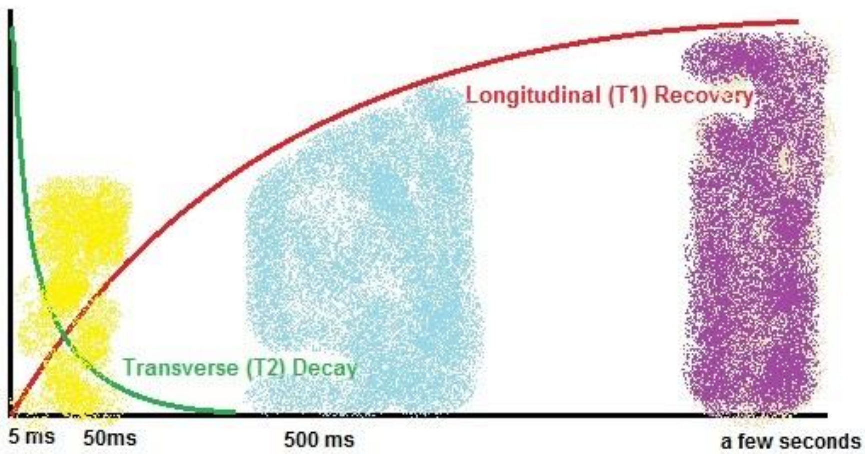
Fast Imaging with Short TRs
(Spoiling and Steady State)

Matthew Benbow, Supt Radiographer, Royal Bournemouth Hospital / BAMRR News Editor

In spin echo MRI T1, T2 and PD image weighting can be obtained by manipulation of the TR and TE times plus flip angle.
Employing a long TR time will allow all tissues to fully achieve T1 recovery (purple area), and so minimise T1 weighting. A long TR is therefore used in T2 and PD imaging to discourage T1 contrast effects.



Magnetisation Relaxation in Spin Echo

However to achieve T1 weighting in spin echo, differences in tissue T1 recovery need to be exploited. To do this, shorter TR times are employed (blue area) to ensure that tissues do not achieve full longitudinal recovery before being exposed to the next RF pulse. When gradient echo imaging is used (which will be discussed later) much lower flip angles are used, and so the T1 recovery time for tissues is significantly reduced.

In contrast to longitudinal recovery, transverse decay is very much faster. For this reason even the long TE times used in T2 weighted imaging are shorter than the TR times used, even for T1 weighted imaging, i.e. transverse decay will have already completed (or at least be well under way) before the next TR.

So what if an extremely short TR time is used? Shorter than even the T2 time of tissues (yellow area)? What effect does this have? Well, by doing this both the longitudinal recovery and transverse relaxation are unable to complete before the next TR. When such a sequence is initiated, the rapid reintroduction of RF at each of the next TR will achieve a persistence of the tilted magnetisation vector, i.e. coexistence of transverse and longitudinal magnetisaton. This is known as the Steady State and can allow very fast image acquisition times. It’s a bit like Rocky being knocked partly over, getting partially up, being hit again, recovering, hit, up, hit, up, etc. The more often he is hit, the more he leans. The harder he is hit, the more he leans. A bit unrealistic, but the best amusing analogy I can come up with.

Rocky Balboa in ‘steady state’, experiencing a 35^o flip angle from an Ernst left hook

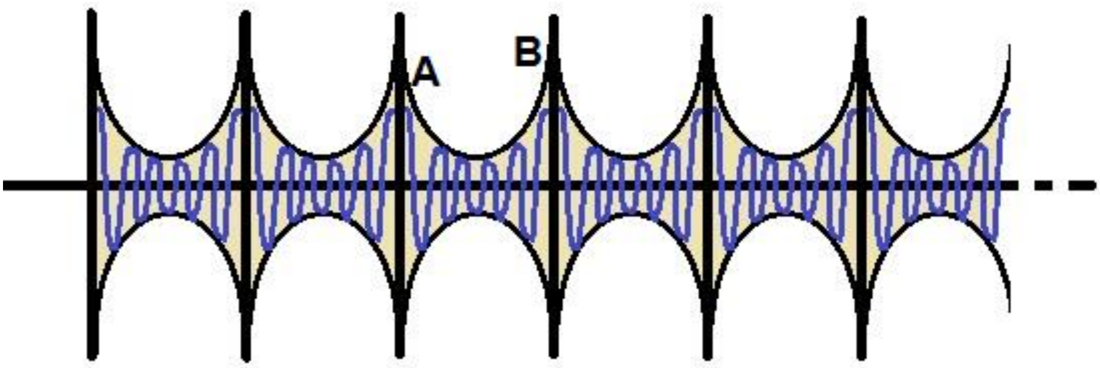
As the sequence starts it will initially take a number of reputations to reach steady state. As we have seen, the short TR time used (maybe 20-50ms) will prevent full longitudinal recovery. Therefore after each subsequent RF input the residual longitudinal magnetisation will be reduced. But as it gets smaller, it will recover faster until equilibrium is reached. The flip angle chosen is important to ensure optimum image signal. Flip too small and all virtually longitudinal magnetisation will recover each time and the signal will be tiny. Flip too much and recovery would barely have a chance to get started before the next RF, and so again, poor contrast. There is therefore an ideal angle for each given tissue that will achieve a maximum signal.
This is called the Ernst angle, which for geeks = arccos ($e^{-TR/T1}$).
Unfortunately it is different for each tissue so any one particular flip angle chosen may not be optimum to achieve maximum SNR for differing tissues being examined (never simple in MRI is it!?).

Think of Rocky again, but this time also some more boxers of varying get-back-up-ability. If every few seconds you gave them all a small jab and just watch them teeter a bit you would only see a tiny difference between them – poor contrast. On the other hand you could land them all with massive right hooks and see them hit the canvas and barley move before you wallop them again. Who would get up first? You don’t know as you never gave them a chance – again, poor contrast. The best way to show the difference in their ability to recover would be to give them reasonably decent left hooks to sort out the men from the boys – good contrast! Plus, it would also be quite good fun to smack Rocky around a bit.

Steady as She Goes

To achieve a signal that can be imaged, proton rephasing is of course needed. Using a 180^o pulse, i.e. spin-echo is not possible as this would ruin steady state, and so therefore gradient rephrasing is used, i.e. Steady State imaging is a gradient echo sequence. Remember, this repahsing is done quickly, so there is residual transverse magnetisation, i.e. the FID does not get a chance to fade away before the echo is again forced to grow.

Both Free Induction Decay (FID) and Spin Echo signals are produced and each if these can cleverly be encouraged or suppressed to achieve several different image weightings.



Steady State FIDs

Signal from the FID can be sampled just after each FR pulse (position A above) and offers a mix of T1 and T2* weighting. Signal from the Echo can be sampled immediately before each RF pulse (position B above) and offers T2 weighting.

Option 1:
Sample the FID signal only (A)
Weighting: Usually T2*   (Longer TE = more T2*)
Names: FISP, GRASS

Option 2:
Sample the Echo signal only (B)
Weighting: T2   (suffer from motion artefact, so not commonly used)
Names: PSIF, SSFP, T2-FFE

Option 3:
Sample both the FID and Echo signal together (A&B)
Weighting: T1 and T2
Names: TruFISP, FIESTA, Balanced FFE (CISS, FIESTA-C, COSMIC)

Option 4:
Sample each signal separately (Option 1 and Option 2 above), then combine them
Weighting: mixed!
Names: DESS, MENSA

Now You've Gone and Spoiled it all…

The above are all referred to as 'coherent' sequences as the phase coherence of the transverse magnetisation is preserved between RF pulses. An alternative possibility is to disrupt, or spoil these before the next RF input (incoherent). If there was enough time, a long TR would allow this to happen naturally (long TR spoiling) and this is successfully used in standard gradient echo imaging (MEDIC MPRG, MERGE, M-FFE) but the TR times used for this technique are usually way shorter than the tissue T1 time, so this is not an option. Instead, a combination of gradient and RF spoiling is used whereby the phase of the RF and the amplitude of the gradients are varied in a pseudo-random way to prevent coherence becoming established. So what does spoiling achieve? Generally it is done to remove T2* weighting, i.e. to obtain strong T1 weighting with short acquisition times. As such, this sequence is the standard used for gradient echo imaging, and has been the mainstay of dynamic contrast enhanced MRI /angiography for many years.

Option 5:
FID – spoiled, echo signal only
Weighting: T1 or T2* possible (Large flip angle & short TR = T1, Long TE = T2*)
Names: FLASH, T1-FFE, SPGR (also 3D versions of these - VIBE, LAVA, THRIVE)

Short TR gradient echo imaging can incorporate some clever techniques such as RF spoiling and steady state acquisitions to achieve a plethora of image contrasts. This has enabled us to image challenging subjects such as contrast media that will only be within fast flowing vessels for a short time, or large data sets during a breath-hold or even a heart beat.

- Summary - Allows fast imaging sequences
- Reduce motion unsharpness
- Chase contrast
- Can be coherent to give T2(*) contrast…
- …or spoiled to give T1 contrast
- Some variants are pretty useless and not commonly used
- Most of you will be using the more useful variants on a daily basis

Next edition I will try to expand on these sequences by giving examples and images of where each might clinically be useful.