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Image-guided Radiation Therapy:
Fiducials and Transponders

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Image-guided Radiation Therapy: Fiducials and Transponders

Laura D Alimonte, MHSc, MRT(T)
Brian Liszewski, BSc, MRT(T)

Image-guided radiation therapy (IGRT) is used to define the target volume and normal structures during simulation and planning, and then correct positioning errors before radiation treatment delivery. Radiation oncologists localize targets using fiducial markers implanted in the tumor or the affected organ, as well as externally placed fiducial markers. To locate a target and follow position or motion, some IGRT systems use transponders. This article discusses planning considerations when using internal and external fiducial markers or electromagnetic tracking, particularly as markers assist in tumor localization and patient positioning. The article also provides information on the use of markers to localize various disease sites, quality assurance considerations and a summary of commercially available devices.

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

- Explain the purpose of internal and external tumor tracking, especially in the presence of motion.
- Describe the use of fiducial markers within the context of image-guided radiation therapy.
- List the processes and elements common to all fiducial marker and electromagnetic motion tracking systems.
- Discuss considerations and requirements when using internal and external markers during the simulation and treatment processes.
- Describe how to apply basic quality assurance concepts to tumor motion tracking.
- Explain the role of fiducial marker and electromagnetic motion tracking in treatment delivery.
- Discuss the application of fiducial markers and electromagnetic motion tracking at specific disease sites along with benefits and limitations of each application.

Radiation therapy delivers a prescribed dose to a specified area of the body, traditionally via a linear accelerator. The goal of radiation therapy is to eradicate tumor cells by delivering the maximum dose to the target volume; however, this objective is limited by the need to minimize dose and subsequent radiation-induced toxicities or adverse effects to critical normal structures.

In the past decade, radiation oncology research and treatment have focused on maximizing the target dose. This trend is evident in the development of hypofractionated treatment regimens, treatment techniques such as stereotactic radiosurgery (SRS), stereotactic body radiation therapy (SBRT) and a number of other techniques. Maximizing the dose delivered to the target places even greater emphasis on controlling the dose to surrounding normal tissue, and most importantly, limiting radiation delivered to organs at greatest risk of adverse effects from radiation exposure. In addition, radiation therapists must position patients accurately for each fraction to minimize the chance of a geographic miss of the target that could result in overexposure of surrounding critical structures.

The introduction of intensity-modulated radiation therapy (IMRT) has enabled delivery of highly conformal dose distributions to the target and has minimized dose to surrounding normal structures. Precise patient positioning, setup accuracy and target localization are required to ensure dose distributions are delivered as originally

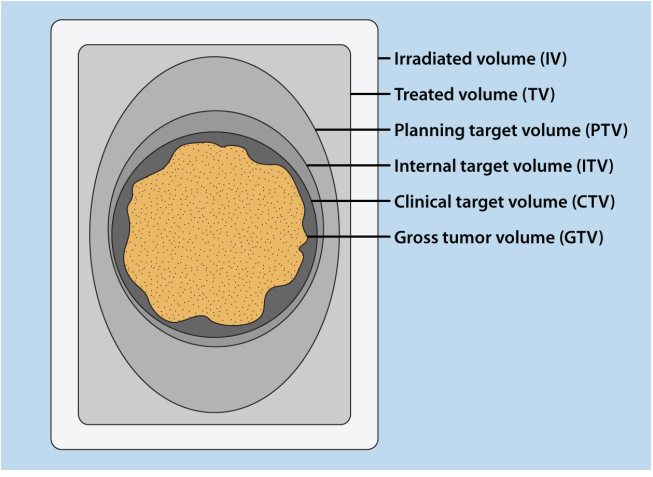

Figure 1. *Volumes used for radiation treatment planning. The gross tumor volume (GTV) includes the palpable or visible tumor. The clinical target volume (CTV) includes the tumor and presumed microscopic spread. The internal target volume (ITV) consists of the CTV and an internal margin built into the 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.*

planned and to take advantage of the dose gradients created by IMRT. Imaging plays an important role in assuring the accurate delivery of radiation therapy.[1]

Image-guided radiation therapy (IGRT) facilitates treatment decisions based on the information the images provide.[2] Computed tomography (CT) images now are a mainstay of simulation and can be used throughout the treatment course for target alignment. Magnetic resonance (MR) imaging and positron emission tomography (PET) also can provide increased resolution for organ and target delineation when planning treatment margins. Onboard IGRT systems such as cone-beam CT, ultrasonography and fiducial marker imaging allow radiation therapists to make positional corrections during treatment, reducing the need for extensive planning target volume (PTV) margins (see **Figure 1** and **Box**).

Historically, radiation therapy treatments used external marks and tattoos on the patient's body surface to represent internal anatomy. Orthogonal electronic portal images using megavoltage (MV) photon beams were acquired before beginning treatment to display bony internal anatomy. The position of the internal bony anatomy displayed on these images was compared to reference images acquired during the radiation planning process. Because most tumors do not directly correlate with bones and because soft tissues move, larger margins were required to account for geographic uncertainties.[3] Unfortunately, larger treatment margins came at the cost of treating greater volumes of normal surrounding tissues.

The drawbacks of portal imaging are poor display of soft tissue and the inability to demonstrate 3-D anatomy because electronic portal images are 2-D projections.[1] The development of 3-D imaging with the patient in treatment position in the radiation therapy suite improved the visualization of anatomy, and onboard 3-D CT imaging further improved soft-tissue display.

Onboard CT imaging has several limitations, however. The image quality of onboard CT is not as good as diagnostic helical CT scans because increased scatter radiation and slower scan times are required to capture internal organ motion during image acquisition. Consequently, onboard CT produces a high number of image artifacts. In addition, onboard CT systems acquire images before or after, but not during, treatment, requiring additional technology to track tumor motion caused by physiological processes such as respiration.[4]

Surrogate markers are used in imaging and tumor tracking to ensure accurate target localization and radiation delivery to the target volume. Fiducial markers typically are implanted within the tumor or near a tumor resection cavity. The fiducial markers act as a surrogate for the tumor or tumor bed position, providing positional information in the x, y and z planes.[4] The drawback of fiducial markers is that they provide no information concerning any deformation or change to the organ or target volume.[5]

Gating options, such as optical tracking, video surface imaging and electromagnetic (EM) transponder