Treatment Planning in Radiation Therapy

Photon Beam Treatment Planning

Radiation therapy is the clinical use of ionizing radiation as part of a comprehensive cancer treatment to eradicate malignant/cancerous cells. It works by damaging the DNA of cancerous cells, which is the primary cause of cell death. Normal cells are also damaged by ionizing radiation; however, they generally have a better recovery mechanism than the cancerous cells.

Therapeutic Response

Optimally effective radiotherapy is not possible without some understanding of the biological effects of radiation. Radiation biology describes the complex biological response of tissue in relation to the given radiation dose. With increasing radiation dose above a certain threshold, tissue response may increase, Practically, such a dose response is expressed by a sigmoidal relationship, shown in Fig. (1), where tumor control probability (TCP) and normal tissue complication probability (NTCP) are plotted as a function of absorbed dose.

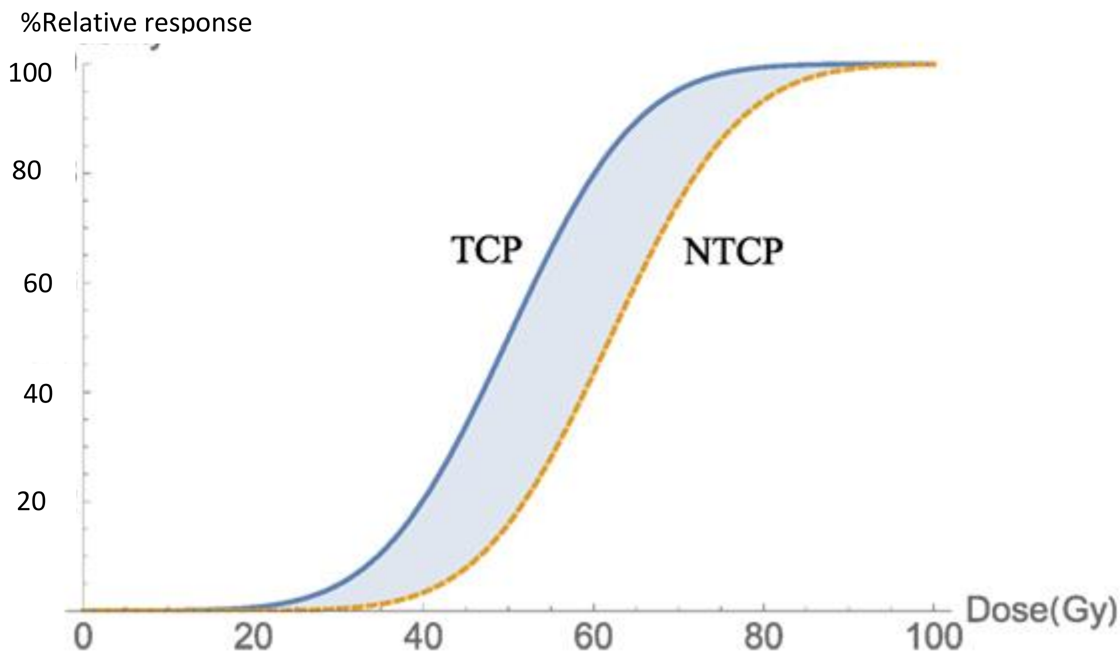

Fig. (1) Conventional representation of normal tissue and tumor response to radiation dose. Cell kill increases in a sigmoidal fashion above a threshold

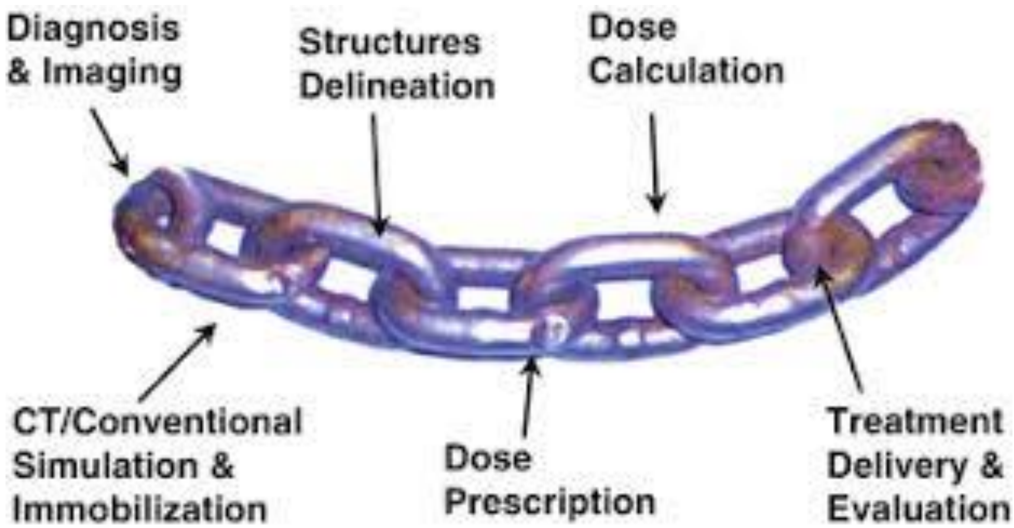

Fig. (2) Radiotherapy treatment planning chain

Different fractionation schemes and, in selected cases, chemotherapy drugs are used to increase the therapeutic index. Frequently, the tumor response to radiation is greater than that of the adjacent normal tissue. This makes radiotherapy an effective cancer.

Radiation Therapy Process

Radiotherapy treatment planning is the process of determining optimal treatment parameters for patient irradiation. The entire process encompasses the following essential activities:

- Diagnostic and imaging
- Patient positioning and immobilization
- Simulation imaging
- Treatment volume and dose-limiting structures delineation
- Radiation dose prescription and fractionation
- Optimal dose distribution calculation and evaluation
- Dose delivery and verification

Figure (2) summarizes these points as a treatment planning chain. Determination of the extent and nature of the tumor, using various diagnostic tools, prior to treatment planning is essential. Depending on the type, extent, and location of the tumor and the patient condition, the tumor is either surgically removed or treated with radiation and/or chemotherapy agents.

Patient Data Acquisition

Figure .2 describes the entire radiation treatment planning procedure. The radiation oncologist assesses the patient and decides a suitable treatment protocol. The first step in the treatment planning process is to decide which volume of the patient needs to be irradiated and which volumes are to be spared. Such information is available to radiation oncologists from state-of the-art imaging modalities such as CT, MRI, ultrasound, and PET. Generally, there are two types of imaging intentions: diagnosis and treatment planning.

Patient Positioning and Immobilization

Patient positioning is one of the most crucial and frequently weakest links in the treatment process (Fig. 2). Accurate and reproducible patient positioning is necessary to make it possible to deliver the prescribed dose precisely to the target and spare healthy tissues over the many fractions that a course of radiotherapy entails. There is also, of course, the possibility that patient who is not immobilized moves during an individual treatment, while on the treatment table. One of the reasons for patient movement during treatment is uncomfortable positioning. Extended treatment duration is another common reason for these movements.

Pretreatment Simulation

Prior to external beam radiation therapy of the patient, it is essential to simulate the proposed treatment on the individual patient anatomy. This can be done with the patient present and positioned on a conventional simulator which mimics the geometry of the treatment machine. Or the simulation can be performed on a computer using three-dimensional images, from CT, for example, of the patient. This entire process is time consuming and therefore cannot be performed on a treatment unit.

Conventional Simulator

A conventional simulator (Fig. (3) is a machine with a diagnostic x-ray tube that mimics the functions and motions of a radiation therapy treatment unit. The main function of a simulator is to correctly position the treatment fields in order to accurately encompass the target and avoid surrounding normal tissues from receiving excessive irradiation. Internal body structures are dynamically visualized using the fluoroscopic capability of the simulator. Radiographic images are finally acquired for the appropriate body site. The radiation oncologist may draw outlines for shielding blocks based on these images.

Fig. (3) A photograph of a conventional radiographic simulator (Courtesy Medical Systems, Palo Alto, CA)

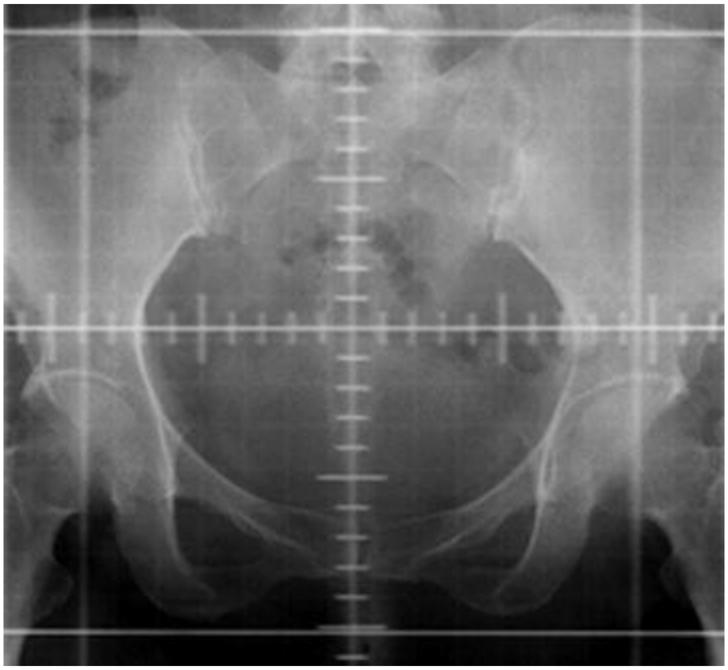

Fig. (4) A planar radiograph of the pelvis, taken on a conventional simulator

In Fig. (4) a planar radiograph of a pelvis is shown. The square region marked by bold white lines encompasses the volume to be treated. The intersection of the dashed lines denotes the central axis of radiation beam. If additional shielding needs to be implemented, for example, to protect a structure in the corner of the rectangular field, it is marked on such a radiograph.

Computed Tomography Simulator

CT simulators have become an essential part of patient simulation for the majority of radiation therapy practices all over the world. CT images provide good tissue contrast in three dimensions, as opposed to the two-dimensional projection of a conventional simulator, allowing for improved tumor localization and contouring. The CT data also provides relative electron density, which can be converted to physical density. A therapy CT simulator as shown in Fig. (5) is similar to a conventional diagnostic CT with a few additional features. A complete CT data set provides a 3D anatomical model of the patient. The CT images can be visualized in transverse, sagittal, and coronal planes (Fig.6).

Fig. (5) A photograph of computed tomography simulator (Courtesy: Philips Healthcare, Cleveland OH)

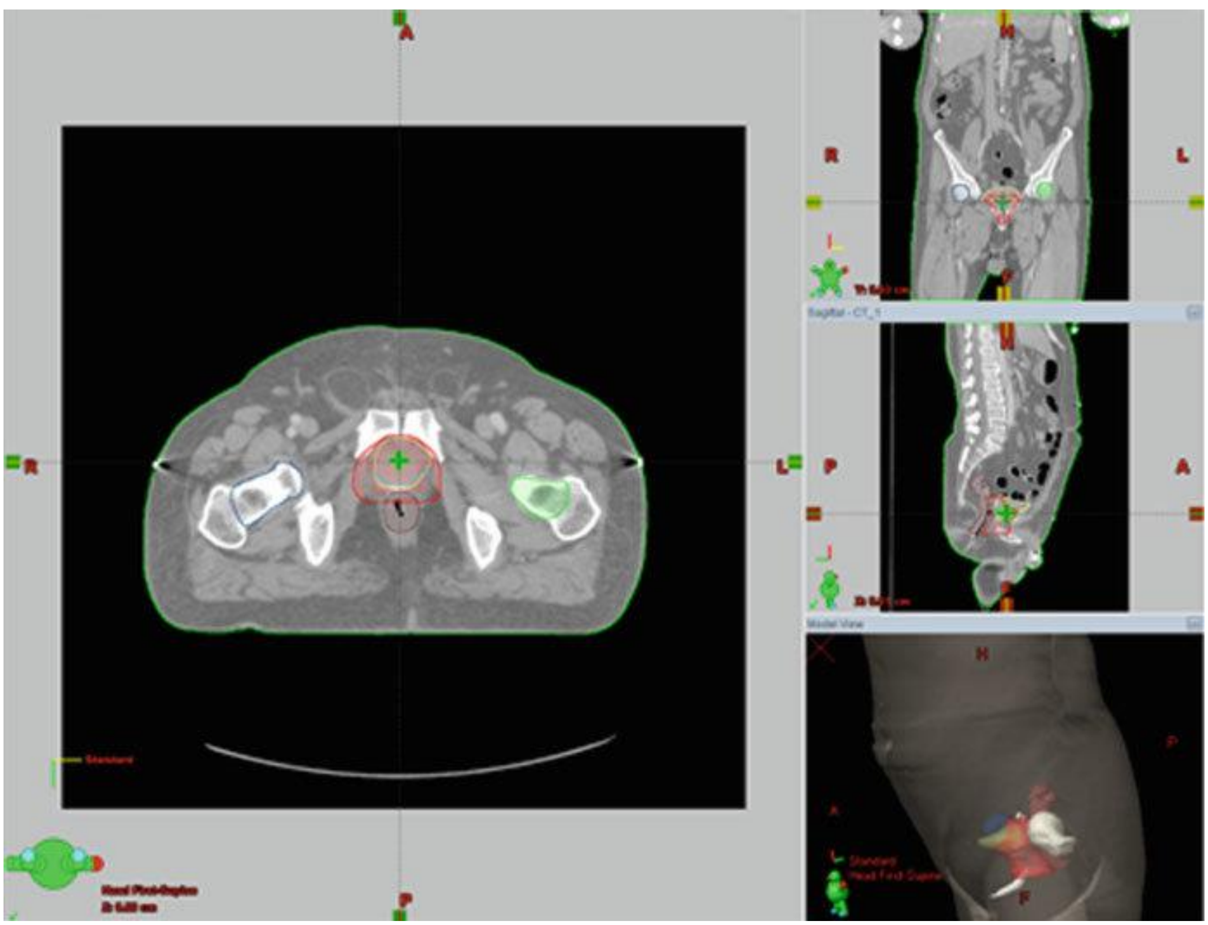

Fig. (6) Three-dimensional view of the patient anatomy, reconstructed from CT data in Eclipse™

Magnetic Resonance Imaging (MRI)

Treatment planning calculations are generally performed on CT images. However, for target delineation, additional modalities can be helpful in some cases. Magnetic resonance (MR) imaging is one such modality that provides better soft tissue contrast compared to CT, and this can be especially useful in brain and prostate tumors. For contouring purposes, MR images are fused (overlapped) with the CT data set. Newer sophisticated algorithms may use MR images for dose computation.

Positron Emission Tomography (PET)

Positron emission tomography (PET) is also used as a complementary imaging tool for target delineation. PET provides useful information on the physiological function of organs based on their metabolic activity. PET-CT is a technique where both the CT and PET images are acquired simultaneously with the same patient setup. The additional information can help the oncologist to accurately and precisely contour certain target volumes.