2 Delivery Techniques

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2.1 Introduction

The role of stereotactic irradiation has been established for the treatment of various benign and malignant intracranial lesions and diseases. The history of current stereotactic radiosurgery starts, after some early experiments in the 1950s and 1960s, in 1968, when Leksell and Larsson started their clinical work with the Gamma Knife. This device was developed to deliver high doses of radiation with great precision to small targets in the brain. A few decades ago, the widespread availability of linear accelerators (linacs) had lead to investigations on their use for single fraction stereotactic radiosurgery (SRS) and fractionated stereotactic radiotherapy (SRT). Special circular collimators were developed to allow for the use of narrow beams. Linac-based radiosurgical technologies were further advanced by incorporating improved stereotactic positioning devices and methods to measure the accuracy of various components. Since the 1990s, beam shaping is predominantly being achieved by the use of high-definition multileaf collimators (micro-MLCs). Just as in non-stereotactic radiotherapy, these MLCs also make it possible to deliver intensity-modulated SRS and SRT. In the last decade, dedicated linac-based devices were developed, including the Brainlab Novalis® Radiosurgery system (Fig. 2.1) and the Accuray Cyberknife (Fig. 2.2). The original version of the Novalis Radiosurgery system uses a 6 MV

Fig. 2.1 Novalis Tx

Fig. 2.2 Cyberknife

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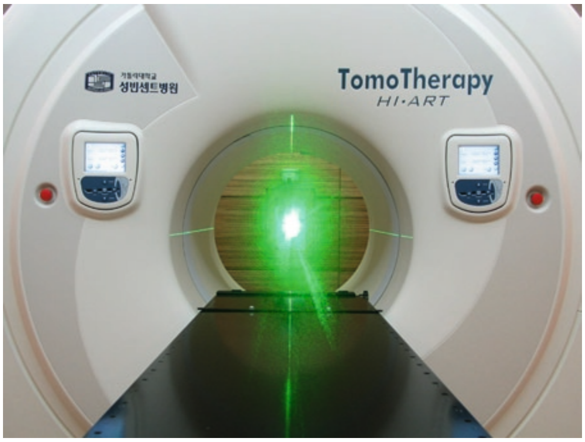

Fig. 2.3 Tomotherapy

linac, in combination with infrared and kilovoltage imaging positioning systems and a couch that allows adaptation in all dimensions. The Cyberknife uses a 6 MV linac attached to a six-axis robotic manipulator that positions the linac at different source positions, constantly aiming the center of the radiation beam at the target. The Tomotherapy Hi-Art system, a linac that is combined with a CT scanner, can also be used for the delivery of SRS and SRT (Fig. 2.3). Narrow proton beams can also be used for SRS and SRT of small targets. However, thus far, the physical advantages of protons, including the Bragg ionization peak to reduce doses to the tissue outside the target to a minimum, have not yet been substantiated in clinical studies. The high cost and limited number of facilities available are important factors that preclude the more widespread use of protons in SRS. A small proportion of patients currently treated with protons receive stereotactic proton-beam radiosurgery. In this chapter, various types of equipment for SRS and SRT, including the Gamma knife, linac-based radiosurgery, including Novalis Radiosurgery, Elekta Access and Cyberknife, and Tomotherapy, are briefly described, as well as some important considerations for the comparison of the equipment. Proton SRS/SRT will not be discussed in this chapter.

2.2 Gamma Knife and RGS-System

The Leksell Gamma Knife (Elekta AB, Stockholm, Sweden) was developed for SRS about 40 years ago and is currently being used in over 200 sites throughout the world. The system consists of about 200 Cobalt-60 sources that are all directed to a single focal point. Leksell Gamma Knife Perfexion (Fig. 2.4) is the current high-end model with improved access to the intracranial structures and improvements in workflow, such as automated collimator changes. This leads to better shielding and more flexibility. A derivative of the Gamma knife, the RGS system with 30 Cobalt-60 radiation sources contained in a revolving hemispheric shell, was more recently developed. A secondary collimator is formed by a coaxial hemispheric shell with six groups of five collimator holes, which are arranged in the same pattern as the radiation sources. These systems, as a result of their design, can only be used to treat intracranial lesions in a single fraction (SRS). A head ring, attached to the head of the patients is used for immobilization and localization. For the generation of treatment plans and the delivery of treatment of irregularly shaped lesions, multiple isocenters are used.

Fig. 2.4 Gamma knife

2.3 Linac Radiosurgery

An adapted linear accelerator can also be used for very precise stereotactic treatments. Since a number of decades, linear accelerators are being used for SRS/SRT and clinical results are similar to those obtained with a Gamma Knife. Initially, a floor stand was needed for support of the treatment couch. More recent couches have sufficient stability for SRS and SRT treatment themselves. For single-fraction SRS, in general an invasive frame or head ring is being used. As this cannot easily be used for fractionated treatments over a longer period of time, noninvasive systems have been developed making use of dental and occipital impressions, or fixation using ears and nose bridge.

These fixation systems can be used as a frame of reference for imaging, treatment planning, and stereotactic treatment delivery. Some of the current noninvasive fixation systems, such as the Brainlab mask system; have similar precision as the systems using an invasive head ring for fixation (Solberg et al. 2008).

With linac-based SRS/SRT, stereotactic treatment of lesions outside the brain is also possible. Stereotactic radiotherapy has proven its benefit for various indications and this is a rapidly expanding field. For the treatment of extracranial lesions, positioning and immobilization systems have been developed, one of which is the Elekta Stereotactic Body frame. With the introduction of improved imaging devices, including cone beam CT on the linacs, such frames are no longer required. In the early years, predominantly circular collimators were used to obtain sharp beams with rapid dose fall off. A number of arcs were used with one or more isocenters. For irregular lesions, customized blocks were used with a large number of static fields. In the 1990s, the circular collimators and customized blocks were mostly replaced by high definition multileaf collimators. These micro-MLCs are similar to the standard MLCs of the linacs, with the exception of having smaller leaf sizes (2.5–3 mm versus 5 or 10 mm), smaller maximal field sizes, and improved dosimetry specifications. The micro-MLCs were initially used to create “shaped” static fields. Subsequently, they were used for dynamic conformal arc therapy, where the treatment aperture changes during irradiation according to the shape of the target and presence of critical structures. Nowadays, micro-MLCs are also used to deliver intensity-modulated SRS/SRT, by not only changing the shape of the aperture, but also changing the fluency within the field. Current linear accelerators capable of performing SRT also have imaging devices for Kilovoltage and/or Megavoltage imaging and eventually cone beam CT scanning. Two linear accelerator-based systems, which were specifically developed for SRS/SRT, the Brainlab Novalis Radiosurgery and Accuray Cyberknife, will be discussed in more detail.

2.4 Novalis Radiosurgery

Novalis Radiosurgery (Brainlab AG, Feldkirchen, Germany) is an integrated system featuring treatment planning, automated patient positioning, image-guidance, and treatment delivery for intra- and extracranial SRS and SRT. More than 150 systems have been installed. Image-guided target positioning takes place with reference of the treatment isocenter to internal or external localization markers. The original version of Novalis Radiosurgery is a single energy 6 MV dedicated linac with a built in micro-MLC, which is also capable of delivering dynamic arcs and intensity-modulated radiosurgery (IMRS). The maximum dose rate is 800 MU/min. Image-guided radiotherapy (IGRT) is provided by the ExacTrac® system that automatically aligns the target volume with the treatment beam based on infrared tracking of external body markers. It also uses automated registration of bony structures and implanted radiopaque markers using stereoscopic X-ray imaging. The Exactrac 6D Couch enables fast and precise couch correction in all directions to account for any misalignment or rotation. For the treatment of tumors that move with respiration, a respiratory gating system, which makes use of implanted markers, can be used. The most recent version, Novalis TX®, is a dual energy, dedicated linac that includes a new micro-MLC (120 leafs, of which 64 of 2.5-mm width in the center), stereo-KV imaging, and an On Board Imager including cone beam CT scan. The maximum dose rate is 1,000 MU/min. The new delivery technology RapidArc (Varian medical systems, USA), is also available on this linac. RapidArc is a volumetric intensity-modulated arc therapy, which can deliver the required dose distribution with one or a few arcs. For most treatments, this can be performed within a few minutes. During the rotation, the dose rate, micro-MLC setting, and speed of the gantry change simultaneously. Early studies using this technique indicate that it can also be used for SRS/SRT (Slotman et al. 2008). RapidArc combines high conformity with significantly shorter treatment times, which reduce the risk of patient or tumor movement, is more comfortable for the patient and allows a higher throughput of patients.

2.5 Cyberknife

The Cyberknife uses a 6 MV linac (maximum dose rate 800 MU/min), which is connected to a robotic manipulator that positions the linac at different source positions with the center of the radiation beam directed toward the target. During treatment, an image-processing system acquires X-ray images of the patient and compares the actual images with images in a database, to determine the direction and amount of motion. About 140 Cyberknife systems have been installed. In contrast to the linac-based systems, where compensation for misalignment due motion is being performed by a change in table position and/or gating of the radiation beam (i.e., turning the beam on when the target volume is in the desired position and turning the beam off when it is not), the Cyberknife system uses the robotic linac to compensate for it. Using this technique, tracking of the target volume is possible. A collimator changer is available for automatic exchange between collimators. The Cyberknife uses X-ray imaging to sense internal anatomy, while information on the motion of the patient surface is detected with an infrared imaging system. The Cyberknife uses a series of images from both sensors (infrared and X-ray), synchronizes one with the other, and calculates a motion pattern. This pattern correlates the external motion to the internal motion. Using the Cyberknife, it is possible to track tumors moving with respiration.

2.6 Tomotherapy Hi-Art

The Tomotherapy Hi-Arts system is a linac (6 MV, output 850 MU/min) combined with a CT scanner. Tomotherapy was developed in the 1990s. At present, more than 150 units are installed worldwide. For the delivery of the treatment, it uses a fan beam, which is modulated by a binary MLC. The leaves rapidly cross the width of the fan beam. The beam is subdivided into small "beamlets" which, depending on opening and closing of the leaves, will receive a high- or low dose-intensity. The leaves are pneumatically driven and can change between these open and closed states in a very rapid fashion. The treatment is delivered in a helical fashion with continuous and synchronous motion of gantry and couch, similar to a CT scanner. The Tomotherapy Hi-Art system includes integrated systems for treatment planning, patient set-up, CT-guided treatment, quality assurance, and recording and verification. Treatment planning differs from linac-based IMRT planning in that no beam angles, beam weights, and MLC patterns have to be determined. A Radionics head ring can be used for immobilization for SRS and SRT treatments, but it is not used for localization. Using the MV beam, CT images are acquired before each treatment and compared with the planning CT scan. For SRT, a single isocenter can be used for several targets.

2.7 Discussion

Apart from differences in costs for purchase, operation, and maintenance, every system has its specific advantages and disadvantages. The choice for a type of equipment should be based on wishes concerning functionality, applicability, flexibility, etc. It is important to consider at least the former points and the following discussion. In general, the specific role for SRS and SRT is disappearing. Differences between stereotactic techniques and other forms of image-guided radiotherapy and intensity-modulated radiotherapy are only gradual. Some types of equipment, such as a Gamma Knife, can only be used for the treatment of intracranial lesions. Linac-based systems, including Tomotherapy, allow for treatment of the rapidly expanding field of extracranial targets as well. There are a number of indications for intra- and extracranial treatments, where fractionated SRT has radiobiological advantages over single fraction SRS. Invasive head rings can only be used for SRS, while mask or frameless systems can be used for both SRS and SRT.

Integration of the system from image acquisition, contouring, treatment planning, setup, delivery to verification, is important for high throughput and reduces the risk of errors. Imaging is of crucial importance in high-precision radiotherapy. Cone beam CT offers the benefit of imaging the tumor (and not only the bony structures as with conventional X-ray imaging) before treatment with the patient in treatment position. Some systems are able to achieve more homogenous dose-distributions than others. In addition, it is important to choose a modern treatment planning system for a correct calculation of the delivered dose. Monte Carlo algorithms have a clear benefit over more conventional algorithms used in treatment planning software. Because of the risk of secondary tumors (Xu et al. 2008), especially in patients with benign lesions, children or patients with a good prognosis, a peripheral dose as low as possible, should also be considered as a factor in the decision-making process. The maximum dose rate influences treatment time. Because of the fraction sizes, which are generally used in SRS and SRT, this is an important factor to consider. Treatment time is related to patient and tumor motion (Purdie et al. 2007), patient comfort and the number of patients that can be treated per machine per day. The way in which the dose is delivered to the target volume is also a factor to consider. Radiobiological studies have shown differences in response when irradiation was given to a volume as a whole, or in smaller parts (Mackonis et al. 2007). The clinical consequences of this factor need to be determined. When SRS or SRT is combined with conventional radiotherapy, an integrated plan with integrated delivery using RapidArc has advantages over standard conventional SRS/SRT plans (Lagerwaard et al. 2008). The maximum field size and the possibility to use noncoplanar techniques are additional important factors when comparing different types of equipment.

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