Even though contrast-enhanced cardiac-gated three-dimensional (3-D) techniques can now be performed in a single breathhold (1), 3-D navigator respiratory-gated methods offer an alternative to patients unable to hold their breath. Moreover, whereas cardiac-gated 3D breathhold sequences for coronary magnetic resonance angiography (MRA) are not yet available on most magnetic resonance imaging (MRI) systems, several of the major MR system manufacturers offer navigator respiratory-gated as part of their commercially available cardiac MR software.

Along with eliminating breathhold requirements, advantages to respiratory-gated 3-D coronary MRA include better signal than short breathhold sequences, which allow the study to be performed without the administration of contrast material. In addition, because a relatively large volume may be covered, navigator techniques often require less precise set up than many breathhold methods and a detailed knowledge of coronary artery anatomy is less necessary, allowing a competent technologist to perform the examination.

Three-dimensional navigator methods, however, also have some shortcomings. As the patient breathes throughout the examination, respiratory gating techniques may not entirely eliminate artifacts caused by respiratory motion. This is especially true for patients with erratic breathing patterns. Because 3-D data acquisition requires 4–15 minutes of imaging time, it is more difficult for patients to keep a consistently regular breathing pattern throughout the entire examination.

Respiratory Gating Techniques

Because of the incompatibility of MR software between manufacturers, and because most MR research laboratories are limited to the MR system of one supplier, a number of different respiratory gating techniques have been developed for coronary artery imaging. These techniques include retrospective respiratory gating, prospective respiratory gating, respiratory feedback, and the diminishing variance algorithms.

Retrospective Respiratory Gating

With retrospective respiratory gating, two excitation bands are placed at either the right or left hemidiaphragm. One band is excited by a 90-degree flip angle radiofrequency (rf) pulse; the second has a 180-degree flip angle rf pulse (2,3). Together these rf pulses create a vertical navigator spin echo beam that measures diaphragmatic motion in the superior–inferior direction corresponding to each in-plane phase-encoding line for each heartbeat (Fig. 6.1). A fixed number of repeated measurements are acquired for each phase-encoding line. A histogram is created after data acquisition. This measures phase-encoding lines as a function of diaphragmatic position. The most common position of the diaphragm is determined (i.e., usually end-expiration) and chosen as the gating center. For a given line in \( k \)-space, only data acquired when the position of the diaphragm falls within a range (usually \( +/-1 \) mm) from the gating center are used for image reconstruction. With this 3-D technique (2–5) a 3.2–4.0-cm slab, composed of 16–20 partitions of 2 mm each, is acquired in each scan with the center of the slab set by the operator. In the most recent version of the software, partitions are automatically interpolated to 1 mm in the \( z \)-axis. In-plane resolution is on the order of 1 \( \times \) 1 mm\(^2\). When contrast agents are used, in-plane resolution can be improved by turning off the posterior channels of the phased array coil and decreasing the field-of-view. Depending on the heart rate of the patient, each sequence takes 4–8 minutes to acquire. This is the technique currently marketed by Siemens Medical Systems (Erlangen, Germany).

Real-Time Respiratory Gating and Feedback

Investigators using real-time respiratory gating employ a two-dimensional (2-D) selective pulse to excite a lon-
itudinal cylindrical beam that is positioned through the diaphragm to monitor its motion (Fig. 6.2) (6). As image data is collected, navigator echoes are acquired immediately before and after the image data readout train in every cardiac cycle. This technique differs from retrospective respiratory gating in that the decision to reject or accept each segment of data is made prospectively or in “real-time.” When the position of the diaphragm sampled by these navigator echoes falls within a specified range, image data are accepted and image collection moves on to the next line of data. If, however, the diaphragm is not in the gate window, the same segment of data is reacquired during the next heartbeat (6). This method has been employed by both users of the General Electric (Milwaukee, Wisconsin) and Philips MR systems (Best, Netherlands). Another sequence available on the Philips system uses a cylindrical excitation pulse that is placed directly through the heart (7,8). A component of adaptive motion correction is coupled with this type of navigator echo acquisition. This feature automatically factors in a superior–inferior displacement correction for the portion of the heart being imaged.

Respiratory triggering or feedback is a method of optimizing the real-time respiratory-gating process, shortening the data acquisition process by obtaining a navigator profile and then visually prompting the patient to hold his or her breath in a consistent location based on the navigator information (9,10). Coaching the patient in this fashion, fewer lines of data need to be reacquired. Although this technique is helpful in shortening the overall scan time, use of this technique requires an alert and cooperative patient.

Diminishing Variance Algorithm

The diminishing variance algorithm combines the advantages of both prospective and retrospective gating methods (11). With retrospective gating, the acceptance window is flexible and the number of acquisitions is fixed. With prospective gating the acceptance window is fixed and the number of acquisitions is flexible. With the diminishing variance algorithm, however, both the acceptance window and number of acquisitions are flexible. This allows for the most efficient collection of data within the gate window. Nevertheless, to perform the diminishing variance algorithm adequately a fast computer is required to update the histogram of diaphragmatic displacements in real-time, after each data acquisition.

Practical Considerations

Patient Positioning and Cardiac Triggering

For most coronary MRI, the patient is positioned supine with EKG leads placed either on the anterior or posterior chest wall. To reduce cardiac motion, EKG triggering is required and data are collected during diastole.