MAGNETIC RESONANCE IMAGING IN CARDIAC DIAGNOSIS

INTRODUCTION

Magnetic resonance imaging (MRI) is a diagnostic imaging technique that uses a magnetic field and radio waves rather than x-rays to produce highly detailed images of internal organs and tissues. Because of the high contrast sensitivity to soft tissue and the safety to the patient resulting from the use of non-ionizing radiation, MRI has replaced many CT methods. The technique has proven very valuable for the diagnosis of a broad range of pathologic conditions in all parts of the body, including cancer, heart and vascular disease, stroke, joint and musculoskeletal disorders. MRI requires specialized equipment and expertise.

MRI is a fast, noninvasive tool for diagnosing coronary artery disease and heart problems. The technique allows visualization of cardiac anatomy, size and thickness of the chambers of the heart, myocardial motion and valvular sufficiency. MRI is the modality of choice to examine the damage caused by a heart attack or progressive heart disease. MRI is becoming very important in the diagnosis of coronary heart disease allowing measurements of coronary arterial flow and coronary flow reserve.

METHODS

The contrast sensitivity of MR images is based on the differences between spin-density, T1 and T2 relaxation time constants of the tissues. The appearance of tissues in MRI depends on the type of imaging technique used.

A. Basic Sequences

1. Spin Echo

Spin echo uses two radiofrequency pulses to generate a signal. The first 90° pulse excites the protons in the sample, while the second 180° refocuses the protons to produce a coherent signal. This technique is used for evaluating cardiac morphology and acute myocardial infarctions. The basic SE sequence generates an MR signal at a time that is typically 20–30 msec after the excitation pulse. A second echo can be generated and is usually at a TE of 50–90 msec. The images obtained with short echo times have a better signal to noise ratio (SNR) than the images obtained with long echo times. They also
provide an excellent contrast between myocardium and flowing blood. These images are called black-blood images because of the signal void created by the flowing blood. The flow void varies with the time of echo (TE). If TE is long the blood leaves the slice before experiencing the second pulse in the SE sequence so no signal is generated. If the TE is short the blood remains in the imaged slice long enough to experience both RF pulses, generating a signal. For typical arterial flow velocities and a typical section thickness of 10 mm, the threshold TE for a flow void is 20–25 msec. Although it is widely available, SE imaging has limited temporal resolution and is degraded by respiratory and other motion-related artifacts. The development of electrocardiographically (ECG) gated SE has substantially reduced the motion artifacts. However, ECG-gated SE imaging is imperfect with slow-flowing blood signal in the cardiac chambers. When flow rates are very slow (e.g., aneurysms), a flow void may also be created by exciting the protons prior to entering the imaged section thus they will not generate signal when within the imaged slice. This technique is referred to as presaturation.

![Figure 1. Spin echo contrast](image)

2. Gradient Echo

The gradient echo (GRE) technique uses a single RF pulse to excite the protons and a magnetic field gradient to induce the formation of an echo (instead of 180° pulse used in SE technique). The GRE technique has a significant sensitivity to field nonuniformity because the dephasing and rephrasing occur in the same direction as the main magnetic field and do not cancel the inhomogeneity effects. Typically gradient echoes are obtained at TE of 2–8 msec, and this can be repeated approximately every 10–20 msec. When gated to the ECG, gradient echoes can be acquired at successive intervals of 20–40 msec throughout the cardiac cycle on almost all current systems. This permits one or more sections to be imaged at multiple phases of the cardiac cycle so that a cine display can be generated. GRE imaging is suited for cardiac studies due to its short echo (TE) and repetition (TR) times. The GRE technique creates bright-blood images and it is good for both morphologic and functional studies. In contrast to the SE images in
which rapid blood flow reduces signal, the signal intensity from flowing blood in
gradient-echo images generally increases as flow velocity increases. Soft tissue GRE-
contrast is less than SE-contrast because the gradient echo signal in static tissues reflects
mostly tissue proton density.

Figure 2. Gradient echo contrast

3. Turbo Spin Echo

The turbo spin echo (TSE) technique (aka rapid acquisition relaxation
enhancement, RARE) uses multiple phase encode steps in conjunction with multiple 180°
refocusing pulses per TR interval to produce a train up to 16 echoes. Each echo
experiences differing amounts of phase encoding that correspond to different lines in k-
space. TSE technique has the advantage of SE image acquisition (immunity from external
magnetic field) with up to 16 times faster acquisition time. The drawback of this method
is lower SNR than conventional SE. The advantage consists of being less sensitive to
respiratory and cardiac motion. It is a black-blood technique.

Figure 3. Turbo spin echo contrast

4. Inversion Recovery

The inversion recovery (IR) technique uses a pair of non-selective and selective
180° RF inversion plus followed by a delay inversion time (TI) that is chosen to null
the blood magnetization while the image plane tissue remains unaffected. A second selective $180^\circ$ inversion pulse can be applied to null fat. This is known as double inversion recovery (DIR). The sequence is acquired with a breath hold. It is a black-blood technique.

Figure 4. Comparison of short-axis views acquired with ECG-gated SE (left) and T2-weighted DIR imaging. The ventricular blood signal is minimized and that the blood-myocardial interface is more clearly depicted on the DIR.

Figure 5. Breath-hold fast spin-echo MR imaging with triple inversion recovery (IR) preparation pulses which suppress both blood and fat signal. Fatty infiltration of the right ventricular free wall is clearly demonstrated in a patient with right ventricular dysplasia.

B. Cine Techniques

With advances in fast imaging techniques, detailed morphology of cardiac structures including coronary arteries can be demonstrated with improved image quality. Cine MRI has been shown to be useful for quantifying ventricular morphology and function.
1. Fast Gradient Echo

Fast gradient echo (fGRE) is a cine technique in which the gradient echo sequence is repeated at 20-30 msec to image a single or multiple slices at a large number of consecutive points throughout the cardiac cycle. Images for different times during the cardiac cycle can be computed. fGRE provides dynamic high temporal and spatial resolution images of the myocardium. This technique can provide excellent diagnostic information about the blood supply to the myocardium. This is a bright-blood technique.

2. k-Space Segmentation

A segmented k-space technique provides high resolution dynamic images of the heart that are acquired very rapidly. Using short TEs and TRs, multiple lines of k-space are acquired during each cardiac cycle while in GRE only a single line of k-space is obtained per cycle. Respiratory artifacts can be completely removed by breath holding. With this technique, bright blood images at different cardiac phases on multiple slice locations can be acquired within a single breath-hold. In pediatric patients, high quality MR images can be obtained without breath-holding by using multiple averaging. This technique improves time efficiency of cine MRI, cine MR images being acquired within a 15-s breath-hold for each slice location.

Figure 6. Breath-hold cine MR images of the left ventricle acquired in the end-diastole with segmented k-space method in a healthy subject (A) and in a patient with hypertrophic cardiomyopathy (B).

3. Echo planar Imaging

Echo planar imaging (EPI) technique provides extremely fast imaging time. Rather than acquiring a single image line in k space after the preparation phase of the pulse sequence, the entire MR image is acquired. Echo planar imaging is very useful in evaluation of myocardial perfusion. EPI can provide full coverage of the left ventricle with an ideal temporal resolution of every heart beat. Echo planar images have poor SNR, low resolution and many artifacts. Spatial distortion and signal attenuation of the heart due to susceptibility effects on the single-shot or two-shot echo-planar MR images are sometimes unacceptable for clinical diagnosis. Multi-shot gradient-echo echo-planar imaging (EPI) provides cine MR images with an acquisition time of only 2 s for each slice location.
slice location. By using multi-shot echo-planar imaging strategy, images can be acquired with decreased susceptibility artifacts and distortion, improved temporal resolution in the cardiac cycle, and better effective spatial resolution compared to those acquired with single-shot echo-planar technique.

![Figure 7. EPI cine contrast](image)

**4. Navigator-Echo**

With navigator-echo techniques one can suppress respiratory motion. Navigator echoes are placed over the right diaphragm for position detection, and the image is triggered for a 4-5 mm window. An end-expiration location is used for the navigator because it is sustained longer and more reliable during tidal respiration. It is used in coronary artery imaging.

![Figure 8. Comparison between (a and b) free-breathing navigator-echo gated 2D spiral imaging and (c and d) breath-held multislice 2D spiral imaging.](image)

**5. Magnetic Tissue Tagging**

Magnetic tissue tagging has shown great potential as a non-invasive tool for myocardial system assessment. Magnetic tissue tagging is a process that introduces landmarks on MR imaging plane non-invasively. The introduced dark-stripes pattern
moves with the moving tissue. Two tagging techniques have been widely used: Spatial modulation of magnetization (SPAMM) and Delays alternating with nutations for tailored excitations (DANTE). Magnetic tissue tagging very useful in the analysis of heart wall motion because it provides temporal correspondence of material points within the heart wall.

Figure 9. Short-axis section through the tagged myocardium, tagline distance 10 mm. Eight of 16 heart phases, the time after the R-wave detection is indicated on the picture. This view is comparable to conventional 2D-CSPAMM images. The tagline deformation illustrates the contraction and rotation of the heart. The dark regions appearing during the cardiac cycle display horizontally tagged material moving into the image plane. This indicates the longitudinal contraction and displacement of the myocardium.

CONCLUSION

Cardiac MRI can be successfully used to image cardiac structure, cardiac function, myocardial perfusion and coronary arteries. MRI is an increasingly important tool for cardiovascular research and the clinical evaluation of patients with ischemic heart disease.

REFERENCES


