

The appropriate subfield(s) of medical physics for this standard are Therapeutic Radiological Physics or Radiological Physics.

A Qualified Medical Physicist should meet the [ACR Practice Guideline for Continuing Medical Education \(CME\)](#). (ACR Resolution 17, 1996 – revised in 2008, Resolution 7)

III. IGRT METHODS

Imaging has been used to position treatment fields since the earliest days of external beam radiation therapy (EBRT). The first methods of imaging internal anatomy to verify the patient's position on the treatment couch used the treatment beam to expose radiographic film. These images were called port films and were acquired during the treatment course with a frequency that varied, but was often at the start of treatment and weekly thereafter. In recent years, a large number of other techniques have been developed to streamline the patient positioning verification process.

Ultrasound and in-room computed tomography (CT) were 2 early methods for routine volumetric imaging at the time of treatment delivery. Digital 2-dimensional techniques were developed along a similar timeline, and have more recently evolved into quasi-3D methodologies. These 2D methods use electronic portal imaging devices (EPIDs) that, like the older port films, use the treatment beam to generate images that can be compared to treatment planning image information. An important addition to all of these techniques is the implementation of computer software that manually or automatically registers the 2 image datasets (planning and periodic IGRT imaging) so that table shift information is generated. A modification of the early EPID approach is the use of a second panel and X-ray source to give more-or-less orthogonal stereoscopic information that can be rapidly gathered to identify the position of a target in

space. These implementations often do not rely on the treatment beam, but instead use X-ray generators that are in the diagnostic energy range to obtain better image contrast. Also, some systems mount the X-ray sources and imaging panels using a fixed geometry in the treatment room. Other manufacturers fix the X-ray source and EPID to the treatment unit so that stereotactic images can be sequentially obtained with a simple rotation of the gantry around the patient.

Other innovations have also been implemented by various linear accelerator manufacturers. These include integrated spiral data acquisition using the treatment beam to produce CT images that are otherwise analogues to the imaging available from diagnostic helical CT scanners. Another technique that is gaining popularity uses an EPID to gather projection data 2-dimensionally so that a full volume representation of the anatomy can be obtained with a single or even partial rotation of the device around the patient. Standard CT reconstruction algorithms are used to build a volume image of the patient; the technique is called cone-beam CT imaging. Like the 2D approaches described above, either the treatment beam can be used for this type of imaging or a diagnostic X-ray head can be mounted on the gantry of a standard accelerator system to improve image contrast.

Systems that use the treatment beam are typically referred to as high-energy (MV) cone-beam systems, while using a low-energy (kV) X-ray source produces kV cone-beam images. It is important to point out that the MV systems do not necessarily use the exact beam that is employed to treat the patient. In some cases, filtration and beam tuning are modified to improve image contrast and reduce patient dose.

The various technologies currently available for in-room patient setup and positioning are categorized below. The differences inherent in the design of each IGRT system dictate the appropriate quality assurance (QA) procedure that is needed for its safe clinical implementation.

- Ultrasound unit.
- In-room diagnostic quality CT scanner.
- kV X-ray head with opposed imaging panel mounted on treatment unit for cone-beam CT (CBCT).
- kV X-ray head with opposed imaging panel mounted on treatment unit for obtaining 2 or more fixed views of the patient's anatomy.
- Dual kV X-ray heads with opposed imaging panel mounted at fixed positions in the treatment room.
- EPID panel mounted on the accelerator unit opposed to the treatment beam for obtaining 2 or more fixed views of the patient's anatomy.
- EPID panel mounted on the accelerator unit opposed to the treatment beam for obtaining CBCT images.

- A 1-dimensional MV beam with opposed 1-dimensional detector for spiral CT data acquisition.
- Systems that use cameras and/or surface mapping systems for external localization.
- Electromagnetic fiducial localization systems.

The IGRT process of care begins with the construction of digitally reconstructed radiographs (DRRs) from the approved computed treatment plan CT data set. These images will be compared to the “live” IGRT images obtained before and/or during the treatment delivery process. The patient will be moved based on the congruence of these image data sets such that the images align to within some predetermined localization criteria. In this manner, the treatment will be delivered precisely and accurately according to the treatment plan approved by the radiation oncologist.

For the purpose of this technical standard, the software components that facilitate image registration and provide the shift coordinates for the patient support system are considered to be an essential part of the IGRT system. For this reason, simple portal imaging using radiographic film is not included in the above list.

Given this wide spectrum of IGRT methodologies, it is difficult to devise a single generic test procedure that is appropriate for guaranteeing the safe use of this important new technology. However, this standard will describe the features such a test should include so that the potential for error is minimized. This information will allow individual institutions to compare a particular quality assurance (QA) procedure against this list of essential features.

IV. IGRT QUALITY ASSURANCE

Like the somewhat earlier technology of intensity modulated radiation therapy (IMRT), IGRT offers the possibility of significantly enhancing the accuracy and precision of radiation therapy methods and is an important advance in terms of margin reduction to better limit the dose to critical structures. However, also like the changes that occurred with the adoption of IMRT, the introduction of this new step in the radiation therapy process leads to additional changes in the overall QA procedure for the dose delivery system. It is critical that a QA program address the equipment, procedures, and safety of image guidance.

The introduction of IGRT requires the addition of checks that guarantee accurate geometric alignment of the imaging system with the treatment delivery system [1]. This procedure must be designed to include tests to assure that the image registration part of the process of adjusting the patient’s position performs within stated tolerances. Moreover, QA tests aimed at monitoring the image quality must be performed periodically when IGRT is used. Given the recent availability of special patient support systems that allow pitch and roll positioning

corrections, the tests must also include some verification of the performance of this part of the IGRT chain.

A. Equipment Performance and Integration

An image guidance system consists of components to acquire images (radiation sources, detectors, and their mechanical assemblies), measure position (image alignment tools), and perform adjustments (interfaces and equipment for position adjustment). Each of these components requires validation prior to implementation as well as routine checks to ensure safe and effective utilization.

1. Image quality
Image quality is typically characterized by physical measurements such as contrast, resolution, and noise. It can also be evaluated by its impact on the performance of a person or alignment system that uses the images (e.g., via a receiver operation characteristic curve). It is important that consistent measurement methods and phantoms are used for image quality evaluation, and that the methods are ultimately tied to the ability to use these images in practices.
2. Mechanical integrity
Whether room-mounted and rigid or gantry-mounted and moving, imaging equipment must be able to maintain a known relationship to the treatment coordinate system. The configuration and its stability should be established and monitored (e.g., checking of flex maps for centering projections as a function of angle in a gantry mounted system).
3. Registration software
IGRT equipment has both manual and automated alignment tools. These tools have advantages and limits, and these should be understood by evaluation prior to patient imaging. Accuracy and reproducibility of alignment results should be tested, using images similar to those expected to be acquired in a clinic.
4. System integration
There are many commercially available QA phantoms for testing IGRT systems, and an appropriate phantom should be considered essential for IGRT implementation. These phantoms and various test devices often come with a description of the recommended test procedure. It is essential that users verify the appropriateness of this test equipment for guaranteeing the accuracy and precision of the different IGRT systems in their clinic.

The following list describes elements of a typical end-to-end test that can be used to evaluate an IGRT system:

- a. A solid phantom that includes a number of high contrast markers can be used to verify the performance of the IGRT system.
- b. The procedure should start with a CT simulation process that scans the phantom to locate the position of the markers.
- c. The treatment planning system is used to target each marker with at least 2 small treatment fields that are orthogonal or near orthogonal.
- d. The phantom is positioned within the coordinate frame of the delivery system in accordance with the previously generated treatment plan. Setup deviations from planned treatment are introduced by displacing the phantom with translations of known magnitude. Rotational errors can also be introduced to test the correction process when a patient support system with 6 degrees of freedom is available.
- e. After phantom imaging and image registration, the calculated translational and/or rotational displacements are applied in accordance with the clinical procedure for error corrections. Positioning errors are commonly corrected by treatment couch displacements controlled remotely from the delivery system console.
- f. An independent imaging system (e.g., EPID or film) is then used to demonstrate that the markers appear with the small treatment fields at the predicted position.
- g. The record of the IGRT procedure registered in the radiation oncology information system should be inspected to confirm accurate reporting on the session in terms of applied displacements and timeline.

The test should be performed each week when standard fractionation treatments are scheduled. It should be performed each morning when hypofractionated stereotactic radiosurgery (SRS), stereotactic radiation therapy (SRT), or stereotactic body radiation therapy (SBRT) treatment is scheduled.

Intrafraction monitoring systems, while still in a nascent state, are available clinically [2]. Use of these systems requires testing with phantoms that provide both expected movements and related signals to the imaging and/or sensing systems.

5. User and technology dependent issues
Image guidance is unique in that routine operation involves alignment, a potentially

subjective process. An observer's ability to discern soft tissue changes using the different IGRT technologies can vary widely. In some cases, it is extremely difficult to directly view the target tissues as well as critical structures that are to receive a reduced dose relative to the prescription. In these situations, some surrogate must be used instead. While surrounding bony structures are often used to verify position, there must be a careful determination that variation of the location the target and surrounding critical structures relative to the skeleton is adequately compensated for with the use of appropriate margins. It is sometimes possible to use implanted metal markers as a surrogate for the position of the target or targets. This approach also requires QA steps aimed at guaranteeing that the marker marks accurately indicate the extent of the target tissues, and that the seeds do not migrate from the time of treatment planning to the end of treatment.

Ultrasound imaging primarily localizes interfaces of tissues that have different acoustic impedances. Whether alignment of ultrasound images to reference ultrasound or to CT images is performed, issues such as interobserver variability, difficulty of standardizing scanning techniques, and organ motion due to probe pressure all affect treatment verification accuracy and should be appropriately considered in safe and effective use of ultrasound for positioning [3].

6. Information technology
Introduction of IGRT allows accurate targeting of treatment beam to tumors. On the other hand, it also creates substantial amount of image data for management. It therefore requires the effective management of vast amounts of imaging data and patient information. Information systems to manage the patient data, image data, treatment data, clinical trials data, etc. can be quite challenging. The efficiency of storage, retrieval, and display may have significant impact on the clinical operation and information accuracy. The information flow from storage to retrieval should be tested for its accuracy, efficiency, and integrity [4].

B. Correction Strategies

Use of image guidance involves determining a strategy for selecting when to measure, which method to use (e.g., laser, X-ray, CT), and how to act on a measurement. Included in these decisions are selection of appropriate staff qualifications and training. It is critical that

implementation and maintenance of IGRT be supported by a rigorous program of documentation and training.

Three classes of correction strategies exist. The most common is online measurement and adjustment of position. For online adjustment, decisions should be made about the tolerance for a correctable action, taking into account both the accuracy with which measurement and correction can be realistically applied and the sensitivity of plan objectives to these actions. Offline corrections based on retrospective analysis of images from 1 or more days need appropriately tested mechanisms for correctly evaluating and implementing measured adjustments [5]. The last method, adaptive adjustment and plan modification, will require a plan-dependent decision process to be in place. At present, adaptive therapy and a related technology deformable image registration are still too early in the developmental stage for appropriate guidelines to be given [6,7].

The QA team, consisting of representatives from physicians, physicists, dosimetrists, and therapists, should work as a group to define correction strategies [8]. Dry runs of a given strategy should be performed to ensure that the processes and documentation are sufficient. Of significant importance is a practical understanding of the limits of information available for alignment. A physician's specific knowledge may be needed for image evaluation at the treatment unit. The practical tradeoff between treatment margins and the effort required to correct for errors needs to be evaluated. Another contribution to error that IGRT does not address is target delineation uncertainty which can be potentially significant [9].

C. Patient Dose

IGRT methods using ionizing radiations will deliver an absorbed radiation dose to the patient that can in some situations be a significant portion of the prescribed dose for treatment. Furthermore, X-ray imaging irradiates a significantly larger region than the treatment volume, and therefore doses to critical structures may be larger than intended. Management of the IGRT radiation doses requires some radiation physics expertise since it is not appropriate to compare simple diagnostic imaging metrics, such as air kerma or CTDI, to therapeutic doses measured in cGy. Task Group 75 of the AAPM [10] has indicated the need to use effective dose in mSv as the appropriate metric for dose comparisons and has provided simple tabular tools and various scenarios of IGRT in its report. These tools should aid the quality management program in the process of dose management. Image quality is to be judged based on the critical endpoint of the IGRT process: targeting. This endpoint provides a distinction in IGRT image quality that is different from that associated with diagnostic image quality. Thus to control IGRT patient dose it is recommended that dose

management techniques that decrease the ionizing radiation imaging dose without affecting targeting be implemented whenever possible.

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Suggested Reading (Additional articles that are not cited in the document but that the committee recommends for further reading on this topic)

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GLOSSARY

AAPM	American Association of Physicists in Medicine
ACR	American College of Radiology
ART	Adaptive radiation therapy
CBCT	Cone-beam CT
CCRT	Computer-controlled radiation therapy
CT	Computed tomography
DDR	Digitally reconstructed radiographs
EBRT	External beam radiation therapy
EPID	Electronic portal imaging devices
IGRT	Image-guided radiotherapy
IMRT	Intensity modulated radiation therapy
kV	kilovoltage
MV	Megavoltage
QA	Quality Assurance
SRS	Stereotactic radiosurgery
SRT	Stereotactic radiation therapy
SBRT	Stereotactic body radiation therapy

*Guidelines and standards are published annually with an effective date of October 1 in the year in which amended, revised, or approved by the ACR Council. For guidelines and standards published before 1999, the effective date was January 1 following the year in which the guideline or standard was amended, revised, or approved by the ACR Council.

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