CYBERKNIFE

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CyberKnife

Stereotactic radiosurgery (SRS) was conceived by Swedish neurosurgeon Dr. Lars Leksell in 1951 (1) and initially relied on rigid fixation of the skull by a stereotactic head frame used as reference in order to precisely target radiation beams to intracranial lesions. A frame-based approach had limitations which included patient discomfort and inability to deliver multi-session treatments. American neurosurgeon Dr. John Adler was inspired to develop a frameless radiosurgical device after a neurosurgical fellowship with Dr. Leksell at the Karolinska Institute in Stockholm in 1985 (2). He believed that frameless targeting could be achieved through X-ray image-to-image correlation and that this type of image-guided radiosurgery would obviate the need for an invasive stereotactic frame. In addition to greater patient comfort, a frameless system would allow for fractionated treatment over several days while maintaining stereotactic accuracy, as well as extracranial radiosurgery.

CyberKnife is a stereotactic radiosurgery (SRS) system. SRS is a combination of principles of stereotaxy, or three-dimensional target localization, and radiation beams from multiple directions cross-firing the tumor precisely. Due to the high degree of precision, it is possible to deliver very high dose of radiation to the target with minimal damage to the normal tissues and structures surrounding the tumor. The ideal aim is to ablate the tumor with high radiation dose noninvasively. It has been proved to be an effective alternative to surgery for small tumors and selected medical conditions

The first CyberKnife prototype, initially called the Neurotron 1000, was installed and treated patients at Stanford University Medical Center between 1994 and 2000. On June 8, 1994, the first patient was treated, an elderly woman with a solitary brain metastasis. CyberKnife was approved by the United States Food and Drug Administration for intracranial applications in 1999, and then received clearance in 2001 for radiosurgical treatment of lesions anywhere in the body where radiation is indicated.

The concept of radiosurgery was developed and put into practice by Dr. Lars Leksell, a Swedish neurosurgeon, in early 1950s.(3) A new device was developed exclusively for radiosurgery with the help of approximately 201 numbers of pencil-type Co-60 sources focused on the region of abnormal brain tissues. These sources were spherically distributed in a helmet around the skull, which is fitted onto the patient's head, and the system is called Gamma Knife.[4] With this system, a relatively spherical dose focused around the target volume, with minimal dose to the surrounding normal cells, could be delivered. The limitation of the Gamma Knife is mainly in its usability outside the head, even though the new generation of Gamma Knife can treat tumors up to C2 vertebra level.

The CyberKnife concept, invented by Dr. John Adler, came into practice by 1990s.(5,6) A lightweight linear accelerator fitted onto an industrial robot makes treatment possible

precisely in a desired way. The robotic arm has 6 degrees of freedom of movement; unlike the conventional linear accelerator, which has only rotational movement in one plane. CyberKnife treatments are non-isocentric, where beams can be directed from any desired angle. This system does not require a rigid frame to be fixed onto the skull of the patient for stereotactic setup and verification. Initially the CyberKnife was put into use for treatment of only intracranial lesions, like other stereotactic systems.(7) Subsequent developments made it possible to extend the facility to extracranial lesions also, thereby making it a whole-body stereotactic radiotherapy system.

There are a few unique features in CyberKnife to track the tumor precisely and deliver radiation accurately as desired.[8] Unlike other linac-based systems, which have accuracy in millimeters, the CyberKnife has sub-millimeter accuracy in tracking tumor position. If sub-millimeter accuracy is not achieved, it gives warning and stops treatment. The orthogonal x-ray images are taken before each beam and verified for accuracy.

There are 5 different tumor-tracking facilities in CyberKnife treatment. They are 6D skull, fiducial, X sight spine, X sight lung with synchrony, and fiducial with synchrony. These tracking methods are used in different types of sites and with various natures of the organ to be treated. 6D skull tracking is used only for intracranial lesions. Fiducial tracking can be used for any other site. The synchrony tracking feature is used for tracking any moving target in a phased manner with breathing cycles.[9, 10] Unlike other systems, where treatment is given on a certain fixed phase of breathing (gated therapy), with synchrony method, the robot can move in synchrony with chest movement during breathing and deliver radiation without interruption as if the tumor is locked to the beam.

Since the initial CyberKnife prototype, there have been five subsequent models through 2017. The second generation CyberKnife in 2001 introduced a new robot system (Kuka Roboter GmbH, Augsburg, Germany) and replaced the fluoroscopic screen/charge-coupled device camera with high resolution flat-panel amorphous silicon detectors. In 2002, the G3 model was introduced with more advanced image-tracking algorithms: six-degree skull tracking (6D Skull Tracking), fiducial-free spine tracking (XSight® Spine Tracking, Accuray, Sunnyvale, CA, USA), and Synchrony (Accuray, Sunnyvale, CA, USA) for dynamic tracking on moving targets. Advances in imaging tracking techniques significantly improved delivery accuracy [11]. The G4 model was introduced in 2005 with an automated exchange table for the beam collimators. With the VSI model in 2009, improvements included a 6D Robot Couch, floor mounted high resolution (1024 × 1024) amorphous silicon detectors, higher dose rate (1000 monitor unite/minutes), the IRIS™ (Accuray, Sunnyvale, CA, USA) variable aperture collimator system, and fiducial-less lung tracking with Synchrony.

Technical characteristics:

The cyberknife combines two advanced technologies to deliver conformal radiosurgery

doses without frame (12). A 6-MV linear accelerator (Linac) radiosurgery designed system and a highly maneuverable robotic manipulator (12). The second special feature is real-time image guidance which removes the need for using skeletal fixation for either target immobilization or positioning. (12). The imaging system consists of two diagnostic x-ray sources mounted to the ceiling paired with amorphous silicon detectors to acquire live digital radiographic images of the tumor or tumor localizing surrogates such as the skull, spine or fiducial markers. The Synchrony system enables 4D real-time tracking of tumors that move with respiration. (13) An advantage of the synchrony subsystem is that the patients can breathe normally. Synchrony combines noncontinuous x-ray imaging of internal fiducial markers as surrogates for the tumor position, with a continuously updated external breathing signal. In more recent system versions, it is possible to track the tumor directly in the x-ray images using the contrast between tumor and surrounding lung tissue, thereby removing the need to implant fiducial markers. The tumor is localized by reconstructing the 3D position of the tumor or the fiducial markers, which are automatically segmented in the x-ray images. The reconstructed position is compared with the position in the planning CT scan. Just prior to the start of the irradiation, the correlation model is built by acquiring approximately eight x-ray image pairs at different phases of the breathing cycle. The Synchrony system makes a correlation model that relates the movement of the tumor or the fiducial markers and the LEDs. Nonlinear models are used to account for hysteresis in the tumor trajectory.

The Cyberknife system can select secondary collimators of 12 different sizes which range from 5-60 mm in diameter defined at 80 cm source-axis distance (SAD). These cone beams are inferior in dose flatness compared to linear accelerator-based SRS cone beams due to the absence of a flattening filter in the Cyberknife treatment head. Therefore, even in the largest field of the 60 mm collimator size, the absorbed dose measured with a Farmer-type ion chamber is underestimated due to the volumetric averaging effect. For example, small volume pinpoint ion chambers are used for small-field dosimetry, but they are not available due to their large active volume for collimator sizes less than 10 mm. The problem with these chambers is their relatively low signal and the resulting noise. The diamond detector is essentially tissue equivalent and thus energy independent, but dose-rate dependent. (14) The diamond detector is also not available due to its large active volume for collimators less than 10 mm. For these reasons, small-field measurements for the Cyberknife system have generally been performed using a P-type silicon diode detector with a very small active volume against an ion chamber and a diamond detector. The problem with the diode detector is that it is water nonequivalent and thus energy dependent. Especially, it is reported that the diode detector exhibits higher response with respect to the output measurements for very small fields. (15, 16)

Another problem with the Cyberknife field measurements is the inapplicability of a beam quality conversion factor, ^{k}Q, based on recent dosimetry protocols. (17, 18) In other words, the

dose calibration of the Cyberknife system is performed with the 60 mm collimator at 80 cm SAD or 80 cm source-surface distance (SSD). It is anticipated that the water-air stopping power ratios, which are a main factor in determining ^{k}Q for Cyberknife dosimetry, differ from those determined with the reference dosimetry conditions (10*10 cm^2) field at 100 cm SSD or 100 cm SAD) in the protocols.

Cyberknife beam compared to linear accelerator beam:

A photon fluence spectrum at a phantom surface from the Cyberknife system was compared with that of a 6 MV photon beam from a Varian 2100C linear accelerator (Varian Oncology Systems, Palo Alto, CA). The fluence spectra for the Cyberknife system and the linear accelerator were calculated for a 60 mm circular field at 80 cm SSD and a 10*10 cm^2 field at 100 cm SSD, respectively. For Monte Carlo simulations of the Varian 2100C linear accelerator, the incident electron mean energy and energy spread were 6 MV and Gaussian with a FWHM of 3%, respectively. The electron radial intensity distribution was taken as Gaussian with the FWHM of 2 mm. The Mote Carlo calculated dose distributions agreed within 2% with those measured for a 10*10 cm^2 field at SSD=100 cm. The parameters of the Monte Carlo transport were the same as the Cyberknife system.

Photon and electron mean energies and Spencer-Attix water-to-air stopping power ratios in a water phantom were also compared between the two beams. Furthermore, they were calculated for 5-60 mm collimators from the Cyberknife system. The phase-space files scored at the phase-space plane 2 were analyzed to obtain the incident photons' energy spectra at the phantom surface, and photon and electron mean energies and water-to-air stopping power ratios in the water phantom. The photon spectra, photon and electron mean energies, and the stopping power ratios were calculated using EGSnrc user codes BEAMDP (19), FLURZnrc (20), and SPRRZnrc (21), respectively. ECUT and PCUT used for FLURZnrc and SPRRZnrc were 0.521 and 0.01 MeV, respectively.

Treatment planning:

Treatment planning with the CyberKnife system occurs in steps. First, regions of interest are delineated manually on CT or MR images by the treating surgeon or radiation oncologist. The amount of radiation required for tumor ablation and that will be tolerated by critical regions is specified by the user. Next, the system utilizes contour data to create a 3-D representation of the lesion. Based on this geometry, an initial set of beam configurations is defined which originate from a set of discrete points in space (nodes) where the robot stops to aim the L1NAC.

During treatment, multiple radiation beams are delivered according to a pre-defined treatment plan. A 6MV linear accelerator mounted on a robotic positioning arm (KUKA, Germany,www.kuka.de) accurately targets the beams at tumours and other lesions in the head and body. The radiation beams, and their resultant dose distribution, are designed to destroy the tumour while minimizing exposure to nearby

healthy tissue. Prior to and during treatment, a system composed of two orthogonal imaging chains made of diagnostic(kV) X-ray sources and digital amorphous silicon detectors provides a continuous update of the patient's position. This system allows the robotic manipulator to correct for changes in patient position during treatment beam delivery. A five-degree of freedom treatment table (AxumTM) is also available for automatic patient (re)positioning prior to or during treatment.

Treatment delivery:

Beam alignment at the time of treatment is based on automatic registration of digitally reconstructed radiographs (DRRs) generated from the 3D patient model, with live images acquired using the X-ray imaging system in the treatment room. This results in two independent transformations, one for each of the live image and DRR pairs, which are combined and converted into a 3D transformation by geometric backprojection. Since the geometry of the X-ray imaging system relative to the treatment room is known (*i.e.*, in room space) this transformation allows the transformation between room and target space to be obtained. Moreover, since the geometry of the couch and robotic manipulator are known in room space, this transformation allows the pose (*i.e.*, position and orientation) of each treatment beam relative to the target volume that was simulated on the TPS to be achieved during treatment. At the start of every treatment, the X-ray image guidance system aligns the patient using an adjustable treatment table. (22)

Both a five-axis table and a six-axis RoboCouch® Patient Positioning System, shown in Figure 1b, are available. With the five-axis table the sixth correction (yaw angle) can be applied manually. The purpose of this initial alignment is to reduce the corrections that will be required from the robotic manipulator below maximum limits, which are ±10 mm or ±25 mm in each direction and ±1° to ±5° about each axis depending on the tracking mode, path set, and couch design. After the patient is aligned within these limits, the image guidance system determines the additional translational and rotational corrections needed to precisely align each treatment beam. These corrections are relayed to the robotic manipulator and used to automatically compensate for small target movements by repositioning the LINAC, *i.e.,* fine alignment is achieved uniquely by adjusting the beam position and orientation relative to the patient and not the patient relative to the beam. (22)

During treatment, the robot moves in sequence through the nodes selected during treatment planning. An optimized path traversal algorithm allows the manipulator to travel only between nodes at which one or more treatment beams are to be delivered, or through the minimum number of additional zero-dose nodes required to prevent the robot trajectory intersecting fixed room obstacles or a 'safety zone' surrounding the couch and patient. At each node, the manipulator is used to re-orient the LINAC such that each beam originating at the node can be delivered. (22)

Image acquisition, target localization, and alignment corrections are repeated continually during treatment delivery, typically every 30–60 s; the imaging interval can be adjusted during treatment based on the stability of the target position. The robotic manipulator compensates for small translations and rotations based on the corrections obtained from the most recently acquired image pair; large translations and rotations automatically pause the treatment and prompt the operator to reposition the patient before proceeding. The repositioning can be performed automatically using the RoboCouch table for all translations and rotations, or automatically using the five-axis table for all translations and rotations except the yaw angle. Dose placement accuracy is assured by imaging and correcting beam aim frequently throughout each treatment fraction. No stereotactic frame is required, and one need not assume that motion will not occur after initial patient setup. For targets that move due to respiration an additional tracking system enables beams to move in real time to follow the target while the patient breathes freely. (22)

Treatment Delivery System Software:

6D Skull Tracking: This method can be used for intracranial targets as well as head and neck targets that are considered to be fixed relative to the skull. Image registration is performed using high contrast bone information contained within the entire field of view. Each 2D registration is performed in multiple stages, using two image similarity measures and several search methods. The resulting 2D transformations for each orthogonal projection are combined and backprojected to determine the 3D rigid transformation that aligns the position and orientation of the skull in the treatment planning CT image with the treatment delivery coordinate system. Fu & Kuduvalli describe this algorithm in detail (22, 23).

Xsight Spine Tracking: This method can be used for targets located anywhere in the spine, or targets located near the spine and considered to be fixed relative to it. As with the skull tracking method, image registration is based on high contrast bone information. For spine tracking, however, image processing filters are applied to enhance the skeletal structures in both the DRR and the treatment X-ray images. This improves estimation of local displacements for these structures. Optionally, the DRRs can be generated by restricting attenuation to voxels within a region surrounding the spine such that the DRRs represent only spine anatomy and do not include image artifacts from tissue motion or from non-spinal bony anatomy such as the rib cage. Registration is performed in a region of interest (ROI) that generally includes the vertebra of interest plus the two adjacent vertebrae. The local displacement vector that aligns a point in the DRR image with the corresponding point in the X-ray image is estimated at each node point in a grid laid over the ROI. A small region or block surrounding the node point in the DRR image is compared with regions in the X-ray image. Block matching,

which is essentially the estimation of local displacements of skeletal structure, is performed in a multi-resolution approach to increase efficiency and robustness. The position (translation) and orientation (rotation) of the skeletal anatomy, and thus the target, is computed from the resulting local displacement fields between the X-ray image and the DRR image. Details of this algorithm have been described elsewhere (22, 24-26).

Xsight Lung Tracking: This method can be used to track tumors located within the lung without the use of implanted fiducial markers. The lung tracking approach differs from other tracking methods in that patient alignment and tumor tracking are performed in two stages rather than one. Xsight Lung Tracking begins with global patient alignment, including both position and orientation, using the region of the spine nearest the lung tumor. Global alignment happens only once, at the beginning of treatment. After the patient is globally aligned, the treatment couch moves the patient from the spine alignment center to the tumor treatment center (these are defined during treatment planning). After this movement, the tumor will be close to the reference position around which it will move during breathing. Direct tumor tracking is performed by image registration of the tumor region in the DRRs to the corresponding region in the treatment X-ray images. Specifically, the image intensity pattern of the tumor region in the DRR is matched to the most similar region in the X-ray image. A matching window for the tumor is defined based on the tumor silhouette in each projection. The registration process is conducted separately for each projection, resulting in 2D translations for each projection; the 3D tumor translation is determined by backprojection of the 2D translations. This requires that the image intensity pattern of the tumor is distinguishable from other objects in the image, which requires the tumor to have sufficient contrast relative to the surrounding region. The two primary factors that determine tumor visibility are size (which influences contrast) and location (which can influence contrast if the tumor is superimposed in the X-ray image on radiopaque structures such as the spine or mediastinum). The tracking algorithm works best for tumors larger than 15 mm in diameter that are located in the peripheral and apex lung regions. Retrospective analysis of clinical image data for more than 100 patients suggests that the Xsight Lung Tracking system may be appropriate for treating slightly more than 50% of lung radiosurgery candidates (27). The treatment planning system also provides a quality review of the tracking DRRs to help confirm patient eligibility for lung tracking. This tracking method can be combined with the respiratory tracking system described later. The original algorithm is described in detail by Fu *et al.*, (22, 28). Recent enhancements include DRRs generated from local tumor neighborhoods, an automatic preferred projection epipolar constraint, tumor template matching allowing for in-plane rotations, and automatic X-ray image enhancement (27).

Fiducial Marker Tracking: This method can be used for soft tissue targets that are not fixed

relative to the skull or spine (*e.g.*, prostate, pancreas, liver), including lung tumors for which the Xsight lung tracking method is unsuitable. Radiopaque fiducial markers are implanted in or adjacent to the lesion being treated to provide an internal frame of reference. Cylindrical gold seeds are often used, with dimensions of 0.8–1.2 mm in diameter and 3–6 mm in length. Fiducial markers are often implanted percutaneously under image guidance. Implantation in the lung can also be performed bronchoscopically (22, 28, 29). Between three and five fiducial markers are typically implanted, and in most instances the treatment planning CT scan is acquired a week or more after implantation to allow the fiducial marker positions to stabilize. Fiducial markers are identified in the planning CT scan and therefore their positions are known in the DRR images. Image registration is based on alignment of these known DRR positions with the marker locations extracted from the treatment X-ray images. This process is described in detail elsewhere (22, 30-31). An assessment of potential marker migration is made automatically by determining individual marker misalignment after registration, allowing individual markers to be omitted from the registration calculation if necessary.

Clinical experience:

As of July 1, 2001, over 350 intracranial tumors and AVMs and 31 spinal lesions have been treated at Stanford University with another 1,500 intracranial and 25 spinal lesions treated at other Cyberknife centers worldwide [8, 11, 32, 33]. The results with treatment of intracranial lesions closely parallel that described for other radiosurgical techniques [33]. Meanwhile, the 31 spinal lesions that have been treated at Stanford (hemangioblastomas, AVMs, spinal metastases, ependymomas, schwannomas, meningiomas, and chordomas) demonstrate the Cyberknife's unique ability to administer accurate radiosurgical treatment throughout the cranial-spinal axis. Such spinal treatments utilize percutaneously implanted fiducials to direct the radiosurgery beams. Treatment dose in these cases ranged from 11 to 25 Gy using one to five fractions. Although these initial doses were deliberately chosen to be conservative, no tumor demonstrated progression on follow-up MR imaging nor were any complications observed. More recently the Cyberknife has been used to treat over 35 tumors of the lung and pancreas, thereby demonstrating the feasibility of also treating extraneural targets. Ongoing larger studies will better quantify the benefits of such extracranial radiosurgery.

The developments of the CyberKnife System have resulted in substantial improvements in dose calculation accuracy, treatment plan optimality, treatment delivery geometric accuracy, treatment time, and the range of body sites that are technically accessible to treatment. Most recently, technical developments included in the CyberKnife VSI System have for the first time made practical the delivery of more extended fractionation schemes (such as those common to IMRT). (22)

Clinical development over the years (most of it generated by CyberKnife users themselves) has both prompted technical innovation and has been enabled by it. Early intracranial outcomes (34) prompted improvements in skull tracking (35) that supported development of a wide range of intracranial applications that are helping to validate the newest skull-tracking algorithm (31). The desire to treat spinal lesions (36) lead to the development of fiducial tracking algorithms (37), which both set the stage for further spinal treatments (*e.g.,* Gerszten *et al.,* (38)) and continued growth of extracranial applications outside the central nervous system (39-41), as well as providing inspiration for the development of the fiducial-free Xsight Spine Tracking system (23). As treatments extended to tumors in organs that move with respiration (40, 41), Synchrony tracking was introduced and tested in phantom studies (42, 43) and in clinical practice (44). Today researchers worldwide are employing the technologies described in this review in daily clinical practice to treat brain (45-49), spine (50-54), lung (55-58), prostate (59-62), liver (63-65), pancreas (66, 67), head & neck (68-72), and emerging applications such as breast (73) and other extracranial sites (74). The total number of patients treated has increased from just 30 in 1999 to over 90,000 in 2010.

CyberKnife clinical use development:

Brain tumors

The CyberKnife has been used to ablate a broad spectrum of brain tumors including all the lesions commonly treated with conventional stereotactic radiosurgical devices like the Gamma Knife. However, because the CyberKnife is frameless, it is also possible to incorporate fractionation or multiple sessions into radiosurgery in ways that appear to improve clinical outcome. Fractionation appears to enhance treatment safety for larger metastatic brain and skull-based tumors, acoustic neuromas and perioptic lesions. (75)

The vast majority of brain tumors are metastatic. Extensive clinical experience with the Gamma Knife shows these lesions to be best treated in a single radiosurgical session, which results in a high rate of local control. Chang et al. (76) published the early Stanford CyberKnife experience with brain metastases. Seventy-two patients with 84 lesions were treated, all with a single 10 to 36 Gy dose. Comparable to other types of radiosurgery, the tumor control rate was 95% and a 4% incidence of radiation injury was observed. (76).

Acustic neurinoma

Initially, treatment of acoustic neurinoma was performed with open cranial surgery. Due to the high risk of intervention, microsurgery interventions for the removal of the tumor were carried out later, as the technique progressed. However, the emergence of stereotactic radiosurgery was an effective and safe treatment alternative. The CyberKnife tool allows for very precise targeting, which does not require the use of an invasive head frame, thus allowing fractional radiation therapy. With repeated irradiation in smaller doses, fewer side effects should be expected, and hearing loss and minimization after treatment due to better nerve sparing.

Perioptic lesions

A number of tumors arise in close proximity to the anterior visual pathways and are largely unresectableusing

conventional surgical techniques. Such lesions include many pituitary adenomas, meningiomas, craniopharyngiomas, and malignant skull-base tumors. Although single-fraction radiosurgery now has a proven

role in managing many of these tumors, the limited radiation tolerance of the optic nerves and the optic chiasm makes it impossible to treat those perioptic lesions that are immediately adjacent to or surrounding the anterior visual pathways. (77, 78, 97).

Spinal radiosurgery

Spinal tumors

Most brain tumors occur within or adjacent to the spine. The frameless CyberKnife targeting system makes it a relatively straightforward process to

apply the principles of radiosurgery to these lesions. Nevertheless, the close proximity of the radiation-sensitive spinal cord poses a unique challenge. Despite the risks and uncertainty of the advantages, our team at Stanford began investigating spinal radiosurgery almost a decade ago. These effects were directed primarily towards patients who harbored either unresectable or otherwise poorly treated lesions. During this time, our team developed considerable confidence in the targeting

accuracy of the CyberKnife for virtually all paraspinal lesions. Even more importantly, we have acquired a much more nuanced understanding of the spinal cord's tolerance to ionizing radiation, and in particular, hypoffactionated CyberKnife radiosurgery.

IntrameduUary spinal cord A VMs

Intramedullary spinal cord AVMs (SCAVMs) are high-risk lesions which, because of their location within the spinal cord parenchyma, are rarely amenable to traditional endovascular embolization and microsurgical resection. Because there are so few treatment options for most patients with SCAVM, spinal radiosurgery is now proving to be an important new therapeutic tool. Despite initially being uncertain about the potential for catastrophic spinal cord injury, our team at Stanford embarked on an investigation of Cyber-Knife radiosurgery for SCAVMs almost a decade ago.

Lung tumors

Focal treatment of lung neoplasms can be beneficial, and even curative, in many clinical situations. Cyber- Knife-radiosurgical ablation of lung lesions is a minimally invasive alternative to other more invasive techniques such as mini-thoracotomy and radiofrequency ablation. Like all radiosurgical procedures, lung radiosurgery is intended to deliver the most accurate, conformal and aggressive radiation treatment possible. Also a problem is the description and monitoring of displacements alongside tumor movements. CyberKnife radiosurgery currently requires fiducials implanted in or near lung lesions for target identification. Other advanced approaches to more precise radiation treatment of lung tumors employ breath- holding, respiratory gating, or abdominal compression exerted by body frames. In contrast, the CyberKnife uses Synchrony ® a method for targeting and tracking tumors in real time that move throughout the respiratory cycle.

Hepatocelluar carcinoma (HCC) and liver metastases

There are several modalities currently used to treat HCC, including transarterial chemoembolization, surgical resection, radiofrequency ablation, radioisotope injection, chemical ablation, and radiation therapy. However, none of these has

become standard practice. Because it is less invasive, CyberKnife radiosurgery is a potentially more attractive option for such tumors.

Pancreatic cancer

Pancreatic cancer continues to be one of the most lethal of all cancers. With early stage tumors, surgical pancreatectomy and aggressive radiation therapy offer at best limited prospects for cure or palliation; even these modest objectives come at the expense of significant rates of morbidity. Given the shortcomings inherent to state-of-the-art treatment, Stanford University has over the past six years been investigating the potential benefits of CyberKnife ablation for pancreatic cancer.

Prostate cancer

Prostate cancer cells are believed to have a very low a/b ratio, i.e., less than 2. When analyzed by the linear quadratic model, such a value would argue strongly in favor of larger dose fractions than those currently used in conventional radiation therapy. Theoretically such an approach could produce the same or improved tumor control rates, with an even lower incidence of radiation-related complications.

Renal tumors

It is debatable whether conventional radiotherapy should play any role in treatment of primary renal cell carcinoma (RCC). Although a few early series [78,79] suggested an improvement in survival among patients with RCC when Preoperative adjunctive radiotherapy was used, this benefit was associated with a much higher complication rate.

Head and Neck

Nnsophao,nge.al carcinoma OVPC)

NPC has been traditionally treated by radiotherapy alone or in combination with chemotherapy. The present local-regional failure rate is about 20-50% for patients treated by radiotherapy alone. Over the past decade CyberKnife radiosurgical boost after conventional chemoradiotherapy has become a standard part of the management of patients with NPC at Stanford University.

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