Three-dimensional (3D) C-arm computed tomography is a new and innovative imaging technique. It uses two-dimensional (2D) X-ray projections acquired with a flat-panel detector C-arm angiography system to generate CT-like images. To this end, the C-arm system performs a sweep around the patient, acquiring up to several hundred 2D views. They serve as input for 3D cone-beam reconstruction. Resulting voxel data sets can be visualized either as cross-sectional images or as 3D data sets using different volume rendering techniques. Initially targeted at 3D high-contrast neurovascular applications, 3D C-arm imaging has been continuously improved over the years and is now capable of providing CT-like soft-tissue image quality. In combination with 2D fluoroscopic or radiographic imaging, information provided by 3D C-arm imaging can be valuable for therapy planning, guidance, and outcome assessment all in the interventional suite.
3.1 Introduction

Three-dimensional (3D) C-arm computed tomography is a new and innovative imaging technique. Also referred to as C-arm CT, it uses two-dimensional (2D) X-ray projection data acquired with flat-panel detector C-arm angiography systems to generate CT-like images (Saint-Felix et al. 1994; Koppe et al. 1995; Fahrig et al. 1997; Bani-Hashemi et al. 1998; Jaffray and Siewerdsen 2000; Groh et al. 2002; Zellerhoff et al. 2005; Ritter et al. 2007; Kalender and Kyriaku 2007). To obtain 2D radiographic projection data, the C-arm performs a sweep around the patient, e.g., over 200°. Up to several hundred images are acquired depending on the acquisition protocol selected. Reconstruction of three-dimensional voxel data sets from 2D raw projection data is performed using a 3D cone-beam reconstruction algorithm. Resulting voxel data sets can be visualized either as cross-sectional images or as 3D data sets using different volume rendering techniques.

Initially targeted at neuroendovascular imaging of contrast-enhanced vascular structures, 3D C-arm imaging has been continuously improved over the years. It is now capable of providing CT-like soft-tissue image quality directly in the interventional radiology suite. Beyond their use for trans-arterial catheter procedures, these 3D data sets are also valuable for guidance and optimization of percutaneous treatments such as liver tumor ablations. In combination with 2D fluoroscopic or radiographic imaging, information provided by 3D C-arm imaging can be very valuable for therapy planning, guidance, and outcome assessment—in particular for complicated interventions (Missler et al. 2000; Anxionnat et al. 2001; Heran 2006; Meyer et al. 2007; Wallace et al. 2007).

C-arm CT requires state-of-the-art C-arm systems equipped with flat-panel detector (FD) devices. It is commercially available from various vendors, e.g., marketed as syngo DynaCT (Siemens AG, Healthcare Sector, Forchheim, Germany), XperCT (Philips Healthcare, Andover, MA), or Innova CT (GE Healthcare, Chalfont St. Giles, UK).

The goal of this book chapter is to provide an overview of how 3D C-arm imaging works and for what it can be used. To this end, we focus on important C-arm system components first. Then we explain how X-ray input images are acquired and take a look at the resulting patient dose. In the next step, we cover three-dimensional image reconstruction and the correction methods needed to obtain low-contrast 3D results with CT-like image quality. After we explained how C-arm CT images are generated, we analyze them in terms of spatial resolution and contrast resolution. In the remainder of this chapter, we look at clinical imaging results and C-arm CT applications including instrument guidance.

3.2 Technology of C-Arm CT Systems

3.2.1 C-Arm System Components

3.2.1.1 X-Ray Beam Generation and Exposure Control

The X-ray tube, X-ray generator, and X-ray control system are crucial components of any C-arm imaging system. They determine tube voltage, tube current, and irradiation time, respectively. These exposure parameters are essential for X-ray imaging, since contrast-detail perceptibility and dose depend on them.

Better contrast visibility, in particular of iodine, is the main reason why angiographic C-arm systems usually operate at lower tube voltages than CT scanners. Since decreasing tube voltage can lead to an increase in image noise, the question arises if better low contrast visibility at lower tube voltages can compensate for higher noise or not. Recent studies not only support this hypothesis, but they also indicate that there is great potential for dose reduction by scanning with lower tube voltages (McCollough 2005; Nakayama et al. 2005).

The requirement to obtain high 2D image quality for fluoroscopic and radiographic imaging led to C-arm systems equipped with automatic exposure control (AEC). The use of AEC turns out to be extremely beneficial for C-arm CT imaging as well. In fact, it is very similar to attenuation-based tube current modulation used in CT. Tube current modulation can either improve image quality through noise reduction at a given dose, or it can reduce radiation exposure without impairing image quality (Gies et al. 1999; Kalender et al. 1999).

3.2.1.2 Flat-Panel Detector Technology

Until the 1990s, C-arm systems for real-time angiographic imaging used to rely on X-ray image intensifiers (XRIIs). Although optimized over decades, this technology has a number of inherent disadvantages that