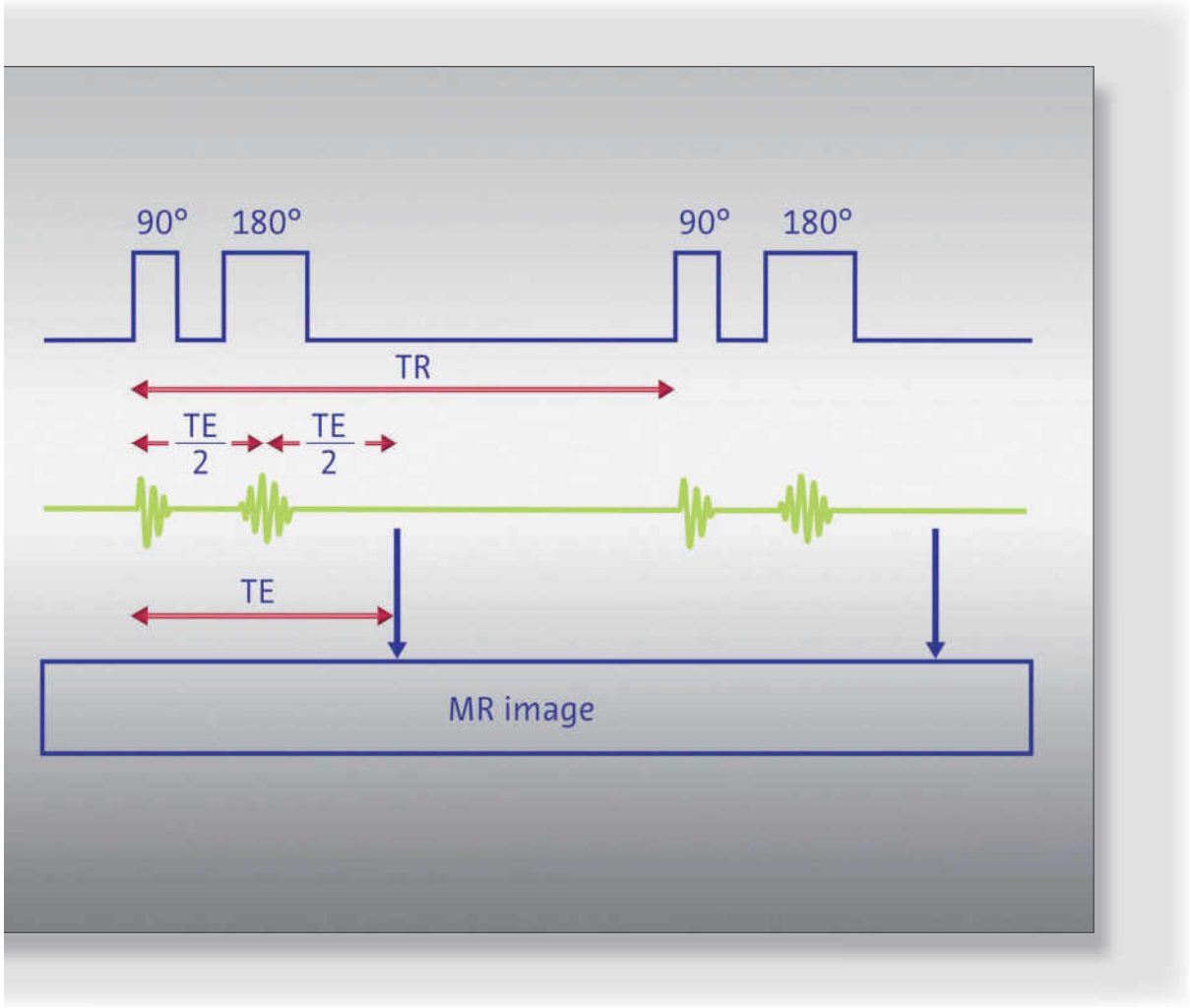
The pattern of a spin echo sequence

Let us go back to our spin echo pulse sequence.

This sequence can be illustrated schematically as in figure 38: 90° pulse – wait TE/2 – 180° pulse – wait TE/2 – record signal. For certain different reasons, such a pulse sequence is repeated two or more times. The time to repeat a pulse sequence was TR, time to repeat. So what we get is the following scheme:

1. 90° pulse – TE/2 – 180° pulse – TE/2 – recording signal at TE.
After TR (time from the beginning of one 90° pulse to the next 90° pulse) follows another pulse cycle and signal measurement:

2. 90° pulse – TE/2 – 180° pulse – TE/2 – recording signal at TE.



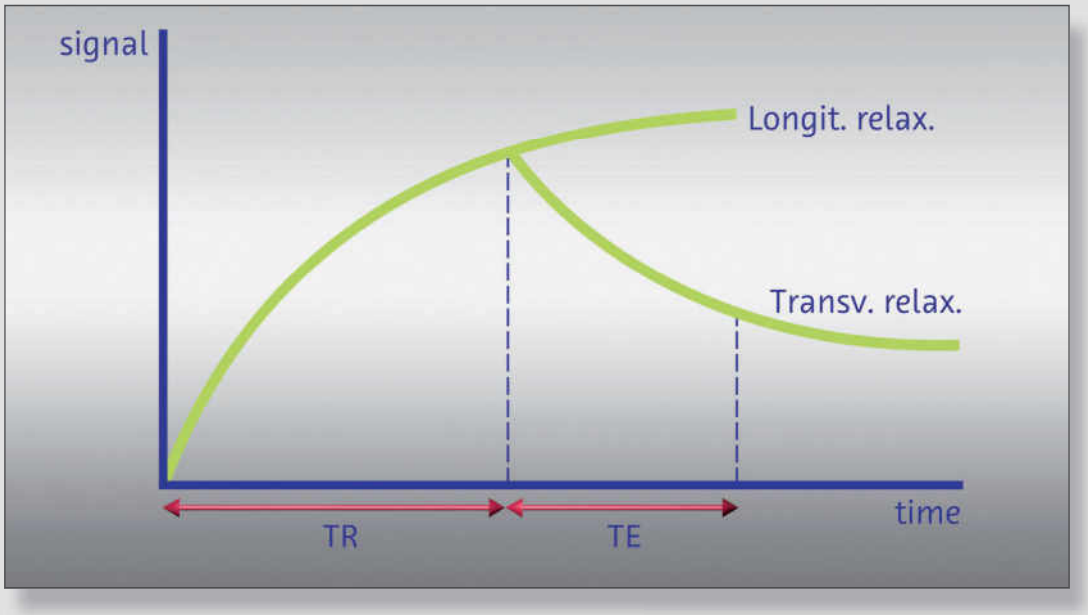


Fig. 39: It is possible to determine signal intensity for a tissue using a **spin echo sequence** by combining the T_1- and the T_2-curve for that tissue. The longitudinal magnetization after the time TR is equal to the amount of transversal magnetization we start out with, as it is "tilted" 90 degrees. This transversal magnetization immediately starts to disappear by a rate which is determined by the transversal relaxation time, and thus by the T_2-curve. The signal intensity of the tissue after a time TE can then be inferred from the T_2-curve at this time TE (which starts after TR!).

TR and TE

To figure out how much signal you get from a certain tissue with certain parameters of a **spin echo sequence**, you actually have to do no more than combine its T_1- and T_2-curves, as it is illustrated in figure 39. Here we have the T_1- and T_2-curve of a certain tissue. T_1 represents the longitudinal relaxation and T_2 represents the transversal relaxation. Which parameter determined the amount of **longitudinal magnetization**? That was TR. To see how much longitudinal magnetization will be tilted 90° to the side (and thus to figure out, with how much transversal magnetization we start out with), we just look at the intensity of the longitudinal magnetization at the time **TR.**

The **longitudinal magnetization** at this point, "tilted" in the transversal plane, is the starting point from which transversal magnetization decays. So we just attach the **T_2-curve** at this point.

How much signal we get with a spin echo sequence to construct the image,

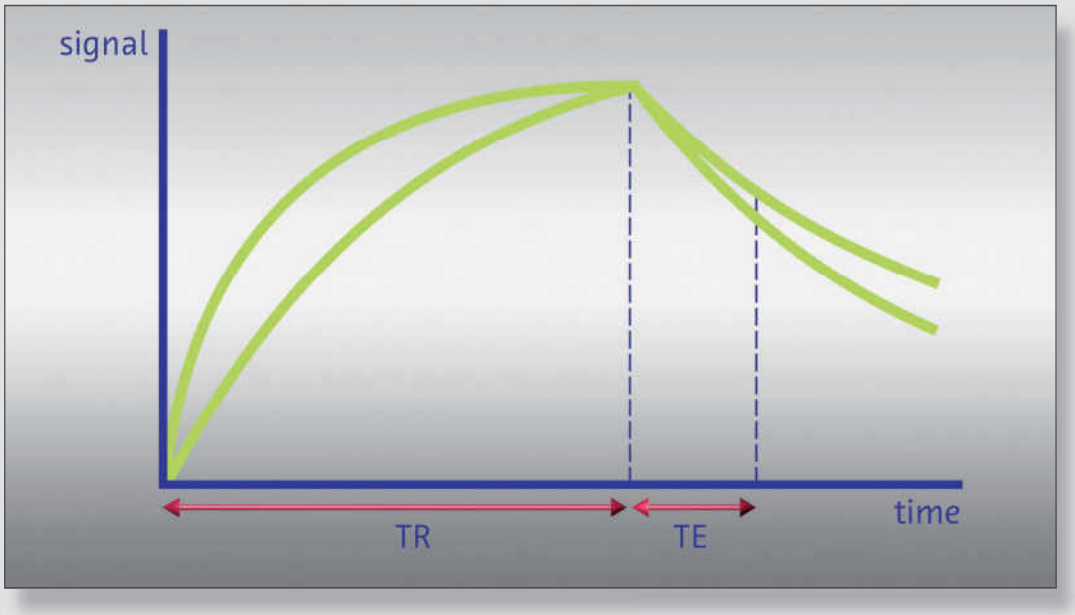


Fig. 40: By combining T_1- and T_2-curves, signal intensity of certain tissues can be determined for a pulse sequence using TR and TE as illustrated, and as explained in figure 39. What happens, when we choose a long TR, as illustrated? With a long TR, differences in T_1, in longitudinal magnetization time are not very important any more, as all tissues have regained their full longitudinal magnetization. When we only wait a very short TE, then differences in signal intensity due to differences in T_2 have not yet had time to become pronounced. The resulting image is thus neither T_1- nor T_2-weighted, but mostly determined by the proton density of the tissues (for this, ideally TE should be zero).

also depends on TE, the time that we wait after the 90° pulse. So we now only have to look for the signal intensity at the time TE on the **T_2-curve.**

What image do we get, when we choose a long TR and a short TE?

This is illustrated in figure 40. Here are the T_1- and T_2-curves for two different tissues.

As we heard earlier, with a very long TR, all tissues will have totally recovered their longitudinal magnetization; differences in T_1 of the tissues examined will not influence the signal, as enough time has passed by to allow even tissues with a long T_1 to relax totally. So when we choose a long TR, as we just said, then differences in T_1 do not really matter.

When we also use a short TE, differences in signal intensity due to differences in T_2 have not had enough time to become pronounced yet.

The signal that we get, is thus neither T_1- nor T_2-weighted, but mainly influenced by differences in **proton** or **spin density.**

The more protons, the more signal, if you look at it simply (figure 40).

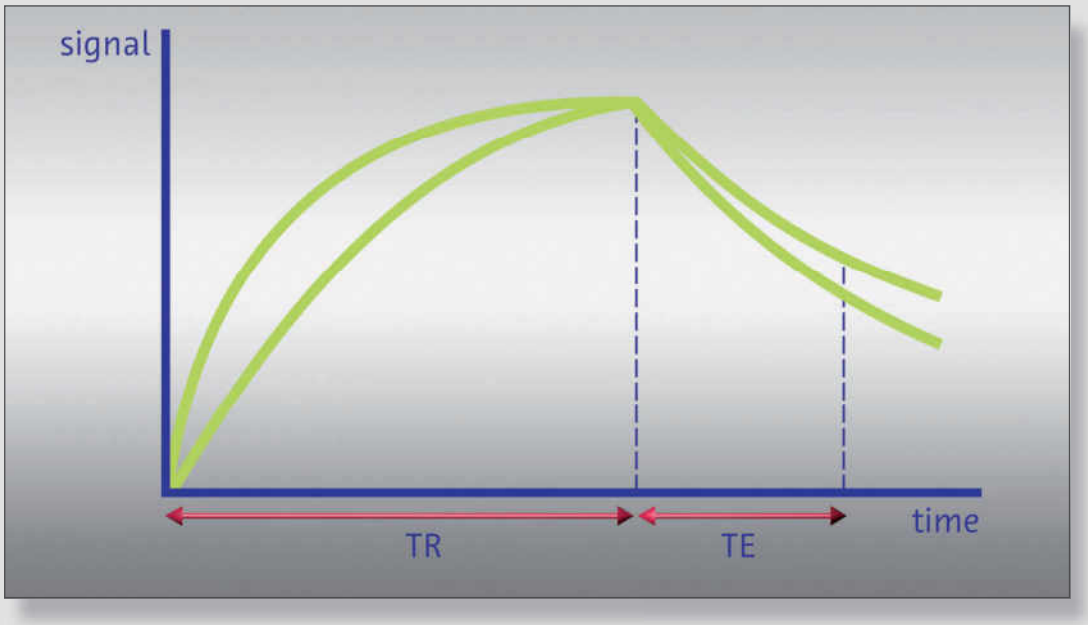


Fig. 41: When we wait a long TR and a long TE, differences in T_2 have had time enough to become pronounced, the resulting picture is T_2-weighted.

And what happens when we use a long TR and a long TE?

With a long TR, there are no prevailing differences in T_1. With the long TE, however, differences in T_2 become pronounced. Thus the resulting image is T_2-weighted (figure 41).

What if we use a shorter TR and a short TE?

With a short TR, tissues have not recovered their longitudinal magnetization, thus differences in T_1 (which determines how fast longitudinal magnetization is regained) will show up in form of signal intensity differences (figure 42).

When TE is short, differences in T_2 cannot really manifest themselves, so the resulting image is still T_1-weighted (there is a lower limit for TE, because it takes some time for the 180°

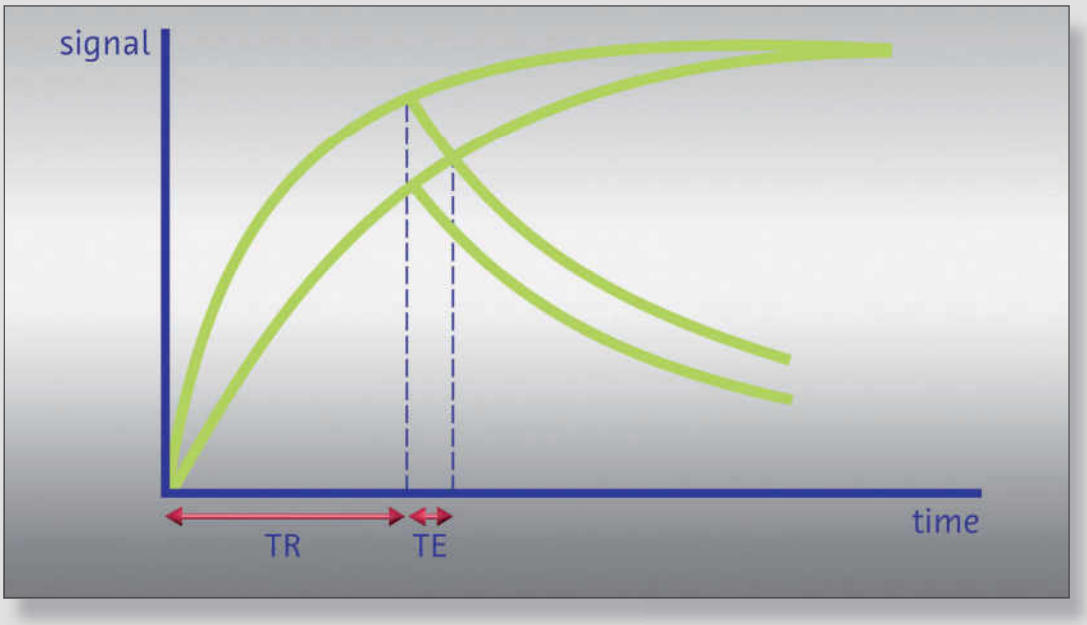


Fig. 42: When we wait a shorter time TR, differences in T_1 influence tissue contrast to a larger extent, the picture is T_1-weighted, especially when we also wait a short TE (when signal differences due to differing T_2s have not had time to become pronounced).

pulse to be "produced", sent in and do properly take effect, see also in the book "MR Buzzology").

What if we use a very short TR and a very long TE?

This is only a theoretical question. Why?

With a very short TR, there will only be very little longitudinal magnetization which is "tilted". And with a long TE, we even allow the small amount of transversal magnetization resulting to disappear to a large extent. The resulting signal will be so small, of so little intensity that it cannot be used to make a reasonable image.

If you have not been concentrating

for the last few minutes, you are probably thinking about giving up right now. How to remember this – even if you do not understand all of it (which hopefully is not the case)?

Try looking at figure 43. What can you see? A man with short TRousers. And considering the weather conditions, this makes only one person in the picture happy.

This should remind you that a short TR (TRousers) gives a T_1-weighted image (only 1 is happy).

And what do you see in figure 44? The same couple is having tea. Now, having tea which is usually served hot, always takes a long time. And in the illustration the long TEa makes two people happy. This should remind you that a long TE gives a T_2-weighted image.

Fig. 43: What to choose for a T_1-weighted image?

Fig. 44: What to choose for a T_2-weighted image?

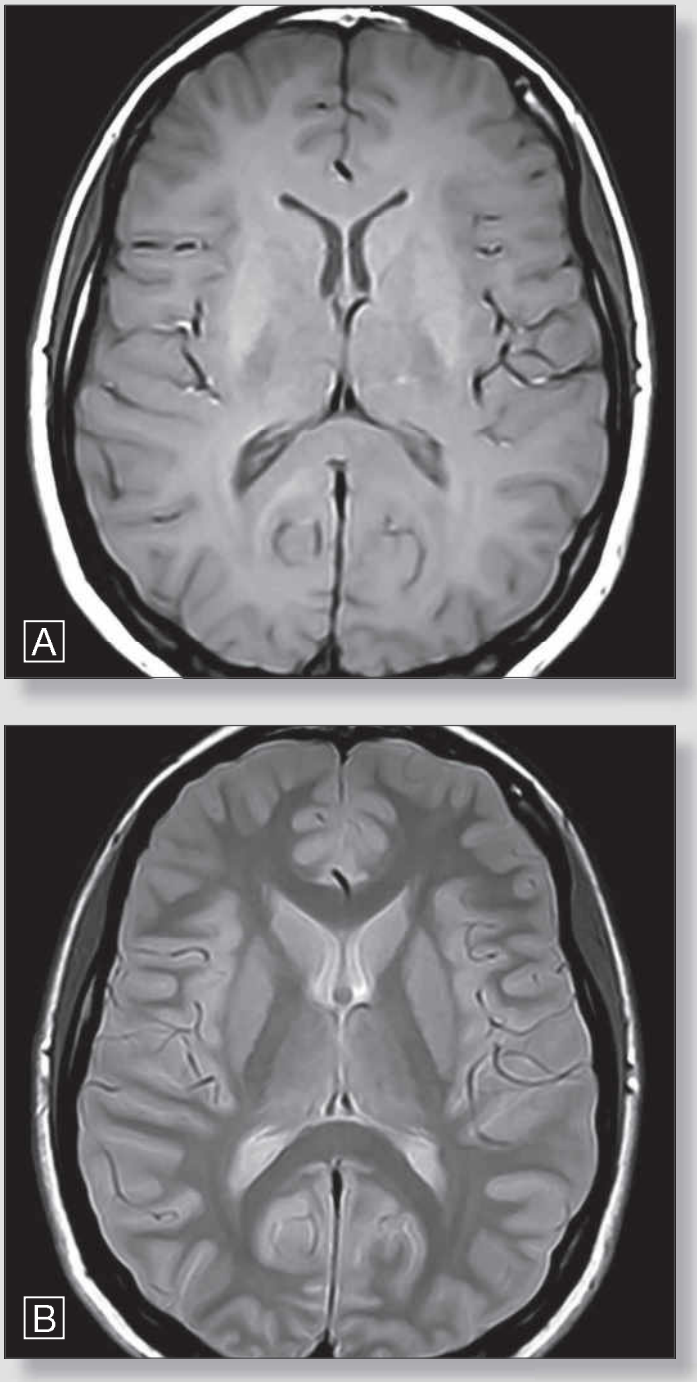
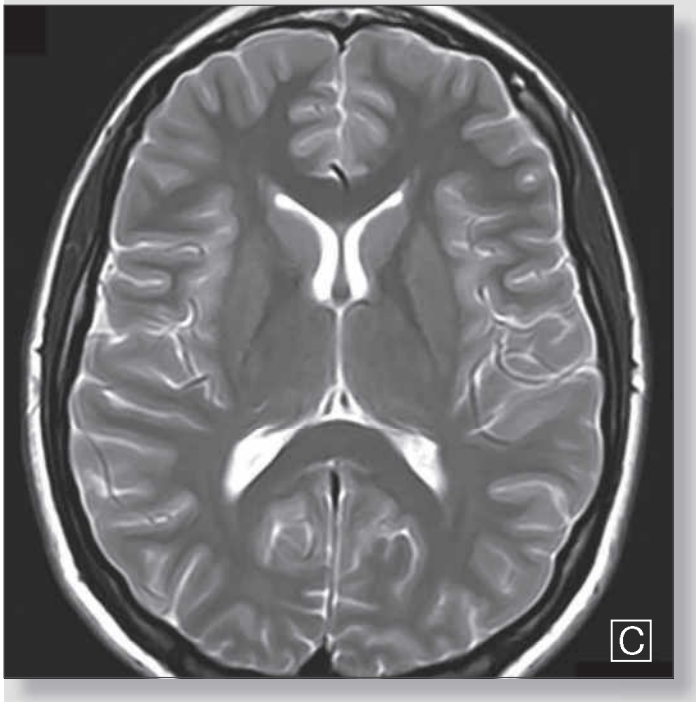


Fig. 45: T_1- (A), proton (spin) density- (B), and T_2-weighted (C) images of the same patient. The CSF is black on the T_1-weighted image. However, it has the strongest signal in the T_2-weighted image. On the spin-density image, it is of intermediate signal intensity.



Some practical hints to image interpretation

How can we tell from an image, whether it is a T_1- or a T_2-weighted image, when imaging was done with a normal pulse sequence, not one of the fast sequences (which we will hear about a little later)?

As a rule of thumb: if you see white fluid, e.g. CSF or urine, you are dealing with a T_2-weighted image. If the fluid is darker than the solids, we have a T_1- or a proton-density image.

Look at the scan (figure 45): CSF is dark, the grey matter is darker (greyer) than the white matter; this is a typical **T_1-weighted image.**

In (B), CSF is still dark, even though its signal intensity is slightly higher than in the T_1-weighted image; contrast between the grey and white matter is becoming reversed. This is a proton or spin density-weighted image, and as the grey matter has a higher water content, i.e. contains more protons, its signal intensity is higher than that of the white substance.

In (C), CSF has a higher signal intensity than grey and white matter, the image is **T_2-weighted.**

These are rules of thumb only. Actually, to be really sure, you would have to look at two images taken with different imaging parameters. Why?

Look at figure 46. You can see that in this example the T_2-curves start at different "heights", and cross each other.

They do not have to run parallel, as we depicted them in the previous illustration, which was only done for didactic reasons, as it is easier to understand at the beginning.

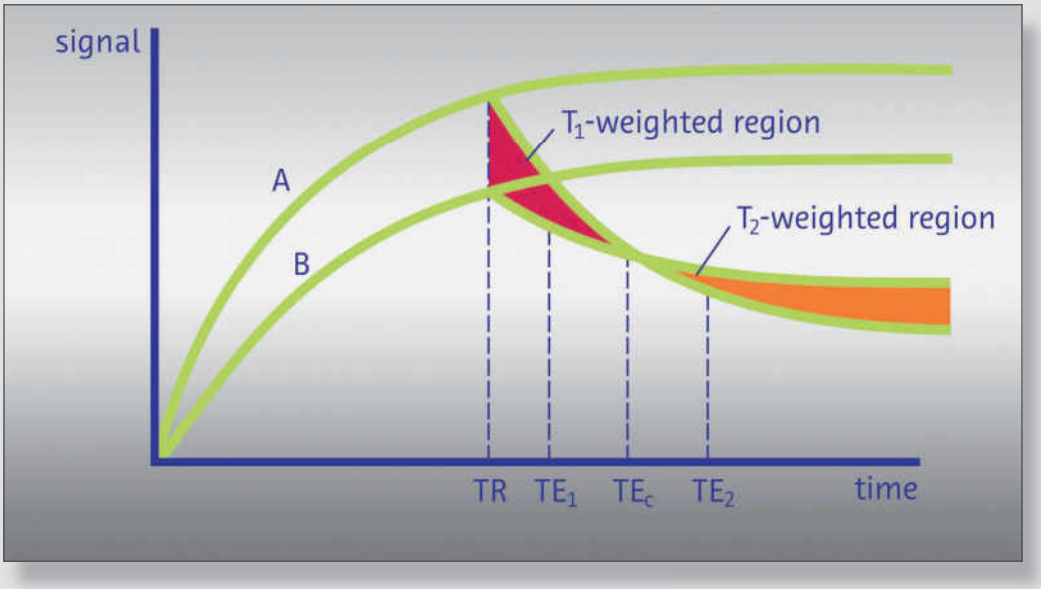


Fig. 46: T_2-curves of different tissues can intersect. The signal intensity of the tissues is reversed choosing a TE beyond the crossing point (TE_C): before this crossing point (e.g. at TE_1), tissue A has a higher signal intensity than tissue B. This means that image contrast is still determined by differences in T_1: the tissue A with the shorter T_1 has the stronger signal intensity. At TE_C, both tissues have the same signal intensity, and thus cannot be differentiated. After this crossing point (e.g. at TE_2), the relative signal intensities are reversed, and tissue B has the stronger signal.

The fact that the curves intersect is very important:

- With a TE before the crossing point (TE_1), tissue A will have a higher signal intensity.
- With a TE right at that point (TE_c), we cannot distinguish the tissues at all, as they have the same signal intensity.

Thus, you might be unlucky, and choose a pulse sequence with just those imaging parameters that do not allow tissue differentiation (which is the reason for performing two different examinations with different T_1- and T_2-weightings).

- With a TE beyond the crossing point (TE_2), tissue A will have a lower signal than tissue B.
- Before this crossing point (which you do not know, looking at an image normally), the relative signal intensities are still governed by differences in T_1.

The tissue with the shorter T_1 (or the higher proton density, if we have a long TR) still has the higher signal intensity.

Only with longer TEs does the T_2-weighting come up. Think about that for a moment!

How does flow influence the signal?

Now we have already heard about many parameters that influence the MR image, T_1, T_2, proton density, pulse sequences, TR and TE – but there are more, e.g. contrast media, and flow.

The fact that **flow** influences the MR signal has been known for a long time. The first experiments on this subject were carried out more than forty years ago. Interestingly, this phenomenon was used to measure flow in the fuel pipes of satellite rockets, without having to put any obstruction into the flow lines.

The subject of how flow influences the MR signal is rather complex and difficult, but let us at least get some idea about it.

In figure 47, we have a body section through which a vessel is crossing.

When we send in our first 90° pulse, all the protons in the cross section are influenced by the radio wave. After we turn the RF pulse off, we "listen" into the section and record a signal.

At this time, all the original blood in our vessel may have left the slice being examined. So there is no signal coming out of the vessel; it appears black in the image. This phenomenon is called **flow-void** phenomenon.

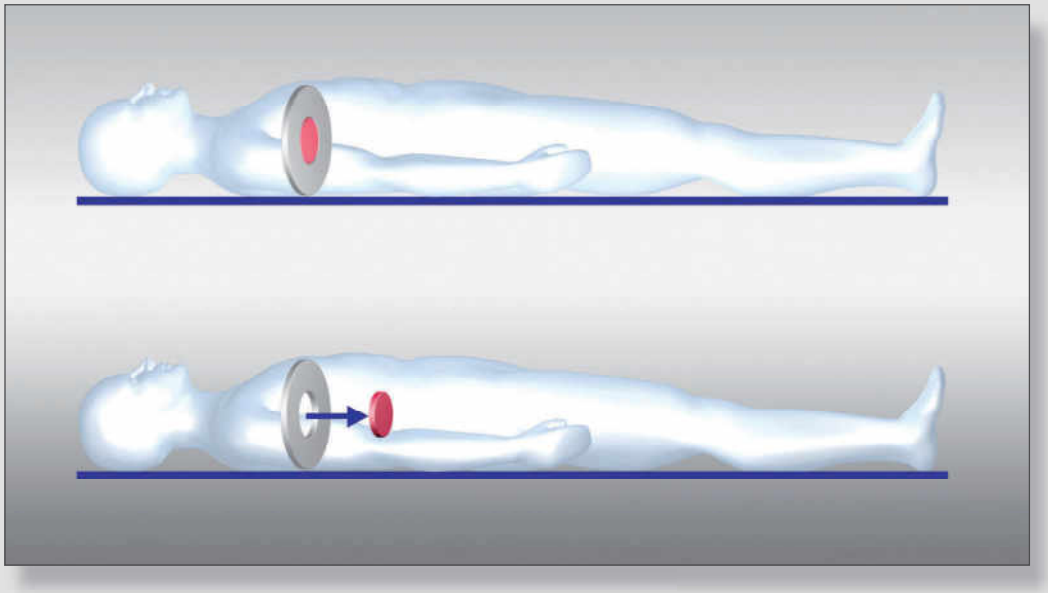
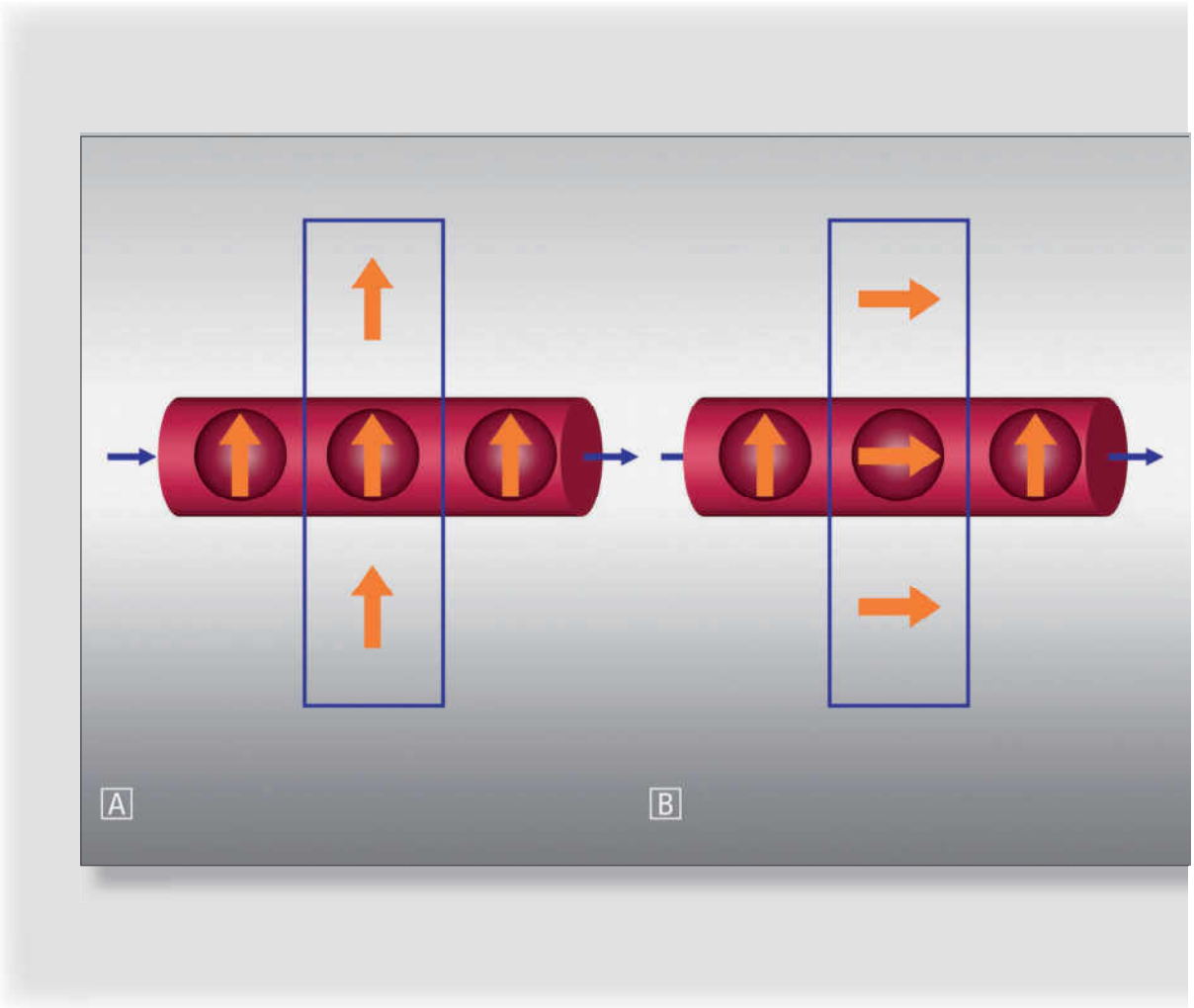


Fig. 47: Flow effects are responsible for the black appearance of flowing blood, the signal void in blood vessels.



This is not the only way in which flow may influence the image, there may be all kinds of things, e.g. also flow-related enhancement.

Illustration 48 shows a blood vessel going through a slice which is being examined. (A) represents the situation before the 90° pulse and (B) immediately after the pulse, longitudinal magnetization is "tilted" 90°.

If we wait some more time, before we send in a second 90° pulse, like in (C), protons will have undergone some relaxation, and there is some longitudinal magnetization again, as shown by the arrows pointing back up. The protons in the blood vessel, however, have left the slice and been replaced by protons that still have all of their longitudinal magnetization.

If we send in a second 90° pulse now, there will be more signal coming from the vessel than from its surroundings, because there is more longitudinal magnetization at this

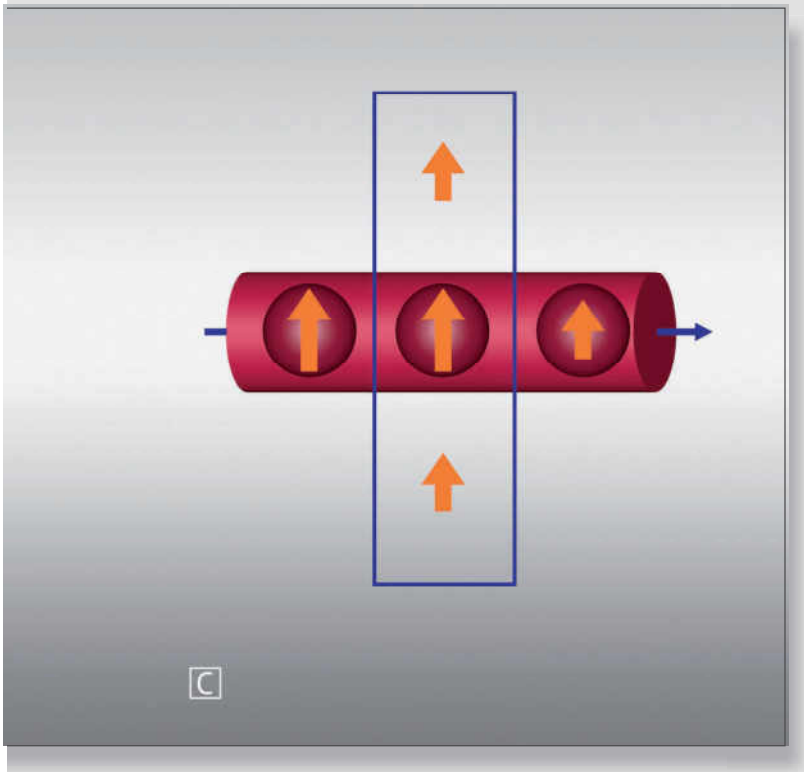


Fig. 48: Flow can have differing effects on signal intensity, and can also cause flow-related enhancement, which is explained in detail in the text.

time. The whole subject of signal strength and flow effects is actually much more complicated.

For example, when you do multislice imaging, i.e. taking images of more than one slice at the same time (see page 83), the signal also depends on the direction of the **flow**. In addition, it differs over the cross section of a vessel, depending on the flow profile, and whether there is laminar or turbulent flow. If you want to know more about this, you should look it up in one of the comprehensive standard text books (or before that in the book "MR Buzzology").

They will also give you more information on MRI angiography.

In this technique, the fact that flow influences the MRI signal is used positively by displaying the moving protons.

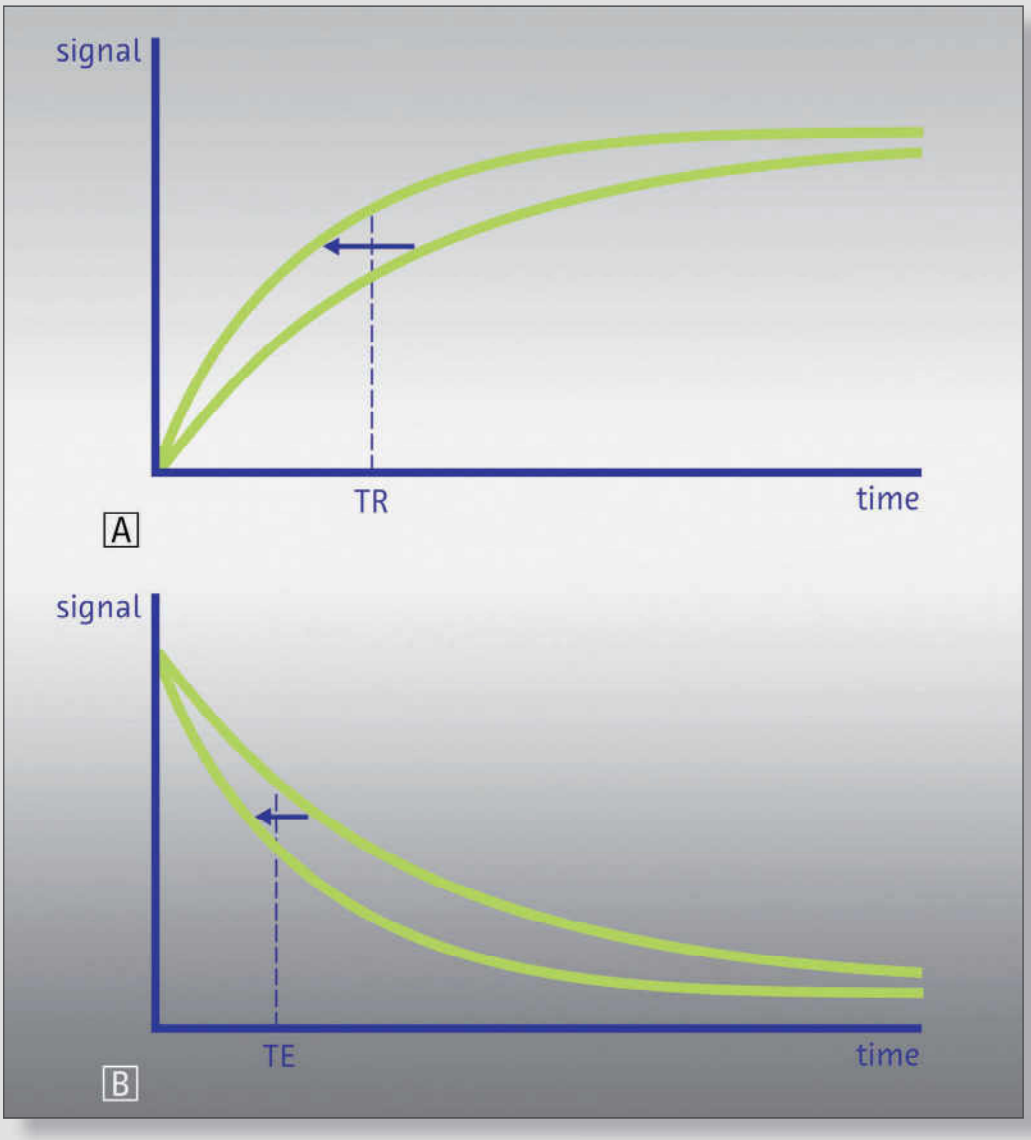


Fig. 49: Paramagnetic substances like gadolinium shorten the T_1 and the T_2 of their surroundings. The respective T_1- (fig. 49A) and T_2-curves (fig. 49B) are shifted towards the left. In effect, this means that for a certain TR there is more, for a certain TE, however, there is less signal.

What about MR contrast media?

Certain so-called **paramagnetic substances** have small local magnetic fields, which cause a shortening of the relaxation times of the protons in their neighborhood. This effect is named proton **relaxation enhancement**.

The body contains such paramagnetic substances under normal circumstances. Examples are degradation products of **hemoglobin**, e.g. **deoxyglobin** and **methemoglobin**, which are found in hematomas, or also molecular oxygen.

Gadolinium (Gd), a paramagnetic substance, is used in MR contrast media, like in Magnevist® or Gadovist®.

Chemically, Gadolinium is a rare earth, which, however, is toxic in its free state. Because of this it is bound to "some other chemical" in a certain way called chelation, which solves the problem of toxicity. For example, in Magnevist®, this chemical is DTPA.

The pharmacological properties of many Gadolinium-containing contrast media like in Gadopentetate Dimeglumine or Gadolinium DTPA (Magnevist®) or Gadobutrol (Gadovist®) are very similar to iodinated contrast media in conventional radiology: however, these Gadolinium-containing contrast media are even better tolerated.

The Gd-containing **contrast media** have an effect on both the signal intensity of T_1- and T_2-weighted images, as they shorten the T_1 and the T_2 of their surroundings (figure 49), meaning that the respective curves are shifted towards the left.

In effect, for a given **TR**, there is more signal, for a given **TE**, there is less signal.

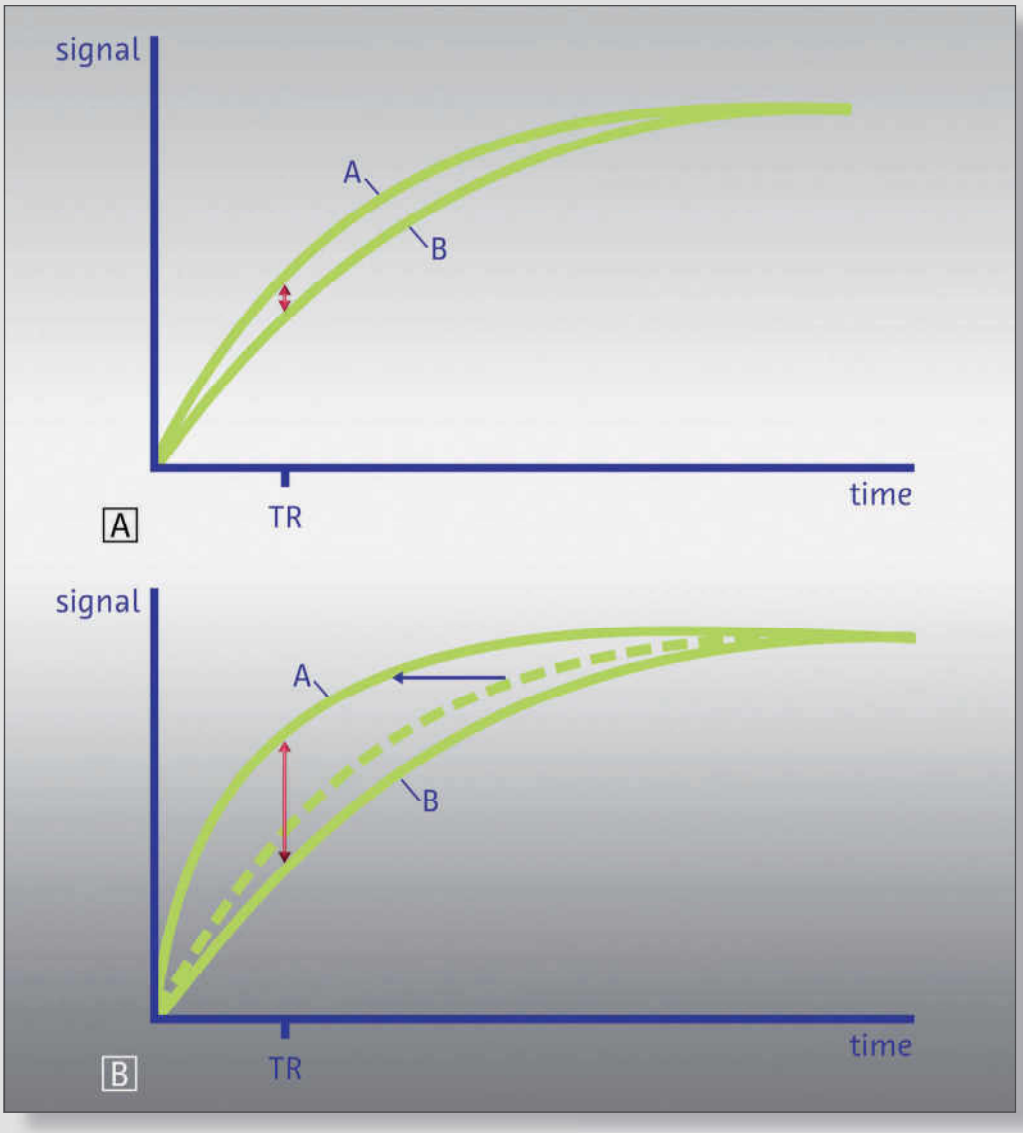


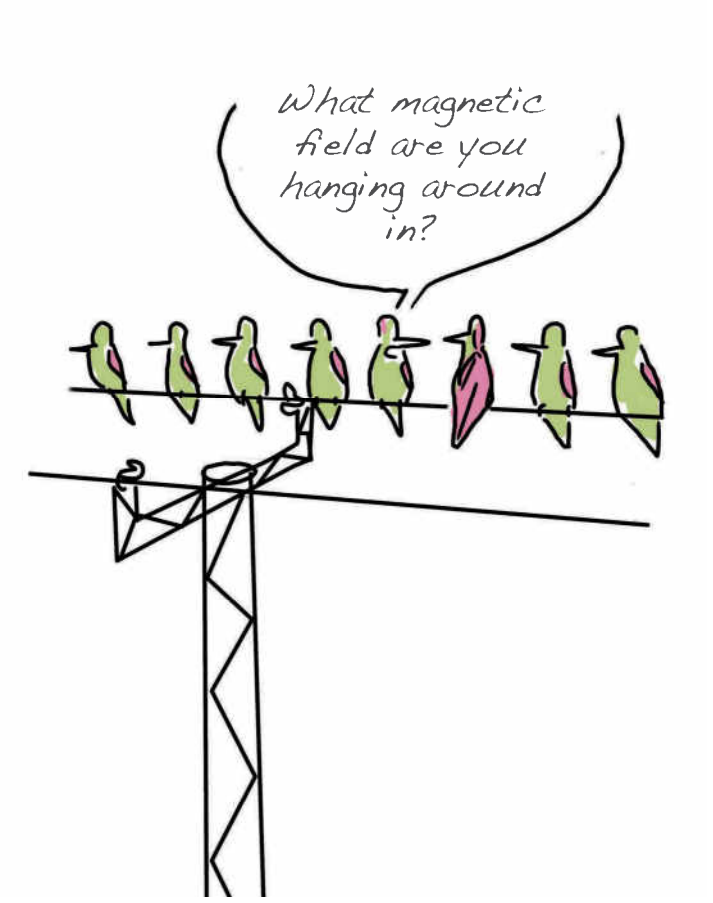
Fig. 50: In (A), the T_1-curves for tissue A and B are very close to each other, resulting in only a small difference in signal intensity between the tissues at TR. In (B), the T_1-curve of tissue A is shifted to the left, as contrast agent entered tissue A but not tissue B. At the same time TR, there now is a much greater difference in signal intensity, i.e. tissue contrast.

In figure 50, the signal intensity for two tissues, A and B, is illustrated. The i.v. administered Gd **contrast medium** enters tissue A, but not tissue B.

The T_1 of tissue A becomes shorter and the **T_1-curve** is shifted to the left.

The result is that the signal from tissue A at time TR is stronger than it was before, and the two tissues can be better differentiated, because there is better contrast.

What happens, when we perform a T_2-weighted examination after contrast medium application, we have seen in figure 49: the **T_2-curve** is shifted to the left, reducing the signal coming at a given TE.



As loss of signal is often more difficult to appreciate than a signal enhancement, T_1-weighted images are the predominant imaging technique used after contrast medium injection. As the **contrast media** are not distributed evenly throughout the body, signals from different tissues will be influenced differently. Vascularized tumor tissues are enhanced, for example. This may, for example, help with differentiation between tumor tissue and surrounding edema, which might otherwise be indistinguishable.

It is also important that the Gd compounds do not go through the intact, but only through the disrupted **blood-brain barrier.**

In general, it has been shown that the use of contrast media increases lesion detection and diagnostic accuracy of MRI in very many cases.

Ready for a review?

As we know by now, many parameters, e.g. T_1, T_2, proton density, pulse sequence parameters, influence the appearance of tissues in an MR image.

- With a short TR, we get a T_1-weighted image.
- With long TE, the image is T_2-weighted.
- Flow effects can be variable, and cover the spectrum from signal loss to signal enhancement.
- Paramagnetic substances, e.g. the contrast medium Gadolinium-DTPA,shorten T_1 and T_2 of the surrounding protons. This results in a signal increase in T_1-weighted images and a signal decrease in T_2-weighted images.
- T_1-weighted imaging is the preferred technique after contrast medium injection.