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ACR–AAPM TECHNICAL STANDARD FOR MEDICAL PHYSICS PERFORMANCE MONITORING OF STEREOTACTIC BODY RADIATION THERAPY (SBRT)

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 care¹. 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 in light of 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 the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document 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 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 sole purpose of this document is to assist practitioners in achieving this objective.

¹ Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing, ___ N.W.2d ___ (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 technical standard was developed collaboratively by the American College of Radiology (ACR) and the American Association of Physicists in Medicine (AAPM).

The purpose of this technical standard is to provide guidance to medical physicists and to define quality criteria in view of the high technical demands of stereotactic body radiation therapy (SBRT).

SBRT delivers a high dose of radiation to a relatively small extracranial tumor or a few nearby tumors in five or fewer fractions, with a precise positioning and targeting system using stereotactic equipment and methods. The biological effectiveness for any SBRT treatment is equivalent to or larger than that given with conventional radiation treatment schedules, and the clinician must be cognizant as to the corresponding dose tolerances of normal tissues [1]. To minimize tissue toxicity in SBRT, extensive, highly conformal planning efforts are made to generate an isodose distribution that results in tight conformity with the target volumes, and achieves rapid fall-off in the dose to the surrounding normal tissues. As a result of the highly conformal dose distributions of SBRT treatment plans, accurate and precise delivery of the planned dose to the target volumes is a necessity. Suboptimal targeting may not only lead to underdosing of the target volumes but also increase the risk of radiation damage to the surrounding normal tissues.

The accuracy and precision of treatment delivery requires a combination of calibrated radiation delivery systems, dedicated imaging systems, and proper patient immobilization devices [2,3]. The radiation delivery system (usually a linear accelerator) should be calibrated for accurate radiation output and desired mechanical specifications. The imaging systems should be able to locate, verify, and, if equipped, track the position of the target. Immobilization devices are needed to help reproduce the patient's simulation position determined at the time of simulation and reduce intrafraction motion. Proper motion management techniques should be applied for moving targets.

This document addresses medical physics performance monitoring of SBRT delivered with megavoltage photons, although other radiation beams may be used for SBRT. Exclusion of other beams, such as protons, from the scope of this document does not imply any ACR-AAPM position regarding the appropriateness of delivering such treatments using protons. During irradiation with photons, multiple options are available for the radiation beams. These options include multiple conformal fields at different fixed gantry positions, with or without intensity-modulated radiation therapy (IMRT) techniques: multiple unmodulated conformal arcs, multiple, modulated rotational arcs, and multiple robotically directed circular or shaped beams.

II. QUALIFICATIONS AND RESPONSIBILITIES OF QUALIFIED MEDICAL PHYSICIST

A Qualified Medical Physicist (QMP) must carry out acceptance testing and monitoring of SBRT equipment.

A QMP is an individual who is competent to practice independently in one or more of the subfields in medical physics. The American College of Radiology (ACR) considers certification, 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 strongly recommends that the individual be certified in the appropriate subfield(s) by the American Board of Radiology (ABR), the Canadian College of Physicists in Medicine, or the American Board of Medical Physics (ABMP).

A QMP should meet the [ACR Practice Parameter for Continuing Medical Education \(CME\)](#). (ACR Resolution 17, adopted in 1996 – revised in 2012, Resolution 42). [4]

Additional information can be found in the AAPM-RSS Medical Physics Practice Guidelines 9.a. for SRS-SBRT [5].

The appropriate subfield of medical physics for this standard is Therapeutic Medical Physics (including medical physics certification categories of Radiological Physics, Therapeutic Radiological Physics, and Radiation Oncology Physics).

The QMP must also meet any qualifications imposed by the state and/or local government agency to practice radiation oncology physics and/or to provide oversight of the establishment and conduct of the physics quality management program.

In addition, specific training in SBRT should be obtained prior to the starting of an SBRT program.

The QMP is responsible for the technical aspects of SBRT and must be available for consultation and supervision throughout the entire SBRT procedure. Those responsibilities must be clearly defined and should include the following:

1. Planning and acquisition of equipment/devices for SBRT program.
2. Acceptance testing and commissioning of the SBRT system, thereby ensuring its geometric and dosimetric precision and accuracy. This includes the following:
 - a. Localization devices used for accurate determination of target coordinates
 - b. The dedicated beam model in the treatment planning system (TPS)
 - c. The SBRT external beam-delivery unit and associated record and verify system (R&V)
 - d. Imaging units for simulation and image guidance (IG) in the treatment room
 - e. The motion management equipment
3. Implementing and managing quality assurance (QA) programs for the SBRT system to ensure proper functioning of the following:
 - a. The SBRT external beam-delivery unit
 - b. Imaging units for simulation and IG in the treatment room
 - c. The TPS commissioned for SBRT
 - d. Immobilization devices
 - e. Patient-specific QA (PSQA) software and devices
4. Monitoring the treatment delivery process
 - a. Verification of proper delivery of planned treatments by way of end-to-end testing
 - b. Establishing a comprehensive quality control (QC) checklist that acts as a detailed guide to the entire treatment process
5. Monitoring the treatment planning process
 - a. Directly supervising or checking the treatment planning process
 - b. Communicating with the radiation oncologist to develop an appropriate patient plan
 - c. Using the plan approved by the radiation oncologist to determine and check the appropriate beam-delivery practice parameters; this includes the calculation of the radiation beam parameters consistent with the beam geometry
 - d. PSQA
6. Supervision of the procedure
 - a. Ensuring that the beam-delivery process on the treatment unit accurately fulfills the prescription of the radiation oncologist
7. Providing written reports and any follow-up procedures to the appropriate personnel

III. PERFORMANCE CHARACTERISTICS TO BE MONITORED

A. Acceptance Testing

Initial performance testing of SBRT equipment must be performed upon installation and should be completed before clinical use. This testing should be more comprehensive than periodic performance testing and should be consistent with current acceptance testing practices.

The QMP must be involved with the process of facility or department design, equipment selection and specifications, and must provide direct supervision during the acceptance testing process. Customer acceptance test procedures are intended to ensure that the equipment satisfies the performance requirements stated in the purchase agreement, including that the equipment is safe to operate. In some cases, measurements completed as part of the

acceptance procedures may also serve as components in establishing the routine QA program. The vendor must demonstrate acceptable system performance.

Additional information can be found in the AAPM-RSS Medical Physics Practice Guideline 9.a. for SRS-SBRT [5].

B. Performance Evaluation

1. Commissioning

To determine the scope of SRS-SBRT commissioning, the QMP must understand the scope of clinical procedures/services to be offered. Commissioning encompasses the overall process of validating the planning and delivery system for the services to be offered, and developing appropriate QC and technical procedures to support these services.

Commissioning of SBRT systems includes, but is not limited to, a safety and geometric accuracy evaluation of the treatment and imaging components, comprehensive small-field data measurement with appropriate detectors, evaluation of TPS capabilities, including multimodality image processing and calculation accuracy for small fields, end-to-end testing, and the development of a comprehensive QA program.

Additional information can be found in the AAPM-RSS Medical Physics Practice Guideline 9.a. for SRS-SBRT [5].

2. Treatment delivery machine

Procedures for calibrating treatment machines must follow those protocols currently published by the AAPM and adhere to state and federal guidelines.

Acceptance, commissioning, and ongoing QA of the SBRT treatment machine should follow manufacturer recommendations, the recommendations of AAPM Task Group report 106, AAPM Task Group report 135 (for robotic linac systems), and AAPM Task Group 142 as well as any other pertinent published documents [6-8]. For acceptance testing, the manufacturer's protocol should be followed and documented. For commissioning, one should pay particular attention to the requirements delineated by the TPS as well as small-field measurement considerations set forth in the TG-106 document [6]. For ongoing QA, one should pay particular attention to the SBRT tolerances set forth in the TG-142 document [8].

3. R&V

R&V systems not only record and verify the correct delivery of an SBRT treatment but also control all technical aspects of the SBRT delivery system. Because of the high patient safety risk potential, careful deliberation evaluation for quality and safety settings must be completed specific for SBRT treatments. The validity of R&V settings must be tested, verified, and documented.

4. Immobilization devices [9]

Immobilization devices are essential to the reduction of motion, stability, and reproducibility of the setup that is needed for accurate SBRT treatments. The effective performance of such devices will vary depending on IG system, effective staff training, and patient selection. Initial evaluation of specific devices should be done to determine the effective range of variability and accuracy with individual systems. The physicist and team should review relevant vendor documentation and the literature when identifying limitations in the devices and methods to achieve appropriate accuracy and precision. Evaluation of beam attenuation and surface dose should be included in the process. An ongoing evaluation of the effectiveness of the immobilization devices should be conducted to identify areas of improvement and deviations from normal accuracy of the devices. Details of the specific devices should be reviewed by physicians, physicists, dosimetrists, and therapists, with each group receiving sufficient training to achieve expected reproducibility and stability in setup [2,5].

In many situations, additional immobilization may be needed beyond that which is typically used in conventional radiotherapy.

5. Ancillary systems for imaging and motion management

IG is used to reduce the spatial uncertainty in the positioning of targets prior to radiation delivery and may also be used to monitor the position of the target or a surrogate during radiation delivery.

The image-guided radiation therapy (IGRT) system(s) used to support the SBRT service should be assessed for systematic and random uncertainty, including user-dependent factors, and the impact of such uncertainties on targeting accuracy and precision should be summarized for the clinical team.

If the SBRT service includes treatments affected by respiratory motion, the entire treatment chain (CT simulation, treatment planning, and treatment delivery) should be assessed with process testing using a dynamic phantom setup with clinically relevant motion parameters (amplitude, cycle time). The tests should include assessment of spatial targeting accuracy and measurement of delivered target dose.

6. TPSs

The treatment planning computer model must be verified using beam data measured under the supervision of the QMP on the same treatment unit for which the model will be applied for patient planning. To ensure that the calculated data agree with measured radiation beam data, treatment planning computer systems must undergo rigorous acceptance tests and commissioning. (See the [ACR Practice Parameter for 3-D External Beam Radiation Planning and Conformal Therapy](#) [10] and the AAPM Medical Physics Practice Guideline 5.a [11]). Also, the absolute dose calculation must be confirmed by measurements under normal conditions in radiation fields of various sizes, including small fields commensurate with a SBRT treatment.

All features of the system that are used in clinical practice must be tested. Both central-axis and off-axis beam characteristics at specific points should be tested for various field sizes to confirm the spatial accuracy of the dose display. Studies must be performed to test all types of external-beam planning used at the site with additional validation tests as appropriate for the specific SBRT delivery technology and scope of clinical services, such as evaluation of multimodality image fusion accuracy, validation of clinically relevant small-field dose calculations, calculation accuracy for couch attenuation, and effect on surface dose and heterogeneity corrections.

The validity of dose-volume histograms must be verified. Various dose distributions can be calculated whose characteristics are known. The dose and volume results from the dose-volume histogram can be checked against the known values.

The limitations/uncertainties of the dose-calculation algorithm(s) must be reviewed, documented, and made available to all clinical personnel at the time of commissioning.

Periodic tests (eg, standard plans) must be performed routinely and after any major service or software change to ensure the accuracy of monitor unit and/or dose calculation algorithms, to ensure that any software changes (including editing of beam data files) were implemented correctly and have not corrupted the beam data, to ensure that any hardware changes were installed properly, and to verify that the system performance is consistent with its initial commissioning.

All users must receive documented training by the QMP (or their designee) or manufacturer. In addition, documented training should be given to all new users. Software releases should be reviewed and documented by all users.

C. QA Program

The delivery of high radiation doses delivered over short fractionation schedules necessitates a robust initial and ongoing QA program to ensure patient safety. The mechanical properties of the equipment used to deliver therapeutic doses must be tested and found to be appropriate for the type of cases treated. Additionally, setup errors and variation of target localization should be considered. It is incumbent upon the Qualified Medical Physicist to design and oversee the QA program utilizing the most recent society recommendations. Additionally, the QMP should have ready access to radiation measurement equipment suitable for small-field dosimetry as well as phantoms to evaluate the imaging system and the beam alignment at a minimum, including dynamic phantoms if respiratory management is used.

D. QC checklist for procedure

The use of a checklist has been shown, in numerous industries, to reduce errors [12-14]. A checklist should be designed by the SBRT team, to ensure that all critical elements of the SBRT treatment are double-checked prior to each treatment. The team should utilize the AAPM Medical Physics Practice Guideline 4.a [15] to aid in the development of an institution-specific checklist for SBRT treatments.

E. Supervision of procedure

This document follows supervision levels defined in AAPM Professional Policy 18 [16]. For the delivery of all radiation therapy services, the two responsible professionals are the radiation oncologist and Qualified Medical Physicist. All other team members work under the supervision of these professionals with clinical procedures supervised by the radiation oncologist and technical procedures supervised by the Qualified Medical Physicist.

Additional information can be found in the AAPM-RSS Medical Physics Practice Guideline 9.a. for SRS-SBRT [5].

F. Treatment planning process

Treatment planning involves contouring of targets, objects-at-risk (OARs), and the normal structures; use of appropriate margins; design of appropriate fields or arcs; application of optimization algorithms; and review of the dose distribution and dose/volume statistics for tumor and planning target volume (PTV) coverage, OAR constraints and normal tissue fall-off by the radiation oncologist. SBRT is distinct from that of conventional radiotherapy in several important aspects; thus, added diligence is required during TPS commissioning and in planning individual patients.

1. The SBRT approach is generally appropriate for the treatment of gross disease, and, correspondingly, in many cases, no expansions are typically made to include subclinical disease (there is no clinical target volume [CTV]). However, in some cases, such as the spine, a CTV is created per consensus guidelines [17]. Protocols may also stipulate a CTV. From a nomenclature perspective then, the gross tumor volume (GTV) should be contoured (and CTV created in some cases), with expansions made to account for setup and other uncertainties (PTV). Although SBRT utilizes small PTV margins, typically on the order of 5 mm or less in all directions, target margins should be based on data from current literature, along with knowledge of the limitations of institutional IGRT localization capabilities, motion management technique, and other factors on a site-specific basis. These are typically specified by the radiation oncologist in collaboration with the Qualified Medical Physicist. The QMP should ensure that clinicians are aware of the delivery system's limitations relative to the PTV and OAR margins. Target coverage requirements and margins should be clearly documented in the planning directive. See [ACR-ASTRO Practice Parameter for the Performance of Stereotactic Body Radiation Therapy](#).
2. Each treatment site must have a defined list of critical structures, with tolerances based on clinical trial data or peer-reviewed literature appropriate for each stereotactic fractionation scheme employed. All target coverage parameters and OAR constraints should be clearly documented in the planning directive. Naming of all planning structures should follow current AAPM TG-263/NRG nomenclature.

3. The dosimetric goal of SBRT is to ensure a high dose is delivered to the tumor while effectively minimizing dose to adjacent organs. This is optimally accomplished through the use of many nonoverlapping beams or arcs, which converge only on the target, together with appropriately small PTV margins. The intermediate dose levels can be characterized by “compactness” or “spillage” constraints and should follow clinical trial data or peer-reviewed literature. The utilization of noncoplanar beams or arcs may substantially improve the dose conformity and OAR avoidance. However, such beam arrangements should be used with caution as the potential for gantry/couch/patient collisions is increased. If noncoplanar beams or arcs produce a superior dose distribution to planar beams or arcs, it should be verified on the treatment unit for any potential collisions prior to commencing treatment (typically called a dry-run process). The sharp dose gradients desired can also result in a less homogeneous dose distribution (ie, greater hotspots within the target) than in conventional radiotherapy. Target dose coverage, hot spots, conformity and gradient metrics, and compliance with critical structure dose objectives should be clearly reported and signed by the radiation oncologist. Planning strategies and treatment technique should be clearly documented in the planning directive.
4. SBRT treatment targets may have significant motion that is due to respiration or other physiological processes. It is critical that a motion assessment be performed during the simulation process and that motion be appropriately managed during planning and delivery. Either fluoroscopy or 4-D CT can be used to assess motion and define a motion envelope—this is often referred to as the internal GTV (iGTV). Active motion management is recommended when the GTV excursion exceeds 5 mm [18]. Techniques for motion management can include inhibition strategies (voluntary or assisted breath hold, abdominal compression), active gating, or tracking. Four-dimensional, breath-hold, or gated CT are a prerequisite for planning of disease sites affected by respiratory motion; free-breathing scans are not recommended for treatment planning. Additionally, the CT or TPS must be capable of computing additional imaging sets: maximum intensity projection and minimum intensity projection (MinIP) images are helpful to aid in iGTV definition for thoracic and abdominal tumor sites, respectively. However, dose calculations should be performed on the average intensity projection (AveIP) image [19]. The AveIP also serves as the reference image for cone-beam CT (CBCT) localization. Simulation and treatment imaging procedures and tolerances should be clearly documented in the planning directive.
5. Small targets are often encountered in SBRT, and, combined with the need for steep dose gradients, the resulting fields/beamlets used in delivery can be quite small. Therefore, the use of an isotropic calculation grid size of 2 mm or smaller is recommended, and, for very small targets, a 1-mm calculation grid size may be necessary. Additional information can be found in the AAPM-RSS Medical Physics Practicer Guideline 9.a for SRS-SBRT [5]. TPSs must be specifically commissioned for small targets and small fields. Additionally, small fields are particularly susceptible to loss of electronic equilibrium, such as lung-tissue interfaces and in low-density medium. For this reason, the use of beam energies above 10 MV is not recommended [20]. Additionally, planning systems must be able to accurately calculate dose in such geometries. Only those algorithms listed by the Imaging and Radiation Oncology Core (IROC) Houston Quality Assurance Center as acceptable should be used for SBRT [21]. As a final part of the TPS algorithm commissioning process, independent verification of calculation accuracy should be completed, using an appropriate mailed-phantom dosimetry service, such as that provided through IROC, or independent measurement and TPS beam model review conducted by a QMP with relevant SBRT commissioning experience.
6. A mechanism for independently verifying the results of the treatment planning process must be performed prior to each patient treatment. Ideally, this is performed by a phantom measurement, though a robust independent dose calculation may also be acceptable.

G. Treatment delivery process

A well-defined site-specific SBRT checklist should be developed and utilized using the methodology in AAPM MPPG 4.a as part of SOPs. The checklist should be reflective of the type of SBRT being performed as well as the technology and equipment utilized.

A clearly defined pretreatment QA check should be performed on all the technology that will be employed for SBRT. This should include, but is not limited to:

1. Collision check
2. Correct site (body areas and laterality)
3. Correct body markings for treatment site
4. Correct immobilization equipment
5. Prescribed IG technique
6. Appropriate double checks and signatures (Rx, plan)

In addition, a timeout should be performed and documented in the patient's medical record prior to the initiation of every treatment. The timeout should include, at a minimum, confirmation of the following: patient identity (two identifiers are preferred), treatment site and laterality (as appropriate), dose per fraction, and fraction number.

Localization and imaging are a crucial component of the SBRT treatment delivery process. In the written directive, the radiation oncologist should define the type of imaging to be utilized, the frequency of imaging, as well as the desired alignment structure(s). The department or facility must also have a policy that details reimaging following shifts that exceed a threshold and that describes critical features of the respiratory management system.

H. Commissioning Reports and Patient Safety Recommendations

The QMP must provide a written report of the findings of acceptance testing and performance evaluation to the responsible physician(s) and radiation oncology administration. Written reports must be provided in a timely manner consistent with the importance of any adverse findings.

The QMP should summarize the findings of validation tests relevant to the intended scope of clinical services, including simulation systems, TPS, IG and treatment delivery systems, and motion management systems. Any limitations in the aforementioned systems relevant to the intended scope of clinical services must be clearly described and should be reviewed with the responsible physician(s) prior to initiation of the clinical service.

If appropriate, the QMP should notify the facility to initiate any required service. The facility must complete corrective actions in a timely manner consistent with the importance of any adverse findings. The facility should retain service reports from competent service personnel as verification that the issue(s) were appropriately resolved. The reports may be reviewed by a QMP to confirm that the equipment is performing in a safe and acceptable fashion after the required service is performed or as required by federal, state, or local regulations.

IV. SBRT QA

As stated in the AAPM-RSS Medical Physics Practice Guideline for SRS and SBRT [5]:

A comprehensive QA program for SRS-SBRT is critical to ensure the correct dose is delivered to the target, given the very small target volumes and rapid dose fall-off associated with SRS-SBRT. QA processes and procedures related to SRS-SBRT should be designed to cover the following aspects of the SRS-SBRT program: equipment-specific QA, PSQA, and procedure-specific QA. Safety and QA recommendations have been extensively described in several publications. When equipment performance is found to be out of tolerance, the affected module(s) of the delivery system should be promptly adjusted, and the QMP should verify proper performance before clinical SRS-SBRT services resume. In the event of a significant service interruption, the QMP should coordinate closely with treating physicians to evaluate the impact on patients' treatment schedules given the importance of completing SRS-SBRT treatment courses in a short overall time interval (generally 14 days or less). Patient safety should be the primary consideration in determining when to resume clinical services.

The QA program should be designed by a QMP who has specific training in SRS-SBRT, and should be reviewed by another QMP with SRS-SBRT experience. The daily QA procedure can be performed by a physicist or radiation therapist and be reviewed by the QMP prior to any SRS-SBRT treatment. Other routine QA or PSQA may be performed by an appropriately trained medical physicist, and reviewed and co-signed by the Qualified Medical Physicist.

The AAPM has published task group (TG) reports with recommendations for QA related to SBRT. These reports include, but are not limited to, the following: TG-117, TG-135, TG-142, TG-148, MPPG 2.a, MPPG 5.a, and MPPG 9.a. The QMP is responsible for the clinic's QA program should consider all recommendations in the aforementioned AAPM publications for their relevance to the clinic's overall scope of SBRT services. The baseline performance values for routine equipment QA (daily, monthly, and annual QA) should be established during machine commissioning and initial calibration. The SBRT-relevant QA tests, frequencies, and tolerances are summarized in MPPG 9.a tables 1–3 for C-arm linac, robotic linac, and ring-mounted helical tomotherapy systems, respectively.

A. Equipment Performance and Integration

1. Imaging Devices QA

Image quality of both simulation and localization imaging devices can have a direct impact on the accurate delivery of SBRT because of the high target conformality of SBRT dose distributions and the consequent requirement for high treatment delivery precision. CT simulation scan protocols should be optimized for image quality with slice thicknesses on the same scale as the dosimetric grid size (ie, comparatively lower emphasis on image dose), and, in addition to the routine daily QA program, the CT simulation protocols should be reviewed at least annually in conjunction with annual CT scanner testing. If MR images are used for target definition, the MR imager(s) should be assessed at least annually for spatial distortion with the imaging parameters used for SBRT patient imaging. IGRT imaging components used for treatment localization and verification should be monitored in accordance with the relevant AAPM Task Group recommendations, and the QMP should establish clear action levels relevant to the SBRT service's requirements.

2. TPS QA

Documentation must exist indicating that the medical physicist has authorized the system for clinical use and has established a QC program to monitor the TPS's performance as it relates to the SBRT planning process.

Data input from medical imaging devices is used in conjunction with a mathematical description of the external radiation beams to produce an anatomically detailed patient model illustrating the dose distribution with a high degree of precision.

Both dosimetric and nondosimetric elements may be included in a QC program. Furthermore, it is recognized that various testing methods may be used to ensure that a system feature or component is performing correctly. The commercial manufacturer may also recommend specific QC tests to be performed on its planning systems. For these reasons, the important elements of the QC program for the 3-D image-based TPS are identified below, but the method and testing frequency are not specified.

Additional information can be found in the AAPM–RSS Medical Physics Guideline 9.a for SRS-SBRT [5].

3. Mechanical integrity of SBRT delivery system

Whether delivered via a linear accelerator, robotic arm system, fixed or helical, the equipment utilized to deliver SBRT treatments must be capable of accurately targeting and delivering high doses of shaped radiation. The mechanical accuracy of the system must be validated prior to the start of an SBRT program, and its stability over time should be established and monitored. Exact methods for evaluating the

mechanical isocenter will depend on the delivery unit itself. However, the frequency and tolerances should be based on the most current recommendations for equipment type. A Winston-Lutz type test should be conducted periodically to verify the mechanical accuracy of the SBRT treatment delivery system. In addition to validating the mechanical accuracy of the treatment unit, the performance of the imaging system as well as the beam-shaping system must also be evaluated.

4. Registration software of SBRT delivery system

SBRT equipment has both manual and automated alignment tools. The QMP should characterize the limitations of the registration software used for SBRT and summarize the findings for the clinical team. The QMP should also establish a routine QA program for the registration system, consistent with the requirements of the clinic's SBRT service. After any major upgrade of the treatment delivery system, the QMP should ensure that the integration of the registration software with the beam delivery system is assessed prior to clinical use.

5. Motion management system

Each motion management methodology in SBRT requires careful evaluation of its accuracy and effectiveness. Appropriate QA tests should be performed prior to its incorporation into the SBRT process. For example, AAPM TG-76, TG-101, and AAPM TG-142 contain useful recommended guidelines for QA and implementation of respiratory motion management for linear accelerators.

6. System integration—end-to-end testing

The purpose of end-to-end tests is to validate treatment workflow, to check system dependencies, to ensure that the intended information is correctly passed between various system components, to verify that clinical team members understand their tasks, and to assess overall treatment process accuracy. Each step in the end-to-end testing should be performed by the QMP communicating with the designated staff member who will perform the step before the program is clinically implemented.

To ensure the accuracy and precision of the SBRT systems in their clinic, users must perform an end-to-end test, or “dry-run,” when commissioning an SBRT program to investigate the geometric and dosimetric accuracy of the system. This test must be performed for each category of SBRT service and when a key aspect of the process is changed. Such tests utilize an appropriate SBRT phantom and simulate the entire patient treatment process.

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

- a. A phantom that includes a number of discernable markers or targets can be used to verify the performance of the SBRT system. This phantom should have the ability to accept measurement devices (eg, film, small-volume ionization chamber). A motion simulator may be used in conjunction with the phantom to evaluate motion management strategies.
- b. The procedure should start with a CT simulation process that scans the phantom to locate the position of the markers (or targets and critical organs).
- c. The TPS is used to target each marker with a conformal dose as specified by the institution's SBRT planning guidelines.
- d. The phantom is positioned within the coordinate frame of the delivery system in accordance with the previously generated treatment plan. It is recommended to introduce setup deviations from planned treatment 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. Verification images should be taken after positioning to validate the intended shifts.

- f. The plan calculated in step “c” is then delivered with the measured doses being compared to the planned doses. It is also recommended to deliver the plan to a separate measurement system (eg, portal dosimetry, ion chamber/diode device) to compare measured fluence to calculated fluence. Acceptable pass rate criteria should be set and results documented.
- g. The record of the SBRT 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.

End-to-end tests should be included as part of the ongoing QA program. The frequency of the ongoing end-to-end tests should be based on the equipment utilized for the SBRT program and the most recent AAPM recommendations. Additionally, in order to provide an independent verification of the dosing and targeting performance of the system, the clinic should strongly consider utilizing either a testing service (eg, IROC QA phantom) or an independent review by a Qualified Medical Physicist who has documented experience in SBRT.

7. User- and technology-dependent issues

IG inherently involves alignment to a target anatomy, a potentially subjective process. An observer’s ability to discern soft-tissue changes using the different SBRT technologies can vary widely. In some cases, it is 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. Although surrounding bony structures are often used to verify positioning, there must be a careful determination that variation of the location of the target and surrounding critical structures relative to the bony landmarks is adequately compensated for with the use of appropriate margins. It is sometimes possible to use implanted metal markers as a surrogate for the positioning of the target or targets. This approach also requires QA steps aimed at confirming that the markers accurately indicate the location of the target (and that the motion of the surrogate models the motion of the target).

8. Information technology

The extensive use of image data in the planning and delivery of SBRT requires a robust management system. The efficiency of storage, retrieval, and display may have significant impact on the clinical operation. The information flow from storage to retrieval should be tested for its accuracy, efficiency, and integrity. Often, multiple information systems are involved in a single radiation oncology facility; effective and accurate communication between these systems should be assessed when implementing an SBRT service, and formal service-level agreements should be implemented to ensure that roles and responsibilities are clearly delineated for clinical staff, institutional Information Services staff, and vendor support.

B. Correction Strategies [22]

Use of IG involves determining a strategy for selecting when to measure, which method to use (eg, 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 SBRT be supported by a rigorous program of documentation and training.

The QA team, consisting of representatives from physicians, physicists, dosimetrists, and therapists, should work as a group to define IG and correction strategies. 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 trade-off between treatment margins and the effort required to correct for errors needs to be evaluated.

C. PSQA

1. Overview

The term PSQA for SBRT, in the context of this technical standard, refers to the QA process of verifying that the approved treatment plan can be accurately delivered.

A PSQA program should be developed by the Qualified Medical Physicist. This program should be based on the most current recommendations for the technology utilized in the clinic and with consideration given to the anatomic sites treated with SBRT.

2. Scope of PSQA

The scope of a PSQA program is to verify that the patient's treatment plan can be accurately delivered. Tasks performed and documented by the QMP prior to the patient commencing treatment should include:

- a. Reviewing the patient's treatment chart, specifically paying attention to patient setup and immobilization documentation.
- b. Reviewing the patient's approved treatment plan, specifically paying attention to the treatment delivery parameters.
- c. Performing an independent secondary calculation.
- d. Performing the appropriate dose delivery measurements on the treatment machine to verify absolute dose if the dose is modulated.
- e. When appropriate, a dry-run of the patient's treatment on the treatment machine to check for potential collisions.

3. Instrumentation for PSQA

When an institution is deciding what type(s) of instrumentation are needed for PSQA, the QMP determines what appropriate devices are needed. This decision should be based on the technique of SBRT treatments to be verified. Typical commercially available instrumentation is listed below:

- a. Phantoms that hold film and/or small-volume ionization chambers/diode detectors.
- b. Diode detector and ionization chamber array devices.
- c. Portal imaging devices. These devices should be calibrated for dose response.
- d. Any other device deemed appropriate by the QMP for the SBRT technique to be verified.

Performing SBRT treatments at the institution should not commence until the appropriate PSQA instrumentation is available and has been calibrated by the Qualified Medical Physicist.

D. Procedure-specific QA

Facilities should have documentation defining the workflow for each SBRT technique. This documentation should be reviewed and updated periodically, with at least an annual frequency of review. Procedure-specific QA should address the following issues related to this documentation:

- a. The documented, specific workflow is being consistently followed.
- b. Staffing levels are appropriate.
- c. Appropriate initial and continuing staff training.
- d. Competency assessments—given the rapid evolution of SBRT technology and treatment methods, ongoing competency assessment is necessary. Employees without prior SBRT experience should be required to perform a certain number of cases deemed appropriate by the facility under the supervision of an experience employee.
- e. Specific patient-related SBRT treatment incidents should be documented with proper follow-up actions.

V. SUMMARY

The quality and safety of an SBRT program depends on the coordinated efforts of a team of skilled radiation oncology professionals, including the Qualified Medical Physicist. The QMP should work closely with the facility's

medical director to develop proper policies and procedures for SBRT treatments. Because there is little chance for adjustment once treatment has been started, planning and delivery of SBRT treatments should follow an approach that is highly structured. Such structure should include clearly defined roles, responsibilities, procedures, and action levels. If the personnel responsible for the SBRT service do not have direct prior experience with the SBRT treatments to be offered, the facility must arrange for on-site review and proctoring of the first clinical procedure by professionals with experience relevant to the new service.

Safe implementation of an SBRT program should include, but is not limited to: adequate medical physics, dosimetry, therapist, and physician staffing and SBRT-specific training, proper QC instrumentation, appropriate devices for patient setup and immobilization, appropriate devices for proper motion management, a computerized treatment verification system, an appropriate treatment delivery system relevant to the scope of SBRT services offered, an appropriate patient-specific QA program, and a robust preventive maintenance and field service program for the treatment delivery system.

It is the responsibility of the QMP to follow the appropriate published guidelines to implement a new SBRT program. The results of this commissioning work should be presented to the medical director and clinical team in the form of a written report. This report should contain the acceptance and commissioning results as well as any limitations of the systems used to plan and deliver SBRT treatments. It also recommended that the QMP independently validate the beam model and machine calibration prior to the clinical implementation of the SBRT program.

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