Module 4
Sequences and applications I

After reading this module, you will:

- Be able to differentiate between a spin echo and a gradient echo sequence and understand their respective advantages and disadvantages.
- Be familiar with the parameters and their adaptation to generate various image weightings.
- Be familiar with the purpose of the Inversion Recovery Stimulus

SE, IR, STIR, FLASH, FFE, GE, LAVA, FIESTA EPI, GRAPPA, HEFEWEIZEN, SENSE?

The major manufacturers of MRI scanners tend to cause confusion amongst MRI operators by using a large number of acronyms with which to refer to a handful of the most common procedures. This gives the mistaken impression that many more sequences exist than is actually the case. This chapter restricts itself to providing a description of the most important sequences which provide the basis of work with a MRI scanner.

4.1 Spin Echo

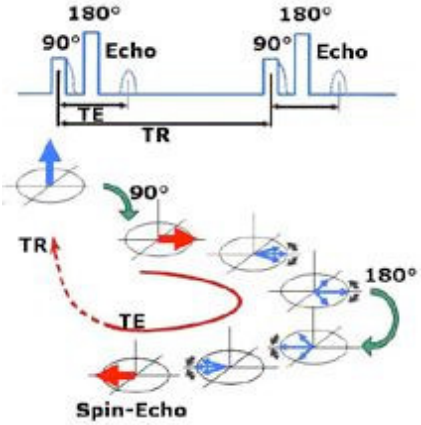
The type of sequence	Philips	Siemens	GE	Hitachi	Toshiba
Spin echo	SE	SE	SE	SE	SE

The SE sequence was the first ever procedure used for MR imaging. All manufacturers call it the SE sequence. In terms of the contrast-to-noise ratio, it acted as the reference for all further developments.

The spin echo sequence is the simplest sequence used in MRI. The spin echo sequence consists of three fundamental events (which are repeated very often): A 90° stimulus pulse, a 180° re-phasing pulse after half of the echo time (TE) and the signal recording exactly after this TE.

The sequence is repeated step-for-step. The TR time (repetition time) includes a further waiting time until the next "round" begins with a 90° stimulus pulse. A line in the k-space is filled with every repetition (the various respective phase encoding) until the spatial image can be reconstructed.

4.1.1 The 90° and 180° pulses



Two types of pulse appear in the spin echo sequence. The 90° pulse deflects the spins straight in the state of their maximum transverse magnetization (x-y area, see chapter 2) and brings them into phase. They begin to relax.

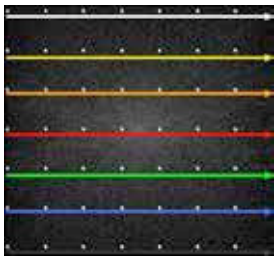
The transverse relaxation is the process of de-phasing of the spin on the x-y area. Some run quicker, others slower, until the signal has degraded completely. The 180° impulse turns the spins around their own axis once. This means, once all the spins have rotated rightwards around their own axis once, they now run in the opposite direction leftwards.

The fast spins have already travelled a greater distance by the time at which the 180° pulse is issued. As a result, they have a greater return length to cover.

Figure 4.1:
Generation of the spin echo

The slow spins have not travelled so far by TE/2, and manage to cover the return distance to their starting position in the second half. Finally, when all the spins are back in phase by TE and give off a clear, superimposed signal: the spin echo. In the meantime, the gradients for encoding have also been activated. This can be depicted in a sequence diagram.

4.1.2 Contrast and duration



The duration of the spin echo sequence can be calculated in dependence on the Repetition Time (TR), Phase Encoding Step (NPH) and the number of stimuli (averages/NSA/NEX):

$$T=TR \bullet NPH \bullet NEX$$

The phase encoding steps influence the spatial resolution and thus indirectly the scan time. The SE sequences possess two essential parameters for the image weighting mentioned at the outset of this chapter: TR and TE.

The TR time exercises a considerably influence on the duration of the SE sequence. In an unaccelerated spin echo sequence, every line of the k-space is scanned in sequence. Each scan requires a TR.

T_2-weighting

TE refers to the time between the 90°pulse and the reception of the signal. Transverse magnetization degrades in all tissues in accordance with the specific time constant T_2. A T_2-weighted SE sequence involves selection of a long TE (> 80 ms) in order to depict differences in the T_2-times of different tissues, thus establishing a contrast between the two. The selection of TR determines (in dependence on tissue-specific T_1) the longitudinal relaxation of the tissue subject to examination. The longer the TR, the more complete is the longitudinal magnetization change from Mz towards M_0. TR is selected for a very long period so that the longitudinal magnetization is almost completely degraded at the point at which the next stimulus is given and the differences of the tissue in T_1 do not influence the weighting of the images. The images are light in the tissue regions with a longer T_2-time; they are darker in the locations with tissues with a short T_2-time.

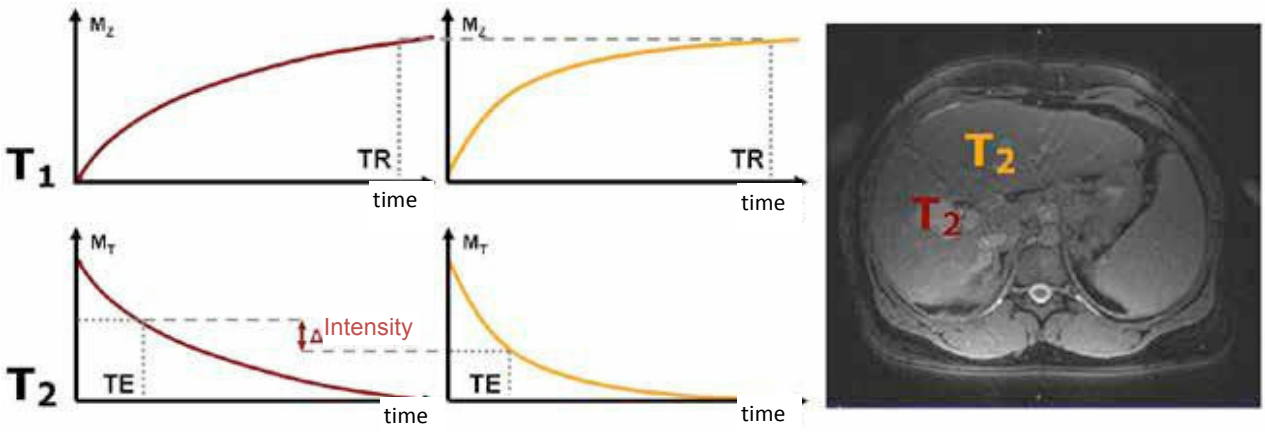


Figure 4.3
Below: T_2-sequence for a suspected cancerous liver tissue (left) and a normal liver parenchyma (centre). A long TE weights the images according to the intensity differences resulting from the various T_2 times. A long TR suppresses T_1 influences on the image contrast (above).

ρ-weighting

The spin density-weighted SE sequence was optimized so that the TR is very long and the TE is very short.

This minimizes/suppresses the influence of various T_1 and T_2 times. The contrast of the images results from the differences in the number of hydrogen nuclei per volume.

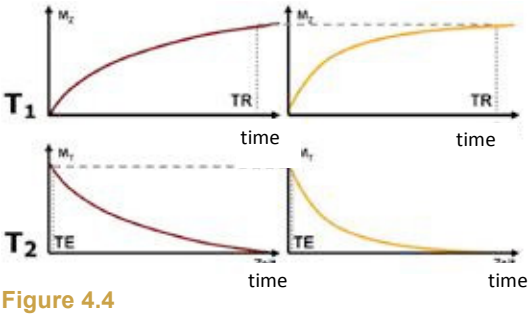
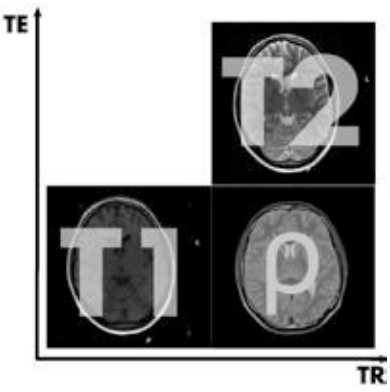


Figure 4.4
ρ-weighting



Summary

The spin echo sequence provides highly-contrasted images with all possible weightings.

The main disadvantage of the T_2-weighting lies in the very long imaging times. This can represent a problem with T_2-weighted images (long TR).

4.2 Turbo or fast spin echo

The type of sequence	Philips	Siemens	GE	Hitachi	Toshiba
Fast spin echo	Turbo SE	Turbo SE	Fast SE	Fast SE	Fast SE

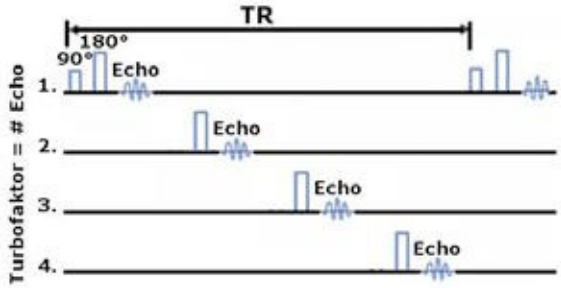


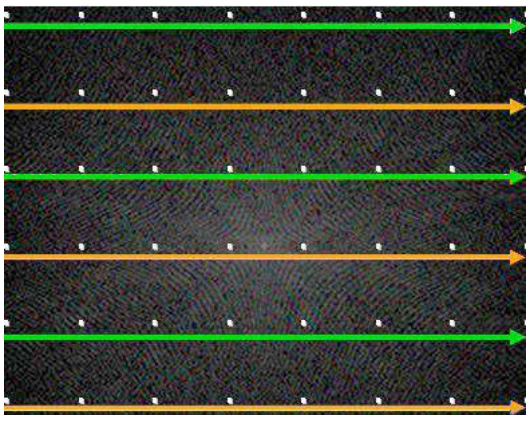
Figure 4.5:
Multiple echoes in a TR

With a conventional SE sequence, the operator must first wait for TR until he can issue a stimulus to dephase, encode etc. lines in a new k-space. This makes the sequence very time-consuming. Instead, it is also possible to fill a number of lines of the k-space within a single slice at the same time (recording a signal). This is performed by using the interval of time after the first echo to send a new 180° pulse. In this way, it is possible to generate a further echo which then requires phase encoding thus enabling to fill another line of the k-space.

The number of echoes recorded within a TR time is referred to as the turbo factor / echo train length. The formula for calculating the acquisition time involves division of the number of phase encoding steps required,(averages/NSA/NEX) by the turbo factor TF:

$$T = TR \cdot \frac{NPH}{TF} \cdot NEX$$

The example on the right involves the simultaneous scanning of 3 k-spaces in a single TR sequence (each with a single colour). This corresponds to a turbo factor of 3.



The advantage of this sequence lies in the quick acquisition of SE images (not very susceptible for artefacts) but also has a number of limitations: First of all, the short TR in a T1 weighting only allows the simultaneous acceptance of a very restricted number of k-space lines; the turbo method no longer functions correctly.

Secondly, the echoes of the individual k-space lines are generated with TEs of various effectiveness:
Nevertheless, as the spins

relax further between every echo, the contrasts in the image are falsified. This can be partially compensated by reading out the central k-space rows in dependence on the various times. With the T1-weighting (important: short TE) this is the case at the start of the echo train; with the T2-weighting (long TE), approximately in the middle of the echo train.

4.2.1 Multi-echo SE

The type of sequence	Philips	Siemens	GE	Hitachi	Toshiba
Multi-echo SE	Multi SE	Multi echo	Multi echo		

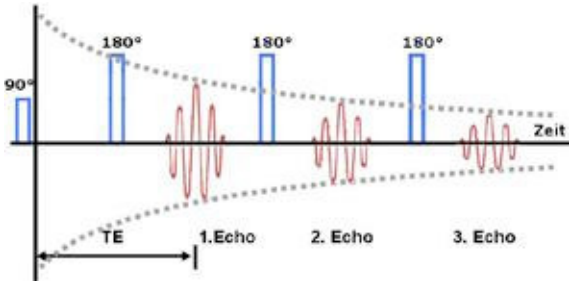


Figure 4.6:
Multiecho

The multi or double-echo sequences present a special case. After the first echo has been generated and received, a 180° pulse is applied, thereby producing a new echo with a different TE.

This occurs in the same k-space line. Thus it is no longer possible to scan multiple rows within a single TR time and the sequence is not faster than a conventional SE, but it produces multiple images with different weightings.

As a rule, these sequences are used to generate ρ and T_2-weighted images in a single set.

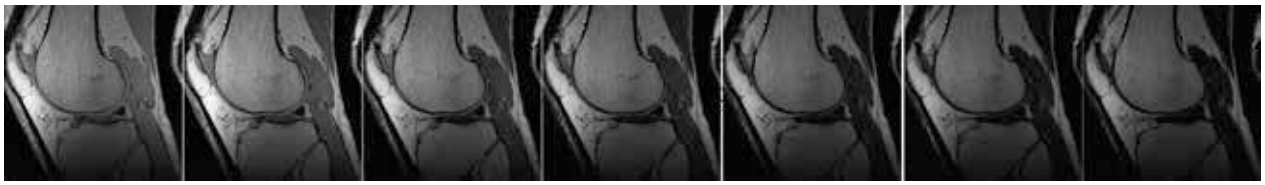


Figure 4.7:
A knee pictured with echo times of 5-40 ms (interval 5ms) within a TR.

4.3 Inversion recovery

The type of sequence	Philips	Siemens	GE	Hitachi	Toshiba
Inversion recovery	IR	IR / IRM	IR	IR	IR
e.g. IR Turbo spin echo	R TSE	Turbo IR / TIRM	FSE-IR	FIR	Fast IR

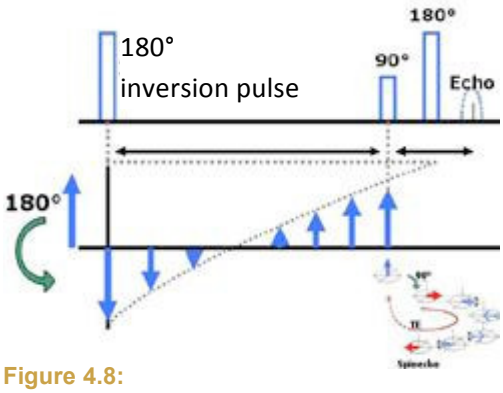


Figure 4.8:
The inversion pulse

"Inversion recovery" is a type of sequence in which the magnetization of the spin is prepared in a special manner via the stimulus pulse.

This can be followed by both an SE and a GE sequence. The name "IR TSE" indicates, for example, that magnetization has been "prepared" with inversion recovery and will then be evaluated as with the "normal" Turbo SE.

The sequence begins with a 180° stimulus pulse which turns the spins and thus the longitudinal magnetization Mz in the opposite (negative) direction (-Mz). The longitudinal relaxation (T_1) means an increase in the longitudinal magnetization which then proceeds through the null value and changes its sign before returning to a steady state at M0. A signal can only be measured along the x-y direction.

A further stimulus pulse is applied (90° pulse) after the "inversion time" TI; as with the SE sequence, transverse magnetization is generated. This enables measurement of a number of different relaxation states of the longitudinal magnetization depending on the choice of TI.

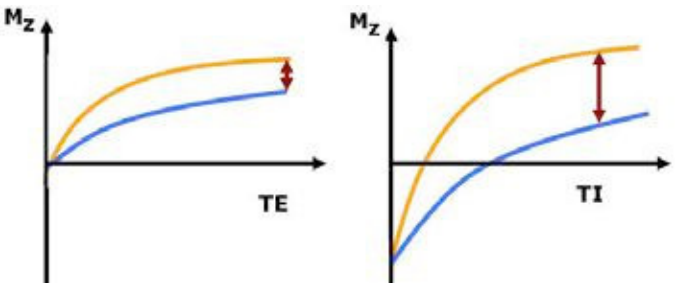


Figure 4.9:
Reinforcement of the T_1-weighting

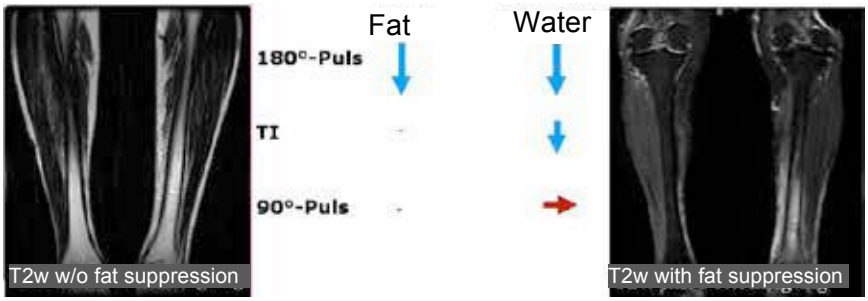
Whilst the spin echo sequence brings a good T_2 contrast, the inversion recovery sequence provides a higher T_1 contrast: The inversion causes the longitudinal magnetization to relax from the negative area, and T_1 relaxation requires more time than without inversion recovery sequence. In a number of tissues, proceeding through the null value results in a large-scale splitting of the curves, thus reinforcing the T_1 contrast. This can be optimized by selecting the inversion time TI.

This is balanced by the disadvantage of a longer measurement time. The inversion recovery technique also provides the possibility of suppressing the influence of specific tissues or substances in the images, as far as the T_1 time is known and TI is adapted to it. This is referred to as "fat suppression" or "water suppression."

The STIR and FLAIR sequences are important IR techniques.

4.3.1 STIR

The type of sequence	Philips	Siemens	GE	Hitachi	Toshiba
STIR	STIR	STIR	STIR	STIR	STIR
	STIR TSE	Turbo STIR	Fast STIR	Fast STIR	Fast STIR



The STIR sequence supplements a "conventional" sequence with its own 180° pulse issued at the beginning of the procedure.

The short T_1 time of fat means that a T_1 of c. 140 milliseconds can suppress the contribution of fat to the signal almost completely.

Figure 4.10:
Fat suppression

This is how it functions: The magnetization in the fat has returned to approx. zero 140 ms after the 180° pulse. Water relaxes more slowly and a negative magnetization on the z direction is still present. The 90° pulse does not find any relevant z components to turn, whilst the water spins are tipped in the transversal level.

This is followed by the familiar set of dephasing, the rephasing pulse and then the echo (see SE). As a result, water is depicted light and fat dark. The simultaneous acquisition of multiple k-space lines produces a sequence with an acceptable length for clinical practice. The STIR can be weighted as a conventional SE or TSE to T_1 or T_2.

It is important to note that this sequence is not suitable for suppressing a fat signal after gadolinium injection. Gadolinium-enhanced tissue has its own T_1 and the STIR is adapted to the tissue-specific fat T_1.

An adaptation of the sequence parameters is required, as the T_1 time of the fat is shortened and the fat is no longer at the null value after the inversion time.

4.3.2 FLAIR

The type of sequence	Philips	Siemens	GE	Hitachi	Toshiba
FLAIR	FLAIR	FLAIR	FLAIR	FLAIR	FLAIR
	FLAIR TSE	Turbo FLAIR	Fast FLAIR	Fast FLAIR	Fast FLAIR

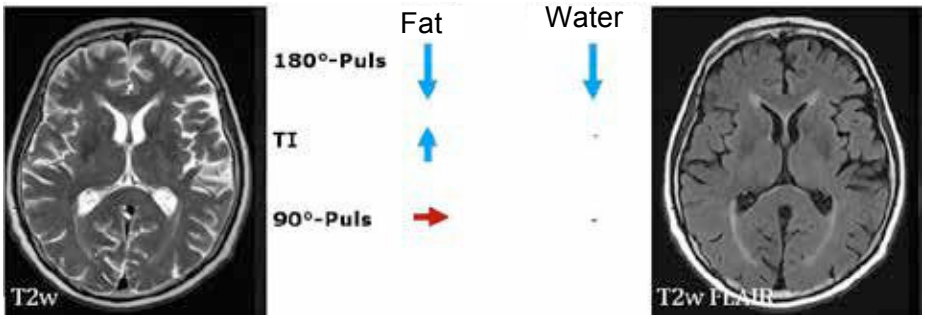


Figure 4.11:
Water suppression

Fast IRThe FLAIR sequence seeks to suppress the signals emitted by fluids using IR. As water has a long T_1-time, TI is selected in such a way (c. 2000-2500 ms) that no "tippable" magnetization ($M_Z^{\sim 0}$) is present at the point at which the 90° pulse is issued.

Turbospin sequences are especially well-suited for this purpose as they compensate for the long TR of water. These sequences find application in neurological contexts (depicting oedema).

Summary

The method of excitation applied in the inversion recovery method can be combined almost at will with the sequences presented earlier in this chapter (SE, TSE). In practice, the TSE sequences are often applied, as the recovery of z-magnetization requires a very long TR.

Conventional imaging protocols have pre-set filter options in which the IR pulse of the sequence is prefixed; an automatically-set TI permits the desired signal suppression.

IR is also used to enable a T_1-weighting in the Gradient Echo Sequences (see the following chapters).