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ACR –ASTRO PRACTICE GUIDELINE FOR INTENSITY MODULATED RADIATION THERAPY (IMRT)

PREAMBLE

These guidelines are an educational tool designed to assist practitioners in providing appropriate radiation oncology 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

This guideline was revised collaboratively by the American College of Radiology (ACR) and the American Society for Radiation Oncology (ASTRO). It is an updated version of the [ACR–ASTRO Practice Guideline for Intensity Modulated Radiation Therapy \(IMRT\)](#) previously adopted in 2007 [1]. Separate, but complementary ACR–ASTRO Practice Guidelines exist for Stereotactic Body Radiation Therapy (SBRT) and Image-Guided Radiation Therapy (IGRT) [2-3].

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 is different than the older treatment technique of 3D conformal radiation therapy (3D-CRT) that conforms each field to the beam’s-eye view outline of the target [4]. Instead, IMRT irradiates subregions of the target to different levels, “painting” the dose so that isodose lines better conform around critical healthy tissues. In order to efficiently generate the desired dose distribution for complex target and critical structure geometries, a new

treatment planning technique, called inverse planning, was introduced [5].

The process of care for IMRT consists of multiple steps for treatment planning and delivery of radiation. Inverse planning should be used for IMRT. In this process delineation of both the target volume and the surrounding tissues at risk is required to decrease the dose to volumes of nontarget structures while achieving prescription doses to the target volume. An optimized treatment plan is developed that respects the target dose requirements as well as the dose constraints of the surrounding dose-limiting structures. IMRT treatment delivery demands careful, day-by-day reproduction of the treatment plan within the patient. 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.

IMRT has become widely used for a variety of clinical indications, such as tumors of the central nervous system, head and neck, breast, prostate, gastrointestinal tract, and gynecologic system, as well as sites previously irradiated [6-9]. In general, the ability of IMRT to deliver dose preferentially to target structures in close proximity to organs at risk (OAR) and other non-target tissues makes it a valuable tool enabling the radiation oncologist to deliver dose to target volumes while minimizing dose to adjacent normal tissues.

This guideline focuses on multileaf collimator (MLC)-based IMRT techniques for photon treatment, such as multiple static segment (step-and-shoot) treatment, dynamic segment (sliding-window) treatment, volumetric modulated arc therapy (VMAT), and binary-collimator tomotherapy. Compensator-based beam modulation is also used as a means of achieving IMRT.

IMRT demands levels of precision and accuracy that surpass the requirements of conventional radiotherapy treatment planning and delivery techniques. The IMRT process requires a coordinated team effort between the radiation oncologist, the medical physicist, the medical dosimetrist, and the radiation therapist. 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 [10]. This guideline 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 guideline supplements the [ACR Practice Guideline for Radiation Oncology](#) [11] and the [ACR Technical Standard for the Performance of Radiation Oncology Physics for External Beam Therapy](#) [12].

II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the [ACR Practice Guideline for Radiation Oncology](#) where qualifications, credentialing, professional relationships, and development are outlined [11].

A. Radiation Oncologist

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

1. Participate in and approve the immobilization/repositioning system 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 tumor and specify and approve target volumes, preferably using appropriate methodology of the International Commission on Radiation Units and Measurements (ICRU).
4. Contour critical normal structures not clearly discernible on cross-section.
5. Review and approve all critical structures contoured.
6. Perform final evaluation and approve the final IMRT plan for implementation.
7. Participate in peer review of IMRT treatment plans in conjunction with other members of the team.
8. Continue management of the patient throughout the course of radiation therapy, including the ongoing acquisition, review, and verification of all treatment-related imaging.

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 treatment-planning system and all subsequent upgrades, including the systems interface with the treatment delivery software and hardware.
2. Understand the limitations and appropriate use of the radiation therapy treatment planning (RTP) system, 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.
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 clearly discernible critical normal structures.
2. Ensure proper orientation of volumetric patient image data on the IMRT RTP system (from CT and other fused image data sets).
3. Design and generate the IMRT treatment plan under the direction of the radiation oncologist and medical physicist as required.
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 medical physicist, perform initial (planning) simulation of the patient and generate the medical imaging data appropriate for the IMRT RTP system.
3. Under supervision of the radiation oncologist and medical physicist, perform verification (implementation) simulation and verify that the IMRT treatment plan was correctly imported for treatment.

4. Implement the IMRT treatment plan under the supervision of the radiation oncologist and the medical physicist or of the medical dosimetrist under the direction of the medical physicist.
5. Acquire periodic verification or image-guided radiation therapy (IGRT) images for review by the radiation oncologist.
6. Perform periodic evaluation of the stability and ongoing reproducibility of the immobilization/repositioning system and report inconsistencies immediately to the radiation oncologist and the medical physicist.

E. Continuing Medical Education

Continuing medical education programs should include radiation oncologists, 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 Guideline for Continuing Medical Education \(CME\)](#) [13].

III. QA FOR THE IMRT TREATMENT PLANNING SYSTEM

IMRT RTP systems 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 organs at risk (OAR) and nontarget tissues. Based on the dose constraints and on imaging data, a treatment plan is generated that shows the resulting dose distribution and the beam parameters required for its realization. If the dose distribution is not satisfactory, the initial dose constraints are modified, and a new plan is developed. This iterative process is continued until a clinically acceptable dose distribution has been found. In mathematical terms, this plan is referred to as the optimized dose distribution. Documentation must exist indicating that the medical physicist has authorized the RTP system for the intended clinical use and has established the QA program to monitor the delivery system's performance as it relates to the inverse planning process [14-16].

It is recognized that various testing methods may be used, with equal validity, to assure 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 guideline, the important elements of the QA program for the IMRT RTP system 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 treatment planning systems be used [17].

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. If fused or registered image data sets are used, the accuracy should be verified.

C. System Output Devices

The functionality and accuracy of all printers, plotters, and graphical display units that produce, using digitally reconstructed radiographs (DRRs) or the like, a beam's-eye view (BEV) rendering of anatomic structures and/or treatment aids should be assured. There must also be checks to assure correct transfer of MLC control point information along with the corresponding dose for each field shape defined by these points (see section IV).

D. System Software

The system's software should facilitate:

1. Assuring the continued integrity of the RTP system's 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. Assuring the integrity of the system to render the anatomic modeling correctly, including CT number consistency for conversion to relative electron density.
4. Assuring the consistency of dose optimization software.
5. Confirming the accuracy of the system-generated dose volume histograms (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, not only in the planning aspects but also in the implementation process. The planning process must

include inhomogeneity correction in optimization and dose calculations. The inhomogeneity correction algorithm should have been 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 [18]. Some systems use these algorithms for initial optimization. This practice is acceptable when a more accurate algorithm (e.g., 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 two 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 be in correct registration relative to the treatment unit. Immobilization devices are necessary to assure accurate, reproducible positioning of the patient relative to the treatment unit. Specific organ-immobilization or motion-gating devices may aid in reproducible treatment delivery. Many modern treatment delivery systems include IGRT capabilities. These systems work together with good patient immobilization to guarantee reproducible patient positioning [2,19]. An important aspect of daily target localization is the accurate implementation of positioning instructions 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.

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 QUALITY ASSURANCE

IMRT is often delivered with a standard MLC, a binary MLC, multiple pencil beams, or milled compensating filters. Typically, 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), binary-collimator tomotherapy, sequential pencil-beam treatment, and high-resolution, milled compensator-based systems. The volume arc delivery techniques also use a standard MLC. 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 individual leaf position and the 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 VMAT delivery it 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 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. Precise localization and modeling of the MLC leaf end are equally important for both segmental and dynamic MLC delivery. As discussed in section C below, precise localization and modeling of the MLC are also important for VMAT dose 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 (sMLC) 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

Volumetric Modulated Arc Therapy (VMAT) makes it possible to deliver IMRT using arc rotation techniques [20-21]. 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 coordinated 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 two recent publications [22-23]. 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 [24-25]. Relative to the use of the MLC, compensators have advantages and disadvantages. However, a major advantage of this approach is that gantry mounted treatment equipment that does not include an MLC 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 from CT simulation to treatment of a single process. 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 [26-27]. It is not intended as a replacement for individual component testing, but rather as a supplement to assure 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 established using the inverse planning system, and the 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 treatment 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 QUALITY ASSURANCE

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, assuring 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 setting, treatment aids, gantry angle, collimator angle, patient support table angle and position, treatment distance, and MLC setting. Record-and-verify systems allow for ongoing verification of the patient specific treatment parameters on the dose delivery unit and capture details of the actual treatment unit parameters in a computer record for each patient.

B. Image-Based Verification Data

In addition to documentation of treatment unit data, congruence between portal images and approved simulator films or DRRs is necessary for accurate treatment delivery. This method involves a comparison between the simulated images and actual images obtained with the treatment unit. Traditionally, this method used pretreatment images recorded on film, which, when approved by the radiation oncologist, assured that the

subsequent treatment delivered is properly administered to the designated clinical volumes.

Although each facility establishes its own provisions for initial and ongoing portal imaging throughout the treatment process, consideration should be given to the use of two different BEV images, such as concurrent lateral and anteroposterior (AP) views, 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. Verification images for each field should be acquired for each treatment field to verify the orientation of the MLC arrangement for that field.

C. Dose Delivery Verification by Physical Measurement

The medical physicist should assure verification of actual radiation doses being received during treatment delivery. Prior to the start of treatment and 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 [26-29]. 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 medical physicist to assure the equivalence or superiority of an alternative testing procedure. For example, one such method uses a two-dimensional detector array to verify intensity patterns of individual fields as well as the summed pattern for the entire IMRT plan. This technique may be considered to provide equivalent information for IMRT fixed gantry angle delivery, as long as the pattern for each gantry position is verified together with the summed pattern, and as long as the treatment planning system provides the necessary analogous information for comparison.

D. Backup Monitor Unit Calculations

Backup monitor unit calculations are strongly recommended. These repeat the process that is performed by the treatment planning system, using an independent software system. Data are gathered and input into the software package, including basic treatment unit commissioning information as well as information from the treatment planning system, 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 Practice Guideline for Communication: Radiation Oncology](#) [30-31].

Documentation of delivered doses to volumes of target and nontarget tissues, in the form of dose volume histograms and representative cross-sectional isodose treatment diagrams, should be maintained in the patient's written or electronic 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 *Position Statement on QC & Improvement, Safety, Infection Control, and Patient Education* on the ACR web site (<http://www.acr.org/guidelines>).

A. Patient and Personnel Safety

Due to 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 [32]. Beam leakage and secondary scatter should also be documented at the time of IMRT commissioning and periodically monitored over the equipment's lifespan.

B. Continuing Quality Improvement

The Medical Director of Radiation Oncology is responsible for the institution and ongoing supervision of the continuing quality improvement (CQI) program as described in the [ACR Practice Guideline for Radiation Oncology](#) and the [ACR Technical Standard for the Performance of Radiation Oncology Physics for External Beam Therapy](#) [11-12]. 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 assuring patient safety.

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Collaborative Committee – members represent their societies in the initial and final revision of this guideline

ACR

Alan C. Hartford, MD, PhD, Chair
James M. Galvin, DSc, FACR
Geoffrey S. Ibbott, PhD, FACR
Seth A. Rosenthal, MD, FACR

ASTRO

David C. Beyer, MD, FACR
Thomas J. Eichler, MD
Brian Kavanagh, MD
Christopher J. Schultz, MD

Guidelines and Standards Committee – Radiation Oncology – ACR Committee responsible for sponsoring the draft through the process

Seth A. Rosenthal, MD, FACR, Chair
Alan C. Hartford, MD, PhD, Vice Chair
Nathan H. J. Bittner, MD
Patrick D. Conway, MD
Nancy A. Ellerbroek, MD, FACR
Beth A. Erickson-Wittmann, MD, FACR
Felix Y. Feng, MD
James M. Galvin, DSc, FACR
Brian J. Goldsmith, MD
Geoffrey S. Ibbott, PhD, FACR
Tariq A. Mian, PhD, FACR
Louis Potters, MD, FACR
Michael A. Samuels, MD, FACR
Steven K. Seung, MD, PhD
Maria T. Vlachaki, MD, PhD, MBA, FACR
Suzanne L. Wolden, MD, FACR
Albert L. Blumberg, MD, FACR, Chair, Commission

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*As of May 2010, all radiation oncology collaborative guidelines 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:

Development Chronology for this Guideline

2002 (Resolution 17)

Revised 2007 (Resolution 17)

Revised 2011 (CSC/BOC) – Effective August 1, 2011