

Image-guided Radiation Therapy: Intrafraction Monitoring



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Image-guided Radiation Therapy: Intrafraction Monitoring

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Image-guided radiation therapy (IGRT) uses advanced imaging modalities to localize targets in patients undergoing radiation oncology treatment. Much of the clinical focus for IGRT has been on correcting for variations that occur from 1 treatment fraction to the next. However, clinicians are increasingly concerned about variations that occur within a treatment fraction, or from moment to moment. Most intrafraction variation occurs because of organ motion. This article discusses the sources of intrafraction motion, its effect on imaging and treatment, and new and emerging strategies that can be used to manage intrafraction motion.

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

- Discuss the sources of intrafraction motion.
- Describe the impact of motion on computed tomography imaging.
- Provide details of how motion affects radiation treatment delivery.
- List methods that have been used to address respiratory motion during simulation, treatment planning and treatment delivery.
- Describe current breath-hold techniques used in radiation therapy.
- Define hysteresis, interplay and surrogate.
- Explain gating and real-time tracking techniques.
- Discuss quality assurance needs associated with motion management techniques.

Many sources of error can arise in radiation therapy preparation and delivery. A single error can have a minimal effect, but the cumulative effect of all the errors that occur during a patient's treatment course can be substantial and reduce treatment precision or cause harm. A radiation therapy error can be defined as any discrepancy between the planned treatment and the delivered treatment, regardless of how small the error is.¹ As defined, it is impossible to completely avoid errors in the treatment process, largely because of motion. The traditional quality assurance measures taken in radiation therapy decrease the number of large, significant treatment errors. However, smaller, almost imperceptible, errors that occur during every fraction or from fraction to fraction can accumulate and have a large dosimetric effect on the treatment.

Imaging mistakes can produce geometric error and image distortion that create inaccuracies in the delineation of the tumor and target margins. This causes systematic inaccuracies that occur at every treatment. Setup errors, organ motion, anatomic changes, image-guidance errors and uncertainties related to treatment unit parameters are random sources of error that can vary from day to day.¹

Image-guided radiation therapy (IGRT) helps to eliminate many potential sources of error. Most IGRT techniques focus on reducing daily setup error, correcting for daily anatomic changes in the target and minimizing the effect of geometric uncertainties inherent in treatment units. This article focuses on the effect of organ motion, particularly respiratory motion, on radiation therapy precision and IGRT techniques that can maximize treatment accuracy in the presence of motion.

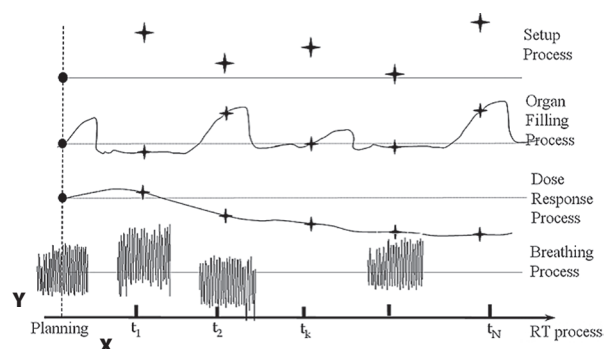


Figure 1. The breathing process exhibits both interfraction and intrafraction motion. The x-axis represents the treatment fraction. The y-axis demonstrates tumor position, in a broad sense, including shape change. Reprinted with permission from Jiang SB. *Radiotherapy of mobile tumors*. *Semin Radiat Oncol*. 2006;16(4):240.

Defining Intrafraction Motion

During treatment delivery, radiation therapists position the patient and the treatment equipment for each fraction, duplicating the reference geometry that was modeled during simulation and treatment planning. Patient geometry must be consistent throughout the entire treatment course to ensure that radiation therapy is delivered as planned. Therefore, the actual patient geometry during each treatment fraction must be the same as, or as close as possible to, the reference 3-D patient model created during simulation and used for the treatment planning process.² Matching the reference geometry to daily changes in patient geometry is at the heart of IGRT.

Differences between the actual patient geometry and the reference model arise from 2 types of variation: interfraction and intrafraction differences. Interfraction variation occurs during the treatment course from 1 treatment to the next, possibly because of daily variability in patient positioning, patient setup error or volumetric changes in the tumor. Intrafraction variation occurs during a single treatment fraction, causing geometric alterations from moment to moment. Intrafraction variation can be caused by intentional or unintentional patient movement, usually organ motion, while the patient is on the treatment table.²

Organ motion can be defined as the mobility of organs relative to the bony anatomy.¹ This type of motion involves physiologic processes, such as swallowing,

respiration, heartbeat, organ filling and peristalsis.

Many of these physiologic activities can lead to interfraction or intrafraction shifts in organ and target position.³

Jiang points out that most types of organ motion have both an interfraction and intrafraction component.² For example, in **Figure 1**, the breathing process demonstrates both interfraction and intrafraction movement. On the graph, the y-axis shows changes in tumor position during each fraction, and the x-axis demonstrates that organ position varies from fraction to fraction.²

Generally, researchers have thought that respiratory motion is purely intrafractional; however, both interfraction and intrafraction motion can occur depending on the area being treated and therefore must be taken into account. For example, the magnitude of interfraction motion of lung and liver tumors frequently can be comparable to the intrafraction motion. Changes in lung capacity over the treatment course or daily differences in stomach filling can alter lung position. As another example, interfraction motion of the prostate has been well documented, but in some patients, a significant amount of intrafraction motion also occurs.²

Because organ motion may involve significant interfraction and intrafraction elements, a moving organ's position can be broken down into the average position and the instant position relative to the average position.² The daily home position of a moving organ is the mean position averaged over the fraction; however, this position might correspond only to a particular breathing phase. For example, if the radiation beam is to be turned on at the end-of-exhalation phase, the tumor home position might be defined as the end-of-exhalation position averaged over the fraction. In practice, the home position of a moving organ for a treatment fraction often is measured during patient setup. The position is not averaged over the entire treatment fraction and could vary after the treatment begins.²

Jiang has used mathematical notations to help understand organ motion.² At a specific time (t) during the treatment fraction (n), the tumor position can be described as

$$R_n(t) = \bar{R}_n + r(n,t)$$

where \bar{R}_n is the home position of the tumor at the n -th fraction and $r(n,t)$ is the tumor's instant position