11 PET and PET/CT for Radiotherapy Planning

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11.1 Introduction

During the 1990s the radiation oncology community embraced the 3D conformal radiation therapy (3DCRT; Perez 1995; Purdy 1997) as a standard of care for many treatment sites. This acceptance stems from the postulate that 3DCRT allows for dose escalation to tumor volumes while preserving tolerance doses for normal structures. It is believed that 3DCRT improves outcomes while minimizing complications and side effects. Researchers and manufacturers have developed a variety of treatment planning and delivery devices for 3DCRT. These efforts have culminated in widespread use of intensity modulated radiation therapy (IMRT; Ezzel et al. 2003), a delivery of non-uniform radiation beam intensities that have been calculated by a computer-based optimization technique. Modern treatment planning systems can relatively efficiently calculate optimized treatment plans to complex target volumes and linear accelerators can deliver these treatment plans with high precision in short treatment times.

One of the fundamental components of the 3DCRT and IMRT process is a volumetric patient scan. This scan is the basis for the treatment plan and the main guide for the design of treatment portals and dose distributions. The image study is used to delineate target volumes and normal structures. The quality of the study and the data contained in the study have a direct impact on the patient treatment and potentially on the outcomes and complications.

The 3DCRT process based on X-ray computed tomography (CT) imaging was first described in the 1980s (Goitein and Abrams 1983; Goitein et al. 1983; Sherouse et al. 1990). Since then, CT has remained the primary imaging modality in radiation therapy. X-ray computed tomography offers excellent spatial integrity, which is important for accurate patient treatments (Mutic et al. 2003a). Computed tomography also provides radiation interaction properties of imaged tissues for heterogeneity based dose calculations and digitally reconstructed radiographs (DRRs) can be calculated from volumetric CT data sets (Sherouse et al. 1990). The three main limitation of CT are relatively poor soft tissue contrast, the fact that motion information is generally not appreciated as CT images are acquired as snapshots in time, and limitation to record functional properties of the imaged tissues. Magnetic resonance imaging (MRI), nuclear medicine imaging (single photon emission tomography (SPECT), and positron emission tomography (PET)) can provide certain advantages over CT with respect to these limitations.

With regard to the first limitation, MRI has a superior soft tissue contrast to CT and can provide often more useful anatomic information (Fig. 11.1). The MRI is often preferred for treatment planning of the central nervous system tumors and some other treatment sites. The two main MRI limitations are susceptibility to spatial distortions and the small size of scanner openings which in turn limits the size of
immobilization devices and patient positioning that can be used for radiation therapy treatment.

It is possible that the second CT limitation and inability to record motion could be overcome with multi-slice CT technology and special acquisition sequences which are designed to capture patient motion as a function of breathing (Low et al. 2003). This type of image acquisition has been referred to as 4DCT. The scanning technique is based on acquisition of multiple image sets through the volume of interest and reconstruction of this data as a function of time or as a function of air volume in the lungs, or some other reference.

The third limitation relates to the fact that CT primarily records anatomic information and does not convey functional properties of imaged tissues. Knowledge of functional properties of imaged tumors and surrounding critical structures can be very important in design of radiation dose distributions within target volumes and in guidance for sparing of critical structures. Ling et al. (2000) have proposed a concept of biological target volumes (BTVs). In addition to recommendations for target volume definitions proposed by the International Commission on Radiation Units and Measurements (ICRU) reports 50 and 62, portions of target volumes would be identified as having increased growth activity or radioresistance. Identification of these volumes would be performed with functional imaging and these volumes would be labeled as BTVs. Biological target volumes would then have a special consideration during the treatment planning process and would be subject to dose escalation. Magnetic resonance imaging (proton spectroscopy, diffusion, perfusion, functional) and nuclear medicine imaging can be used to identify BTVs. Additionally, these imaging modalities can be used for the overall improvement in disease detection, staging, treatment modality selection (intra-modality and inter-modality), target volume definitions, treatment planning, and outcome estimation and patient follow-up.

This chapter addresses the use of PET imaging in planning of radiotherapy treatments. The main emphasis is on the use of images and not on the image acquisition and PET tracers; these are described in detail elsewhere (Valk et al. 2002).

### 11.2 Potential of PET Imaging in Radiation Therapy

Imaging is involved in all steps of patient management, disease detection, staging, treatment modality selection (intra-modality and inter-modality), target volume definitions, treatment planning, and outcome estimation, and patient follow-up. An overall goal of imaging in radiotherapy is to accurately delineate and biologically characterize an individual tumor, select an appropriate course of therapy, and predict the response at the earliest possible time. The requirement to biologically characterize an individual tumor means that an imaging modality must be capable of imagining not only the gross anatomy but also recording information about physiology, metabolism, and the molecular makeup of a tumor; therefore, the image information used in radiotherapy can be classified as anatomical and/or biological. The four primary imaging modalities used in radiation therapy are CT, MRI, ultrasound (US), and nuclear medicine imaging. Weissleder and Mahmood (2001) have reviewed molecular imaging and the ability of the above-listed imaging modalities to record different types of information. Table 11.1 summarizes their findings.