ACR–ARS PRACTICE PARAMETER FOR THE PERFORMANCE OF BRAIN STEREOTACTIC RADIOSURGERY

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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). Stereotactic radiosurgery (SRS) historically referred to treating targeting intracranial lesions. As various technologies have advanced, SRS has come to refer also to treating targeting extracranial lesions. For the purpose of this document, SRS is strictly defined as radiation therapy delivered via stereotactic guidance with approximately 1-mm targeting accuracy to intracranial targets in 1 to 5 fractions. For information regarding extracranial target treatments, refer to the ACR–ARS Practice Parameter for the

Performance of Stereotactic Body Radiation Therapy [1,2].

SRS has been applied to a number of benign and malignant intracranial conditions [3-13]. The delivery of a high dose of ionizing radiation that conforms to the shape of the target mandates an overall accuracy of approximately 1 mm [14]. Gamma ray photons generated from radioactive material [15], X-ray photons created by linear accelerators (LINACS) [16], and protons or heavy particles ions created by particle accelerators [17] have been utilized as ionizing radiation sources for SRS. used for SRS. SRS beam delivery has been accomplished via a variety of forms, including multisource gamma ray treatment systems stereotactic units [18], C-arm (isocentric) linear accelerators [19], helical delivery linear accelerators [20], robotic (nonisocentric) linear accelerators [21], and both fixed beam line [17] and rotational beam line particle beams [22]. can be delivered using a medical linear accelerator, a gamma ray treatment device, or a particle beam accelerator. Despite the variety of stereotactic radiosurgical delivery techniques, many commonalities exist [23-26], most significantly the objective of delivering of a high dose of ionizing radiation that conforms to the shape of the target with an overall accuracy of approximately 1 mm or less [14].

The dosimetric objectives of SRS are achieved by concentrating radiation dose on the target(s) of interest. Photon-based techniques utilize numerous cross-firing beams or arcs to spread out entrance dose over a large surface area and deliver the desired dose at the target. Gamma stereotactic units use numerous fixed gamma ray beams to simultaneously irradiate a single point (called the isocenter) within the patient [15]. The beams are individually collimated so that the summation of the beams at the isocenter is roughly spheroid in shape. Multiple isocenters may be used to create geometrically complex dose distributions [27].

Some implementations of linear accelerator SRS follow a similar isocentric strategy, but arcs of radiation are often used rather than many individual beams. Supplementary beam collimation (often referred to as radiosurgery "cones”) placed at the end of the treatment head are used to reduce the beam penumbra [28]. The shape of the beam aperture used with linear accelerator–based systems is usually defined by secondary collimation positioned near the patient to reduce the beam penumbra. A large number of Several noncoplanar treatment arcs such beams sequentially irradiate the target, typically using a dynamic delivery with the isocenter at the center of rotation of each arc to concentrate dose at the target. More recently, intensity-modulated radiation therapy (IMRT) techniques have been applied to SRS to achieve an effect similar to that obtained with multiple isocenters [29]. Gamma ray treatment devices also position the collimation near the patient’s skin surface to control the penumbra. In this case, multileaf collimators (MLCs), either added as tertiary collimation [30] or incorporated into the linear accelerator itself [29], are used to shape beams or arcs. Beam delivery is possible either through numerous fixed noncoplanar beams or through one or more treatment arcs. The MLCs can be used to collimate the beam to either wholly or partially irradiate the target at any given beam direction [29]. An extension of this termed volumetric modulated arc therapy (VMAT) modulates the beam using MLCs while simultaneously rotating the linear accelerator gantry and controlling the dose rate. It is also possible to irradiate multiple targets with only a single isocenter by creating off-axis beam apertures in the MLC during arc-based delivery, a technique known as single-isocenter multitarget (VMAT) [31]. gamma ray beams simultaneously irradiate a single point (called the isocenter) within the patient. In the early implementation of either the x-ray or gamma ray treatment approach, all beams were directed to converge to this single point in space so that a dose distribution devoid of surface concavities was produced. More recently, multiple points in space (isocenters) are irradiated to shape the dose distribution to allow for critical structures that surround or invaginate the target.

Robotic nonisocentric, frameless SRS involves a compact linear accelerator mounted on a robotic arm capable of movements through a large number of degrees of freedom. Robotic SRS also uses a large number of beams that crisscross through the target(s) from different directions; however, they are not necessarily oriented toward the same single point in space, and thus robotic SRS is not necessarily isocentric. Each beam usually irradiates a subregion of the target, with multiple beams utilized in order to paint the dose for complex, irregularly shaped targets [32]. Beam collimation may be achieved with replaceable radiosurgical cones, variable circular iris collimation, or MLC collimation. is a type of SRS treatment consisting of dozens of nonisocentric beams with distinctive quality assurance procedures and continuous target tracking that results in comparable dose conformality to gamma ray treatment devices and reduction in interfraction systematic error when more than 1 fraction is used.

Helical tomotherapy–based SRS likewise uses a compact linear accelerator, however in this case, it is mounted on a ring-gantry in a manner analogous to a CT scanner. The beam is collimated by primary collimators as a fan-beam rather than a diverging cone as in C-arm linear accelerators. Beam delivery proceeds in a helical fashion, with the linear accelerator treating in continuous arcs as the patient translates through the bore of the treatment machine. A built-in binary MLC modulates beam shape during treatment. As the treatment couch typically does not rotate, beams are delivered in a co-planar fashion [33].

Consistent with their naming, proton and particle-beam radiosurgery techniques make use of charged particles rather than photons. Rather than converging a large number of beams or arcs at an isocenter in order to concentrate dose on a target, proton and particle beams rely on a characteristic of particle beams called a Bragg peak, which is a phenomenon of heavy particles in which the bulk of energy loss via ionization occurs at the end of particles path [34,35]. Because of this, particle beams also have a certain characteristic, that is, just beyond the Bragg peak the absorbed dose to the tissue approaches zero (except for a relatively small amount of dose due to photon contamination). Thus, each beam has negligible exit dose. The combination of the Bragg peak and minimal exit doses of particle beams lead to a radiosurgery technique in which one or, at most, a few converging beams are created, wherein the energy of each beam is selected so that the spread-out Bragg peak regions correspond with the depth of the target from each beam's trajectory. Proton and particle beams have a theoretical advantage in terms of lower integral dose and larger relative biological effect. However, uncertainties in anatomical position in addition to relative biological effectiveness and range of protons can have a large dosimetric impact, and penumbra spread due to particle scattering can cause difficulties for treating small radiosurgical targets [36].

Intensity-modulated radiation therapy (IMRT) is also used for SRS. In this case a single isocenter can be used with off-axis beams created by a multileaf collimator (MLC) so that the equivalent effect obtained with multiple isocenters is achieved. The MLC is often placed as a tertiary device nearer the patient and with narrow leaves to improve penumbra. A related approach that is used for robotic dose delivery does not have a mechanical isocenter as a reference in space for the treatment beams. Like IMRT, this technology also uses a large number of beams that crisscross through the target(s) from different directions that are not necessarily oriented toward any single point in space. As is the case for a number of the other SRS approaches, the robotic delivery approach usually irradiates a subregion of the target with any 1 beam in order to paint the dose for complex, irregularly shaped targets.

Stereotactic localization of the lesion uses an appropriate imaging modality to identify a reference point for positioning the individual treatment beams. Traditionally, a rigid frame that included includes a fiducial system for precisely locating coordinate positions within the frame was is attached to the patient's head [37,38]. More recently, "frameless" approaches have been introduced, most often involving immobilization with a patient-specific mask or other noninvasive frame. These approaches incorporate image-guided radiation therapy (IGRT) techniques using imaging systems either built into or external to the treatment machine. While being irradiated, The patient may be immobilized when appropriate, and patient and target positioning relative to the treatment-planning position are verified prior to treatment to ensure accurate treatment delivery [39]. A variety of techniques can be utilized to ensure proper patient positioning—including intrafraction imaging using orthogonal x-rays, optical marker tracking, surface tracking, and radio frequency beacons—while the treatment proceeds. Some of these systems can automatically gate or interrupt treatment if the target deviates from its intended position beyond a threshold amount.

Imaging, planning, and treatment typically are performed in close temporal proximity. Critically, treatment may be ineffective if anatomically obsolete images are used for treatment planning [35]. The combined uncertainty for treatment delivery should be accurate to within approximately 1 mm. This leaves little room for error in the overall process. any individual step of the overall process. Therefore, strict protocols for quality assurance (QA) must be followed, and multiple checking, preferably repeated by different individuals, is required at critical junctures. It is necessary to understand the limitations of various SRS approaches. For instance, with single-isocenter techniques, angular tolerances must be considered [40]. Head frame, although felt to be the standard in immobilization, may shift, and IGRT may be utilized to confirm positioning prior to treatment [41,42]. SRS

requires the is therefore best performed with the active participation of a multidisciplinary team, as outlined below.

The practice parameters outlined in this document describe a minimal set of criteria for an SRS QA program. The reader is also referred to other publications regarding quality control for SRS and its related procedures [43-59]. In some cases, an SRS stereotactic radiosurgery procedure may incorporate IGRT. The recommendations are described in both the ACR–ARS Practice Parameter for Image-Guided Radiation Therapy (IGRT) [60] and the ACR–AAPM Technical Standard for Medical Physics Performance Monitoring of Image-Guided Radiation Therapy (IGRT) [61].

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 [62].

The following are minimal recommendations for staffing levels and staff responsibilities while participating in an SRS procedure. Specific duties may be reassigned where appropriate.

A. Radiation Oncologist

1. Certification in radiology in radiation oncology or therapeutic radiology by the American Board of Radiology (ABR), the American Osteopathic Board of Radiology, the Royal College of Physicians and Surgeons of Canada (RCPSC), or the Collège des Médecins du Québec, or certification in radiology by the American Board of Radiology (ABR) of a physician who confines his/her professional practice to radiation oncology.
   and/or
2. Satisfactory completion of a residency program in radiation oncology approved by the Accreditation Council for Graduate Medical Education (ACGME), the Royal College of Physicians and Surgeons of Canada (RCPSC), the Collège des Médecins du Québec, or the American Osteopathic Association (AOA).

   If the radiation oncology residency training did not include SRS training and direct clinical experience, specific training or mentoring in SRS should be obtained prior to performing any radiosurgical procedures [63]. In addition, there may be vendor-specific delivery systems that require additional training.

   For SRS treatment devices that use sealed isotope sources, the radiation oncologist is the "authorized user" as defined by Nuclear Regulatory Commission (NRC) regulations. The responsibilities of the radiation oncologist must be clearly defined, and irrespective of the treatment device, his or her duties should include the following:

   1. Participating in initial treatment decision making and obtaining informed consent
   2. Overseeing radiation therapy management of the patient
   3. Working in concert with the neurosurgeon, neuroradiologist, or other physicians, specifying the target volume and relevant critical normal tissues
   4. Participating in the iterative process of plan development and approving the final treatment plan and dose prescription
   5. Ensuring that patient positioning on the treatment unit is appropriate
   6. Attending and directing the radiosurgical treatment delivery according to NRC regulations where appropriate
   7. Following the patient and participating in the monitoring of disease control and complications

B. Neurosurgeon (or Appropriate Designate such as Neuro-otologist or Neurologist)
   Satisfactory completion of an ACGME-approved neurosurgical (or other appropriate) residency program.

If the neurosurgical residency training did not include SRS training and direct clinical experience, specific training or mentoring in SRS should be obtained prior to performing any radiosurgical procedures [63]. In addition, there should be vendor-specific delivery systems that require additional training.

An appropriately trained neurosurgeon (or designate) may be is an integral member of the multidisciplinary SRS team, and his or her their services may include:

1. Participating in initial treatment decision making and obtaining informed consent
2. Placement of stereotactic head frame, when necessary
3. Locating and specifying the target volume and relevant critical normal tissues in concert with the radiation oncologist and neuroradiologist or other physicians
4. Participating in the iterative process of plan development and approving the final treatment plan and dose
5. Ensuring that patient positioning on the treatment unit is appropriate
6. Attending and directing treatment delivery according to NRC regulations as appropriate
7. Following the patient and participating in the monitoring of disease control and management of treatment complications

C. Continuing Medical Education (CME)

The radiation oncologist's CME should be in accordance with the ACR Practice Parameter for Continuing Medical Education (CME) [64].

The physician should also meet the CME requirements as is the standard at the physician's institution.

D. Qualified Medical Physicist

A qualified medical physicist is an individual who is competent to practice independently one or more of the subfields in medical physics. The ACR considers that certification, continuing education, and experience in the appropriate subfield(s) 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 Physics in Medicine, the American Board of Science in Nuclear Medicine (ABSNM), or the American Board of Medical Physics (ABMP).

A qualified medical physicist should meet the ACR Practice Parameter for Continuing Medical Education (CME). [64].

The appropriate subfield of medical physics for this practice parameter is therapeutic medical physics (previous medical physics certification categories, including radiological physics and therapeutic radiological physics, are also acceptable). (ACR Resolution 17, adopted in 1996 – revised in 2008, 2012, 2022, Resolution 41f)

If the above training did not include SRS, then specific training or mentoring in SRS should be obtained prior to performing any radiosurgical procedures. There may be vendor-specific delivery systems that require additional training. For SRS treatment devices that use sealed isotope sources, the qualified medical physicist is the "Authorized Medical Physicist" as defined by NRC regulations.

The qualified medical physicist is responsible for many technical aspects of radiosurgery and must be available for consultation throughout the entire procedure: imaging, treatment planning, and dose delivery. Those responsibilities must be clearly defined and should include the following:

1. Acceptance testing and commissioning of the radiosurgery system to ensure its initial geometric and dosimetric precision and accuracy [14,65]. This includes:
    a. Localization devices used for accurate determination of target coordinates
    b. The treatment-planning system (TPS) [66]
    c. The radiosurgery external-beam delivery unit
    d. Any onboard IGRT imaging systems and/ or intrafraction motion management systems
    e. The precision of the imaging device(s), such as the MRI/CT/PET scanners, used for target and normal tissue identification, including their suitability for radiosurgery procedures.
2. IImplementing and managing a QA program for the radiosurgery system to monitor and ensure its proper function [67-69]

a. Localization devices used for accurate determination of target coordinates
b. The TPS
c. The radiosurgery external-beam delivery unit
d. Any onboard IGRT imaging systems and/ or intrafraction motion management systems
e. The imaging device(s), such as the MRI/CT/PET scanners, used for target and normal tissue identification, including their suitability for radiosurgery procedures
f. The radiosurgery external beam delivery unit
g. The treatment-planning system
h. The precision of the imaging device, such as the MRI scanner, used for target and normal tissue identification

3. Initiating and maintaining a comprehensive QA checklist procedures that standardize criteria for monitoring system and procedural performance, ideally separately from the non-SRS QA program (ie, 3-D, IMRT, VMAT delivery) that acts as a detailed guide to the entire treatment process
4. Directly planning, supervising, or overseeing the treatment-planning process, including verification of dosimetric calculations using monitor unit double-check software
5. Consulting with the radiation oncologist and/or medical dosimetrist to determine the optimal patient plan
6. Using the plan approved by the radiation oncologist and an appropriate patient-specific measurement technique, performing checks of the appropriate beam-delivery parameters
7. Supervising the technical aspects of the beam-delivery process on the treatment unit to ensure accurate fulfillment of the prescription of the radiation oncologist
8. Coordinating and implementing a training program for radiation oncologists, neurosurgeons (or designate if applicable), and radiation therapists on technical aspects of treatment machine clinical use

E. Radiation Therapist (when applicable)

A radiation therapist must fulfill state licensing requirements and should have American Registry of Radiologic Technologists (ARRT) certification in radiation therapy.

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

1. Preparing the treatment room for the SRS procedure
2. Assisting the treatment team with patient positioning/immobilization
3. Operating the treatment unit after the clinical and technical aspects of beam delivery are approved

If the dosimetry radiation therapy training did not include SRS training and direct clinical experience, then specific training or mentoring in SRS should be obtained prior to performing any radiosurgical procedures. In addition, there may be vendor-specific delivery systems that require additional training.

F. Medical Dosimetrist (when applicable)

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

1. Contour clearly discernible critical normal structures, which will need to be verified by a qualified physician
2. Ensure proper orientation of volumetric patient image data on the radiation therapy treatment-planning (RTP) system (from CT and other fused-image data sets)
3. Design and generate the treatment plan under the direction of the radiation oncologist and a qualified medical physicist as required
4. Generate all technical documentation required to implement the treatment plan
5. Be available for the first treatment and assist with verification for subsequent treatments as necessary

If the radiation therapy dosimetry training did not include SRS training and direct clinical experience, then specific training or mentoring in SRS should be obtained prior to performing any radiosurgical procedures.

In addition, there may be vendor-specific delivery systems that require additional training.

III. QA PROGRAM OF THE TREATMENT UNIT

The accuracy and precision required for SRS and the complex mechanical, electronic, and computerized systems involved in beam delivery require careful monitoring through the implementation of and adherence to an ongoing QA program. This program ensures that the integrated SRS system is in compliance with recommendations of the treatment unit manufacturer, with the specified clinical tolerances recommended by the ACR, American Association of Physicists in Medicine (AAPM), and ASTRO with applicable regulatory requirements. It also provides a mechanism to detect deviations in machine performance over time that may affect clinical results.

Modern SRS delivery techniques involve aspects of IGRT and IMRT. In addition to the recommendations given in this section, it is further recommended that the ACR Practice Parameter for Intensity Modulated Radiation Therapy (IMRT) [70,71] be followed when IMRT is used as well as when other techniques that use inverse planning are used. It is recommended that qualified medical physicists implementing the QA program additionally follow the recommendations of the Furthermore, it is recognized that various testing methods may be used, with equal validity, to assure that a system feature or component is performing correctly. However, it is the responsibility of the Qualified Medical Physicist to determine that the alternative testing methods are equivalent to the testing procedures presented in the ACR–ARS Practice Parameter for Image-Guided Radiation Therapy (IGRT) and the ACR–AAPM Technical Standard for Medical Physics Performance Monitoring of Image-Guided Radiation Therapy (IGRT) [60,61] as appropriate for the treatment machine/technique [72].

It is recognized that various test procedures, with equal validity, may be used to ascertain that the treatment delivery unit is functioning properly and safely. However, it is the responsibility of the qualified medical physicist to determine that the testing procedure(s) used are equivalent to the recommendations listed above. The test results should be documented, signed by the person doing the testing, and archived according to institutional and regulatory requirements.

A. QA of the Treatment Delivery System

The mechanical precision and electronic complexity of the treatment-delivery unit require the implementation of and adherence to an ongoing QA program. This program assures that the SRS treatment unit is in compliance with recommendations of the treatment unit manufacturer, with the specified clinical tolerances recommended by the ACR, AAPM, and ASTRO and with applicable regulatory requirements. It is recognized that various test procedures, with equal validity, may be used to ascertain that the treatment-delivery unit is functioning properly and safely. However, it is the responsibility of the Qualified Medical Physicist to determine that the testing procedure used is equivalent to the recommendations listed above. The test results should be documented, signed by the person doing the testing, and archived.

Important elements of the treatment delivery unit QA program are:

1. Radiation-beam alignment testing to ensure the beam can be correctly aimed at the targeted tissues (see Section IV for a complete list of the references describing this test) [65]
2. Calculation of radiation dose per unit time (or per monitor unit) based on physical measurements for the treatment field size at the location of the target. These measurements should be carried out by a qualified medical physicist using detectors suitable for small fields encountered in radiosurgery following guidelines stated in AAPM Medical Physics Guideline 9a for SRS/SBRT [73] and the IAEA/AAPM Code of Practice for reference and relative dose determination for small fields [74]
3. QA of automated dose-shaping systems, such as MLCs, to ensure they correctly shape the treatment beam per intended treatment plan
4. QA of synchronized functions (when applicable), such as MLC motion synchronized with gantry motion, and dose rate in order to ensure all subsystems appropriately interoperate

B. QA of Stereotactic Immobilization Systems

Immobilization systems, such as stereotactic head frames, noninvasive relocatable head frames, and thermoplastic mask systems, should be maintained and tested per manufacturer recommendations. It is

the responsibility of the qualified medical physicist to determine the specific QA procedures to ensure these recommendations are achieved.

C. QA of Localization and Onboard Image Guidance Systems

In some cases, SRS may be an IGRT procedure. As such, all of the recommendations previously stated in the ACR–ARS Practice Parameter for Image-Guided Radiation Therapy (IGRT) and the ACR–AAPM Technical Standard for Medical Physics Performance Monitoring of Image-Guided Radiation Therapy (IGRT) [60,61] apply to this treatment modality. Additionally, the AAPM Task Group 142 report [75] was written to extend the information in the previous AAPM Task Group 40 report [76] to specifically include guidelines for SRS. This document calls for daily verification of the correspondence of the treatment and imaging reference coordinate systems. Tolerance limits for this test are also stated in the AAPM Task Group 142 report [75]. AAPM Medical Physics Guideline 9a for SRS/SBRT [73] also provides specifics for both SRS and SBRT, including minimum equipment QA and tolerances. For the use of frameless localization systems, a precise description of the required test is given in the practice parameter and technical standard referred to above. For frame-based linear accelerator–based systems, the classic Winston-Lutz test is recommended on a regular basis when applicable [48].

D. QA of Motion Management Systems

QA procedures for intrafraction motion management and tracking systems, as applicable, should be implemented to ensure the systems meet manufacturer performance standards. Where such devices are used to interrupt beam delivery if the target moves out of position, this functionality should be included in the QA program. It is the responsibility of the qualified medical physicist to determine that the testing procedure used is appropriate to the device and requirements.

In some cases, stereotactic radiosurgery may be an image-guided radiation therapy (IGRT) procedure. As such, all of the recommendations previously stated in the ACR–ASTRO Practice Parameter for Image-Guided Radiation Therapy (IGRT) and the ACR–AAPM Technical Standard for Medical Physics Performance Monitoring of Image-Guided Radiation Therapy (IGRT) apply to this treatment modality. Additionally, the AAPM Task Group 142 report [75] was written to extend the information in the previous AAPM Task Group 40 report [76] to specifically include guidelines for SRS. This document calls for daily verification of the correspondence of the treatment and imaging reference coordinate systems. Tolerance limits for this test are also stated in the AAPM Task Group 142 report [75]. For the use of frameless localization systems, a precise description of the required test is given in the practice parameter and technical standard referred to above. For frame-based linear accelerator–based systems, the classic Winston-Lutz test is recommended on a regular basis when applicable [48].

E. QA of Imaging Systems

SRS is image-based treatment. All salient anatomical features of the SRS patient, both normal and abnormal, are defined with CT, MRI, angiography, and/or other applicable imaging modalities. Both high 3-D spatial accuracy and tissue-contrast definition are very important imaging features if one is to utilize SRS to its fullest positional accuracy. When the imager is located in the radiology department and not under direct control of the radiation oncology department, considerable cooperation is required for good quality control specific to the needs of SRS.

The medical images used in SRS are critical to the entire process. They are used for localizing target boundaries as well as generating target coordinates at which the treatment beams are to be aimed (see Section IV). They are used for creating an anatomical patient model (virtual patient) for treatment planning, and they contain the morphology required for the treatment plan evaluation and dose calculation. The accuracy and precision required by SRS are to be ensured. This assurance issue is addressed in Section VI below. However, general consideration should be given to the following issues.

Imaging, whether by CT, MRI, or other applicable modalities, should ensure creation of a spatially accurate anatomical patient model for use in the treatment-planning process. The chosen image sets should also allow optimal definition of target(s) and normal tissue(s). The chosen imaging modality must be thoroughly investigated before use in the SRS treatment-planning process. Some imaging considerations are the following: partial volume averaging, pixel size, slice thickness, distance between slices, image reformatting

for the TPS, spatial distortion and image warping, motion artifacts, magnetic susceptibility artifacts, and others. It is critical to reiterate that the requirements for SRS treatment-planning images can differ from the requirements for diagnostic images, especially regarding the spatial accuracy of the images in the stereotactic coordinates used for localization and targeting.

F. QA of TPSs

SRS TPSs are very complex. Data from medical imaging devices are 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. The level of complexity is also related to the treatment-planning techniques used for SRS. When IMRT/VMAT techniques are employed, inverse treatment-planning methodologies are necessary. However, these same inverse planning approaches are used for some of the multi-isocenter and nonisocentric treatment approaches. Inverse treatment planning provides computer-selected weights for a very large number of independent treatment beams. As such, it significantly complicates the treatment-planning process and requires QA steps that are different than the information provided in some earlier reports on treatment-planning QA (AAPM TG-53 report) [66]. Because of the system's complexity, the qualified medical physicist may elect to release the system in stages, and the required validation and verification testing will only reflect the features of the system that are in current clinical use at the facility. Documentation must exist indicating that the qualified medical physicist has authorized the system for clinical use and has established a QA program to monitor the system's performance as it relates to the treatment-planning process.

Some important aspects of the TPS include:

1. System data input devices: Check the input devices of image-based planning systems for functionality and accuracy. Devices include digitizer tablets, input interfaces for medical imaging data (CT, MRI, angiography, etc), and video digitizers. Ensure correct anatomical registration: left, right, anterior, posterior, cephalad, and caudad from all the appropriate input devices.
2. System output devices: Ensure the functionality and accuracy of all printers, plotters, and graphical display units that produce, using digitally reconstructed radiographs or the like, a beam's-eye-view rendering of anatomical structures near the treatment beam isocenter. Ensure correct information transfer and appropriate dimensional scaling.
3. System software: Ensure the continued integrity of the RTP system information files used for modeling the external radiation beams. Confirm agreement of the beam modeling to currently accepted clinical data derived from physical measurements. Similarly, ensure the integrity of the system to render the anatomical modeling correctly.
4. System electronic data transfer: Verify the accuracy of imaging data transferred electronically from the imaging simulator or PACS system to the TPS. Verify the accuracy of electronic data transfer between multiple vendor TPS's. Verify the accuracy of treatment plan data, including localization images submitted electronically from the TPS to the treatment delivery system or vice versa.

Although the AAPM document on QA for treatment planning does not fully include recommendations on IMRT, it should be used as a reference for general QA of TPSs (AAPM TG-53 report) [66]. It is also noted that the commercial manufacturer may recommend specific QA tests to be performed on its planning systems. Although a manufacturer's testing procedure can be very helpful, it is the qualified medical physicist's responsibility to attest that the total QA is complete in that it addresses all modes of possible failure.

The QA program for SRS involves elements that may be considered to be both dosimetric and nondosimetric. In addition to the IGRT recommendations given in section IV, it is further recommended that the ACR Practice Parameter for Intensity Modulated Radiation Therapy (IMRT) [70,71] be followed when IMRT is used as well as when other techniques that use inverse planning are employed. Furthermore, it is recognized that various testing methods may be used, with equal validity, to assure that a system feature or component is performing correctly. However, it is the responsibility of the Qualified Medical Physicist to determine that the alternative testing methods are equivalent to the testing procedures presented in the ACR–AAPM Technical Standard for Medical Physics Performance Monitoring of Image-Guided Radiation Therapy (IGRT) and ACR–ASTRO Practice Parameter for Image-Guided Radiation Therapy (IGRT), the, and the ACR Practice Parameter for Intensity Modulated Radiation Therapy (IMRT) [60,61,70]. Although the AAPM document on QA for treatment planning does not fully include recommendations on IMRT, it should be used as a reference for general QA of treatment planning systems (AAPM TG-53 report) [66]. It is also noted that the commercial manufacturer may recommend specific QA tests to be performed on its planning systems. Although a manufacturer's testing procedure can be very helpful, it is the Qualified Medical Physicist's responsibility to attest that the total QA is complete in that it addresses all modes of possible failure. The references given above should be consulted to make this determination.

G. System Log

Maintain an ongoing system log indicating system component failures, error messages, corrective actions, and system hardware or software changes. This can, over time, become a valuable source of information for triaging system faults.

H. System Data Input Devices

Check the input devices of image-based planning systems for functionality and accuracy. Devices include digitizer tablets, input interfaces for medical imaging data (CT, MRI, angiography, etc), and video digitizers. Assure correct anatomical registration: left, right, anterior, posterior, cephalad, and caudad from all the appropriate input devices.

I. System Output Devices

Assure the functionality and accuracy of all printers, plotters, and graphical display units that produce, using digitally reconstructed radiographs or the like, a beam's-eye-view rendering of anatomical structures near the treatment beam isocenter. Assure correct information transfer and appropriate dimensional scaling.

J. System Software

Assure the continued integrity of the RTP system information files used for modeling the external radiation beams. Confirm agreement of the beam modeling to currently accepted clinical data derived from physical measurements. Similarly, assure the integrity of the system to render the anatomical modeling correctly.

IV. VALIDATION OF THE TECHNIQUE AS IMPLEMENTED

Once the individual components of the SRS planning and treatment technique are commissioned, it is recommended that the QA program include an "operational test" end-to-end testing of the SRS system before clinical treatment begins or whenever a plan modification is implemented for a fractionated treatment schedule. This testing should mimic the patient treatment and should use all of the same equipment used for treating the patient. The testing is given the name "patient-specific end-to-end testing" and is described in the ACR Practice Parameter for Intensity Modulated Radiation Therapy (IMRT) [70,71] and ACR-AAPM Technical Standard for Medical Physics Performance Monitoring of Stereotactic Body Radiation Therapy (SBRT) [77]. An added benefit to this approach is that it provides training for each team member who will participate in the procedure.

V. SRS TREATMENT PLANNING AND DELIVERY

A. Simulation (typically required for mask-based treatment):

The radiation oncologist is responsible for choosing appropriate immobilization and motion management if

needed, with collaboration with the qualified medical physicist. High-resolution CT and often MRI are required to properly define targets and organs at risk (OARs).

B. Volume delineation/contours:
Tumor volumes and OARs should be delineated or verified by the physician (radiation oncologist, neurosurgeon, or appropriate designate, or both). Variability in target delineation is recognized, thus using consensus guidelines may help standardize contouring [78].

C. Treatment planning:
Performed by physician (radiation oncologist, neurosurgeon, or appropriate designate, or both), physicist, or dosimetrist. The physician is responsible for choosing the dose and dose fractionation, and dose limits to OARs. Plan needs to be verified by physician prior to treatment.

D. Patient-specific quality assurance (PSQA):
Overview of PSQA is well described in ACR-AAPM Technical Standard for Medical Physics Performance Monitoring of Stereotactic Body Radiation Therapy (SBRT) [77].
IMRT-based radiosurgery techniques should be validated on a per-patient basis to ensure that the treatment plan as developed by the TPS can be properly executed on a patient. PSQA procedures should follow guidance such as ACR Practice Parameter for Intensity Modulated Radiation Therapy (IMRT) [70].

E. Treatment delivery:
The radiation oncologist is responsible for ensuring that patient positioning and field placement are accurate for each fraction. If required, the image-guided stereotactic procedure is used to verify or correct the patient's position relative to the planning image data set. Given how critical patient positioning is for this procedure, positioning prior to each treatment must be verified. The team (radiation oncologist, physicist, and therapist) must be aware of the limitations of the setup, and the tolerance or threshold for stopping, repositioning, and reimaging. To accomplish this, treatment site–specific protocols may be developed and standardized for each department based on available equipment and its limitations. The team must communicate and update each other when errors or malfunctions are suspected so that they can be readily corrected. Patient treatment should be paused if it is felt that the patient is out of position, beyond any thresholds previously specified by the radiation oncologist. For patients being treated using a frameless radiosurgery system, the use of 3-D optical surface–guided monitoring systems can help provide an additional tool for intrafraction motion management. The qualified medical physicist should be present for the setup, image guidance, and motion review for the entirety of the first fraction. The radiation oncologist should approve the image guidance and motion review and be present at the start of each treatment fraction. The qualified medical physicist and radiation oncologist must be readily available should issues arise during treatment delivery.

F. Toxicity management and treatment follow-up:
The radiation oncologist and/or neurosurgeon are responsible for managing acute and late toxicities associated with treatment. This may include referrals to other physicians for monitoring and managing late toxicities, such as endocrinologists, ophthalmologists, and/or otolaryngologists. Follow-up from treatment should be arranged by the radiation oncologist and/or neurosurgeon to assess treatment efficacy as well as toxicity, typically with follow-up imaging.

VI. FOLLOW-UP

There should be follow-up of all patients treated and maintenance of appropriate records. The data should be collected in a manner that complies with statutory and regulatory guidelines to protect confidentiality.

VII. DOCUMENTATION

Procedure documentation should be in accordance with the ACR–ASTRO Practice Parameter for Communication: Radiation Oncology [79].

VIII. SUMMARY

The quality of an SRS program is defined by the strength of the multidisciplinary team involved in the management of the patient, as well as the attention to detail for this highly complex and demanding procedure. Radiosurgery is an involved procedure that requires participants from many disciplines. High spatial accuracy is expected, and there may be time constraints. Numerous systems to achieve optimal accuracy have been developed, and specific training in their use is required. All of the above demands a highly organized and efficient

SRS team. Checklists are required to ensure that all aspects of the procedure are completed properly by each team member. The procedure must be appropriately staffed.

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*As of May 2015, all practice parameters and technical standards that are collaborative with Radiation Oncology societies are approved by the ACR Council Steering Committee and the ACR Board of Chancellors and will not go through the ACR Council (ACR Resolution 54, 2015). The effective date is the first day of the month following a 60-day period that begins on the date the document was approved.

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