self-**directed**
LEARNING

*essential***education**

Image-guided Radiation Therapy:
Computed Tomography

asrt
American Society of Radiologic Technologists

Image-guided Radiation Therapy: Computed Tomography

Breann Bollinger, BS, R.T.(T)

Advanced technology and complex treatments such as intensity-modulated radiation therapy, volumetric arc therapy, brachytherapy and stereotactic radiation therapy require that radiation therapy setups be more precise and accurate than ever. Image-guided radiation therapy (IGRT) uses digital imaging to localize internal anatomy and tumor position. In addition to localization, image-guided adaptive radiation therapy (IGART) uses imaging to modify treatment plans after detecting a significant change in anatomy. Computed tomography (CT) is an important modality for radiation therapy image guidance because it can render 3-D anatomical images. This article discusses the use of CT for treatment planning, target localization and patient positioning. The article also reviews various CT guidance platforms and quality assurance checks and balances.

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

- Explain how computed tomography (CT) is used for image guidance.
- Describe special considerations and requirements for image guidance during simulation and treatment planning.
- List available in-room CT platforms.
- Describe quality assurance (QA) practices and the radiation therapist's role in QA.
- Demonstrate target definition and localization during online matching at the treatment unit.
- Explain the role of CT during image-guided adaptive radiation therapy.
- Discuss the role of image guidance using CT for intensity-modulated radiation therapy, volumetric-modulated arc therapy, stereotactic radiosurgery and brachytherapy.

Advanced technology and increasingly complex treatment procedures require more precise patient setups to ensure treatment delivery to a well-defined area. The accuracy of treatment delivery depends on the radiation therapist's ability to precisely reproduce a patient's position from simulation to treatment.[1]

Maximizing radiation dose to the tumor and minimizing dose to the normal surrounding tissue are crucial goals of radiation therapy.[1] Uncertainties in patient reproducibility, tumor movement and inherent patient motion during treatment require the radiation oncologist to include a margin of healthy tissue around the volume to receive the prescribed radiation dose. With the help of image-guided radiation therapy (IGRT) and image-guided adaptive radiation therapy (IGART), the treatment team can verify tumor location and patient positioning. As a result, image guidance improves the accuracy of radiation therapy delivery, allows for smaller treatment volumes and makes dose escalation possible.[1,2]

IGRT uses 2-D and 3-D digital imaging to localize bony anatomy, soft tissue, tumor pathology and any fiducial markers used for guidance.[1] The radiation therapist initially aligns marks placed during simulation to the treatment machine lasers, which represent the treatment isocenter, and then further refines the alignment with the help of 2-D imaging. Two-dimensional megavoltage (MV) and kilovoltage (kV) radiographs are matched to digitally reconstructed radiographs (DRRs).

These images show any discrepancies of bony alignment between the patient's simulation and treatment room position in the vertical, longitudinal and lateral directions, but they do not display soft-tissue differences.

With 3-D (volumetric) imaging, the radiation therapist matches a computed tomography (CT) image acquired in the treatment room, with the patient in the treatment position, to a planning CT scan showing both bone and soft tissue. Volumetric imaging permits additional adjustments in patient positioning, such as roll, pitch and yaw, that cannot be displayed on 2-D planar images.[1] Volumetric imaging also helps the alignment of soft-tissue structures, including the tumor volume. After the images are aligned, the radiation therapist determines the new treatment coordinates and adjusts the patient's position.

Although IGRT can take day-to-day variations and setup errors into account, intrafraction movement and soft-tissue changes can cause the treated dose distribution to deviate from the dose distribution of the original treatment plan. Therefore, treatment delivery precision can be improved by using image guidance to adapt treatment.[3] IGART involves monitoring daily tumor and normal tissue variations and modifying the treatment plan to compensate for any detected changes.[4]

Daily imaging before and during treatment detects subtle changes in tumor shape and alerts the treatment team to any tumor movement. When a change is detected, the team can modify the plan at 3 different points: offline between fractions, online immediately before delivering a fraction and in real-time during delivery of a treatment fraction.[4] This flexibility represents a distinct advantage when treating tumors that are affected by surrounding organs (eg, the prostate or prostate bed) and when treatment changes normal tissue (eg, weight loss).

IGART uses CT imaging to detect soft-tissue changes from the original planning CT scan. The radiation oncologist places the dose distribution on the new image and determines the displacement of the planning target volume, after which the original plan is modified to take into account any changes.[4] IGART allows real-time updates that improve treatment precision. The radiation therapist can reduce systematic errors by adjusting the patient's position after aligning bony and soft anatomy and while monitoring motion during treatment. The adjustment ensures dose coverage to the intended target and minimizes dose to healthy tissue.

As radiation therapy techniques become more complex and precise, it is important that radiation therapists are able to identify the tumor's exact location and how nearby organs affect tumor position and movement during treatment. Performing a CT scan at the time of treatment allows the treatment team to see the patient's internal anatomy and determine how the radiation dose will affect the targeted area.

The use of CT as an image guidance tool is a detailed process; radiation therapists require the proper education and clinical training to use volumetric image guidance effectively. This article focuses on 3-D alignment using CT during IGRT and IGART.

Computed Tomography Overview

British engineer Godfrey Hounsfield first introduced the concept of computed tomography in 1972. The term *tomography* comes from the Greek word *tomos,* meaning slice or section, and *graphia,* meaning describing.[5] CT imaging produces high-resolution, cross-sectional images that can differentiate between bone, air and soft tissue.

A CT unit consists of an x-ray tube and detectors that rotate around the patient, capturing multiple 2-D x-ray projections that show the patient from superior to inferior. The multiple projections are then partitioned by the detector, sent to a dedicated computer and reconstructed into a 3-D image. The number of images generated is determined by the thickness of each slice. The computer assigns each picture element, or pixel, a CT number called a Hounsfield unit (HU). This number, based on an arbitrary scale, is related to the composition and density of the anatomy scanned. CT numbers range from -1000 (air) to +1000 (bone).[6]

Many factors affect the quality of a CT image, such as spatial resolution, contrast resolution, linearity, noise and artifacts. Spatial resolution refers to the scanner's ability to differentiate small objects adjacent to each other. Reducing the thickness of each slice improves spatial resolution. Contrast resolution is the ability of the CT unit to display anatomy that attenuates the same number of x-ray photons. Minimizing scatter, such as using smaller collimation, and adding bowtie filters improves contrast resolution.[6] Linearity relates to the accuracy of the HU.