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Image-guided Radiation Therapy: Overview

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Image-guided Radiation Therapy: Overview

Lisa Bartenhagen, M.S.R.S.T., R.T.(R)(T)

Since Wilhelm Conrad Roentgen's discovery of x-rays, imaging modalities have changed modern medicine. Medical imaging also plays a role in radiation oncology for treatment localization, planning, verification and image guidance. Image-guided radiation therapy (IGRT) can improve treatment delivery precision by helping radiation oncologists make adjustments during treatment to guide dose distributions. Changes made in treatment parameters based on the modified dose distributions are considered image-guided adaptive radiation therapy (IGART). Several imaging modalities make IGRT possible, but true IGART has not become standard practice because of some important limitations. The goal of radiation therapy is to escalate doses to the tumor volume while minimizing dose to surrounding tissue; IGRT and IGART play an important role in reaching this goal.

After completing this article, the reader should be able to:

- Explain the importance of image guidance and adaptation in radiation therapy practice.
- Identify various IGRT and IGART strategies.
- Define the terminology used in imaging, planning and treatment.
- Discuss the processes involved in planning, dose comparison and adaptation of treatment delivery.
- Incorporate methods of limiting dose into imaging practices.
- Summarize the relationship between public and private payers and radiation oncology providers, specifically concerning IGRT and IGART.

The role of imaging in radiation oncology today is as important as the role of treatment delivery. Incorporating imaging techniques into radiation therapy practice has led to improved outcomes such as reduced toxicity, better tumor control and shorter fractionation schedules.[1] In particular, these outcomes have occurred through the use of image-guided radiation therapy (IGRT) and, more recently, image-guided adaptive radiation therapy (IGART).

Imaging has been used in medicine since Wilhelm Conrad Roentgen's discovery of x-rays in 1895. Various medical imaging modalities have evolved to help health care professionals diagnose and localize disease, and several imaging modalities have helped to shape the radiation therapy profession.

Radiation oncology uses imaging in several different ways. Fluoroscopy- and computed tomography (CT)-based simulation allow the radiation oncologist to localize a malignancy following diagnosis. Fusion of CT, magnetic resonance (MR) and positron emission tomography (PET) imaging helps the medical dosimetrist plan treatment and incorporate organ motion into the treatment plan. Verification imaging ensures that the radiation therapist delivers a dose to the entire treatment volume while sparing healthy tissue and organs at risk.

Finally, image guidance can lead the radiation oncologist to make changes in the treatment when there is tumor regression or to account for anatomical motion, either during treatment (intrafraction) or from 1 fraction to the next (interfraction).[2]

Image Guidance

Image guidance serves 2 distinct purposes. First, imaging for treatment verification, or offline correction, documents the patient's position before or after treatment delivery. This type of imaging can be used to help the radiation therapist reposition a patient after a misalignment or to create a record of the treatment for quality assurance (QA) purposes.[3]

The other purpose of image guidance is to assist in treatment delivery, a practice also known as online correction. Treatment guidance is needed with dose escalation and intensity-modulated radiation therapy (IMRT) protocols. The high doses delivered to the tumor during these protocols require a steep dose falloff outside the planning volume. Uncertainties that occur during treatment, such as intrafraction movement caused by respiration, day-to-day organ motion and setup discrepancies, make maintaining conformal fields a difficult task.

IGRT was developed to keep the normal tissue tolerance dose lower than the lethal dose to the tumor. By frequently imaging the treatment volume during the course of treatment, decisions based on these images can more precisely guide dose delivery.[4] Initial modalities used for image guidance included transabdominal ultrasonography and in-room CT imaging. Additional imaging methods now used in IGRT include helical CT scans and cone-beam CT (CBCT).

A successful IGRT program requires a system that can:

- Extract and analyze image data and apply that information in an acceptable time frame to design an optimal treatment plan.
- Use computers with high-speed capabilities to accurately design treatment plans and produce efficient image segmentation and registration to meet treatment protocol requirements.
- Detect inaccuracies in image acquisition so as to minimize errors and uncertainties in the entire planning and treatment process.
- Formulate and monitor action plans that include the dose received from the image guidance procedures.[2]

Several areas are critical to the successful implementation of IGRT, including:

- Standard terminology to describe treatment.
- A method to determine how and where to document absorbed dose.
- Effective immobilization techniques and devices.
- A stringent quality assurance (QA) program.

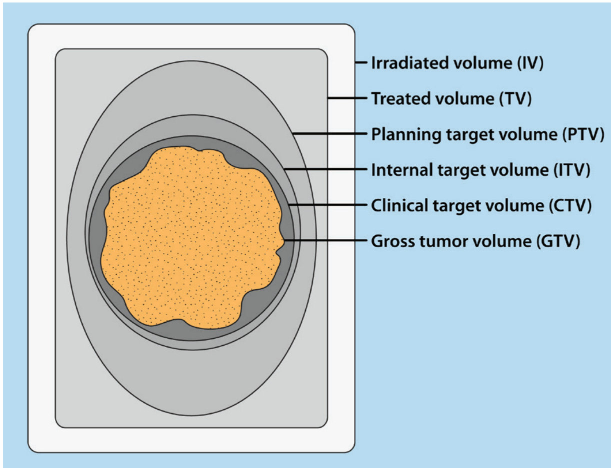

Figure 1. *Volumes used for radiation treatment planning. The gross tumor volume (GTV) includes the palpable or visible tumor. The clinical target volume (CTV) includes the tumor and presumed microscopic spread. The internal target volume (ITV) consists of the CTV and an internal margin built into the treatment plan. The planning target volume (PTV) includes the CTV and margins that account for geometric uncertainties. The treated volume represents the minimum target dose that adequately covers the PTV plus an additional margin to cover limitations in treatment technique. The irradiated volume contains tissue that receives a significant amount of the prescribed dose. Artwork based on ICRU Report 50.* Prescribing, Recording, and Reporting Photon Beam Therapy. *Bethesda, MD: International Commission on Radiation Units and Measurements; 1993.*

Terminology

Consistent treatment planning terminology has become extremely important as IMRT becomes the standard of care in many facilities. Report 50 of the International Commission of Radiation Units and Measurement (ICRU) has defined the volumes that must be considered when planning a course of radiation treatment (see **Figure 1**).[5,6] These definitions help to precisely document volumes for proper treatment setup and reproducibility. Starting from the smallest to the largest volume, these definitions are:

- **Gross tumor volume (GTV)** — consists of the gross demonstrable tumor, including the primary mass, any metastasis and lymphadenopathy. The GTV is determined by visual or palpable assessment and through diagnostic imaging. If the tumor has been resected, an outline of the tumor volume from preoperative images can be substituted.