IMAGE-GUIDED RADIATION THERAPY:
PART 3—STEREOTACTIC BODY RADIATION THERAPY

Three-dimensional conformal radiation therapy (3DCRT) requires that the field outline of each radiation beam just covers the target, and intensity-modulated radiation therapy (IMRT) requires that the exact 3D shape of the targets be defined. This has led to the realization that the location of the target relative to the critical surrounding normal tissues must be determined prior to dose planning. It is also not sufficient to know the location of the target itself but also the shape of the target in 3 dimensions. As such, patients undergoing radiation therapy are initially scanned by an imaging modality, such as computed tomography (CT) or magnetic resonance imaging (MRI), for target and relative organs-at-risks (OARs) information for the dose planning purposes. The current tools available for target localization prior to and during treatment are less than satisfactory. As a result, there has been an emergence of the concept of image-guided radiation therapy (IGRT) as a methodology to devise more accurate ways of localizing target volumes, positioning these targets relative to the isocenter of the medical linear accelerator, and also tracking the target during dose delivery. Recently, there have been dramatic developments of positioning and/or tracking devices, which were described in the first and second special issues of the IGRT series (Medical Dosimetry Volume 31, Spring and Summer 2006). A clinical paper by Pawlicki et al., for hypofractionated prostate radiotherapy, illustrating the use of the imaging system, is included in this third issue of the IGRT series.

Crucial to the development of IGRT has been the introduction of cone-beam imaging technique, which has the potential for use in real-time adaptive radiation therapy. In this imaging technique, the patient is set up in the treatment position and a 3D patient dataset is acquired by rotating the gantry around the patient prior to and/or after treatment. If the dataset is acquired prior to treatment, it can be used to localize the target by appropriately adjusting the patient relative to the isocenter or perform dose distribution to adjust for patient anatomy change. If the dataset is acquired after treatment, it can be used to compute the overall dose distribution over several fractions. Another advantage of the cone-beam imaging technique has been the use of limited hardware in the treatment room. The imaging system is typically mounted or attached to the medical linear accelerator and can be retracted when not in use to maximize the work space. The hardware and operational principles of cone-beam imaging techniques were described by Amies et al. in the first special issue, and Thorson and Prosser in the second special issue on IGRT. The performance characteristics and quality assurance aspects of cone-beam imaging is presented by Saw et al. in this special issue.

The integration of imaging systems into radiation therapy has provided an understanding and thereafter development of processes to manage or to compensate target motion. Large target motions are generally due to the inherent movement within the patient, such as physiologic or respiratory motion. Some simple mechanisms such as breath-hold techniques and forced-shallow breathing techniques have been used to control these target motions. Forced-shallow breathing technique in stereotactic body radiation therapy is described by Murray et al. in this third special issue on IGRT. However, altering the normal respiratory processes may cause discomfort to the patient during treatment. As an alternative, respiratory gating systems have been introduced and are now in clinical use in many centers. However, these motion management systems assume that the respiratory motion is periodic and the target moves in a similar periodic fashion. The radiation beam is turned on when the target moves into the same treatment (or field) position as planned. A number of mechanisms have been used to synchronize energizing the radiation beam to the breathing motion, which was described in the second special issue on IGRT. D’Souza et al. described the clinical implementation of a gating technique for stereotactic body radiation therapy in this special issue.

There seems to be strong interest in stereotactic body radiation therapy (SBRT). It is an imaged-based treatment described as a newly emerging radiotherapy treatment method in delivering a high dose of radiation to the target using either a single dose or a small number of fractions with a high degree of precision within the body. In accordance to the ASTRO practice guideline, SBRT is applicable to very localized malignant conditions in the body using minimally invasive stereotactic tumor localization and radiation delivery techniques; however, it requires a high degree of precision when directing the ionizing radiation. Hence, mechanisms of limiting the movement of the target volume before acquiring patient data for dose planning and localization are often required to achieve the necessary precision. For frame-based systems, the stereotactic accessories include a cranial or head-and-neck mask frame with fiducial box or a stereotactic body frame. For frameless systems, the stereotactic method includes metallic seed implantation within a tumor, use of surrogate anatomy such as bone.
whose position is well established in relation to the target, or use of the target itself as a fiducial. A review of stereotactic body radiation therapy is made by Fuss et al. for this special issue.

Stereotactic treatment techniques command a much higher level of precision compared to external beam radiation therapy. As such, the need for higher degree of accuracy and precision is expected from stereotactic radiosurgery (SRS) and stereotactic radiation therapy (SRT). To attain this expectation, target localization is typically performed using a stereotactic frame. In addition to mechanical limitation, the use of stereotactic frame is not practical if the treatment regimen consists of multiple fractions. With advances in imaging technology, frameless techniques are introduced to facilitate stereotactic treatment technique. One of the frameless techniques is the optical tracking technique described by Wagner et al. in this special issue. This technique can be integrated in a medical linear accelerator as described by Huntzinger et al. and Bayouth et al. Linac-based stereotactic radiosurgery and stereotactic radiotherapy are complemented with image-guidance tools that are available on modern medical linear accelerators.

Stereotactic radiosurgery and stereotactic radiation therapy are also performed on specialized machines such as the Cyberknife and Novalis. The Cyberknife is a robotic radiosurgery system consisting of a 6-MV linear accelerator mounted on a robotic arm. The movement of the robotic arm is computer-controlled so that the beam can be directly aimed at the target from many orientations. It is capable of generating non-isocentric dose distributions. The Novalis is also a dedicated radiosurgery unit. Externally, it looks like a typical linear accelerator with a 6-MV photon beam. However, it has a built-in small microleaf collimation system with a projected leaf width of 3 mm at isocenter and a small opening of up to 9.8 × 9.8 cm. The newly introduced treatment unit, Tomotherapy is being examined for use in stereotactic radiosurgery and radiotherapy. Externally, the unit looks like a helical CT scanner. It has a 6-MV photon beam linear accelerator mounted on a ring gantry. The photon beam is modulated using a binary multileaf collimator consisting of 64 leaves that covers a diameter of 40 cm. The leaf resolution at the isocenter is 0.625 mm. The incorporation of IGRT devices into these units will be discussed in the fourth and final issue of this IGRT series.

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REFERENCES