Radiosurgery and radiotherapy: observations and clarifications

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Object. Radiosurgery and radiation therapy represent important but unique treatment paradigms for patients with certain neoplasms, vascular lesions, or functional disorders. The authors discuss their differences.

Methods. Reviewing the authors’ experiences shows how the roles of these approaches vary just as their techniques differ. The distinct differences include the method of target localization (intraoperative compared with pretreatment) and irradiation (focused compared with wide-field), their radiobiology (effects of a single high-dose compared with multiple fractions), the physicians and other health personnel involved in the conduct of these procedures (surgical team compared with radiation team), and the expectations that follow treatment. During the last decade, considerable confusion has grown regarding nomenclature, requisite physician training, and the roles of the physician and surgeon. Ten years ago, two task forces on radiosurgery were created by national organizations in neurosurgery and radiation oncology to address these issues of procedural conduct and quality-assurance requirements. At the present time these guidelines are widely ignored. Currently, many patients, payers, and regulatory agencies are bewildered. What are the differences among stereotactic radiosurgery, fractionated radiation therapy, and stereotactic radiation therapy? Radiosurgery is to radiation therapy as microsurgery is to “microtherapy.”

Conclusions. In this report the authors discuss terminology, training, and physician roles in this expanding field.

KEY WORDS • radiosurgery • radiotherapy • fractionation • neurosurgery

Things are seldom what they seem; skim milk masquerades as cream.—W. S. Gilbert

The incorporation of stereotactic radiosurgery into neurosurgery and recent improvements in the administration of fractionated radiation therapy represent fundamental paradigm shifts in modern medical care. Neurological surgery has focused on minimal access procedures, searching for the molecular responses of tissues so that they may be eradicated or inactivated, and relying on the multidisciplinary talents and backgrounds of practitioners in neurological surgery, radiation oncology, medical physics, bioengineering, and molecular biology. Radiation oncologists now routinely incorporate high-resolution imaging during treatment planning to spare the central nervous system and contain the tumor. From the patient’s point of view, both procedures may be attractive, with no or small incisions, short hospital stays or outpatient care, and a rapid return to full activity. Nonetheless, both techniques remain invasive to the target and surrounding tissues. As greater numbers of clinicians from various disciplines weigh the risks and benefits of radiosurgery and radiation therapy, we believe it is important to reiterate the differences in terminology, techniques, training requirements, and clinician roles during the selection and performance of these procedures. The authors of this report include neurosurgeons and a radiation oncologist who have used LINAC, gamma knife, and proton-beam device and have served as leaders of a multidisciplinary radiosurgery society.

The History of Radiosurgery

Although microsurgical techniques were pioneered in the 1960s and 1970s, radiosurgical techniques developed earlier. The term stereotactic radiosurgery was coined in 1951 by Lars Leksell,1 a visionary neurosurgeon who practiced at the Karolinska Institute in Stockholm. Leksell was a physiologist, surgeon, and inventor; his use of the term stereotactic radiosurgery was remarkably prescient. He referred to a rigidly fixed skull and a stereotactic guiding device that directed cross-firing ionizing beams of radiation to inactivate or destroy a target identified by the appropriate imaging modality in a single treatment. In partnership with the talented radiobiologist Börje Larsson, Leksell explored methods to destroy intracranial targets by using photons (from LINAC) or protons (from a cyclotron) to inactivate a
Clarifications on Technique

Because radiosurgery is a multidisciplinary specialty, it is not surprising that there has been some confusion in the use of terms associated with the concept. First, we emphasize the word “surgery.” Surgery is the definitive single-session manipulation of a disease or organ system in which energy is used to achieve a specific purpose. The energy used in surgery may be mechanical (the surgeon’s arm moving a scalpel), thermal (radiofrequency heat ablation or cryosurgery), chemical (glycerol rhizotomy), light (laser surgery), or focused radiation (radiosurgery). Webster’s Ninth New Collegiate Dictionary defines surgery as “a branch of medicine concerned with diseases and conditions requiring or amenable to operative or manual procedures” and an operation as “a procedure carried out on a living body usually with instruments for the repair of damage or the restoration of health.”

The adjective “stereotactic” refers to a rigidly fixed, precise, accurate, and image-compatible guiding device that is coupled with high-resolution imaging to define a target in three-dimensional space. The noun “radiosurgery” refers to a single-session surgical procedure that uses ionizing radiation to destroy the target. Although brachytherapy also relies on radiation to achieve a desired radiobiological effect, the radioactive sources are surgically implanted to deliver a continuous radiation dose over a period of time (often over many days depending on the source strength). The noun “radiotherapy” refers to an extended treatment course in which external-beam fractionated radiation is delivered, usually by an LINAC. Any treatment may or may not be relatively innocuous; it is the sum of the treatment sessions that leads to an effect. Stereotactic radiosurgery is no more radiation therapy than microsurgery is “microtherapy.” The adjective “fractionated” refers to the fact that treatment is divided into multiple fractions or sessions. A reduced number of fractions may be called hypofractionation and a greater number of fractions may be termed extended fractionation or hyperfractionation. Radiosurgery, by definition, cannot be fractionated.

Recently, an administrator for the American Society for Therapeutic Radiation and Oncology sent a letter (dated October 1, 2003) to the Center for Medicare and Medicaid Services, US Department of Health and Human Services. In this letter the administrator stated, “The term stereotactic radiosurgery refers to the precise delivery of radiation to lesions of the brain, head, and upper neck, with sparing of the surrounding normal tissue with the concomitant use of stereotactic localization and planning. It includes therapy that is completed in a single session or therapy that is completed in multiple sessions (‘fractionated.’)” This gratuitous statement sent on behalf of a national medical organization to a government agency uses specious terms, but for what purpose? Are the authors lobbying the Center for Medicare and Medicaid Services to pay for each fraction of irradiation as if were a separate radiosurgical procedure? Interestingly, this letter states that the two basic methods of radiation delivery are “linear accelerator-based treatment” and “cobalt-60 based treatment,” completely failing to mention charged particle irradiation, which has been in use in the US for more than 40 years.

Some open craniotomy surgical procedures are “staged.” This may occur during the removal of a large skull base tumor, in which the first stage achieves bone exposure in preparation for a second-stage removal of the tumor. When radiosurgery is staged, and it is done so infrequently, different anatomical components of the target are destroyed. The stages are usually spaced by several months to reduce adverse radiation effects. An example of staged radiosurgery might include irradiation of the anterior half of an AVM in the first procedure, followed by irradiation of the posterior half in the second. In both sessions, a definitive effect is created on the target tissue. The effect on each portion of the AVM is not given in fractions.

As a surgical procedure, radiosurgery follows the paradigm of an entire procedure performed in a single continuous session (“skin to skin,” or “frame on to frame off”). The components of patient preparation, stereotactic frame application, intraoperative imaging, dose planning, dose delivery, and frame removal constitute the procedure. In a sense it is completely analogous to open stereotactic brain surgery, in which a probe is inserted into the brain after targeting and trajectory planning. Cross-firing, focused, high-dose beams of photon or proton radiation replace the probe. Computers are used to calculate the attenuation of each beam as the beams silently penetrate the scalp, skull, and intervening tissue before the summed radiation is delivered to the small target volume. The performing of radiosurgery relies on special technologies, trained personnel, and dedicated suites.

“Stereotactic radiation therapy,” sometimes called “fractionated stereotactic radiotherapy,” refers to an enhanced method to deliver fractionated radiation. The procedure in-
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volves daily application of a non–skeleton-affixed guiding device. We prefer the term stereotactic radiation therapy. Although there are no conclusive data to substantiate the value of these approaches over nonstereotactic conventional radiotherapy, such procedures are performed in an attempt to reduce the dose to adjacent critical brain or spine structures and to provide greater dose homogeneity to the target tissue. The principle of stereotactic radiation therapy is quite different from that of radiosurgery. Regardless of whether radiation is delivered by LINACs or proton generators, stereotactic radiation therapy is performed in an attempt to reduce the risks associated with radiation falloff in surrounding normal tissues adjacent to the targeted tissue. The role of the neurosurgeon in a stereotactic radiation therapy procedure can include participation in a preradiotherapy discussion, use of a relocatable stereotactic frame, image interpretation, dose planning, and posttherapy follow up.

The conformity of radiation dose delivery (that is, the matching of the volumetric radiation field to the target volume) is less than the conformity achieved during radiosurgery. Presentations at meetings of the International Stereotactic Radiosurgery Society that show dose plans with radiosurgery or radiotherapy techniques indicate that there is less conformity with radiotherapy and more use of single isocenter plans. In a seminar on the management of vestibular schwannoma in 2001, an oncologist from Staten Island University stated that “conformality does not matter.” The accuracy of radiation delivery is also less because rigid fixation is not used. At some centers no attempt is made to conform the radiotherapy volume to the target, but instead simply to provide regional irradiation by using image guidance. This approach may be an improvement over conventional radiotherapy techniques in which frame-based delivery is not used. With “intensity-modulated radiation therapy,” an LINAC and microleaf collimators are used to create radiotherapy dose plans that are more conformal than conventional plans, but still use the principal of a standard fractionation regimen. Intensity-modulated radiation therapy may prove to be an important improvement over the techniques of radiation therapy used for the past several decades. In some instances, radiation can be delivered using robotic assistance, as performed using the Model C Gamma Knife (Elekta Instruments, Inc., Atlanta GA) or the CyberKnife (Accuray, Inc., Sunnyvale, CA). The use of a robotic device for movement of the radiation emitter or stereotactic frame does not affect the radiobiological effect of the treatment.

The term “fractionated stereotactic radiosurgery” is oxymoronic and sophistic. Those who use the term desire to speak of the known benefits of radiosurgery for certain indications, but do not actually provide radiosurgery to their patients. Use of this term is confusing to patients, physicians, regulators, and third-party insurance payers who may think they are approving one therapeutic modality, but are paying for another. All radiotherapy requires fractionation. Perhaps the term “radiotherapy” commotes a lesser quality of care to some, but this should not be the case. Radiotherapy is an effective treatment for a wide variety of clinical problems. It is performed differently, with different expectations, and requires the efforts of multiple individuals performing different tasks. Radiosurgery is a single surgical procedure that takes advantage of an energy source that can be focused through tissue without incising it.

Training in Radiosurgery

Does residency training in neurosurgery adequately prepare neurosurgeons to perform radiosurgery? Neurosurgical residency programs provide trainees with knowledge and clinical expertise in neuroanatomy; in the management of a wide variety of neoplastic, vascular, and functional neurological disorders; and in image interpretation. Residency programs provide training in stereotactic surgical procedures and the use of computerized image-guided navigation. The American Board of Neurological Surgery specifically recommends that training programs provide training in radiosurgical procedures. At the University of Pittsburgh and at many other institutions, radiosurgery is incorporated formally into the residency program as part of a specific rotation. Importantly, neurosurgery training focuses on the clinical judgment necessary in choosing between different available treatment options and on the management of complications should they occur.

Does residency training in radiation oncology adequately prepare radiation oncologists to perform radiosurgery? Such residencies do not provide a focused education in neuroanatomy or in the clinical management of many disorders for which radiosurgery may be appropriate. Management of AVMs, cavernous malformations, vestibular schwannomas, trigeminal neuralgia, and movement disorders are not part of the traditional educational experience offered to the radiation oncologist. The principles of stereotactic localization (rigid frame or relocatable frame) are not part of radiation oncology training. Radiation oncologists do learn computer-based planning techniques as well as the principles of radiation administration and safety. They also learn how cumulative radiation administration may interact within the same patient, information of particular value for patients with selected tumors. It is interesting that a nonphysician technician rather than the oncologist actually delivers each fraction of radiation to a patient.

Is the amount of this training received by an individual in each specialty adequate to perform radiosurgery? How should this be determined? Some neurosurgeons receive formal fellowship training (6–24 months) before incorporating radiosurgery into their practice. At one of our centers, all neurosurgical residents spend 4 months on the image-guided radiosurgery rotation, in which they are exposed to approximately 200 radiosurgical procedures. If resident surgeons desire to perform radiosurgery in practice, we recommend that close to the end of their training they spend several more months participating in radiosurgery. Similarly, radiation oncology residents spend one rotation working closely with the oncologist primarily assigned to the radiosurgery program. Such extensive training exposures are uncommon among physicians already in practice who simply start performing radiosurgery. Most centers at which gamma knife technology is used require their neurosurgeons, radiation oncologists, and medical physicists to attend a formal immersion course in radiosurgery, followed by mentorship practice at their home institution. Some centers offering LINAC-based radiosurgery request a similar level of commitment, but many do not. We recommend that any physician who has not received formal training in radiosurgery, either during residency or afterward, should seek and receive such training before treating patients. In 1993 the Task Force on Stereotactic Radiosurgery of the American
Physician Roles

Neurosurgeons, radiation oncologists, and medical physicists each play important roles in a radiosurgical procedure. The decision to use radiosurgery or fractionated radiation therapy is often a group decision and patients may be referred to or by either a neurosurgeon or oncologist. Patients with neoplasms may be referred by their surgeon or oncologist, whereas patients with vascular malformations usually see a surgeon first. Both neurosurgeons and radiation oncologists must provide informed consent. When patients are admitted to the hospital, they are usually assigned to the care of the neurosurgeon.

When the patient arrives in the radiosurgery unit, the neurosurgeon supervises patient preparation, working with nurses who often come from the operating room environment. The surgeon applies the stereotactic frame to the patient’s head and should then supervise the acquisition of stereotactic images. Images are transferred to the radiosurgery planning computer, usually by the physicist. In many centers, it is the neurosurgeon who primarily performs the radiosurgical dose planning; in others it may be the radiation oncologist. Nevertheless, final agreement on the radiosurgery plan is made by the team, which then chooses an appropriate radiation dose that has been selected to meet the clinical goals of the patient. The radiosurgical dose is delivered by a physician, rather than by a technician, as occurs in radiation therapy. The surgeon or oncologist should attach the frame to the unit and have the coordinates triple-checked by other members of the team. The Nuclear Regulatory Commission mandates that a responsible and trained surgeon remain present during gamma knife surgery. Stereotactic frame removal is then performed under the supervision of the surgeon, who may be required to suture a pin site in some patients. The immediate postoperative care is given by the surgeon. Patient follow-up visits can be with the surgeon or oncologist, often depending on how the patient was initially referred to the unit. A survey performed by the American Society for Therapeutic Radiation and Oncology found that the average number of specialist hours (M.D. or Ph.D.) required during a radiosurgery procedure was high (>13 hours).9 In radiosurgical procedures in which a frame is not used, the neurosurgeon must ensure that an accurate targeting and irradiation technique is in place. For example, when CyberKnife spinal radiosurgery is performed at the University of Pittsburgh, the neurosurgeon is responsible for inserting fiducial markers into the spinal column, which serve as the framework for accurate irradiation, and is expected to participate in the dose planning and irradiation.

Medical physicists have a key role in radiosurgery, beginning with the installation, maintenance, and system upgrades for the hardware and software used. They are involved in meeting regulatory oversight requirements depending on the technology used. Physicists may act to ensure that the images used are of high quality, and they may have obtained experience in radiosurgery dose planning so that they can assist in the creation of the plan. It is important to remember that physicists have not been trained in neuroanatomy, in interpreting images, or in medical decision making. They should not serve as final arbiters of the radiosurgery dose plan. The physicist remains on site for radiation dose delivery and for technical support as needed.

Indications for Radiosurgery

The role of radiosurgery has expanded well beyond its initial application for functional neurosurgery, pain management, AVMs, and selected skull base tumors.9 The clinical spectrum now includes a wide variety of benign and malignant skull base neoplasms, serves as the primary treatment of metastatic brain cancer, and provides adjuvant management of malignant primary brain tumors. Radiosurgery has or should replace the role of microsurgery in the treatment of skull base tumors located in the cavernous sinus or surrounding critical vascular structures such as the carotid artery or sagittal sinus. Although open surgical techniques are required for removal or decompression of symptomatic large brain masses, radiosurgery can be used as a secondary procedure for the effective management of residual disease. Because of a remarkably low incidence of cranial nerve complications, high long-term tumor control rates, and overall safety, radiosurgery will continue to be practiced on a wide scale. Ten- to15-year follow-up results in patients with benign intracranial tumors have demonstrated low morbidity rates and high rates of tumor growth prevention.7 At the same time, we must continue to be diligent about recording clinical outcomes in patients undergoing radiosurgery or radiotherapy and to be mindful of potential long-term adverse effects.

Disclosure

Dr. Kondziolka is the current president of the International Stereotactic Radiosurgery Society. Drs. Lunsford, Loeffler, and Friedman have served as past presidents of the Society.

References

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