Lecture Five

MRI DESIGN: T1 Weighting

All intrinsic contrast mechanisms affect image contrast, regardless of the pulse sequence used. For example, tissues with a low proton density, and air, are always dark on an MR image, and tissues in which spins move may be dark or bright depending on their velocity and the pulse sequence used (An **MRI pulse sequence** is a programmed set of changing magnetic gradients. Each sequence will have a number of parameters, and multiple sequences grouped together into an MRI protocol).

In order to produce images where the contrast is predictable, parameters are selected to weight the image towards one contrast mechanism and away from the others. This is achieved by understanding how extrinsic contrast parameters determine the degree to which intrinsic contrast parameters are allowed to affect image contrast. Extrinsic contrast parameters must be manipulated to accentuate one intrinsic contrast parameter and diminish the others. Proton density effects cannot be changed. T1 and T2 influences are manipulated by changing the TR and TE in the following way.

In a **T1 weighted image**, differences in the T1 relaxation times of tissues are accentuated and T2 effects are reduced. To achieve this, a TR is selected that is short enough to ensure that the NMV in neither fat nor water has had time to fully relax back to B_0 before the application of the next excitation pulse. The NMV in both fat and water is saturated. If the TR is long, the NMV in both fat and water recovers and the respective T1 relaxation times can no longer be distinguished.

A T1 weighted image is an image whose contrast is predominantly due to the differences in T1 recovery times of tissues. For T1 weighting, differences between the T1 times of tissues are exaggerated and to achieve this the *TR must be short*. At the same time, however, T2 effects must be minimized to avoid mixed weighting. To diminish T2 effects the *TE must also be short*.

In T1 weighted images, tissues containing a high proportion of fat, with short T1 relaxation times, are bright (high signal, hyper-intense), because they recover most of their longitudinal magnetization during the short TR period and Therefore, more magnetization is available to be flipped into the transverse plane by the next RF pulse and contribute to the signal (Table 10.1).

Tissues containing a high proportion of water, with long T1 relaxation times, are dark (low signal, hypo-intense), because they do not recover much of their longitudinal magnetization during the short TR period and therefore less magnetization is available to be flipped into the transverse plane by the next RF pulse and contribute to the signal (Table 10.1).

Table 10.1 Signal intensities seen in T1 weighted images.

High signal	fat haemangioma intraosseous lipoma radiation change degeneration fatty deposition methaemoglobin cysts with proteinaceous fluid paramagnetic contrast agents slow-flowing blood
Low signal	cortical bone avascular necrosis infarction infection tumours sclerosis cysts calcification
No signal	air fast-flowing blood tendons cortical bone scar tissue calcification

T1 weighted images best demonstrate anatomy, but also show pathology if used after contrast enhancement (Figures 10.1, 10.2 and 10.3).

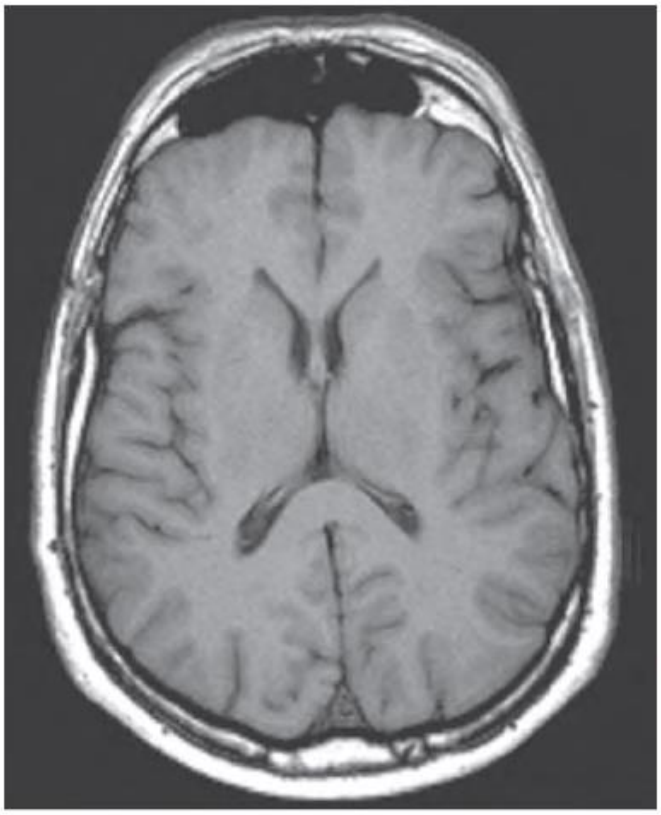

Figure 10.1 Axial T1 weighted image of the brain.

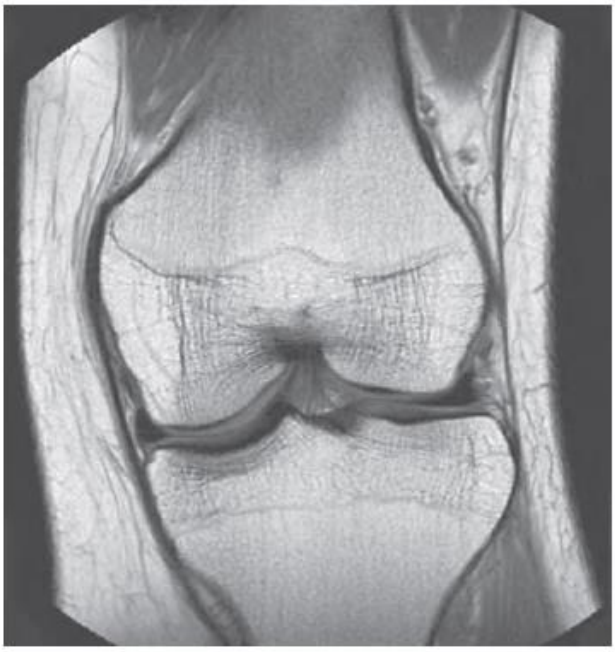

Figure 10.2 Coronal T1 weighted image of the knee.

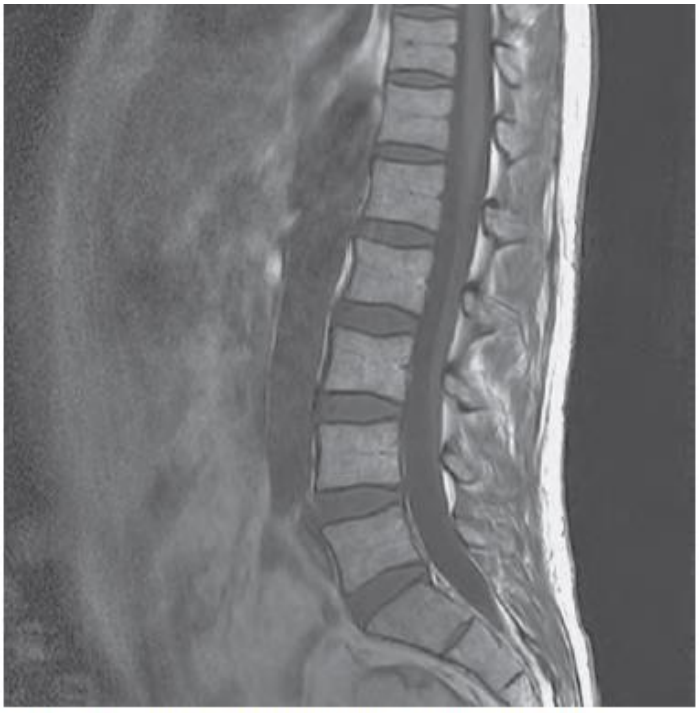

Figure 10.3 Sagittal T1 weighted image of the lumbar spine.

Typical values

• TR: 400–700 ms (shorter in gradient echo sequences).

• TE: 10–30 ms (shorter in gradient echo sequences).

The principal pulse sequences that are capable of producing T1 weighted images are:

• spin echo (produced by two successive RF pulses);

• turbo spin echo (produced by rapid acquisition with relaxation enhancement);

• inversion recovery (a conventional spin echo (SE) sequence preceded by a 180° inverting pulse);

• incoherent gradient echo (the utilization of gradient fields to generate transverse magnetization flip angles of less than 90°).

KEY POINTS

✓ All intrinsic contrast parameters contribute to image contrast.

✓ Extrinsic contrast parameters are used to control how much influence each intrinsic parameter has on image contrast.

✓ TR controls T1 contrast. TE controls T2 contrast.

✓ To produce a T1 weighted image it is necessary to create contrast in which the differences in the T1 recovery times of the tissues dominate image contrast.

✓ A short TR (e.g. 400ms) combined with a short TE (e.g. 10ms) maximizes T1 and minimizes T2 contrast respectively.

✓ T1 weighted images are used for anatomy and pathology post contrast enhancement.

MRI DESIGN: T2 Weighting

All intrinsic contrast parameters affect image contrast, regardless of the pulse sequence, TR and TE used. For example, tissues with a low proton density, and air, are always dark on an MR image, and tissues in which nuclei move may be dark or bright depending on their velocity and the pulse sequence used.

Therefore, parameters are selected to weight the image towards one contrast mechanism and away from the others. This is achieved by understanding how extrinsic contrast parameters determine the degree to which intrinsic contrast parameters are allowed to affect image contrast. Extrinsic contrast parameters must be manipulated to accentuate one intrinsic contrast parameter and diminish the others. Proton density effects cannot be changed. T1 and T2 influences are manipulated by changing the TR and TE in the following way.

In a **T2 weighted image** the differences in the T2 relaxation times of tissues are accentuated and T1 effects are reduced. To achieve this, a long TE is selected to ensure that the NMV in both fat and water has had time to decay. If the TE is too short, the NMV in neither fat nor water has had time to decay and the respective T2 times cannot be distinguished. A T2 weighted image is an image whose contrast is predominantly due to the differences in the T2 decay times of tissues. For T2 weighting the differences between the T2 times of tissues are exaggerated, therefore the *TE must be long*. At the same time, however, T1 effects must be minimized to avoid mixed weighting. To diminish T1 effects *the TR must be long*.

Tissues containing a high proportion of fat, with a short T2 decay time, are dark (low signal, hypo-intense) because they lose most of their coherent transverse magnetization during the TE period (Table 11.1).

Table 11.1 Signal intensities seen in T2 weighted images.

High signal	water
	synovial fluid
	haemangioma
	infection
	inflammation
	oedema
	some tumours
	haemorrhage
	slow-flowing blood
	cysts
Low signal	cortical bone
	bone islands
	deoxyhaemoglobin
	haemosiderin
	calcification
	T2 paramagnetic agents
No signal	air
	fast-flowing blood
	tendons
	cortical bone
	scar tissue
	calcification

Tissues containing a high proportion of water, with a long T2 decay time, are bright (high signal, hyper-intense), because they retain most of their transverse coherence during the TE period (Table 11.1). T2 weighted images best demonstrate pathology, as most pathology has increased water content and is therefore bright on T2 weighted images (Figures 11.1, 11.2 and 11.3).

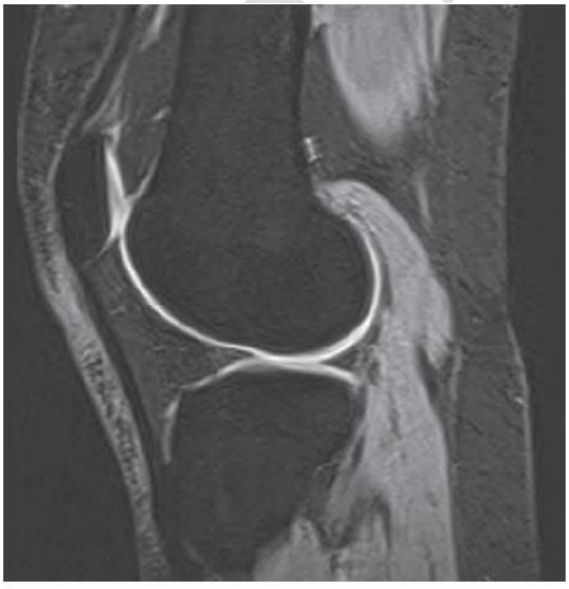

Figure 11.1 Axial T2 weighted image of the brain.

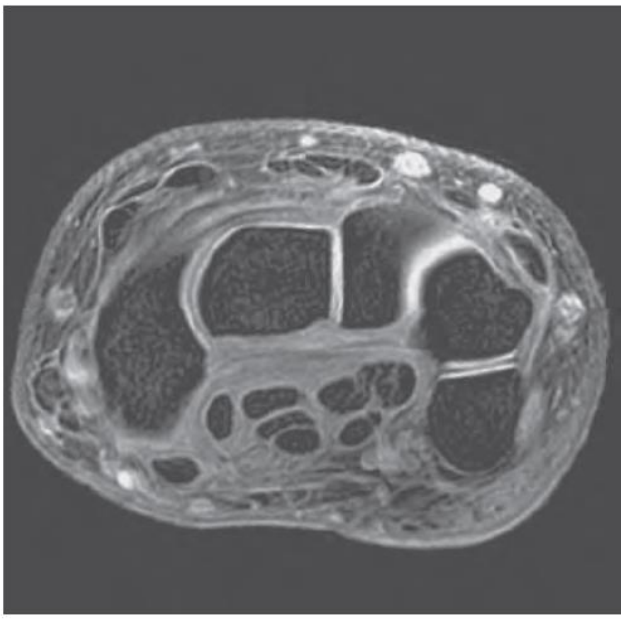

Figure 11.2 Axial T2 weighted image of the wrist.

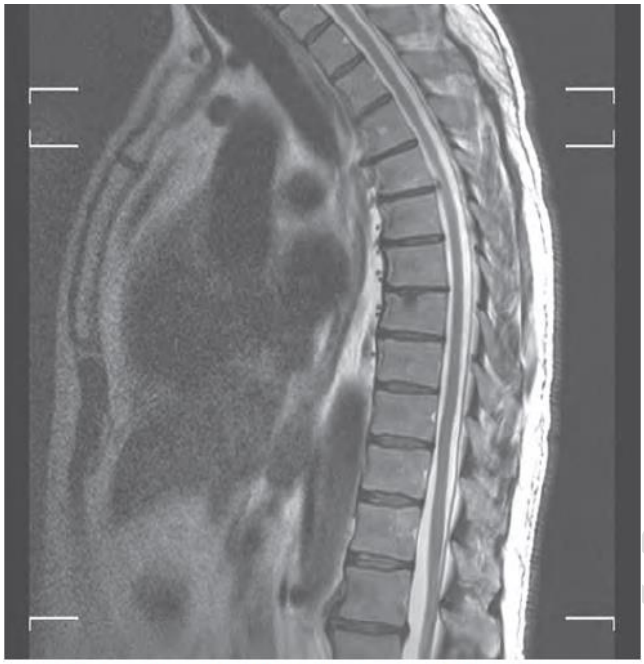

Figure 11.3 Sagittal T2 weighted image of the thoracic spine.

Typical values

• TR: 2000+ ms (much shorter in gradient echo sequences)

• TE: 70+ ms (shorter in gradient echo sequences)

The principal pulse sequences that are capable of producing T2 weighted images are:

• spin echo.

• turbo spin echo.

• STIR/FLAIR (STIR: stands for Short-T1 Inversion Recovery and is typically used to null the signal from fat. FLAIR: Fluid Attenuated Inversion Recovery).

The following pulse sequences produce T2* weighting that has similar characteristics in that water is bright. However, contrast in other tissues may be different.

• coherent gradient echo.

• balanced gradient echo.

KEY POINTS

- ✓ All intrinsic contrast parameters contribute to image contrast.
- ✓ Extrinsic contrast parameters are used to control how much influence each intrinsic parameter has on image contrast.
- ✓ TR controls T1 contrast. TE controls T2 contrast.
- ✓ To produce a T2 weighted image it is necessary to create contrast in which the differences in the T2 decay times of the tissues dominate image contrast.
- ✓ A long TR (e.g. 4000ms) combined with a long TE (e.g. 100ms) minimizes T1 and maximizes T2 contrast respectively.
- ✓ T2 weighted images are used for pathology.

MRI DESIGN: D Weighting

All intrinsic contrast parameters affect image contrast, regardless of the pulse sequence, TR and TE used. For example, tissues with a low proton density, and air, are always dark on an MR image, and tissues in which nuclei move may be dark or bright depending on their velocity and the pulse sequence used.

Therefore, parameters are selected to weight the image towards one contrast mechanism and away from the others. This is achieved by understanding how extrinsic contrast parameters determine the degree to which intrinsic contrast parameters are allowed to affect image contrast. Extrinsic contrast parameters must be manipulated to accentuate one intrinsic contrast parameter and diminish the others.

In a **proton density (PD) weighted image**, differences in the proton densities (number of hydrogen protons in the tissue) are demonstrated. To achieve this, both T1 and T2 effects are diminished. Selecting a long TR reduces T1 effects and T2 effects are diminished by selecting *a short TE*.

A proton density weighted image is an image whose contrast is predominantly due to differences in the proton density of the tissues.

Tissues with a low proton density are dark (low signal, hypointense) because the low number of protons results in a small component of transverse magnetization. Tissues with a high proton density are bright (high signal, hyper-intense) because the high number of protons results in a large component of transverse magnetization (Table 12.1).

Table 12.1 Signal intensities seen in PD weighted images.

High signal	CSF synovial fluid slow-flowing blood infection inflammation oedema cysts fat
Low or no signal	air fast-flowing blood tendons cortical bone scar tissue calcification

Cortical bone and air are always dark on MR images regardless of the weighting, as they have a low proton density and therefore return little signal. Proton density weighted images show anatomy and some pathology (Figures 12.1, 12.2 and 12.3).

Typical values

- TR: 2000ms+
- TE: 10–30ms

The main pulse sequences that are used to obtain PD weighting are:

- spin echo;
- turbo spin echo.

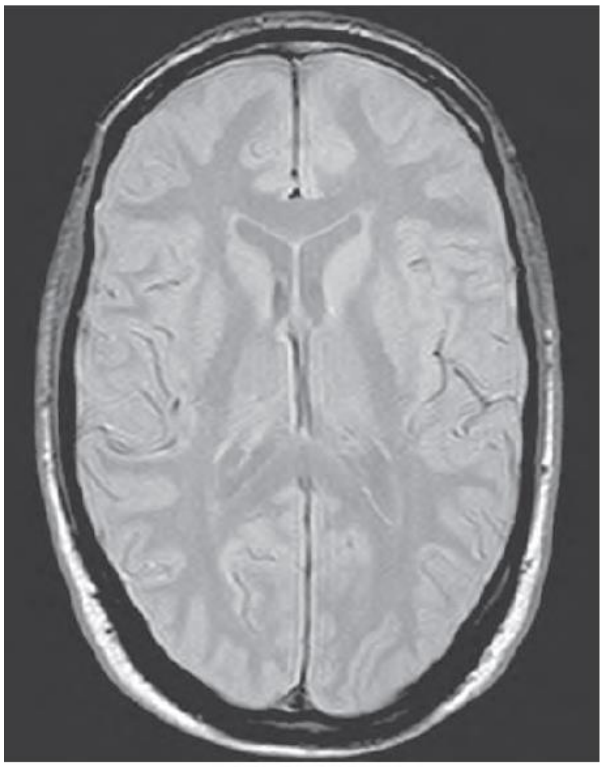

Figure 12.1 Axial proton density weighted image of the brain.

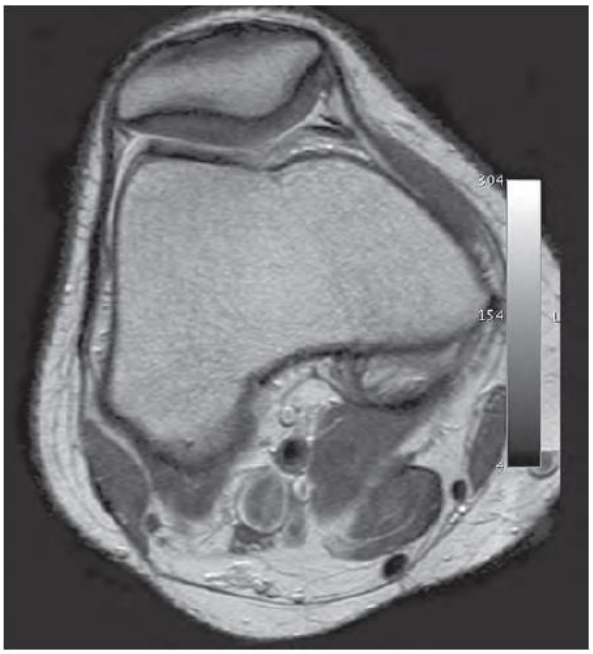

Figure 12.2 Axial proton density weighted image of the knee.

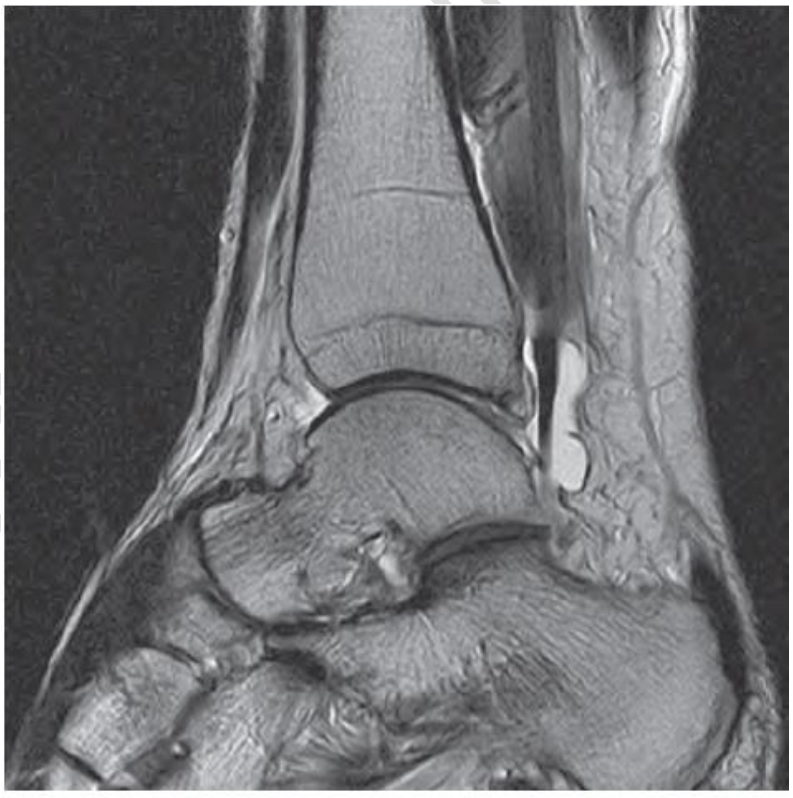

Figure 12.3 Sagittal proton density weighted image of the ankle.

Other types of weighting

Flow and the ADC of a tissue also affect weighting, as they are intrinsic contrast mechanisms. Flow mechanisms can be used to weight the image specifically to flowing spins. Flow-related weighting is achieved in MR angiography techniques. ADC-related weighting is achieved in diffusion weighting.

KEY POINTS

- ✓ All intrinsic contrast parameters contribute to image contrast. Extrinsic contrast parameters are used to control how much influence each intrinsic parameter has on image contrast.
- ✓ TR controls T1 contrast. TE controls T2 contrast.
- ✓ To produce a PD weighted image it is necessary to create contrast in which the differences in the proton densities of the tissues dominate image contrast.
- ✓ A long TR (e.g. 4000 ms) combined with a short TE (e.g. 20ms) minimizes T1 and T2 contrast respectively so that PD can dominate.
- ✓ PD weighted images are used for anatomy and pathology.

MRI DESIGN: Conventional Spin Echo

Pulse sequences are defined as a series of RF pulses, gradient applications and intervening time intervals. All pulse sequences contain these elements. They differ only in the way they are coordinated and timed.

Conventional spin echo (SE or CSE) pulse sequences are used to produce T1, T2 or proton density weighted images and are one of the most basic pulse sequences used in MRI. In a spin echo pulse sequence, there is a 90° excitation pulse followed by a 180° rephasing pulse followed by an **echo**.

Mechanisms of CSE

After the application of the 90° RF pulse, the magnetic moments of the spins lose precessional coherence because of an increase or decrease in their precessional frequency caused by the magnetic field inhomogeneities. This results in a decay of coherent magnetization in the transverse plane and the ability to generate a signal is lost.

Magnetic moments that experience an increase in precessional frequency gain phase relative to those that experience a decrease in precessional frequency, which lag behind. Dephasing can be imagined as a 'fan' where magnetic moments that lag behind precess more slowly, and those that gain phase precess more quickly.

A 180° RF pulse flips magnetic moments of the dephased spins through 180°. The fast edge of the fan is now positioned behind the slow edge. The fast edge eventually catches up with the slow edge, therefore **rephasing** the spins (Figure 13.1).

The coherent signal in the receiver coil is regenerated and can be measured. This regenerated signal is called an **echo** and, because an RF pulse has been used to generate it, it is specifically called a **spin echo**.

Rephasing the spins eliminates the effect of the magnetic field inhomogeneities. Whenever a 180° RF rephasing pulse is applied, a spin echo results. Rephasing pulses may be applied either once or several times to produce either one or several spin echoes.

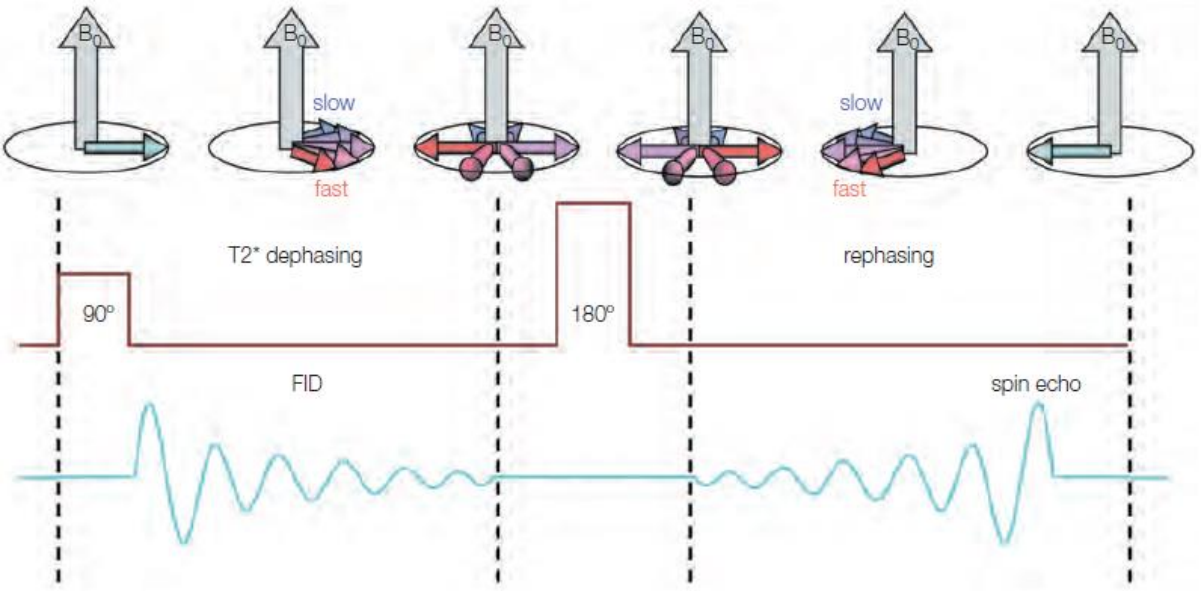

Figure 13.1 180° RF rephasing.

Contrast

CSE is usually used in one of two ways:

• A **single spin echo** pulse consists of a single 180° RF pulse applied after the excitation pulse to produce a single spin echo (Figure 13.2). This a typical sequence used to produce a T1 weighted set of images.

The **TR** is the length of time from one 90° RF pulse to the next 90° RF pulse in a particular slice. For T1 weighted imaging a short TR is used.

The **TE** is the length of time from the 90° RF pulse to the midpoint or peak of the signal generated after the 180° RF pulse; that is, the spin echo. For T1 weighted imaging a short TE is used.

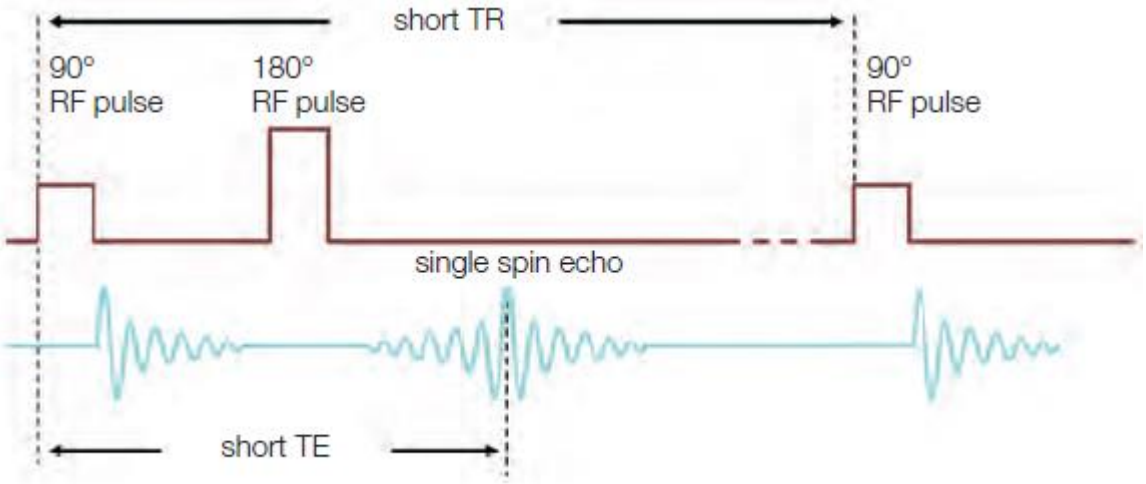

Figure 13.2 Single-echo spin echo sequence.

• A **dual echo sequence** consists of two 180° pulses applied to produce two spin echoes. This is a sequence that provides two images per slice location: one that is proton density weighted and one that is T2 weighted (Figure 13.3). The first echo has a short TE and a long TR and results in a set of proton density weighted images. The second echo has a long TE and a long TR and results in a T2 weighted set of images. This echo has less amplitude than the first echo because more T2 decay has occurred by this point.

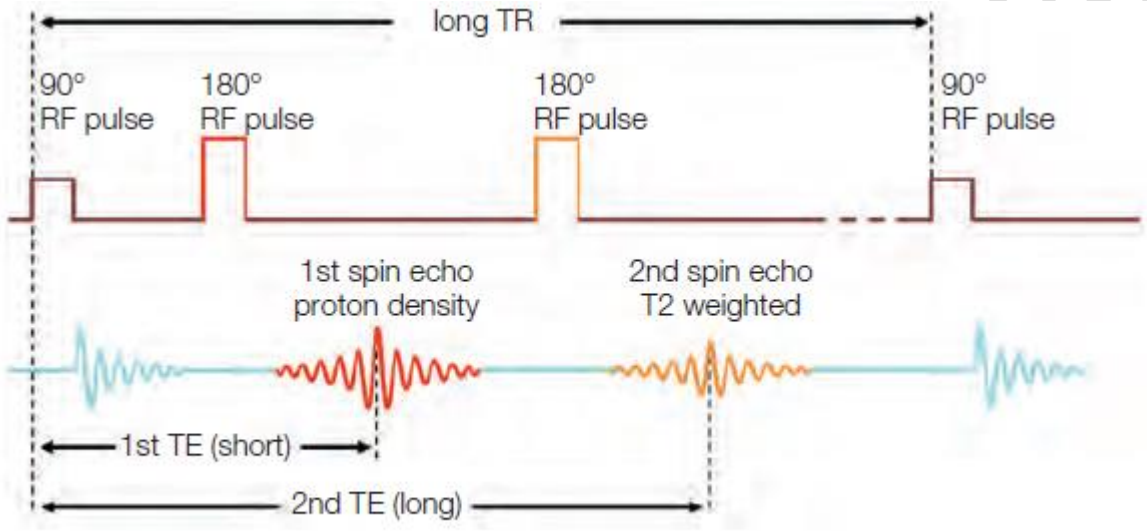

Figure 13.3 Dual-echo spin echo sequence.

Typical values

Single echo (for T1 weighting)

• TR: 400–700ms

• TE: 10–30ms

Dual echo (for PD/T2 weighting)

• TR: 2000+ms

• TE1: 20ms

• TE2: 80ms

Uses

Spin echo sequences are still considered the 'gold standard' (Table 13.1) in that the contrast they produce is understood and is predictable. They produce T1, T2 and PD weighted images of good quality and may be used in any part of the body, for any indication (Figures 13.4 and 13.5). However, due to relatively long scan times, PD and T2 weighted images are now usually acquired using fast or turbo spin echo.

Table 13.1 Advantages and disadvantage of conventional spin echo.

Advantages	Disadvantage
Good image quality Very versatile True T2 weighting Available on all systems Gold standard for image contrast and weighting	Long scan times

KEY POINTS

- ✓ Spin echo sequences are characterized by 180°RF rephasing pulses that refocus the magnetic moments of spins to produce an echo.
- ✓ T1, T2 and PD weighting are all achievable using conventional spin echo.
- ✓ Conventional spin echo is traditionally used to acquire one or two echoes to achieve T1, T2 or PD weighting.
- ✓ Although quite old sequences, they are still considered the gold standard and can be used to image anatomy and pathology in all body areas.

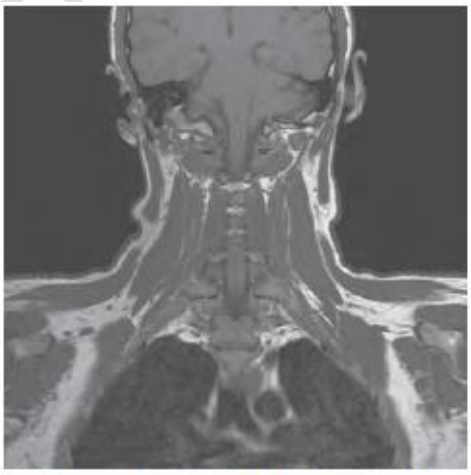

Figure 13.4 Coronal T1 weighted SE image of the brachial plexus.

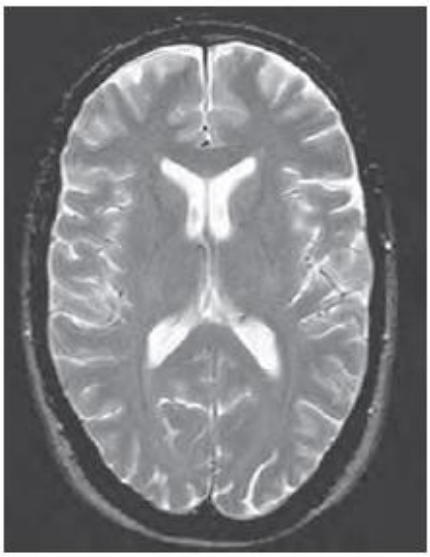

Figure 13.5 Axial T2 weighted SE image of the brain.