ACR–ARS PRACTICE PARAMETER FOR INTENSITY MODULATED RADIATION THERAPY (IMRT)

PREAMBLE

This document is an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. Practice Parameters and Technical Standards are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care[1]. For these reasons and those set forth below, the American College of Radiology and our collaborating medical specialty societies caution against the use of these documents 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 practitioner considering all the circumstances presented. Thus, an approach that differs from the guidance in this document, 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 this document when, in the reasonable judgment of the practitioner, such course of action is indicated by variables such as the condition of the patient, limitations of available resources, or advances in knowledge or technology after publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document may consider documenting in the patient record information sufficient to explain the approach taken.

The practice of medicine involves the science, and 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 the guidance in this document 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 purpose of this document is to assist practitioners in achieving this objective.

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[1] *Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing, 831 N.W.2d 826 (Iowa 2013) Iowa Supreme Court refuses to find that the "ACR Technical Standard for Management of the Use of Radiation in Fluoroscopic Procedures (Revised 2008)" sets a national standard for who may perform fluoroscopic procedures in light of the standard's stated purpose that ACR standards are educational tools and not intended to establish a legal standard of care. See also, Stanley v. McCarver, 63 P.3d 1076 (Ariz. App. 2003) where in a concurring opinion the Court stated that "published standards or guidelines of specialty medical organizations are useful in determining the duty owed or the standard of care applicable in a given situation" even though ACR standards themselves do not establish the standard of care.*

I. INTRODUCTION

This practice parameter was developed collaboratively by the American College of Radiology (ACR) and the American Radium Society (ARS).

In order to achieve optimal patient care outcomes, a major goal of radiation therapy is the delivery of the desired dose distribution of ionizing radiation to target tissue while limiting the radiation dose to the surrounding normal tissues to an acceptable level. With the introduction of intensity-modulated radiation therapy (IMRT) in the early 1990s, it was recognized that dose distributions could be significantly improved to better handle this class of treatment-planning problems. IMRT, like 3-D conformal radiation therapy (3D-CRT), uses beams that conform

each field to the beam's-eye-view (BEV) outline of the target [1]. Before the availability of computer-assisted treatment planning, customized metal alloy blocks were fabricated using rudimentary treatment-planning process with 2-D dosimetry. 3D-CRT was feasible after cross-sectional CT/MRI images became available and allowed radiation fields to be tailored over 3-D target volumes that may have been irregular in shape. Such precision-oriented treatment technology became much more sophisticated with the invention of multileaf collimator (MLC), a motorized beam-shaping device that divides a metal block into an array of inline thin leaves, each being driven swiftly via computerized automation. This revolutionary device enabled the development of IMRT, a modern technique that allows photon beam intensity to be modulated in an intricate manner (within a beam) in order to deliver specific doses to partial target volumes while sparing adjacent critical normal tissues along all BEVs. That is, the beam modulation is created by combining a group of small field segments, each shaped by colinearly paired MLC leaves that allow the radiation beam to traverse through their gap, thereby delivering a specific radiation dose per segment. In essence, IMRT irradiates subregions of the target to different levels, "painting" the dose so that the resulting isodose lines better conform around the target and avoid critical normal tissues.

To efficiently generate the desired dose distribution for complex target and critical structure geometries, a new treatment-planning technique, called inverse planning, was introduced [2]. Through a computerized optimization process, the physicist or dosimetrist enters the anatomic information of tumors and organs at risk (OARs), as delineated by the radiation oncologist, specifies the desired dosimetric outcome and its constraint for each structure of interest (usually in terms of volume-specific dose parameters as depicted on a dose volume histogram [DVH]), and then lets the treatment-planning system (TPS) search for the best beam orientation and intensity pattern over the treatment fields (called "fluence map") to achieve the desired dose constraint goals. The exceedingly efficient computer-assisted iteration approach is described as "inverse" because it differs radically from the traditional "forward" planning of 3D-CRT, in which the dosimetrist must feed into the TPS, beforehand, what field arrangement parameters might bey, and then manually modify the initial assumptions to achieve the desired dose distributions essentially through a trial-and-error process.

The process of care for IMRT therefore consists of multiple steps for treatment-planning and delivery of radiation. After inverse planning, an optimized treatment plan is developed that respects the target dose requirements as well as the dose constraints of the surrounding structures' OARs.

In general, the ability of IMRT to deliver dose preferentially to target structures in close proximity to OARs and other nontarget tissues makes it a powerful tool, enabling radiation oncologists to significantly improve the therapeutic ratio (TR; defined conceptually as the ratio between tumor control and normal tissue toxicity) of external-beam treatment. IMRT has become widely used for a variety of clinical indications, such as tumors of the central nervous system, head and neck, lung, gastrointestinal tract, prostate, female reproductive tract, as well as previously irradiated sites [3-10].

Higher doses can be given via IMRT as a "boost" to the primary tumor bed sequentially after an initial treatment field that covers a broader anatomic region. This follows the traditional practice of the shrinking-field technique, via reduced field sizes with the prescribed dosages of various structures (including the tumor) achieved at different time points, as done traditionally with 3D-CRT.

In addition, IMRT is capable of the so-called simultaneous integrated boost technique. Through the same treatment course, the subclinical spread of cancer cells in a broader area is treated to a relatively lower dose per fraction and lower final dose, whereas the primary tumor is irradiated simultaneously with a higher dose per fraction to a higher final dose. For example, for a head and neck case, one would typically deliver 7,000 cGy in 200-cGy fractions to the primary tumor and bulky lymphadenopathy, 6,300 cGy in 180-cGy fractions to intermediate-risk lymphatic drainage, and 5,600 cGy in 160-cGy fractions to lower-risk lymph node regions, with all 3 volumes treated simultaneously over 35 fractions.

IMRT has the potential of introducing dose heterogeneity within a specific structure because of intensity modulation. The biological consequence remains poorly understood despite collective efforts to propose treatment-planning guidelines such as QUANTEC (Quantitative Analysis of Normal Tissue Effects in the Clinic) for many OARs according their respective DVHs depicting the quantitative spectrum of dose heterogeneity within

the OAR volume. This heterogeneity is the price paid for improved dose conformity.

Another potential pitfall of IMRT is the increased "integral dose"—the sum of total body dose resulting from unintended deposits of radiation dose outside the intended treatment volumes as a result of the use of multiple, fixed fields or rotating arcs. The long-term risks of second malignancies from integral dose are still unclear [11].

Traditional IMRT uses a "fixed-field" or "step-and-shoot" approach that uses a limited number of beam angles for the optimization process. A newer variation of IMRT is volumetric-modulated arc therapy (VMAT), which generates isocentric arcs of radiation beams and provides more degrees of freedom for IMRT planning optimization. Furthermore, by requiring less beam modulation, VMAT can deliver the treatment much faster than a typical fixed-field technique.

This practice parameter focuses on MLC-based IMRT techniques for photon treatment, multiple static segment (step-and-shoot, dynamic segment, sliding window) treatments, VMAT, and binary-collimator tomotherapy. Although compensator-based beam modulation is less common, it remains a means of achieving IMRT.

IMRT treatment delivery demands careful day-by-day reproduction of the treatment plan within the patient. It necessitates levels of precision and accuracy that surpass the requirements of conventional radiation therapy treatment-planning and delivery techniques. The IMRT process requires a coordinated team effort among the radiation oncologist, qualified medical physicist, medical dosimetrist, and radiation therapist. Throughout this complex process, quality assurance (QA) is necessary to achieve the preferred dose distribution with the accuracy and reproducibility that distinguishes such precision treatment. In addition, it is important to have appropriate process design with a well-managed balance between productivity and safety goals, careful attention to maintenance of equipment and interfaces, and adequate training and continuing education of team members, supervisors, and managers—all designed to create and maintain a culture of quality and safety within the radiation oncology department [12]. This practice parameter describes a QA program for IMRT treatment planning and delivery that includes (a) systematic testing of the hardware and software used in the IMRT treatment-planning and delivery process, (b) review of each patient's treatment plan, and (c) review of the physical implementation of the treatment plan.

This practice parameter supplements the ACR–ARS Practice Parameter for Radiation Oncology [13] and the ACR–AAPM Technical Standard for the Performance of Radiation Oncology Physics for External-Beam Therapy [14].

II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR–ARS Practice Parameter for Radiation Oncology, in which qualifications, credentialing, professional relationships, and development are outlined [13].

A. Radiation Oncologist

The responsibilities of the radiation oncologist must be clearly defined and should include the following:

1. Supervise and approve the acquisition of treatment-planning images and the immobilization/repositioning device construction in consultation with other members of the team.
2. Define the goals and requirements of the treatment plan, including the specific dose constraints for the target(s) and nearby critical structure(s).
3. Delineate/contour the tumor or region of interest, preferably using appropriate methodology of the International Commission on Radiation Units and Measurements (ICRU). In certain cases, it will be necessary for the radiation oncologist to request fusion of the computed tomography (CT) planning images with a diagnostic CT, magnetic resonance imaging (MRI), or positron emission tomography (PET) scan to facilitate target delineation. Contour (OARs or "critical normal structures") as clinically appropriate. If contours are done by the dosimetrist, they are reviewed and approved by the physician.
4. Perform final evaluation and approve the final IMRT plan for implementation with attention to whether dose constraints are adequately met.

5. Participate in peer review of IMRT treatment plans in conjunction with other members of the team.
6. Continue management of the patient throughout the course of radiation therapy, including the ongoing acquisition, review, and verification of all treatment-related imaging and clinical management of IMRT-related acute toxicities experienced by the patient.

B. Qualified Medical Physicist

The responsibilities of the qualified medical physicist must be clearly defined and should include the following:

1. Perform acceptance testing, commissioning, and implementation of the IMRT TPS and all subsequent upgrades, including the system's interface with the treatment delivery software and hardware.
2. Understand the limitations and appropriate use of the radiation therapy TPS, including the characteristics of the dose-optimization software, the precision of generated patient and beam geometry, and the applicability of dose-calculation algorithms to different clinical situations, including heterogeneity corrections.
3. Initiate and maintain a QA program for the entire IMRT system, to include the planning system, the delivery system, and the interface between these systems.
4. Act as a technical resource for the IMRT team.
5. Consult and participate with the radiation oncologist and other team members in implementing the immobilization/repositioning system for the patient.
6. Participate in review of contours and anatomic structures for the IMRT plan. When fusion of the planning images with MRI or other diagnostic imaging is performed, the physicist is responsible for accuracy of the image fusion process.
7. Review each patient's IMRT plan for technical accuracy and precision.
8. Provide physical measurements for verification of the IMRT plan.

C. Medical Dosimetrist

The responsibilities of the medical dosimetrist or other designated treatment planner must be clearly defined and should include the following:

1. Contour critical normal structures.
2. Ensure proper orientation of volumetric patient image data on the IMRT TPS (from CT and other fused image data sets).
3. Design and generate the IMRT treatment plan under the direction of the radiation oncologist and qualified medical physicist as required. For step-and-shoot IMRT, this would include ensuring that the beam angles and modulation generated by the TPS optimally fulfill the dose constraints requested by the radiation oncologist.
4. Generate all technical documentation required to implement the IMRT treatment plan.
5. Be available for the first treatment and assist with verification for subsequent treatments as necessary.

D. Radiation Therapist

The responsibilities of the radiation therapist must be clearly defined and should include the following:

1. Understand the proper use of the patient immobilization/repositioning system and fabricate and understand the proper use of devices for IMRT.
2. Under supervision of the radiation oncologist and qualified medical physicist, perform initial (planning) simulation of the patient and generate the medical imaging data appropriate for the IMRT TPS. Under supervision of the radiation oncologist and qualified medical physicist, perform verification (implementation) simulation and verify that the IMRT treatment plan was correctly imported for treatment.
3. Implement the IMRT treatment plan under the supervision of the radiation oncologist and the qualified medical physicist or of the medical dosimetrist under the direction of the qualified medical physicist.
4. Acquire image-guided radiation therapy (IGRT) images prior to individual IMRT treatments to guide target relocalization as set by the radiation oncologist's IGRT directive.
5. Perform periodic evaluation of the stability and ongoing reproducibility of the immobilization/

repositioning system and immediately report inconsistencies beyond accepted tolerances to the radiation oncologist and/or the qualified medical physicist.

E. Continuing Medical Education

CME programs should include radiation oncologists, qualified medical physicists, medical dosimetrists, and radiation therapists.

The continuing education of the physician and qualified medical physicist should be in accordance with the ACR Practice Parameter for Continuing Medical Education (CME) [15].

III. QA FOR THE IMRT TPS

IMRT TPSs are complex. The starting point of the IMRT process is a description of the desired dose distribution in terms of dose volume constraints for the delineated target tissue(s) as well as for the delineated surrounding OARs and nontarget tissues. Based on the dose constraints and on imaging data, a treatment plan is generated (via inverse planning) that shows the resulting dose distribution and the beam parameters required to optimally fulfill the radiation oncologist's goals as set by the IMRT dose constraints. If the dose distribution is not satisfactory, a new plan is created, or if clinically acceptable, the dose constraints can be modified. Based on this iterative optimization process and optimization capabilities used within the IMRT system software, a clinically acceptable dose distribution is found. In mathematical terms, this plan is referred to as the optimized dose distribution. Documentation must exist indicating that the qualified medical physicist has verified and authorized the TPS for the intended clinical use and has established the QA program to monitor each delivery system's performance as it relates to the inverse planning process [16-18].

It is recognized that various testing methods may be used, with equal validity, to ensure that a system feature or component is performing correctly. It is also noted that the commercial manufacturer may recommend specific QA tests to be performed on its planning systems. In this practice parameter, the important elements of the QA program for the IMRT TPS are identified. Information with more scientific detail may be found in appropriate reports of the American Association of Physicists in Medicine (AAPM). It is recommended that the AAPM Task Group 53 procedure for QA of TPSs be used [19].

A. System Log

An ongoing system log should be maintained to record system component failures, error messages, corrective actions, and hardware and software changes.

B. System Data Input Devices

Input systems for image-based planning systems should be checked for functionality and accuracy. There must be correct anatomic registration left, right, anterior, posterior, cephalad, and caudad from all the appropriate input devices (keyboard, mouse, stylus, touchscreen, microphone, etc). If fused or registered image data sets are used, the accuracy of the process should be verified by the radiation oncologist and physicist, even when deformable registration is used.

C. System Output Devices

The functionality and accurary of all system output devices should be tested and verified. System output devices include treatment and immobilization aids as well as printers, plotters, and graphical display units (monitors) that generate BEV rendering of anatomic structures. The functionality, accuracy, and reproducibility of treatment aids, such as immobilization devices, should be confirmed. The correct transfer of MLC control point information along with the corresponding dose for each field shape defined by these points should be tested and confirmed (see Section IV).

D. System Software

The system's software should be periodically verified for the following steps in the planning and delivery processes:

1. Ensuring the continued integrity of the TPSs information files used for modeling the external radiation beams
2. Confirming agreement of the beam modeling to current clinical data derived from physical measurements
3. Ensuring the integrity of the system to render the anatomic modeling correctly, including CT number consistency for conversion to relative electron density
4. Ensuring the consistency of dose optimization software
5. Confirming the accuracy of the system-generated DVHs and other tools for plan evaluation
6. Confirming the accuracy of the calculated monitor units

IV. IMRT TREATMENT PLAN IMPLEMENTATION

Conforming the dose distribution to the target tissues with a high degree of precision and accuracy requires a greater complexity than non-IMRT treatments, not only in the planning aspects but also in the implementation process. The planning process may include inhomogeneity correction, if appropriate, in optimization and dose calculations. The inhomogeneity correction algorithm should be validated for accuracy for a wide range of densities and field sizes. It is important to point out that the use of Clarkson integration or pencil-beam algorithms has been shown to be unacceptable as a final calculation when treating in the thorax region [20]. Some systems use these algorithms for initial optimization. This practice is acceptable when a more accurate algorithm (eg, a Monte Carlo or superposition/convolution calculation) is used for a final calculation. The implementation process may be defined as an accurate registration of the patient geometry with the dose-delivery geometry of the treatment unit. The relationship between those 2 geometries is specified by the IMRT treatment plan that delineates patient anatomy relative to the external-beam parameters of the treatment unit. Implementation requires attention to detail and the combined skills of all members of the treatment team.

The following are required:

A. Correct Patient Positioning

The patient geometry must be reproducible and in correct registration relative to the treatment unit. Immobilization devices are necessary to ensure accurate, reproducible positioning of the patient relative to the treatment unit. Specific organ-immobilization or motion-gating devices may aid in reproducible treatment delivery. The treatment delivery system should include IGRT capabilities. These systems work together with good patient immobilization to guarantee reproducible patient positioning [21,22]. An important aspect of daily target localization is accurately following positioning instructions, especially when the reference point used during simulation differs from the isocenter specified during treatment planning. This shift information must be verified daily during the treatment course and with special attention during the initial patient setup or verification.

B. Correct Beam Delivery Parameters

All beam delivery parameters of the IMRT plan must be correctly transferred to the treatment unit and verified. This means using the approved treatment plan specifications: beam energies, jaw settings, treatment aids, collimator position, gantry position and motion, treatment table settings, treatment distance, and isocenter location. In particular, MLC positioning and motion with the appropriate monitor unit settings must correspond to the approved settings of the treatment plan.

V. IMRT DELIVERY SYSTEM QA

IMRT can be delivered with a standard MLC, a binary MLC, multiple pencil beams, or milled compensating filters. Typically for the use of the MLC device, the leaves of these collimators project to a nominal beam width of 1 cm or less at the treatment unit isocenter. The delivery methods include, for example, multiple static segment treatment (step-and-shoot); dynamic segment treatment (sliding window); rotating gantry with dynamic segment treatment (VMAT); binary-collimator tomotherapy; sequential pencil-beam treatment; and high-resolution, milled compensator-based systems. The precision and reproducibility of an IMRT treatment require the delivery system to accurately carry out the treatment as planned. A fundamental difference with IMRT dose delivery relative to conventional therapy is the mechanical accuracy of the MLC. The accuracy of the delivered dose depends on the accuracy of the individual leaf position at various points in time and leaf-gap width. Incorporating routine QA of the MLC into the facility's ongoing QA program is essential.

A. MLC Leaf Position Accuracy

Leaf position accuracy affects the dose at the edges of a conventional static treatment field, but with IMRT or VMAT delivery, it also affects the dose within the target because the leaves build the dose as they move to different positions across the target volume. A 1- to 2-mm leaf position tolerance may be acceptable for conventional fields, but submillimeter tolerance is necessary for accurate IMRT or VMAT dose delivery. As part of a routine QA process, MLC test patterns should be created to verify precise modeling of the penumbra for each leaf as well as its localization in space. These patterns should be executed at different collimator and gantry combinations and over the entire range of travel for all leaf pairs. These tests should be performed periodically and after each service or repair of the MLC as well as after any changes in the dose-delivery software. Precise localization and modeling of the MLC leaf end are equally important for both segmental and dynamic MLC delivery.

B. Segmental MLC and Dynamic MLC IMRT Delivery

Small field sizes and short treatment times pose particular challenges. Inverse treatment planning can result in either small field gaps for dynamic MLC (dMLC) delivery or small apertures coupled with a small number of monitor units for dose delivery using the segmental MLC technique. Both situations are problematic, and special attention is needed to avoid delivery errors. Nonlinearity within this region can have a significant impact on the dose delivered. An evaluation of beam stability at beam-on and within the first few monitor units is important.

C. Volumetric-Modulated Arc Therapy

VMAT makes it possible to deliver IMRT using arc rotation techniques [23,24] in contrast to static segment, fixed-field, or step-and-shoot IMRT, as discussed in the introduction. The dose rate and speed of gantry rotation may vary in addition to the MLC leaf positions throughout the delivery of therapy. The added variable relative to fixed-gantry IMRT introduces the need for special QA considerations when using VMAT. For example, QA procedures must guarantee that the dose rate, collimator leaf positions, and gantry angle are properly synchronized at each point in time. Leaf calibration and modeling are equally important for the VMAT dose-delivery technique. In this case, it is harder to determine that the MLC leaves track properly with the rotating gantry and changing dose rate. Various tests specific to the use of VMAT delivery are discussed in 2 publications [25,26]. These tests are similar to the ones suggested for dMLC IMRT delivery but add the rotating gantry to the test procedures.

D. Compensator-based System

For gantry-mounted accelerators, beam modulation can be accomplished by substituting a solid-beam attenuator or compensator for the MLC approach [27,28]. Relative to the use of the MLC, compensators have advantages and disadvantages. However, a major advantage of this approach is that linear accelerators without MLCs that depend on gantry-mounted treatment equipment can be used for IMRT. Although some QA requirements for compensator-based IMRT may be different than the tests detailed in this document, it is recommended that a verification testing procedure be used to guarantee that the correct compensator is inserted for each gantry angle (see Section VI below). Furthermore, other testing must be modified to apply to this technology. For example, the equivalent to the localization of the MLC leaf end is a test that guarantees that the compensator is securely locked on the treatment head in the correct position relative to the beam center axis.

E. Benchmark End-to-End Testing

This test is recommended both for commissioning newly delivered equipment and as a routine QA tool, a means for verifying performance of the entire process extending from CT simulation to treatment delivery. The end-to-end test includes CT simulation, inverse treatment planning, transfer of the treatment plan parameters to the delivery system, and actual dose delivery [29,30]. It is not intended as a replacement for individual component testing but rather as a supplement to ensure that the separate components work together to yield the desired dose distribution. A simple version of the end-to-end test uses a block phantom containing a calibrated internal dosimetry system. The phantom is imaged on the CT simulation device. Treatment fields are created using the inverse planning system, and the "fictitious" test plan is sent to the delivery device. The block phantom is placed on the treatment couch with laser triangulation or IGRT imaging used for positioning, and the test plan is delivered to the phantom. The dosimeters may then be used to verify the delivery of the radiation dose as planned.

VI. PATIENT-SPECIFIC QA

Patient-specific QA must be performed before clinical treatment begins. Further QA procedures are then continued throughout the IMRT treatment process. Such patient-specific treatment verification is linked to implementation; it may be considered the confirmatory phase of the IMRT treatment process, ensuring compliance with the aforementioned sections for the individual patient. Through a process that starts before the initiation of treatment and then continues throughout the course of treatment, verification data confirm the correctness of the administered dose using transfer of both the technical setup and the dose-delivery data. The radiation oncologist must remain available to adjust, modify, and revise any aspects of the initial plan as the clinical situation warrants.

Verification of the patient treatment plan includes documentation of all of the elements associated with implementation as well as images of treatment ports and physical dose measurements. Each facility should develop its own policies and procedures to achieve daily correlation between the IMRT plan and dose delivery. Treatment verification elements are described below.

A. Treatment Unit Verification Data

Correct verification of the IMRT plan in the actual clinical setting requires proper understanding, interpretation, transfer, and documentation of all aspects of the patient's clinical setup, positioning, and immobilization, as well as treatment unit parameters, such as jaw settings, MLC settings, patient positioning devices, gantry angles, collimator angles, patient support table angles and position, settings, and treatment distance under reference conditions. Radiation oncology information management systems enable transfer of the patient's specific treatment parameters to the dose-delivery unit and ongoing verifications of the actual treatment unit parameters in a computer record for each patient.

B. Image-based Verification Data

In addition to verification and documentation of treatment unit data, congruence between daily on-treatment images and approved simulation CT images or digitally reconstructed radiographs is necessary for accurate treatment delivery. This method (IGRT) involves a comparison between the simulation images and images obtained with the treatment unit while the patient is in position for treatment. Such images include cone-beam CT, ultrasound, MRI, orthogonal kilovoltage images, and portal megavoltage images produced with the treatment beam. These images, when approved by the radiation oncologist, ensure that the subsequent treatment is properly administered to the designated clinical volumes [31].

Although each facility establishes its own provisions for initial and ongoing imaging throughout the treatment process, at a minimum consideration should be given to the use of 2 different BEV images, such as concurrent lateral and anteroposterior views (orthogonal), to delineate the correct placement of the beam's isocenter relative to patient anatomy. Such confirmation of patient positioning should be performed initially and then periodically, at least weekly, throughout the course of the patient's treatment. When necessary, verification images for each field may be acquired for each treatment field (for plans using fixed fields) to verify the initial settings of the collimator, MLC, and gantry for that field, particularly at sites that do not have access to on-board volumetric imaging (cone-beam CT, MRI).

C. Dose-Delivery Verification by Physical Measurement

The qualified medical physicist should ensure verification of actual radiation doses being received during treatment delivery. Prior to the start of treatment and by using all of the parameters of the patient's treatment plan, the accuracy of dose delivery should be documented by irradiating a phantom containing a calibrated dosimetry system to verify that the dose delivered is the dose planned. Multiple points in the delivered distribution should be compared against the planned distribution, as can be accomplished—for example, using film dosimetry within the phantom [29,30,32,33]. This testing procedure has been termed "patient-specific end-to-end testing."

Acceptable alternative tests provide equivalent or even more detailed verification. It is the responsibility of the qualified medical physicist to ensure the equivalence or superiority of an alternative testing procedure. For example, one such method uses a 2-D or 3-D detector array to verify intensity patterns of individual fields or VMAT arcs as well as the summed pattern for the entire treatment delivery. This technique may be considered to provide equivalent information for IMRT or VMAT delivery as long as the pattern for each gantry position is verified together with the summed pattern and as long as the TPS provides the necessary analogous information for comparison [34].

D. Backup Monitor Unit Calculations

Backup monitor unit calculations are strongly recommended. These repeat the process that is performed by the TPS, using an independent software system. Data should be collected and input into the software package, including basic treatment unit–commissioning information as well as information from the TPS, such as the field apertures selected for the patient's plan and the depth to the calculation point. Of note, although it is a useful supplement, the backup monitor unit calculation is not a replacement for the patient-specific end-to-end test.

VII. DOCUMENTATION

Reporting should be in accordance with the ACR–ARS Practice Parameter for Communication: Radiation Oncology [35,36].

In addition to patient and organ site-specific dose volume constraints, documentation of delivered doses to volumes of target and nontarget tissues, in the form of DVHs and representative cross-sectional isodose treatment diagrams, should be maintained in the patient's medical record. As noted above, various treatment verification methodologies, including daily treatment unit parameters, images confirming proper patient positioning, and records of physical measurements confirming treatment dosimetry, should also be incorporated into the patient's record.

VIII. QUALITY CONTROL AND IMPROVEMENT, SAFETY, AND PATIENT EDUCATION

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control, and Patient Education appearing under the heading *ACR Position Statement on Quality Control and Improvement, Safety, Infection Control and Patient Education* on the ACR website (https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement).

A. Patient and Personnel Safety

Because of the larger number of monitor units needed to deliver IMRT treatments relative to those used in conventional treatment plans, room-shielding issues must be addressed, including primary barrier and secondary barrier requirements [37]. Beam leakage and secondary scatter should also be documented at the time of IMRT commissioning and periodically monitored over the equipment's lifespan. Use of a voluntary error-reporting system, such as the Radiation Oncology Incident Learning System [38], and implementation of checklists and time-outs at important junctures during patient treatment planning and delivery are recommended for ensuring patient safety and treatment efficacy.

B. Continuing Quality Improvement

The medical director of radiation oncology is responsible for the institution and ongoing supervision of the continuing quality improvement program as described in the ACR–ARS Practice Parameter for Radiation Oncology [13] and the ACR–AAPM Technical Standard for the Performance of Radiation Oncology Physics for External-Beam Therapy [14]. It is the director's responsibility to identify problems, see that actions are taken, and evaluate the effectiveness of the actions.

SUMMARY

IMRT is a widely used clinical modality that has enabled radiation oncologists to deliver higher doses of radiation to target structures while reducing doses to adjacent normal critical tissues, thereby improving therapeutic outcomes in many clinical areas. Successful IMRT programs involve integration of many processes: patient selection, patient positioning/immobilization, target definition, treatment plan development, and accurate treatment delivery. Appropriate QA procedures, including patient-specific QA measures, are essential for maintaining the quality of an IMRT program and ensuring patient safety.

ACKNOWLEDGEMENTS

This practice parameter was revised according to the process described under the heading *PP/TS Development Process and Timeline* on the ACR website (https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards) by the Committee on Practice Parameters – Radiation Oncology of the ACR Commission on Radiation Oncology.

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*As of May 2010, all radiation oncology collaborative practice parameters are approved by the ACR Council Steering Committee and the ACR Board of Chancellors and will not go through the ACR Council (ACR Resolution 8, 2010). The effective date is displayed below:

<u>Development Chronology for This Practice Parameter</u>
2002 (Resolution 17)
Revised 2007 (Resolution 17)
Revised 2011 (CSC/BOC) – Effective August 1, 2011
Amended 2014 (Resolution 39)

Revised 2016 (Resolution 40)
Revised 2021 (CSC/BOC)
Revised 2021 (CSC/BOC)
Amended 2023 (Resolution 2c)