Sparing Critical Organs From the Effects of Radiation Therapy

William P. Hogle, RN, BSN, OCN®, and Roya J. Pourarian, RTT, BSRT

Q uestion: How are critical structures, such as the heart and lungs, spared from the harmful effects of radiation therapy?

A nswer: Critical structures are spared from the harmful effects of radiation therapy through precise treatment planning that uses appropriate beam angles and blocking techniques. Although radiation therapy has proven to be a beneficial treatment modality for a number of benign and malignant diseases, tissue dose tolerance limitations must be considered carefully when planning and prescribing radiation therapy. Prior to the advent of three-dimensional conformal treatment techniques, radiation was administered by way of square or rectangular fields and often was delivered in an anterior or posterior approach with little regard to tissue sparing or tolerance. Conformal treatment techniques allow for precise beam targeting that conforms to tumor shape in a specific location inside a patient’s body. Computed tomography (CT) images are obtained and downloaded into a radiation treatment planning computer. This creates a three-dimensional image on which simulated beams of radiation can be superimposed, allowing beam angle and estimated tissue dose exposure to be calculated. With the older treatment techniques, morbidity was high; this dictated the need for extended treatment breaks and a less-than-optimal treatment course. The effectiveness of radiation therapy is influenced directly by the ability to deliver an uninterrupted, optimally therapeutic dose (Withers & McBride, 1998). Occasionally, an anterior or posterior approach still is prescribed as palliative therapy. This is because conformal three-dimensional treatment planning requires additional time to schedule needed CT scans and plan the treatment course. Treatment with palliative intent often needs to be initiated as soon as possible. In addition, the importance of long-term morbidity associated with larger, less precise treatment techniques is not a primary concern when administering radiation therapy with a palliative intent.

Since the 1980s, healthcare providers have had an increased awareness of the long-term side effects of radiation therapy, including the possibility of developing a secondary malignancy. Current radiation treatment planning systems and tissue-sparing techniques developed in the late 1980s have been refined, allowing pinpoint accuracy while limiting unnecessary exposure of normal and sometimes critical structures in or near the prescribed field of radiation. These techniques minimize short- and long-term side effects and decrease the potential for long-term complications. Emami et al. (1991) described radiation tissue dose tolerance levels for specific organ sites. In addition, endpoints, which are specific dose-limiting factors, were identified for each respective organ system. For example, pneumonitis is the endpoint criteria for irradiation of lung tissue. When an entire lung is irradiated, doses should not exceed 2,000 cGy; however, smaller, limited portions of lung tissue can tolerate up to 6,000–7,000 cGy of radiation. Cardiac endpoints are identified as pericarditis, pericardial effusion, or myocardial ischemia. These can be seen at radiation doses between 4,000–7,000 cGy, depending on whether full or partial organ exposure occurs. The criteria set forth by Emami et al. still are considered the standard by which acceptable tissue tolerance is measured. Endpoints are considered to be long-term morbidity that should be avoided. These endpoints are toxic effects seen weeks to months after radiation and have the potential to significantly impair quality of life (Rubin, Constine, & Williams, 1998).

Patients with cancer of the lung, breast, or esophagus as well as Hodgkin’s disease who receive radiation therapy are at significant risk for developing cardiac and pulmonary toxicities simply because these tissues are either included in or adjacent to areas that require radiation. Sometimes, totally eliminating all critical structures within the radiation field is not possible. For this reason, the radiation oncology team must localize and minimize exposure to the heart and lungs during the radiation treatment planning process. This is done through a collaborative approach between the radiation oncologist, medical dosimetrist, and medical physicist, where time and consideration are given to the calculation of the total radiation dose received by each organ and surrounding structure within or near the radiation field. To accurately accomplish this, patients must undergo a radiation treatment planning CT scan while in the radiation treatment position. This allows for precise localization of the tumor in relation to the patient’s anatomic structure. This is an essential component of three-dimensional conformal radiation therapy. These CT images are downloaded into a radiation treatment planning computer, the tumor or treatment area then is localized, and the precise work of tissue sparing in regard to tissue tolerance begins (Kirsner, Prado, Tailor, & Bencomo, 2001).

When a radiation treatment plan is considered, the radiation oncologist, medical physicist, and medical dosimetrist examine multiple treatment options and determine which plan will provide the patient with the most optimal dose distribution of radiation to a specified area. As an example, when planning treatments to the left breast, careful consideration must be given to the heart and lungs to avoid potential toxicity. A radiation treatment planning computer superimposes tangential beams of radiation over the patient’s previously obtained CT images of the chest (see Figure 1). The computer then places multiple lines, known as isodose distribution lines, over the breast image. Each line is assigned a different color, which allows for clear differentiation, and each color represents a different percentage of radiation coverage that encompasses varying volumes of breast tissue (see Figure 2). The goal of radiation planning is to choose the plan that will deliver 100% of the prescribed dose to the tumor or, in terms of postlumpectomy.

William P. Hogle, RN, BSN, OCN®, is a clinical manager and Roya J. Pourarian, RTT, BSRT, is a medical dosimetrist, both in the Passavant Cancer Center at the University of Pittsburgh Medical Center in Pennsylvania.

Key Words: radiotherapy, radiation tolerance

Digital Object Identifier: 10.1188/03.CJON.587-589

William P. Hogle, RN, BSN, OCN®, is a clinical manager and Roya J. Pourarian, RTT, BSRT, is a medical dosimetrist, both in the Passavant Cancer Center at the University of Pittsburgh Medical Center in Pennsylvania.
radiotherapy, the patient’s entire breast. However, this does not always coincide with the 100% isodose distribution line. In Figure 2, the aqua-colored line labeled “100.0%” is, in fact, the 100% isodose distribution line. The treatment planning computer generates an image that displays an area that will receive 100% of the prescribed dose but not necessarily cover the volume of tissue that requires radiation. In other words, the 100% isodose line does not always encompass the entire area of concern. The computer displays only where 100% of the prescribed dose would be delivered. Careful examination of the 100% isodose distribution line in Figure 2 reveals that a small portion of the heart and lung is included in the area that will receive 100% of the prescribed radiation dose. In this case, the volume of heart and lung exposed to the radiation beam is minimal. Precise exposure levels are calculated and considered in the overall treatment plan. If the 100% isodose distribution line happens to include too much heart or lung tissue, thereby increasing the possibility of long-term complications from therapy, a different isodose distribution line may be chosen and additional measures may need to be implemented to ensure that an adequate dose is administered to the patient.

Portions of breast tissue that require treatment may be outside the area outlined by the 100% treatment line. In the case of unresected breast tumors, a patient’s gross tumor volume (GTV) actually may be outside the 100% isodose distribution line. In terms of tumors originating from areas outside the breast, the 100% isodose line may yield adequate radiation coverage to that area but not necessarily adequate tumor coverage, especially if the tumor is large or irregularly shaped. Factors that influence the physician’s choice as to what isodose treatment line is prescribed may include patient anatomy, GTV, or the existence of “hot spots.” A hot spot is an area that receives a higher-than-prescribed dose of radiation that can cause an intensified local reaction. The appropriate isodose treatment line is chosen with respect to adequate radiation coverage to a specific area, acceptable dose limitations to surrounding tissues, and minimization of hot spots within the field. Once the isodose line is chosen, calculations are made to determine how much radiation the targeted and surrounding tissues will receive. This ensures that critical structures in or near the treatment field are not receiving an excessive or unsafe dosage of radiation.

In the case of whole left breast irradiation without nodal field inclusions, the standard approach is to use two tangential beams of radiation. One beam is administered from approximately the 11 o’clock position (see Figure 3), which is the medial tangent, and the other beam is administered from approximately the 4 o’clock position, which is the lateral tangent (see Figure 4). A beam of radiation is administered while the linear accelerator is in a fixed position. A common misconception is that, during standard external beam radiation treatments, the accelerator delivers radiation as it rotates around the patient; this is simply not the case. The medial/lateral tangential approach previously described minimizes radiation exposure to the heart, lung, spine, and esophagus by merely manipulating the angle from...
which the beam is administered. However, after reviewing the treatment plan, the use of blocking techniques may be necessary to reduce adjacent tissue exposure. Older-style blocking techniques entailed producing and mounting cerrobend blocks in front of the collimator, which is the portion of the linear accelerator from where the radiation beam comes, to shape the beam as it was delivered from the machine to the patient. Cerrobend blocks are made of a heavy metal alloy consisting of lead, tungsten, cadmium, and bismuth. A newer method of blocking is accomplished through the use of multileaf collimators (MLCs). An MLC consists of dozens of tiny lead or tungsten leaf-like projections that can be programmed independently to move in and out of the radiation beam to customize its shape, completely encompass the target area, and minimize dose to adjacent critical structures (see Figure 5).

Although these blocking techniques are very effective at reducing the amount of radiation a patient receives to nontarget areas, they are not foolproof. Approximately 2%–5% of the energy that is administered from the linear accelerator can penetrate through the blocks, depending on whether a cerrobend block or an MLC is used (Kahn, 1994). For this reason, careful and precise planning techniques, including the use of blocks and manipulation of radiation beam administration angles, must be utilized well before patients begin treatment.

**References**


