Theoretical Lecture: Slice thickness and receiver Bandwidth, Inter slice gap, and Number of excitation (NEX)

1. Slice Thickness

Slice thickness helps get better resolution and finer detailed images. The slice thickness is governed by the following equation:

$$thk = \frac{BW_{trans}}{\gamma_{\circ} . G_s}$$

thk is the slice thickness,

BWtrans is the transmitted RF bandwidth (the range of frequencies it covers),

γ**o** is the gyromagnetic ratio and

Gs is the magnitude of the slice selection magnetic field gradient.

In Figure 1A show that varying the steepness of the gradient, while keeping the RF-pulse bandwidth the same. Alternatively, ***Figure 1B*** the steepness of the gradient is kept the same, while the bandwidth of the RF-pulse is varied. Can also change the slice thickness, the slice thickness may be reduced by either increasing the gradient of the magnetic field (dashed line in figure 1A) or by decreasing the RF pulse width, (or transmit bandwidth, figures 1B).

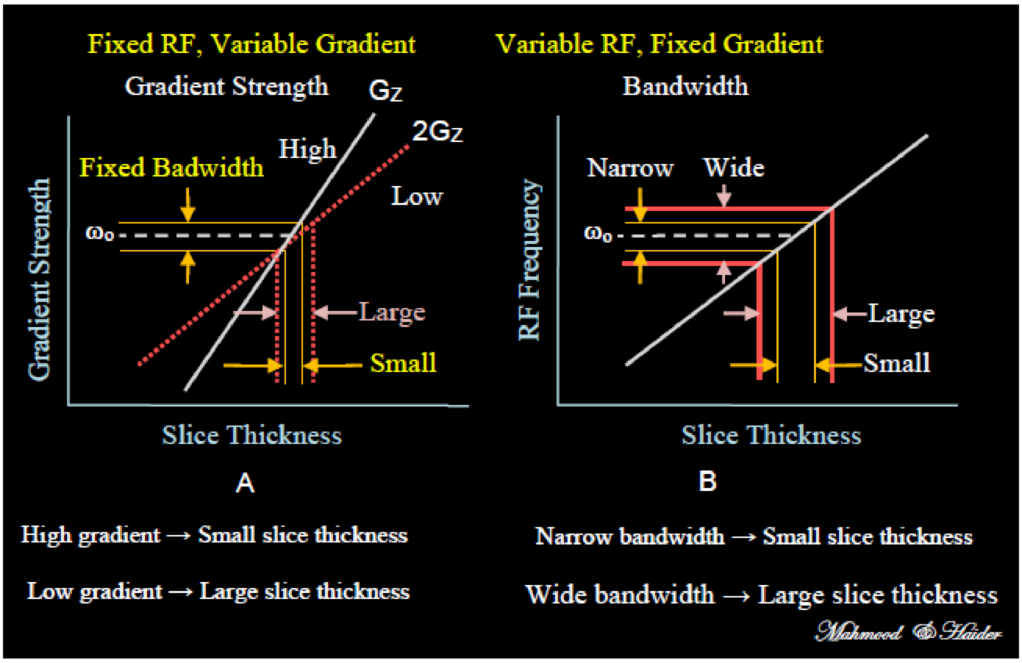


Figure 1: Slice thickness is dependent on RF bandwidth and gradient strength. (A) For a fixed gradient strength, the RF bandwidth determines the slice thickness, (B) for a fixed RF bandwidth, gradient strength determines the slice thickness.

For example, for a 10 mm slice thickness using a gradient magnetic field strength of ($10 mTm^{-1}$), the transmitted RF pulse bandwidth would be about 4.3 kHz (using γ_0 = 42.58 MHz T^{-1}).

2. Receiver Bandwidth

Receiver Bandwidth (BW) is the range of frequencies (measured in Hz) involved in the transmission or reception of an electronic signal.

Recall that one dimension of an image is typically frequency-encoded by applying a spatially-varying gradient (*Gf*) in that direction. This gradient slightly alters the precession frequencies as shown in image (figure 2). In this example the voxels at the extreme left side of the image resonate at 64,000,000 Hz while those at the far right resonate at 64,050,000 Hz figure2. The total rBW is therefore 50,000 Hz. This value is an operator-selectable parameter, chosen by the technologist before the scan begins. Available values for total receiver BW range from about 5-100 kHz with 50 kHz being typical.

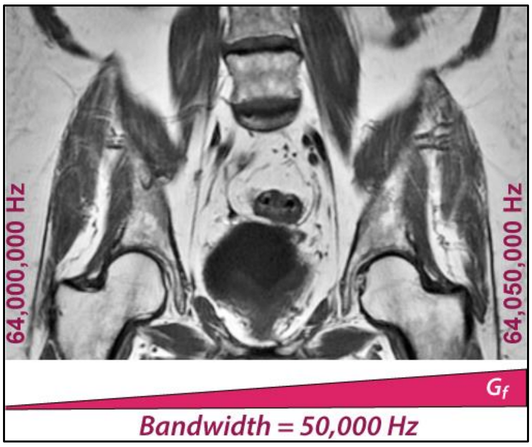
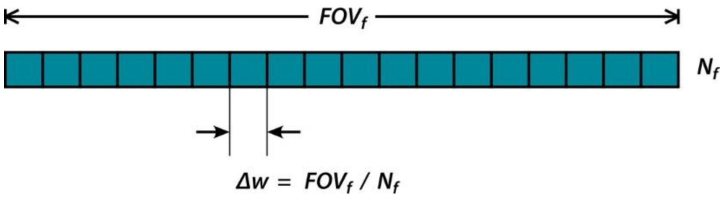


Figure 2: Receiver Bandwidth.

This ***total bandwidth*** is apportioned to pixels along the frequency-encoding direction equally. The *width* (Δ*w*) of each pixel, in turn, is determined by two additional operator-selected parameters: the ***field-of-view in the frequency-encoding direction (FOVf)*** and the ***number of frequency-encoding steps (Nf)***.



BW per pixel = Total BW ÷ *Nf*

Reducing receive bandwidth results in less noise being sampled relative to signal (improve SNR). This is because noise occurs randomly and at all frequencies, whereas signal is not random. Halving the bandwidth improves SNR by about 30%.

So, increasing receiver bandwidth reduces the SNR. By having smaller bandwidth, more signal (non-random) will be sampled compared to noise (random). By applying filter to FE gradient, higher/lower noise frequencies are filtered out

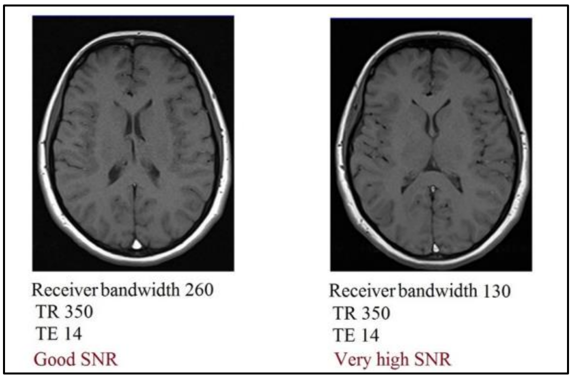


Figure 3: Receiver bandwidth and SNR

3. Inter slice gap

Slice gap is the distance between two adjacent slices and can be measured by millimeters. Slice gap is usually calculated as percentage of the slice thickness. They are necessary on order to avoid slice overlapping (cross talk) due to the imperfection of the RF pulse figure 4 a.

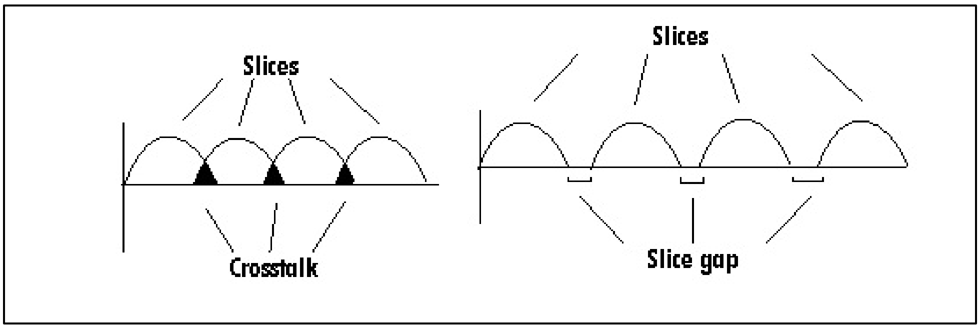


Figure 4a: crosstalk and slice gap.

Even choosing a rectangular slice profile does not produce perfect rectangular signals. By removing the slice gap the two adjacent slices will overlap at their edges. This will result in the RF pulse of one slice exciting a small portion of the adjacent slice (cross talk) figure 4b. The cross talk effect creates a saturation effect in the area of slice overlap and results in a significant reduction of SNR figure 5.

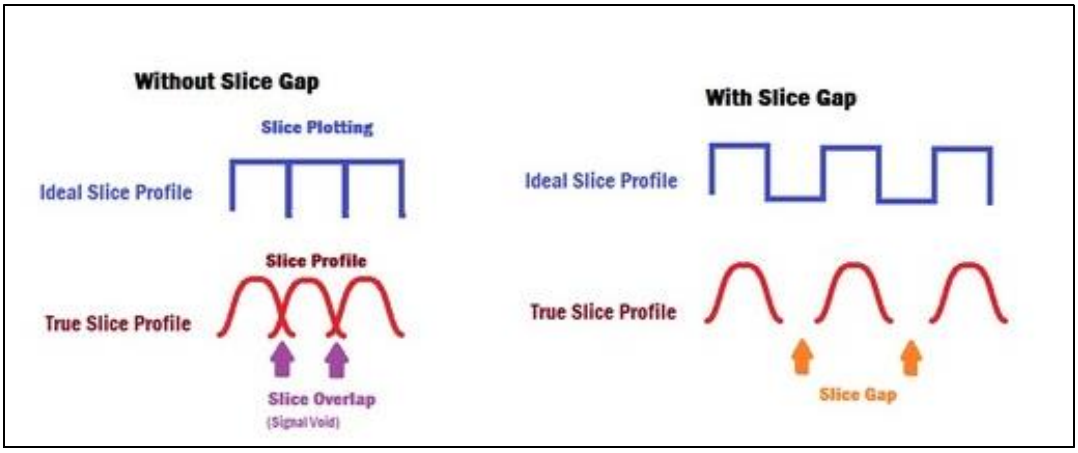


Figure 4b: Signals with and without slice gap.

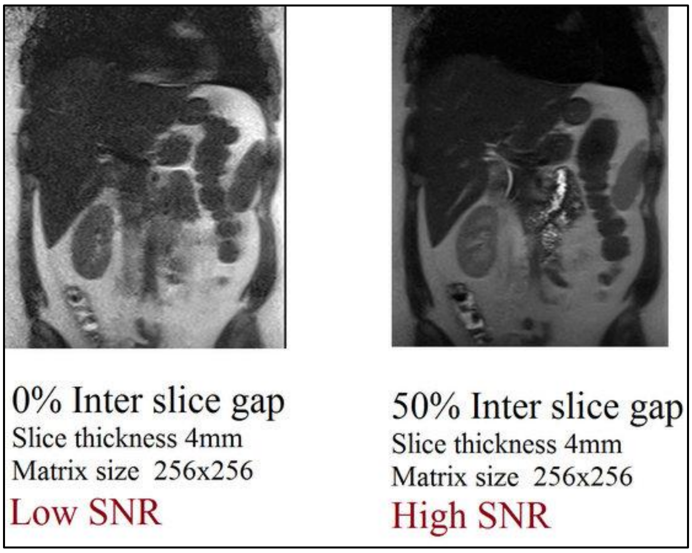


Figure 5: Inter slice gap and SNR.

4. Number of excitation (NEX):

Number of excitation (NEX) (number of signal averages/ acquisition NSA) are measurement parameter that is used to represent the number of times data (K- space data) is repeatedly acquired to form the same image, or how many times a signal from a given slice is measured.

Increasing the number of excitation (averages) will increase the SNR. Increasing the averages when using a low field strength magnet is necessary to maintain signal to noise ratio (figure 6).

Doubling the NEX or averages increases the signal to noise ratio (NSR) by the square root of 2 or by 1.44 times. Increasing the NEX also increases the scan time.

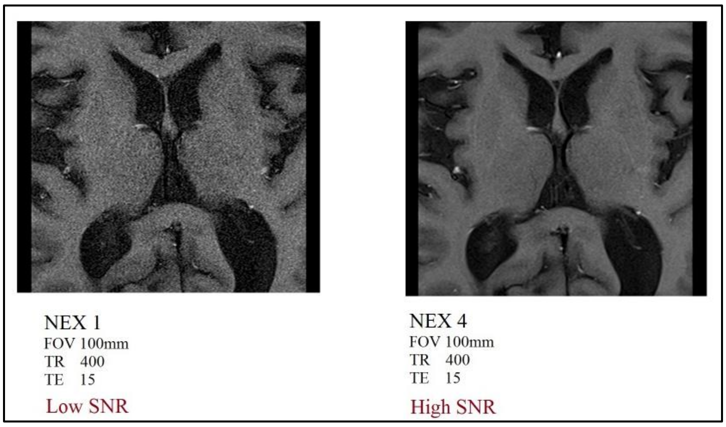
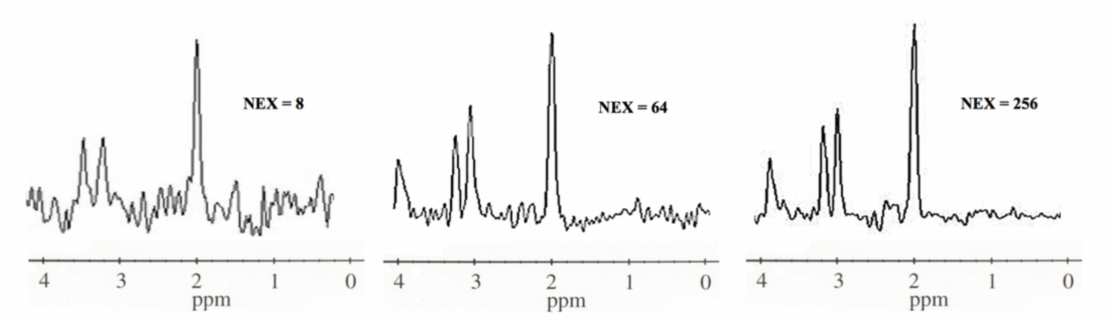


Figure 6: NEX and SNR.

The peaks are sharper and the baseline noise much reduced in the $NEX = 256$ image compared to the $NEX = 8$ image.



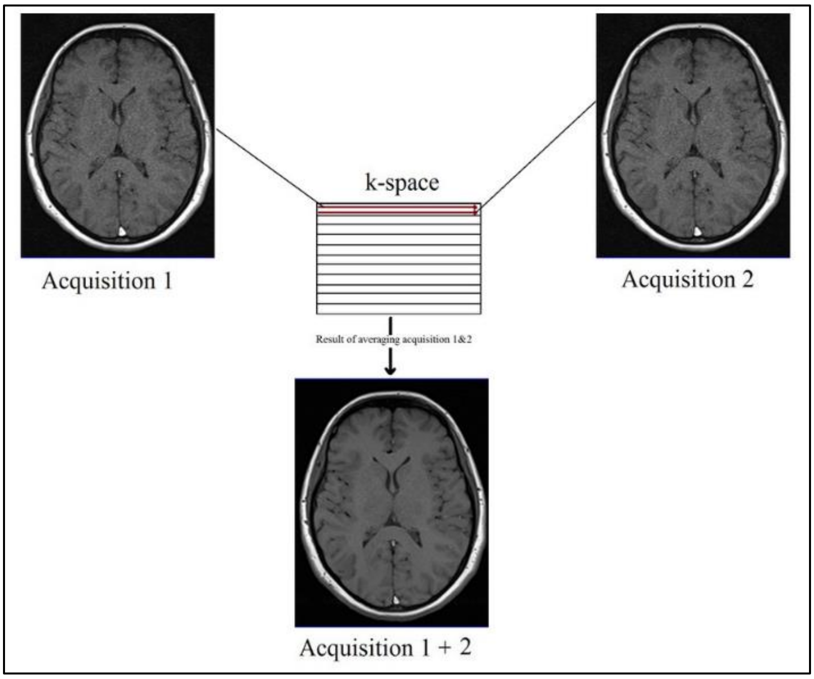


Figure 7: number of acquisition (NSA) and signal image.

5. Scan Parameters (TR, TE, flip angle)

Two controls determine tissue contrast: TR (repetition time) and TE (echo time) of the scan. They can be used for example to produce contrast between different tissues due to their individual relaxation properties. TR and TE both affect signal-to-noise and contrast resolution.

(a) Repetition time (TR) is the time between successive RF pulses, that is, the duration of a phase encoding cycle.

- TR controls the T1 relaxation time of the tissue by allowing a certain amount of the net magnetization to re-grow into the longitudinal plane, back to equilibrium before a signal is read.
- A long TR allows the protons in all of the tissues to relax back into alignment with the main magnetic field.
- A long TR will increase signal to noise ratio because more net magnetization has re-grown back to equilibrium and is available to be excited and flipped once again into the transverse plane.
- A short repetition time (TR) will result in the protons from some tissues not having fully relaxed back into alignment before the next measurement is made decreasing the signal from this tissue.
- A short TR decreases the signal to noise ratio because not as much of the net magnetization has recovered and is not there to be excited and flipped again into the transverse plane.

(b) Echo time (TE) is the time at which the electrical signal induced by the spinning protons is measured. That is, the time between giving the RF pulse (excitation) and the peak (maximum amplitude) of the echo signal (Figure 8). During this time interval, the transverse magnetization decays, e.g. signal decays, due to the T2 relaxation effects. So TE directly determines how much the transverse signal decays.

- For a T2 weighted image, use a TE that is longer than the T2 of some tissues but shorter than the T2 of other tissues.
- A long TE results in reduced signal in tissues like white matter and gray matter since the protons are more likely to become out of phase. Protons in a fluid will remain in phase for a longer time since they are not constrained by structures such as axons and neurons.
- A short echo time reduces the amount of dephasing that can occur in tissue like white matter and gray matter.

In other words, TE controls the T2 relaxation time of the tissue by allowing a certain amount of the net magnetization to decay in the transverse plane before a signal is read.

- ✓ A long TE decreases signal to noise because all of the net magnetization has decayed when the signal is read.
- ✓ A short TE increases signal-to-noise because there is net magnetization in the transverse plane to contribute to the signal.

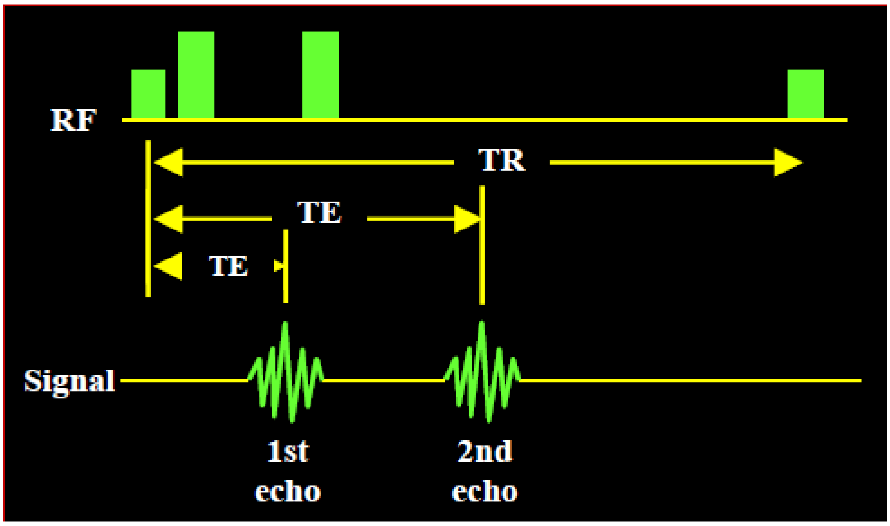


Figure 8: Echo time (TE) and Repetition time (TR).

A long TR and a short TE increase signal to noise ratio and contrast resolution of the MR images. A specific weighting for the combination short TR and a long TE decrease signal-to-noise ratio and contrast resolution in MR. The results three parameters discussed so far are can be summarized in the Figure below together with several other important variables.

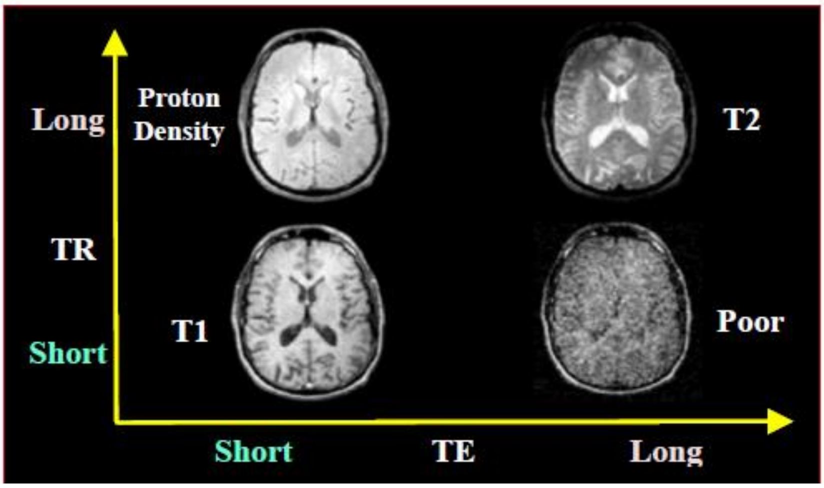


Figure 9: Summarize of TR-TE combinations which also shows some brain images impressively demonstrating the effects of relaxation weighting on the contrast.

Another sequence parameter affecting the signal to noise ratio is the **flip angle**. The flip angle is how far the net magnetization has been moved into the transverse plane. A larger flip angle will increase the signal to noise ratio because there is more net magnetization being moved into the transverse plane for a better signal. A small flip puts less net magnetization into the transverse plane so a strong signal is not possible.

Questions:

1- There are two factors that affect the slice thickness, list them and explain the relationship between them and slice thickness?
2- Draw the relationship between the slice thickness and gradient magnetic field, RF bandwidth?
3- What are the benefits of interslice gap?
4- Define receiver bandwidth?
5- What is total bandwidth and how can determine it?
6- Explain briefly the relationship between NEX and signal to noise ratio?