Lecture Six

MRI DESIGN: Fast or turbo spin echo

Fast or turbo spin echo (FSE or TSE) is a much faster version of conventional spin echo. It is sometimes called a rapid acquisition with relaxation enhancement (RARE) sequence. In spin echo sequences, one phase encoding only is performed during each TR. The scan time is a function of TR, NSA (***number of excitations (NEX)***, also known on some systems as the ***number of signals averaged (NSA)***, is an important determinant of SNR) and phase matrix. One of the ways of speeding up a conventional sequence is to reduce the number of phase-encoding steps. However, this normally results in a loss of resolution. TSE overcomes this by still performing the same number of phase encodings, thereby maintaining the phase matrix, but more than one phase encoding is performed per TR, reducing the scan time.

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Mechanism

TSE employs a train of 180° rephasing pulses, each one producing a spin echo. This train of spin echoes is called an **echo train**. The number of 180° RF pulses and resultant echoes is called the **echo train length (ETL)** or **turbo factor**. The spacing between each echo is called the **echo spacing**.

After each rephasing, a phase-encoding step is performed and data from the resultant echo is stored in a different line of K space (k-space is an array of

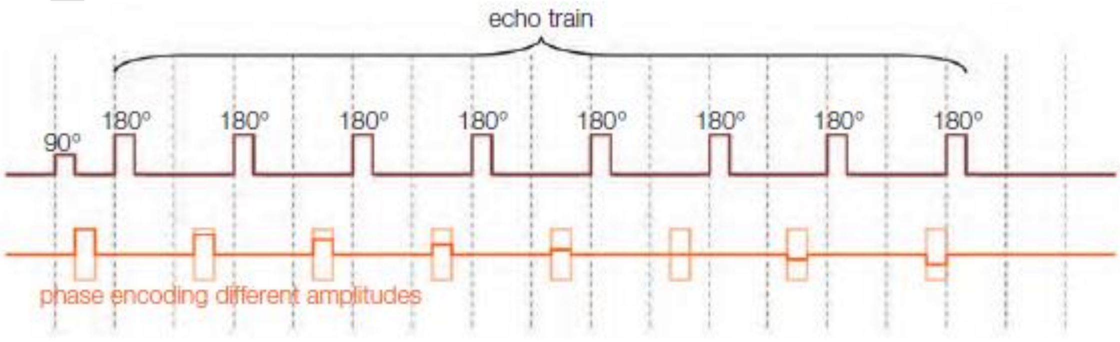

Figure 14.1 The echo train in TSE.

numbers representing spatial frequencies in the MR image) (Figure 14.1). Therefore, several lines of K space are filled every TR instead of one line as in conventional spin echo. As K space is filled more rapidly, the scan time decreases.

Typically, 2 to 30 180° RF pulses are applied during every TR, although many more can be applied if required. As several phase encodings are also performed during each TR, several lines of K space are filled each TR and the scan time is reduced. For example, if a factor of 16 is used, 16 phase encodings are performed per TR and therefore 16 lines of K space are filled per TR instead of 1 as in conventional spin echo. Therefore, the scan time is 1/16 of the original scan time (Table 14.1). The *higher* the turbo factor the *shorter* the scan time (Table 14.2).

Table 14.1 TSE time-saving illustrations.

Pulse sequence	Scan time
SE, 256 phase encodings, 1NSA	$256 \times 1 \times TR = 256 \times TR$
TSE, 256 phase encodings, 1 NSA, ETL 16	$256 \times 1 \times TR/16 = 16 \times TR$

Table 14.2 Equations of TSE scan time.

Equations		
$ST = TR \times Matrix(P) \times NSA/ETL$	ST is the scan time (s) TR is the repetition time (ms) Matrix(P) is the phase matrix NSA is the number of signal averages ETL is the echo train length or turbo factor	This equation enables the scanner to calculate the scan time in TSE. The longer the echo train, the shorter the scan time, but may result in fewer slices per TR

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Contrast

Each echo has a different TE and data from each echo is used to produce one image. This is different from CSE, where several echoes may be generated with a different TE but each echo is used to produce a *different* image. In TSE multiple echoes with a different TE are used to produce the *same* image. This would normally result in a mixture of weighting. In TSE this problem is overcome by using **phase reordering.**

In any sequence, each phase-encoding step applies a different slope of phase gradient to phase shift each slice by a different amount. This ensures that data is placed in a different line of K space.

The very *steep* gradient slopes significantly *reduce the amplitude* of the resultant echo/signal, because they reduce the rephasing effect of the 180° rephasing pulse. *Shallow* gradients, on the other hand, do not have this effect and the *amplitude of the resultant echo/signal is maximized* (Figure 14.2).

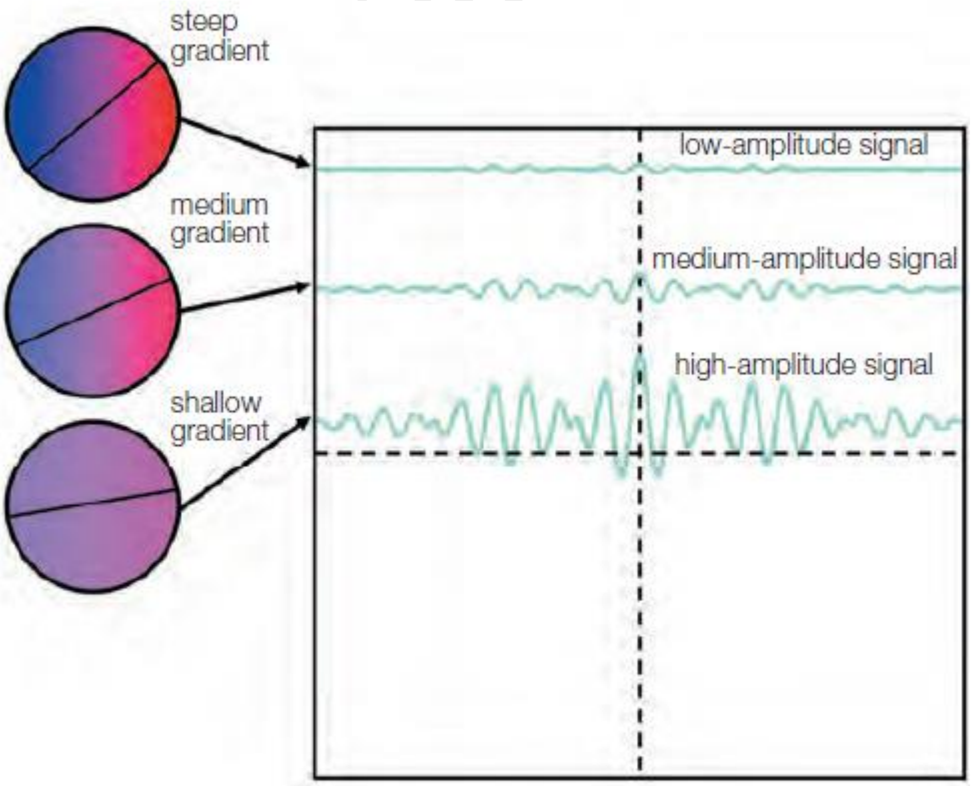


Figure 14.2 Phase encoding versus signal amplitude.

When the TE is selected (known as the **effective TE** in TSE sequences) the resultant image must have a weighting corresponding to that TE; that is, if the TE is set at 102 ms a T2 weighted image is obtained (assuming the TR is long).

The system therefore orders the phase encodings so that those that produce the most signal (the shallowest ones) are used on echoes produced from 180° pulses nearest to the effective TE selected. The steepest gradients (which reduce the signal) are reserved for those echoes that are produced by 180° pulses furthest away from the effective TE. Therefore, the resultant image is mostly made from data acquired at approximately the correct TE, although some other data is present (Figure 14.3).

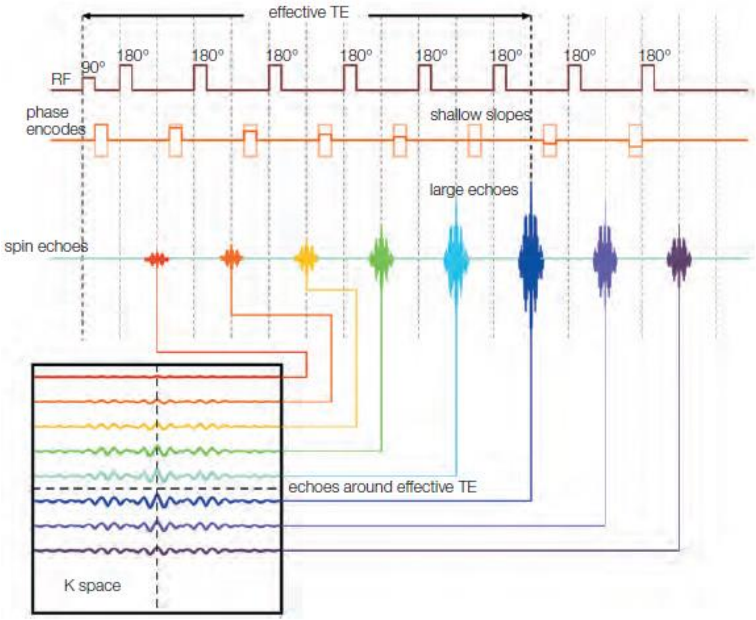
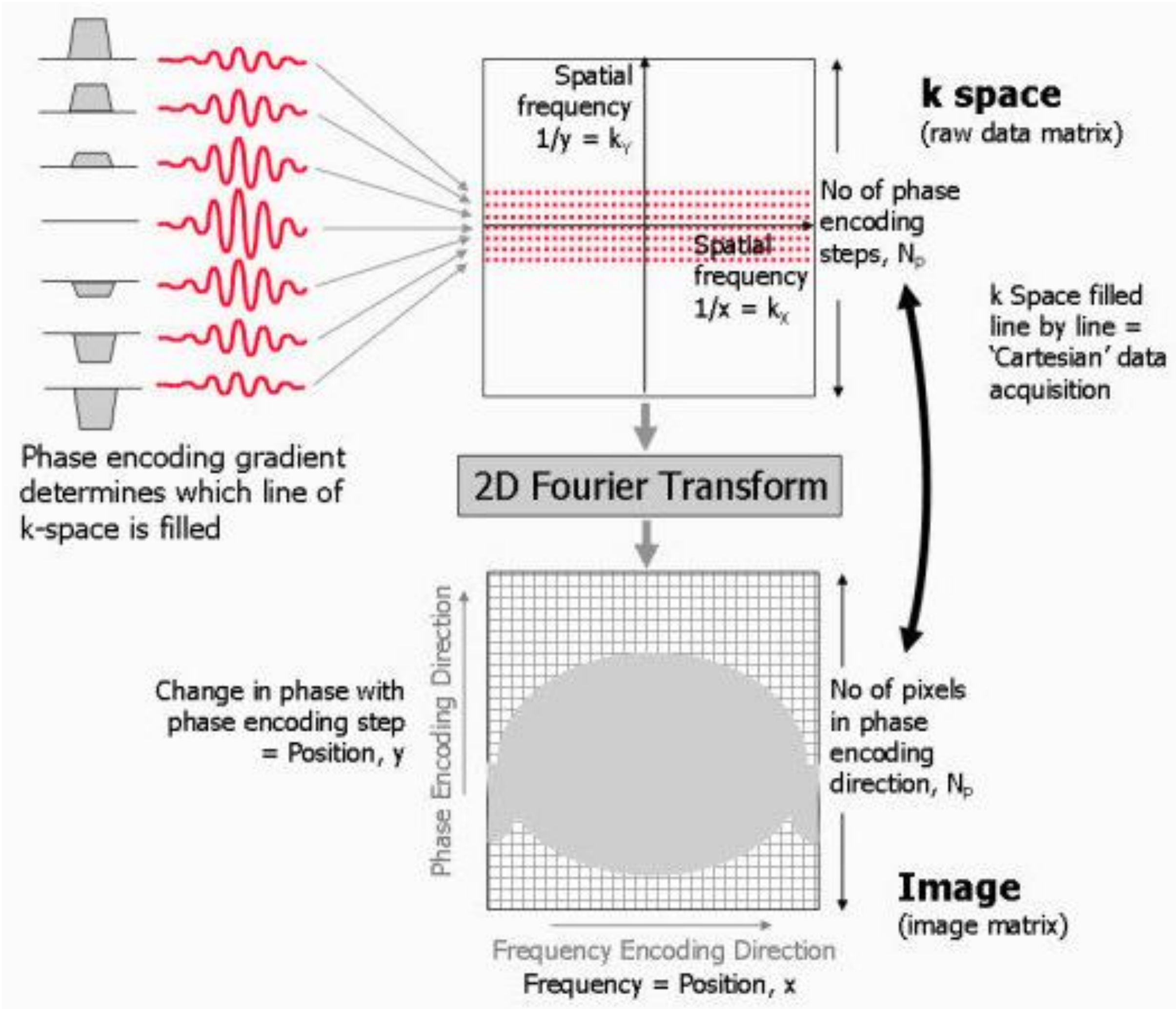


Figure 14.3 K space filling and phase reordering.

On many modern scanners it is possible to reduce the magnitude of the RF rephasing pulse from 180° (e.g. 150°). Rephasing still occurs, because RF energy is delivered at the Larmor frequency, but, as the amplitude of the RF is less, SAR is reduced. Reduction in SAR allows for more slices for a given TR.



KEY POINTS

- ✓ Turbo or fast spin echo sequences involve applying the phase encoding gradient multiple times in a TR period to varying amplitudes and polarity.
- ✓ This means that multiple lines of K space are selected per TR. The number is equal to the echo train length (ETL) or turbo factor.
- ✓ Multiple echoes are produced by multiple applications of an RF rephasing pulse and data from each echo is placed in a different line of K space.
- ✓ Scan times are reduced by a factor equal to the turbo factor or ETL.
- ✓ Image weighting is controlled by phase reordering so that data collected from echoes at or around the effective TE are placed in the signal and contrast areas of K space.

MRI DESIGN: Fast or turbo spin echo – how it is used

Due to different contrasts being present in the image, the contrast of TSE is unique. In T2 weighted scans, water and fat are hyperintense (bright). This is because the succession of 180° RF pulses reduces the spin-spin interactions in fat, thereby increasing its T2 decay time. Techniques such as STIR (short TI inversion recovery) and chemical pre-saturation that suppress fat signal are therefore usually required to differentiate fat from pathology in T2 weighted TSE sequences.

Muscle is often darker than in conventional spin echo T2 weighted images. This is because the succession of RF pulses increases magnetization transfer effects that produce saturation. In T1 weighted imaging, CNR is sometimes reduced so that the images look rather 'flat'. It is therefore best used when inherent contrast is good.

When used with a very long echo train, TSE can sometimes result in images that are blurred. This is particularly the case when combined with a long echo spacing value. Echoes with a *very long TE* are likely to have *low signal amplitude* because of T2 decay. If data from these small echoes is mapped into the resolution lines of K-space, *image blurring* can occur.

This is usually only a problem with a very long echo train, however. The number of slices is determined by the ETL and the echo spacing (see Table 15.1). Extending the TR lengthens the scan time, but this is more than compensated for by the use of long echo trains.

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Table 15.1 Equations of TSE.

Equations		
$N\ slices = \frac{TR}{ETL \times E_S}$	N slices is the number of slices allowed per TR TR is the repetition time (ms) ETL is the echo train length or turbo factor E_S is the echo spacing (ms)	This equation shows how many slices are allowed in TSE and will be less than in conventional spin echo (see Scanning Tip 1).

Typical values

Dual echo	***Single echo T2 weighting***	***Single echo T1 weighting***
• TR: 2500–8000ms (for slice number) • Effective TE1: 17ms • Effective TE2: 102ms • Turbo factor 8: this may be split so that the PD image is acquired with the first four echoes and the T2 with the second four echoes	• TR: 4000–8000 ms • TE: 102 ms • Turbo factor: 20+	• TR: 600 ms • TE: 10 ms • Turbo factor: 4

Uses

TSE produces T1, T2 or proton density scans in a fraction of the time of CSE (Figures 15.1 and 15.2). Due to the fact that the scan times are reduced, phase matrix size can be increased to improve spatial resolution. TSE is normally used in the brain, spine, joints, extremities and pelvis. As TSE is incompatible with phase-reordered respiratory compensation techniques, it can only be used in the chest and abdomen with respiratory triggering, breath-hold or multiple NSA.

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Systems that have sufficiently powerful gradients can use TSE in a single-shot mode **(SS_TSE)** or half Fourier single-shot TSE **(HASTE)**. Both of these techniques permit image acquisition in a single breath-hold. In addition, using very long TEs and TRs permits very heavy T2 weighting (**watergrams**). An example of this technique is in gallbladder imaging, where only signal from bile in the biliary system is seen. Table 15.2 lists some advantages and disadvantages of TSE.

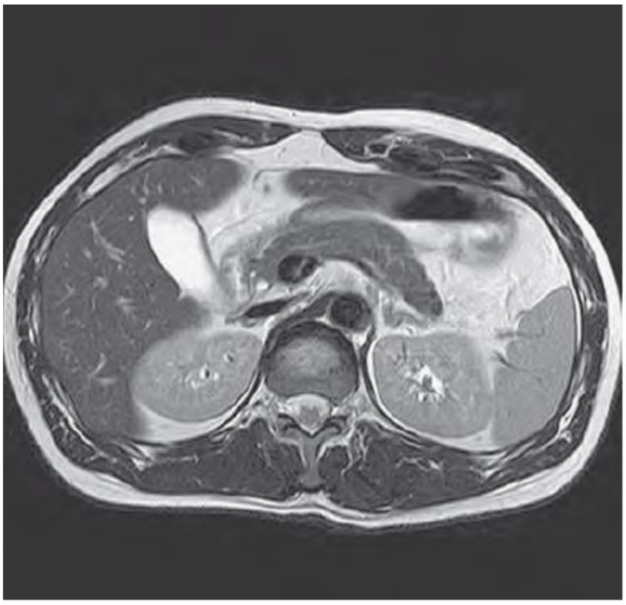

Figure 15.1 Axial T2 weighted TSE image of the abdomen.

Figure 15.2 Axial T1 weighted TSE image of the male pelvis.

A modification of TSE that is sometimes called **fast recovery** or **DRIVE** adds an additional 'reset' pulse at the end of the TR period. This pulse 'drives' any residual magnetization in the transverse plane at the end of each TR back into the longitudinal plane (Figure 15.3).

This is then available to be flipped into the transverse plane by the next excitation pulse. This sequence provides high signal intensity in water even when using a short TR and therefore a short scan time (Figure 15.4). This is because water has a long T2 decay time; therefore, tissue with a high-water content has residual transverse magnetization at the end of each TR. Hence this is the main tissue that is driven back up to the longitudinal plane by the reset pulse and is therefore the dominant tissue in terms of signal.

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Table 15.2 Advantages and disadvantages of TSE.

Advantages	Disadvantages
Short scan times	Some flow artefacts increased
High-resolution imaging	Incompatible with some imaging options
Increased T2 weighting	Some contrast interpretation problems
Magnetic susceptibility decreases*	Image blurring possible

* Also a disadvantage, e.g. haemorrhage not detected/delineated.

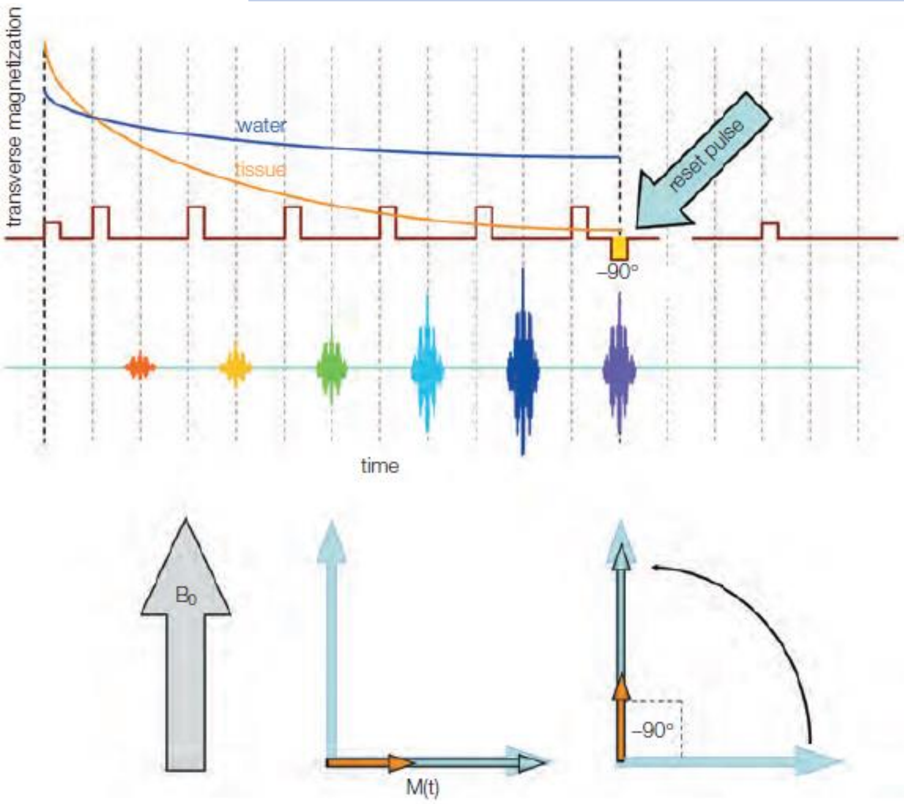

Figure 15.3 The fast recovery or 'DRIVE' sequence.

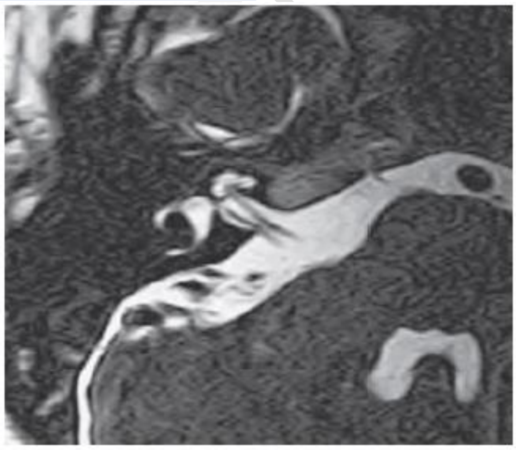

Figure 15.4 Fast recovery or 'DRIVE' image of the internal auditory meatus.

KEY POINTS

✓ In turbo spin echo sequences fat remains bright in T2 weighted images due to J coupling. Fat suppression techniques are commonly employed.

✓ The turbo factor or echo train length is an extrinsic contrast parameter unique to this sequence.

✓ Short turbo factors or echo train lengths are necessary for T1 and PD weighting so that echoes with long TEs do not affect image contrast.

- ✓ A long turbo factor or echo train length is needed for T2 weighting so that echoes with a long TE can affect contrast.
- ✓ The longer the echo train, the shorter the scan time.
- ✓ Turbo or fast spin echo has many applications in most body areas.

HW:

- In T2 weighted scans, water and fat are hyperintense (bright). Why?
- Muscle is often darker than in conventional spin echo T2 weighted images. Why?
- When used with a very long echo train and long TE, TSE can sometimes result in images that are blurred. Why?
- Extending the TR lengthens the scan time, but this is more than compensated for by the use of long echo trains. Discuss!

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