can early imaging discriminate between indolent and aggressive disease? Some cancers progress very slowly and may not affect an individual during his or her lifetime, as is demonstrated by the high prevalence of certain tumor types in autopsy series (Sakr et al. 1994). Today, distinguishing between aggressive and indolent disease remains one of the biggest challenges in oncological imaging.

Fortunately, imaging has also made substantial progress in analyzing tumor heterogeneity and metabolism during the last decade; its role is no longer limited to detection, pretreatment staging and surveillance after curative treatment, but has expanded to include tailoring, and monitoring the response to, therapy. Conventional site-specific treatment regimens, based mainly on tumor stage, are being replaced by individualized and targeted treatment approaches based on individual tumor characteristics. Current technology for delivering 3D conformally shaped external beam radiation therapy (3D-CRT), and in particular intensity modulated radiation therapy (IMRT), may have exceeded our ability to localize tumors and normal tissues using conventional imaging techniques. With IMRT, it is possible to deliver different dose prescriptions to multiple target volumes with steep dose gradients between tumor and normal tissues. Dose escalation studies, driven by the hypothesis that dose nonuniformity within the planning target volume may lead to an increase in local control, have boosted the interest in more precise morphological and biological delineation of target volume. Increasingly important is the role of imaging in providing noninvasive, objective measures of tumor response to therapy in order to validate the biological target volume concept. This multidimensional conformal radiotherapy advocates the full incorporation of molecular medicine into the radiation planning process (Ling et al. 2000; Chapman et al. 2003; Brahme 2004).

Figure 4.1 summarizes the different roles of imaging as applied to radiotherapy. In this chapter, we will discuss some recent advances in computed tomography (CT), magnetic resonance imaging (MRI) and
positron emission tomography (PET), with special emphasis on their application for radiation treatment planning and early treatment monitoring.

### 4.2 Imaging Modalities

#### 4.2.1 Computed Tomography

CT remains the engine for radiation treatment planning; it is the modality of choice for the delineation of target volumes and organs at risk, for virtual simulation and dose computation. Two recent advances in imaging technology have reinforced the role of CT: (1) the advent of multi-slice helical CT scanners and (2) the combined use of PET and CT.

Setup inaccuracy and internal motion, inter- and intrafraction, limit the ability to reduce margins in radiation treatment planning. Adding margins to account for respiratory motion increases the volume of healthy tissues exposed to high doses. In efforts to reduce these margins, plans with sharper dose gradients, for example IMRT plans, are particularly susceptible to inadequate coverage of the target volume. In the case of intrathoracic (lung, mediastinum) and intra-abdominal (liver, pancreas) treatments, intrafraction motion can be significant. Four-dimensional radiotherapy refers to the addition of time to the 3D treatment process (Keall 2004). In 4D-CT imaging, a sequence of CT image sets are acquired over consecutive segments of a breathing cycle. This allows encoding of the tumor and organ motion information in the 4D image set. The advent of multi-slice helical CT scanners, combining high-quality images with a very short acquisition time (in a single breath-hold), has greatly facilitated the use of CT for this purpose. Another advantage of acquiring a planning CT scan at one phase of the respiratory cycle is the reduction of volume and shape

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**Fig. 4.1.** Overview of the role of imaging in radiotherapy. **CTV** clinical target volume, **OAR** organ at risk, **PTV** planning target volume, **PRV** planning risk volume, **CT** computed tomography, **MRI** magnetic resonance imaging, **US** ultrasound, **EPID** electronic portal imaging device, **DCE** dynamic contrast-enhanced, **MRS** magnetic resonance spectroscopy, **PET** positron emission tomography, **SPECT** single photon emission computed tomography