3 Spin- and Gradient-Echo Imaging

Dara L. Kraitchman

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3.1 Introduction

In Chap. 1 the fundamental behaviors of a single spin, or of a group of spins, were discussed. In brief summary, after the spins are aligned in a polarizing magnetic field, it is possible to add energy and to cause them to acquire transverse magnetization while giving up longitudinal magnetization. The recovery of longitudinal magnetization and the decay of transverse magnetization are characterized by relaxation times. Signal arises from the transverse component of magnetization and the interaction of that transverse magnetization with the conductors of the radiofrequency (RF) coil, due to Faraday induction. Certain types of signal loss (dephasing) can be reversed by a refocusing pulse to form a spin echo, which is advantageous in that its signal is relatively strong. In this chapter we begin with the MR signal and the spin echo, and develop the construction of images using combinations of RF pulses and application of gradients.

3.2 The Spin-Echo Pulse Sequence

3.2.1 Image Encoding

3.2.1.1 Slice Selection

In order to examine only a specific slice in the body rather than exciting the entire body with an RF pulse, a gradient magnetic field is superimposed on the external field, B0, during the application of the RF pulse. This external and additional magnetic field is applied with variable intensity as a function of location. Specifically, the gradient field, as well as the total field that is the sum of the B0 and the gradient, increases from the center of the magnet outward in the positive direction, and decreases in the opposite direction. This establishes a characteristic field strength, and thus, resonance frequency, for each position along the gradient axis.

The thickness of the slice can be selected in two ways. One method is by changing the range of RF pulse frequencies or bandwidth. A smaller range of RF frequencies, such as 64–64.5 mHz, will resonate protons in a thinner slice than a larger range of frequencies, such as 64–65 mHz.

Another method of changing the slice thickness is by modifying the slope or the gradient field. A steeper gradient, i.e., one that has a larger variation in field strength, will cause frequency precession to vary to a larger degree and enable a thinner slice selection.
3.2.1.2 Frequency Encoding

By applying a gradient during the RF pulse, one can select a slice or position in the body as well as the thickness of this slice. If we apply another gradient field during the acquisition of the signal, each position along the gradient direction will be associated by the Larmor relationship with a unique resonance frequency, and the spins at that position will precess according to that frequency. For example, if the gradient pulse is applied along x and increases from the left to right side of the body, then the precession frequency will also increase from left to right (Fig. 3.1). Thus, a one-to-one correspondence between frequency and spatial position is created by using an externally applied magnetic field gradient. Because this gradient creates a relationship between spatial location and frequency, it is called the frequency encoding gradient. A one-dimensional (1D) Fourier transform (FT) of the recorded signal will yield signal amplitudes at different frequencies which correspond to the spatial location in 1D. Note that frequency encoding is not sufficient to uniquely determine the two-dimensional (2D) location within the slice since all protons in one column will have the same frequency. The frequency encoding gradient is often referred to as the read or readout gradient since it is applied during data acquisition or read-out.

3.2.1.3 Phase encoding

In order to discriminate between points within the same column after frequency encoding, we apply another gradient at 90° (or orthogonal) to the frequency encoding gradient. This gradient is called the phase encoding gradient. The phase encoding gradient is applied for a brief period of time, typically prior to the frequency encoding gradient, and causes a change in the frequency of precession for a brief period of time. During the gradient operation, proton spins precess in accordance with the altered magnetic field, and acquire phase angles that are specifically attributable to that field. When the gradient is turned off, the frequency of precession returns to the equilibrium value, but the phase of rotation of the protons is locked in. Thus, when the gradient is turned off, each column (from the previous example) will have a different phase. This is known as phase encoding. Clearly, the magnitude of the phase change is proportional to the magnitude of the phase encoding gradient. By using both frequency and phase encoding gradients, the protons are labeled with both a frequency and phase so that 2D spatial localization can be performed.

Typically, one spin echo is acquired for each gradient magnitude of phase encoding. This simple but powerful form of MR imaging is called the spin-warp pulse sequence and is diagrammed in Fig. 3.2.

3.2.2 Single Spin-Echo

The spin-echo pulse sequence is widely used in clinical practice due to the ease of implementation and the ease of varying parameters that will alter MR contrast based on differences in tissue T1, T2, or proton density. The spin-echo pulse sequence (Fig. 3.3)