Chapter 4

Technical Principles of Cardiac Image Acquisition

4.1 Basic Performance Requirements for CT Imaging of the Heart

To virtually freeze cardiac motion and to avoid motion artifacts, very short exposure time is needed for the acquisition of transaxial slices. High temporal resolution is particularly important for imaging the coronary arteries as they are located very closely to the heart muscles and show strong movement during the cardiac cycle. The intensity of movement varies within the cardiac cycle. The strongest movement is present during contraction of the atria and the ventricles in systole. Imaging should be performed during the diastolic phase of the cardiac cycle as less movement is present during the filling phase and the least amount of blurring due to motion artifact is to be expected. Thus, image acquisition and reconstruction needs to be synchronized as accurately as possible with the movement of the heart, i.e. by using ECG information that is recorded in parallel with the CT scan acquisition. The duration of the phase with lowest cardiac motion during diastole narrows with increasing heart rate (Fig. 4.1). According to a rough estimation, a temporal resolution of about 250 ms is appropriate for motion-free imaging up to a heart rate of about 70 bpm, whereas 150 ms is required for clinically usual heart rates up to 100 bpm. Image acquisition during other phases of the cardiac cycle (e.g. systole) based on ECG information can be useful for evaluation of functional information. However, motion-free imaging during other phases than diastole requires about a temporal resolution of 50 ms (Stehling et al. 1991) and will usually not be possible with state-of-the-art CT systems. Thus, only larger or not rapidly moving cardiac anatomy should be assessed during phases of high cardiac motion.
Many parts of the cardiac morphology, especially the coronary arteries and the cardiac valves, including the valve flaps, represent small and complex 3-dimensional structures that require very high and sub-millimeter isotropic spatial resolution with longitudinal resolution close or equal to in-plane resolution. Most proximal coronary segments and the distal segments of the right coronary artery (RCA) are directed parallel to the image plane, while the middle segments are directed perpendicular to the image plane. The lumen diameter of the main segments of the coronary artery tree ranges from 4 mm (left main artery, LM) down to about 1 mm [peripheral left anterior descending artery (LAD) and circumflex (CX)]. Thus, in-plane and through-plane resolutions of 1 mm or less are needed to assess the main coronary segments including narrowing and plaques. Less spatial resolution is sufficient for assessment of larger cardiac anatomy such as the myocardium and the cardiac chambers. However, scans should a priori be acquired at best possible spatial resolution as lower spatial resolution can be generated via data post-processing.

In addition to high spatial resolution, sufficient contrast-to-noise ratio is important to resolve small and low-contrast structures such as atherosclerotic coronary plaques with different attenuation properties. Appropriate low-contrast resolution has to be provided with limited radiation exposure at shortest possible exposure time. For most cardiac applications, appropriate contrast enhancement of the cardiac vessels and the cardiac anatomy has to be provided following peripheral injection of contrast agent with optimized timing of the bolus. Sufficient contrast enhancement is particularly important for imaging the distal coronary segments as they are located very close to the myocardium and are separated only by a thin layer of epicardial fat. Only the assessment of cardiac and coronary calcification is possible without administration of contrast agents.

The scan time for the complete heart volume should not exceed a single breath-hold time with reasonable duration to limit radiation exposure and administration of contrast and to avoid breathing artifacts. Today’s CT technology can not cover the entire heart volume within a single heartbeat. Instead, images at consecutive z-positions that continuously cover the heart volume need to be generated from data acquired in different cardiac cycles. A virtually “frozen” cardiac volume can only be produced by phase-consistent synchronization of the acquisition with the movement of the heart by using simultaneously recorded ECG information. A reasonably stable sinus rhythm without rapid arrhythmic changes is needed to achieve best results in volume imaging. Functional information can be derived if cardiac volume images can be generated in different phases of the cardiac cycle and quantitatively evaluated.

Cardiac imaging is obviously a highly demanding application for CT, as temporal, spatial, and contrast resolution as well as scan time have to be optimized simultaneously and radiation exposure has to be limited. These conflicting performance requirements have to be fulfilled and optimized for the particular application within the same cardiac scan protocol. Optimization of one performance cornerstone (e.g. high temporal resolution, low radiation exposure) by trading-off other important parameters (e.g. spatial and contrast resolution) may not lead to clinically useful results.

### 4.2 Prospective Multi-slice ECG Triggering

For motion-free imaging of the heart, data have to be acquired during phases of the cardiac cycle with little cardiac motion and with an exposure time that is as low as possible. Prospective ECG-triggered sequential scanning has already been used with EBCT (Stanford and Rumberger 1992) and mechanical single-slice CT (Becker et al. 1999). Single slices are acquired with minimum exposure time in consecutive heartbeats within equivalent phases of the cardiac cycle. The total scan time is related to the heart rate of the patient and is often too long for volume coverage with thin slices within a single breath-hold. Multi-slice CT scanners can acquire multiple slices within one heartbeat. Thus, they offer shorter scan times that can be beneficial for clinical application.

#### 4.2.1 Half-Scan Image Reconstruction for Optimized Temporal Resolution

For cardiac imaging with sequential acquisition the best possible temporal resolution can be obtained using the partial-scan technique. Depending on the system geometry a partial-scan fan-beam data set has to cover a projection angle interval \( \alpha_p \) (angle interval between tube positions at start and end points of tube rotation) of \( 180^\circ \) plus the breadth of the X-ray fan: \( \alpha_p = \pi + \beta \). This relation describes that a minimum data segment of \( 180^\circ \) has to be available for every fan angle \( \beta \). As a consequence, a partial rotation usually covers about 2/3 of a