Perspectives In Neuroscience

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Image-guided Robotic Radiosurgery: The CyberKnife

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This quarterly publication is designed for primary care physicians, neurosurgeons, neurologists, neuroradiologists, and other practitioners. The purpose of this publication is to provide these physicians with current management strategies for dealing with a variety of disorders and conditions in the neurosciences, and to provide up-to-date diagnostic and prognostic information written by specialists in the field. It is estimated that it will take the physician 1 hour to complete the activity. The questions at the end of each lesson are designed to test and evaluate the participants' comprehension of the topic. This CME program is sponsored by the Central Illinois Neuroscience Foundation and funded by grants and donations. This CME activity was planned and produced in accordance with the Illinois State Medical Society's Essential Areas for Continuing Medical Education. The Central Illinois Neuroscience Foundation is accredited by the Illinois State Medical Society to provide continuing medical education for physicians. The Central Illinois Neuroscience Foundation designates this activity for a maximum of 1 hour of category 1 credit towards the American Medical Association's Physician Recognition Award. It is the intent of the Central Illinois Neuroscience Foundation to assure that its educational mission, and Continuing Medical Education activities in particular, are not influenced by the special interests of individuals associated with its program.

Dr. John Adler is a major stock shareholder in Accuray, Inc., the makers of The CyberKnife® System which may be perceived as a real or apparent conflict of interest in the context of the subject of this presentation. Drs. Pham, Chang and Rodas have nothing to disclose.

OBJECTIVES

1 Distinguish the fundamental differences between framed based stereotactic Radiosurgery systems and CyberKnife image-guided robotic radiosurgery.
2. Compare the risks and benefits of focused radiotherapy versus whole brain radiation in the management of metastatic cancers to the brain.
3. Identify the various brain lesions that may respond to focussed radiotherapy.

The success in controlling malignancies of the central nervous system has been largely improved over the last two decades through the development of radiation systems that specifically shape and direct beams of radiation at tumor target sites and thus reduce damage to surrounding normal nervous tissue. This issue of Perspectives in Neuroscience reviews the current concepts of radiation treatment employing robotic technology.

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INTRODUCTION

In the 1950's, Professor Lars Leksell of the Karolinska Institute in Sweden coined the term *stereotactic radiosurgery* to define a neurosurgical procedure that combined precision targeting with a large number of cross-fired beams of ionizing radiation.[1] By targeting a very large dose of highly collimated radiation at a discrete location in the brain, the objective of Leksell's operation was to make a lesion (ablate brain tissue) without *cutting*; arguably the ultimate in minimally-invasive surgery. By the 1970's the clinical motivation for such a procedure was a class of operations broadly referred to as functional neurosurgery. These operations, which alter brain function by selectively destroying small discrete areas of the brain, were a primary treatment for the tremor of Parkinson's disease and obsessive-compulsive disorder before the availability of pharmacological therapies for these disorders. Leksell investigated multiple technologies for fulfilling his vision, including linear accelerator (LINAC) and heavy particle based concepts, before focusing his development efforts on the radioactive cobalt-based Gamma Knife® (Elekta Instruments, Inc., Norcross, GA).

The first Gamma Knife was built in the late 1960's, and has since undergone a series of changes to accommodate a gradual evolution in usage. Although Leksell envisioned his brainchild would be used for non-invasive functional neurosurgery, the need for such operations largely disappeared with the parallel emergence of new Parkinson and psychotropic drugs. But as fortune would have it, CT scanning arrived in the 1970's and with it the opportunity to visualize mass lesions in the brain, especially tumors. Quickly the role of the Gamma Knife and the principles of radiosurgery were redirected to facilitate the treatment of brain tumors and malformations. By incorporating the effectiveness and minimally-invasive nature of radiosurgery into the neurosurgical armamentarium, the past 20 years have witnessed a revolution in the management of many brain tumors. Over this period new radiosurgical technologies evolved, including more spatially accurate linear accelerator-based methods (compared to Leksell's earliest experience) and heavy particle beams. The later are the most complex and expensive medical instruments ever. However, the Gamma Knife, by virtue of the large number of patients successfully treated, has always defined the gold standard in radiosurgery.

The Gamma Knife and all other forms of radiosurgery have had a significant impact on nearly every type of brain tumor. This influence continues to grow slowly as indications and treatment parameters are refined. Stereotactic radiosurgery is now one of the most commonly performed neurosurgical procedures in the United States.

TECHNOLOGICAL LIMITATIONS

Despite radiosurgery's near ubiquity, there are inherent shortcomings to present-day technology that limit important new applications. In particular, the Gamma Knife and other related linear accelerator-based technologies all require stereotactic frames for accurate beam targeting. Such skeletal fixation causes enough pain to preclude flexible treatment fractionation. Since the principle of administering a dose of radiation over more than one session is an essential element of all modern radiation oncology, this limitation is not trivial; basic radiobiology and clinical experience have demonstrated the superiority of using fractionation to treat most malignant tumors and/or lesions involving critical yet sensitive anatomic structures, such as the optic apparatus. Even more importantly, stereotactic frames only permit precise targeting of the treatment beam within or very close to the brain. Finally current radiosurgical instruments are isocentric-based, constraining all beams to converge on a common point. This design restricts more flexible and conformal treatment planning. Given the intrinsic limitations of current stereotactic radiosurgical devices, image-guided robotic radiosurgery was developed, and these principles are embodied in the CyberKnife® System (Accuray, Inc., Sunnyvale, CA).

CYBERKNIFE TECHNOLOGY

To establish patient position and orientation, the CyberKnife® System incorporates two amorphous silicon cameras that provide near real time stereo x-rays of the bony skeleton.[2] During CyberKnife treatment these images are automatically compared with computer-synthesized digitally reconstructed radiographs (DRRs) *generated on the fly* from previously obtained computerized tomography (CT) scans; a treatment plan that delineates the deposition of radiation is designed from the same CT scan prior to treatment. A compact and lightweight *X-band* linear accelerator provides the CyberKnife with a therapeutic radiation source. The small size makes it possible to position the LINAC on the end of a robot manipulator with 6-degrees of freedom. The flexibility of robotic targeting has been combined with advanced inverse treatment planning algorithms to enable the CyberKnife to deliver an unusually conformal treatment to non-spherically shaped lesions. Figure 1 depicts all of the above tecnologies integrated into a CyberKnife® System.

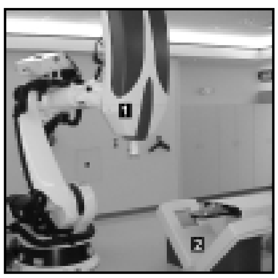


Figure 1: *The CyberKnife installed at the Community Cancer Center, Bloomington, IL.*

1. *Compact X-band linear accelerator mounted on computer-controlled robotic arm (Kuka Roboter GmbH, Germany).*
2. *Two amorphous-silicon flat panel image detectors (dpiX, Palo Alto, CA, USA) with a pixel pitch of 0.125 mm significantly improve radiographic imaging.*

IMAGE-GUIDED ACCURACY

The accuracy of CyberKnife targeting depends on the 1) resolution of the treatment planning CT, 2) real-time registration between CT and treatment radiographs, and 3) the pointing accuracy of the robot. With this understanding, the total system accuracy of the CyberKnife has been extensively tested in anthropomorphic phantoms. Throughout these extensive tests, the net result was that RMS errors ranged between 0.7 and 1.2 mm. This value compares quite favorably with (and is generally better than) measurements of frame-based stereotactic accuracy.[3]

The rest of this report will broadly outline the clinical applications of radiosurgery. In particular we will emphasize the rapidly evolving (expanding) indications for CyberKnife ablation throughout the brain and spine. In writing this paper we will disproportionately rely on our personal clinical experience at Stanford University Medical Center (SUMC), where we have treated more than 1500 patients with frame-based LINAC radiosurgery and over the past few years, almost 700 patients with the CyberKnife.

CLINICAL APPLICATION OF RADIOSURGERY

As a result of continued improvements in radiosurgical technology and better physician understanding of specific clinical applications, the field of stereotactic radiosurgery continues to evolve. However, practically speaking, all forms of radiosurgery have been used to ablate a diverse group of benign and malignant lesions throughout the brain. By far the most common application involves the ablation of brain tumors. Not surprisingly clinical outcome varies significantly with tumor type, but overall, results equal or exceed what might be achieved with open surgical resection. The following sections, broken down along pathologic categories, will broadly outline both the published results and our personal experience with using stereotactic radiosurgery. However, keeping in mind that as this field of radiosurgery continues to evolve, functional neurosurgery will likely assume a more contemporary approach.

BRAIN METASTASIS

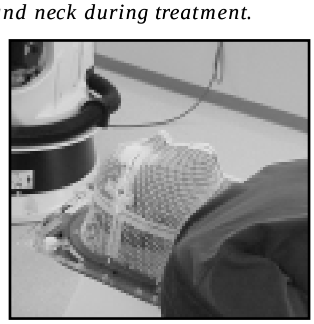
For patients with brain metastases, stereotactic radiosurgery has emerged as the treatment of choice providing the number of lesions is relatively limited and there is reasonable life expectancy. Almost all studies on the subject have concluded that the benefits of radiosurgical ablation compare favorably to surgical resection in terms of survival and neurologic palliation. The rate of local tumor control after treatment ranges from 85% to 95% with or without whole brain radiation therapy (WBRT). Meanwhile, the length of survival in radiosurgically treated patients is reported to range from 6.4 to 10 months.[4] As a result, the use of outpatient radiosurgery has now replaced the open surgical resection of brain metastases in most cases. Undiagnosed primary cancers and tumors larger than 3 cm are examples in which clinical circumstances favor surgical resection. Nevertheless, utilizing staged CyberKnife ablation can now both effectively and safely treat some larger lesions. Such hypo-fractionated radiosurgery is administered over 2 to 5 days thereby minimizing the toxicity of treatment on the surrounding normal brain.

Because of the very high rates of tumor control that can be achieved, and because of the minimal morbidity that ensues, radiosurgery is increasingly being used to ablate brain metastases without WBRT. There is no absolute cut-off for how many brain lesions can or should be managed in this manner. However, the medical literature suggests that the greatest survival benefit is conferred upon those with the fewest brain lesions. This observation, combined with practical considerations and our personal experience, has led us to use radiosurgery as the sole treatment in patients harboring up to four brain metastases. Although this decision results in a somewhat greater risk of regional relapse, additional (i.e. future) tumors can be managed with either a subsequent course of radiosurgery or delayed WBRT. The primary advantage of this approach is the avoidance of the near inevitable morbidity that accompanies WBRT, usually in the form of cognitive impairment.

BRAIN GLIOMA

Gliomas are a class of tumor that develops from glial (neuroepithelial or support) cells. Astrocytes, ependymal, and oligodendroglial are all examples of glial cells that compose the supportive tissue of the brain. Contemporary classification of gliomas is based on the World Health Organization (WHO) system, which classifies the tumors according to the cell of origin and histologic features identified by the pathologist or neuropathologist. Low grade gliomas are slow growing, and are assigned either a I or II grade. From a practical standpoint, grade I tumors (such as the pilocytic astrocytoma) are usually excluded from conversation dealing with glioma tumors, as they constitute a distinctive pathologic and clinical entity. High grade (malignant) gliomas grow much more quickly, and are assigned either a III (anaplastic) or IV (glioblastoma multiforme) grade. Combined, grade III and IV gliomas represent about 60% of all primary brain tumors in patients older than 60 years.

Figure 2: *Aquaplast Facemask. The patient face was fitted with a molded, transparent Aquaplast facemask (WFR/Aquaplast Corp., Wyckoff, NJ, USA) for immobilization and stabilization of head and neck during treatment.*



Malignant gliomas are one of the most devastating tumors that can affect any given individual. These tumors possess a very complex histologic and genetic mosaic pattern that allows these tumors to multiply quickly, invade and infiltrate neighboring brain cells and to form new blood vessels simultaneously.

Traditional treatment options for malignant glioma tumors include: surgery, radiation therapy, and chemotherapy. Open surgery (craniotomy) is the primary form of treatment for malignant gliomas. This allows immediate removal of mass effect that may be caused by the tumor, as well as removing hypoxic tumor cells that might be resistant to radiation therapy and chemotherapy. The invasive and infiltrating nature of malignant gliomas make complete removal of this tumor impossible without sacrificing normal brain cells and thus creating additional neurological deficits.

Daily fractionated radiation therapy and chemotherapy are used as secondary treatments following surgery. Both therapies have a growth-suppressant effect on the tumor. In patients who are poor surgical candidates to undergo an open resection, either radiation or chemotherapy can be used as an initial treatment, but only after a biopsy has established the diagnosis of malignant glioma. Patients who are poor operative candidates generally include those who:

1. are medically unstable
2. have multiple active cancers simultaneously
3. have tumor spread to both brain hemispheres
4. have a glioma in an inoperable location (e.g. brain stem)
5. are opposed to surgery

Inevitably, high grade glial tumors will recur (progress) despite aggressive combined therapies (surgical removal, radiation therapy and chemotherapy). In over 80% of cases, tumor progression will occur within the margins of the previously resected/radiated tumor. Unlike conventional radiation therapy which seeks simply to suppress the growth of the glioma, the goal of radiosurgery is to create a zone of tumor destruction (ablation). Radiosurgery can be used to ablate glial tumors in patients who are otherwise not surgical candidates, patients who cannot tolerate daily radiation, and patients who are opposed to conventional surgical resection. Whether used immediately following surgery, or at the time of glial tumor recurrence, clinical studies suggest that radiosurgery prolongs patient survival and improvement in quality of life (QOL).

Since CyberKnife does not require an invasive frame fixed to the patient's head for precise targeting, radiosurgery can be given in a single session or can be fractionated into 3-5 smaller treatment sessions that last 20-30 minutes each.

BENIGN BRAIN LESIONS

Radiosurgery has revolutionized the treatment of many types of benign brain lesions. Although the actual clinical results will vary with tumor histology, it is worth noting the parameters that define a successful treatment. In particular it is rare for these slow growing lesions to simply disappear on follow-up scans. Instead the most typical outcome begins with signs of central tumor necrosis, and this is then followed by very gradual tumor shrinkage, literally over a period of years. Because lesion shrinkage is a slow process, radiosurgical ablation is not well suited for treating those brain lesions that present with significant mass effect. However, when confronted with large benign brain tumors, often times combined surgical resection and radiosurgical ablation offer a patient prompt amelioration of symptoms while minimizing the risk of morbidity to critical areas of the brain and cranial nerves.

ACOUSTIC NEUROMA

Acoustic neuromas are benign tumors that characteristically arise from schwann cells within the vestibular nerve and are more appropriately termed vestibular schwannomas. These slow growing lesions typically present with hearing loss or a disturbance in equilibrium. Facial weakness, and facial pain and numbness are less common clinical presentations. Vestibular schwannomas are readily diagnosed by contrast MRI, which reveals an enhancing cerebellopontine angle lesion involving the porous acousticus.

The standard treatment for acoustic neuroma over the past several decades has consisted of open surgical resection. Although refinements in operative techniques, especially the introduction of microsurgical methods, have greatly improved surgical outcomes with this disorder, facial weakness is not an uncommon complication of surgery. Meanwhile, it is only possible to preserve useful hearing in roughly half of the most favorable cases (small tumors) even when operated on by the most experienced microsurgeons. Finally, with open surgical resection there is a risk of further complications such as CSF leak, while in very rare instances, peri-operative death can occur. In large part driven by the above complications, stereotactic radiosurgery has evolved during the past 15 years into an increasingly attractive treatment alternative for managing acoustic neuroma.[6] A relatively extensive clinical experience has enabled various single fraction radiosurgical dose parameters to be refined, thereby minimizing the risk profile from this treatment. Meanwhile, the introduction of the CyberKnife concept now permits the use hypofractionated staged radiosurgical ablation for acoustic neuroma. This new approach has allowed the risk profile from radiosurgical ablation to be improved further still.

MENINGIOMA

Radiosurgery is a treatment option for many patients with meningioma. Since most of these benign tumors are located over the cerebral convexity or along the parasagittal region they are well treated with surgical resection. Nevertheless, skull base meningiomas are not uncommon, and resection of such lesions is considerably more problematic. Radiosurgery has proven an invaluable treatment option for many patients with such lesions. Among meningioma the advantages of radiosurgical ablation are greatest for relatively small tumors, i.e. less than 3 centimeters in greatest diameter, that are located in areas of the skull base where resection is difficult if not impossible. These locations especially include the cavernous sinus, cerebellopontine angle and the jugular foramen. Although it is typically difficult to avoid irradiating cranial nerves adjacent or contained within skull-base tumors, these normal structures prove to be relatively resistant to the doses of radiation typically used in radiosurgery. Meanwhile, rates of tumor control are characteristically greater than 95%.[7]

PITUITARY TUMORS

Hormone secreting pituitary tumors such as prolactinomas, ACTH secreting tumors and GH secreting tumors respond well to radiosurgery. Radiosurgery is the treatment of choice for residual pituitary tumor, tumor infiltrating the cavernous sinus or compressing the optic apparatus, or in patients who are not fit for a microsurgery resection.[12] When there is recurrence of pituitary tumor, radiosurgery is an excellent option. Here at SUMC, the prescribed dose for CyberKnife radiosurgery treatment of pituitary tumors is 20-25 Gy in 1-5 stages, and the dose is increased for secreting tumors.

ARTERIOVENOUS MALFORMATIONS (AVM)

Stereotactic radiosurgery (SRS) is an important treatment for small to moderately sized AVMs, particularly those located in surgically inaccessible regions or in patients who are poor operative candidates. Analogous to the time course with other benign lesions, which is typically relatively slow, AVM obliteration typically takes place over two to three years. AVMs of less than 4 cm in diameter treated with 20-25 Gy have a 3-year obliteration rate of 76-95% with relatively low morbidity (2.5-4.5% permanent neurologic deficits, 2.5-4.5% transient deficits).[8] Although highly effective, SRS does not immediately protect candidate patients from acute hemorrhage/re-hemorrhage, as endothelial necrosis (the effect of SRS on arterial vessels) can take months to years to develop.

TRIGEMINAL NEURALGIA

Stereotactic radiosurgery for idiopathic trigeminal neuralgia and for patients with medically refractory trigeminal neuralgia is safe, effective, and results in fewer complications as compared to all other surgeries.

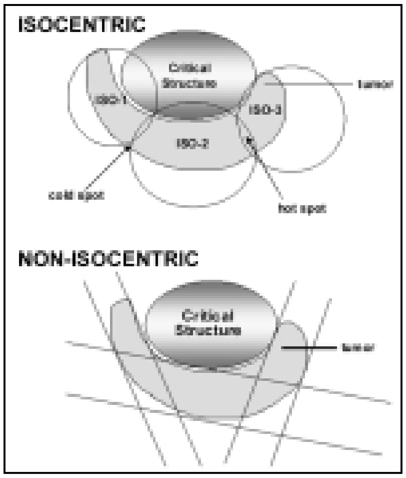


Figure 3: *Isocentric versus non-isocentric.*

Cold Spots: *Target areas receive underdosing or a less optimal dose in which tumor cells are not completely destroyed.* ***Hot Spots:*** *Target areas receive overdosing. Consequently, there is a risk of excessive radiation exposure to normal tissue, including highly radiosensitive critical structures such as optic chiasm and acoustic nerves.*

For patients who had undergone balloon nerve compression, glycerol rhizotomy, or percutaneous thermorhizotomy, one complication is facial paresthesia and/or numbness of varying magnitude. This adverse effect may result from injury of the trigeminal nerve, causing impairment of sensory nerve transmission. In a recent Stanford CyberKnife radiosurgery study, no patient with prior surgery developed facial paresthesia following radiosurgery treatment. The reduced rate of facial sensory disturbance indicates that the effects of radiosurgery are both physiologic and histologic due to lesser irritation
on nerve tissue than other ablative surgeries. CyberKnife technology allows conformal treatment along the nerve and permits highly collimator radiation beams near the dorsal root entry zone. At SUMC, we commonly prescribe total peripheral lesion dose between 66-86 Gy in 1 stage with maximum dose between 78-84 Gy.

HEAD AND NECK CANCERS INCLUDING NASOPHARYGEAL CARCINOMA (NPC)

Nasopharyngeal carcinoma (NPC) arises within the mucosa or submucosa of the nasopharynx, and often spreads to the skull base especially in the vicinity of the cavernous sinus. Because this tumor is relatively radiosensitive, primary radiotherapy (XRT) is the treatment of choice. However, there is a significant incidence of local failure (26-100%) in more advanced NPC after treatment with conventional XRT.[9] Although higher XRT doses or brachytherapy boosts increase local control, the possibility of normal tissue injury and/or the inability to effectively treat tumor extension to the skull base are limitations of these techniques; brachytherapy has a lesser capacity to augment radiation dose to deep tissues as opposed to mucosal surfaces. Because of the significant risk of local failure, a planned radiosurgical boost has proven an important adjunct to conventional XRT in patients with nasopharyngeal carcinoma. The primary tumor in many patients with NPC is relatively low in the neck, which often makes targeting such lesions with frame-based radiosurgical systems impractical. The image-guided localization technology used by the CyberKnife readily facilitates the treatment of such lesions.

From October 1992 to December 2000, forty-five patients underwent planned radiosurgical boost at SUMC following XRT as initial management of a newly diagnosed NPC. To date there were no local failures (median follow up: 40 months). While some patients with more advanced cancers developed metastases elsewhere and their overall survival was only 75%, a 3-year local control rate of 100% is striking.

SPINAL TUMORS

For lesions within or adjacent to the spinal canal, stainless steel screws (Lorenz — Accuray, Inc., Sunnyvale, CA) are implanted percutaneously, with the use of fluoroscopy, into the pedicles of the vertebrae adjacent, above and below the targeted lesion. These screws then function as fiducial markers which are used for targeting and treatment planning for CyberKnife radiosurgery.

Conventional radiation dose guidelines for spinal tumors are generally based upon accepted radiation tolerance and the volume of spinal cord irradiated. The total dose delivered is determined by the tumor grade, the amount of post-operative tumor residual and the spinal cord tolerance. The accepted parameters of spinal cord radiation dose limits to fractionated radiation therapy are based on empirical clinical observations and animal data. Because the risk of myelopathy is less than 1% for fractionated radiation regimens of 4500 cGy in 22-25 fractions, this is a commonly observed dose limit guideline.[13] Conventionally fractionated doses of 5700-6100 cGy are estimated to yield a five percent probability of radiation myelitis. When determining the treatment doses for spinal cord tumors, the risk of myelitis must be weighed against the goal of treatment. Operating within these guidelines, benign ependymomas and low-grade astrocytomas of the spine are treated with a total dose of 4500-5040 cGy in 180 cGy fractions over 28-30 treatment days. However, because of their more aggressive nature, malignant ependymomas and high-grade astrocytomas are treated with a total dose of 5000-5400 cGy in 180 cGy fractions over 28-30 treatment days.

The dose guidelines for spinal radiosurgery are less clear. As with conventionally fractionated radiation therapy, the dose is chosen to maximize the eradication of the tumor while minimizing the risk of spinal cord injury.[14] Unfortunately, there are relatively few sources of clinical empirical observations or animal data to support definitive guidelines for radiosurgical doses. Studies of rat spinal cord show a steep rise in spinal cord tolerance to radiation with dose fractionation. While there are theoretical models of normal tissue complication probability (NTCP) based on the concept of functional subunits, these models do not always reflect clinical experience.

In general, our CyberKnife spinal radiosurgery represents a dose and staging that is somewhere between what is commonly used with conventionally fractionated radiation therapy and a dose that would other wise be used to treat a similar lesion of the brain. Therefore, understanding that dose-volume effects may also important, we observe single staged spinal cord doses of 800-1000 cGy as an acceptable spinal cord limit. Our experience with spinal tumors has been relatively favorable. Almost all patients exhibit tumor shrinkage, and no complication has been reported to date.

EXTRACRANIAL EXTRASPINAL RADIOSURGERY

Recent advancements of the CyberKnife radiosurgery system allows the delivery of multiple highly focused beams of radiation to sites outside the cranium. A newly approved technology, termed Synchrony, now makes it possible through robotics to dynamically target such tumors in real time. Unlike framed based radiosurgical systems, the CyberKnife references the position of the treatment target to internal anatomic radiographic features such as the skull, or percutaneously implanted fiducials rather than the frame itself. The CyberKnife also uses real time radiographic imaging to establish the position of the lesion during treatment and then dynamically brings the radiation beam into alignment with the observed position of the treatment target. The CyberKnife is capable of aiming each beam independently, without a fixed isocenter. These features allow precise detection of positional changes of the patient during treatment, which are then compensated for by adaptive beam pointing (rather than controlling the change in positioning by rigid immobilization). Moreover, these features allow the delivery of precise tumoricidal doses of radiation to lesions within or adjacent to the spinal canal or to lesions in the thoracic, abdominal and pelvic organs.

There are no radiobiologic principles that restrict the application of radiosurgery to lesions in or adjacent to the cranio-spinal axis. Given the effectiveness and ease of performance of CyberKnife radiosurgery, there is growing interest in also using this technology to ablate tumors throughout the abdominal and thoracic cavities. Parameters for such treatment are being refined through a number of ongoing clinical studies.

At Stanford the largest number of patients treated to date with soft tissue cancers are a group of patients with unresectable pancreatic and lung cancer. To date, all these patients were treated as part of a dose escalation study ranging from 15 to 30 Gy in a single stage. Despite an evolving appreciation for the optimal treatment parameters, the preliminary experience with extracranial radiosurgery has been relatively favorable; almost all patients treated had advanced disease yet derived signifi-

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Continuing Medical Education Questions

1. Certain radiosurgical technologies require stereotactic frames for accurate beam targeting.
   ❑ Yes ❑ No
2. Functional neurosurgery is defined as a class of operations that involve targeting discretely small areas of the brain for radiotherapy and includes treating such diseases as Parkinson's disease, movement disorders, and psychiatric disorders.
   ❑ Yes ❑ No
3. Cyber Knife technology allows for accurate beam radiotherapy using real time image guidance and avoids the use of a stereotactic head frame.
   ❑ Yes ❑ No
4. The most common forms of radiosurgical technology are utilized in lesions outside the central nervous system.
   ❑ Yes ❑ No
5. The complications associated with the surgical treatment of acoustic neuromas has driven the development of radiosurgery as a reasonable alternative.
   ❑ Yes ❑ No
6. The accepted parameters of spinal cord radiation dosing are largely based on empirical clinical observations and animal studies.
   ❑ Yes ❑ No
7. Fractionated radiation treatment of dosing at 4500 cGy in 22 to 25 fractions is associated with a 5% risk of radiation myelitis.
   ❑ Yes ❑ No
8. Recommendations for radiosurgical parameters for spinal cord lesions have been outlined through multi-center trials of clinical experience.
   ❑ Yes ❑ No
9. The high incidence of failure in locally controlling nasopharyngeal cancers has boosted the interest in stereotactic radiosurgery.
   ❑ Yes ❑ No

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   ❑ Yes ❑ No

cant benefits from tumor shrinkage and/or pain relief. Furthermore, there have been no complications to date. New radiosurgical protocols are under development for lesions of the kidney, liver and prostate.

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Mission Statement

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