Magnetic resonance imaging of the heart

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Summary

Magnetic resonance imaging (MRI) is a completely noninvasive technique for the evaluation of the cardiovascular system. With a multi-section technique and the spin echo pulse sequence the entire heart can be examined within six to ten minutes. All our cardiac MR studies were performed with electrocardiographic (ECG) gating, to obtain adequate resolution of the cardiac structures. With this technique, patients and animals with a variety of cardiac abnormalities were studied. The examined pathologic conditions included acute and chronic myocardial infarctions and their complications, hypertrophic and congestive cardiomyopathies, congenital heart diseases and pericardial diseases. MRI offers an enormous potential for cardiovascular diagnosis, even beyond the demonstration of pathoanatomy, because of the capability for direct tissue characterization and blood flow measurements.

Introduction

Magnetic resonance imaging (MRI) is a noninvasive method, which provides tomographic images of the whole body. In proton-MRI the images are reconstructed from signal emitted by hydrogen nuclei after being irradiated with radio-frequency (RF) pulses. This interaction of radio waves and protons takes place in a high-strength static magnetic field. At the same time, low-strength changing magnetic fields are used to localize the signal in a particular area of the body.

MRI has some intrinsic advantages for the study of the cardiovascular system (1–5). High soft-tissue contrast allows discrimination between fat, pericardium, and myocardium. Rapidly flowing blood in the lumen of blood vessels and in the cardiac chambers generates little or no MR signal. Consequently, lumina of the vessels and the cardiac chambers appear dark and the internal surface of blood vessels and the walls of the cardiac chambers become visible. Intravenous injection of contrast medium is therefore not required in MRI. Utilizing a proper gating technique and observing the effects of flowing blood on image contrast, functional information about wall motion and flow patterns can be obtained (6). MRI includes also the potential for direct tissue characterization by calculating $T_1$ and $T_2$ relaxation times and spin density. Such measurements in the myocardium provide useful information about different pathological conditions of the heart (7, 8).

The purpose of this work is to describe the imaging technique as used for routine MRI examin-
ations of the heart and to demonstrate clinical utility of MRI for visualization of normal anatomy and pathologic lesions.

**Technique of imaging**

**Instrumentation**

In our institution, MRI studies are performed with a superconducting magnet operating at 0.35 Tesla; the corresponding resonant frequency for hydrogen is 15 MHz (9). The double spin echo sequence is the imaging sequence generally used, which applies a 90° RF pulse followed by two 180° pulses at a given time interval. Subsequently, two signals can be recorded after an echo delay time (TE) of 28 msec and 56 msec. The pulse sequence repetition time (TR) is the interval between successive excitation sequences. The TR interval in cardiac studies equals the RR interval of the electrocardiogram, because all cardiac MRI studies are ECG-gated examinations (discussed below). Multiple imaging planes, e.g., transverse, sagittal or coronal, can be obtained in a direct signal acquisition. Tomograms can also be obtained in nonorthogonal planes which conform more closely to the long and short axis of the heart of left ventricle (10).

**ECG gating**

Cardiac imaging requires some form of physiologic gating of the imaging sequence. The reason for this is a substantial loss in MR signal intensity of moving nuclei (e.g., in cardiac structures), due to their variable position to the imaging volume. Without gating, cardiac images are generally of poor quality and represent an average image which cannot be related to a specific part of the cardiac cycle (Figure 1). ECG gating using low resistance electrodes that contain very little metal proved to be a valuable tool for routine cardiac MRI (11). There has been no measurable increase in the image noise level and the ECG signal has not been affected by the RF fields with the use of low resistant electrodes and non-magnetic ECG lead cables. The RF pulses are triggered by the R-wave of the ECG. Thus, the TR is defined by the R-R interval of the patient. TR gated to every heart beat equals 60/heart rate seconds and to every second heart beat 2 × 60/heart rate seconds.

Image acquisition time for two spin echoes consumes less than 20% of the time for one cardiac cycle in patients with normal heart rates. Five sections easily fit within a cardiac cycle. With this type of multi-section and double-echo imaging, five tomographic planes of the heart can be examined within six to ten minutes for a usual heart rate of 80 to 100 beats per minute (12). However, the time interval between trigger and data collection changes as we advance from slice to slice. Thus, the first section is synchronous with the trigger signal, the second is also synchronous but delayed by 100 msec, etc, to the fifth section, which is delayed by 400 msec beyond the R-wave of the electrocardiogram (Figure 2).

In order to get more dynamic data on heart motion (ejection fractions, measurements of wall thickness) more images are needed for a selected plane throughout the cardiac cycle. A specialized software program provides this type of image acquisition, called ‘rotating’ gated multi-section imaging (12). At five points of the cardiac cycle, separated from each by a time interval of 100 msec, images are obtained in one anatomic level (Figure 3). Examination time increases (factor of 5) if the same image volume is to be covered as with conventional gated studies.

*Fig. 1.* Transverse MR images of a normal volunteer at two different levels. Nongated images (left panels) show poor resolution of cardiac structures. ECG-gated images (right panels) display cardiac anatomy with good resolution. Arrowhead = tricuspid valve, arrow = coronary sinus.

*Fig. 2.* Four slices through the heart of a normal volunteer from base to apex. With regular ECG-gating slices are separated from each other by 100 msec. Open arrow = outflow portion of ventricular septum. Large arrow = inflow portion of ventricular septum. Small arrow = atrioventricular septum.