Bioe 594 – Advanced Topics in MRI
Homework Set #1 - **KEY**

Fast Spin Echo (1/24/06)

Problem #1 (FSE)

Consider a spin system with an average T_2 relaxation time of 100 ms. If spin echoes are acquired prior to the time when the transverse magnetization decays to 20% of its peak value, what is the maximal ETL that can be acquired when ESP = 8 ms? If ESP is shortened to 4 ms by reducing the refocusing pulse width, what is the new maximal ETL?

Hint: recall that the transverse magnetization decays according to $S = S_0 e^{-t/T_2}$
and that t = ETL × ESP.

Answer

The transverse magnetization decays according to the formula listed above. If it has decayed to 20% of its peak, then you can substitute $S = 0.2 \cdot S_0$. With T_2=100 ms, you can solve for t by:

$$
\begin{aligned}
0.2S_0 &= S_0 e^{-t/100} \\
0.2 &= e^{-t/100} \\
\ln(0.2) &= \frac{-t}{100} \\
t &= 160.94
\end{aligned}
$$

If t = 160.94 ms and ESP = 8 ms, then **ETL** = t / ESP = 160.94 ms / 8 ms ~ **20**. If ESP is reduced to 4 ms then **ETL** = 160.94 ms / 4 ms ~ **40**. For further explanation, see pages 777-778 of the textbook.

Problem #2 (FSE)

Consider an FSE sequence where $N_{acq} = 2$, ETL = 64, and the number of phases is 64. If the ETL is reduced to 32 what must be done to the sequence in order to acquire the same number of phase-encoded *k*-space lines? What happens to the sequence in general?

Hint: How does N_{shot} change and what happens to T_{seq}?

Answer

If the ETL of a single FSE sequence is reduced, then multiple sequences must be used to acquire the same amount of *k*-space lines. In this case, because the ETL is cut in half **the number of shots (N_{shot}) must be doubled**, $N_{shot} = 2$. **The length of a single sequence (T_{seq}), or shot, is cut in half ($T_{seq} \sim$ ETL × ESP)**. It is important to remember that T_{seq} is the length of a single FSE sequence (a single shot) and *not* the length of the entire scan (T_{scan}). In this problem, T_{scan} would remain the same in both cases. For further explanation, see pages 780-781 of the textbook.

Echo Planar Imaging (1/26/06)

Problem #1

When determining the scan time for a single-shot EPI sequence in which signal averaging is not used, why isn't TR a factor? How would the formula for calculating the scan time change if signal averaging were used?

Hint: What is the definition of TR and what effect does it have in single-shot EPI?

Answer

In a single-shot EPI sequence without signal averaging, **TR becomes infinite (or undefined) and effectively irrelevant**. This is because the entire *k*-space is sampled in a single sequence, so T_{seq} is the same as the total scan time T_{scan} ($T_{scan} = T_{seq} = C + ETL \times ESP$) and TR is not a factor (no repetitions are needed to complete the *k*-space).

If signal averaging were used, TR becomes a factor again because multiple sequences are used to calculate the same region of k-space (even though the "region" in this case is in fact the entire k-space). **The total scan time therefore becomes $T_{scan} = TR \times NEX \times N_{acq}$**, where NEX is the number of averages and N_{acq} is the number of acquisitions. For further explanation, see pages 717, 721, and 722 of the textbook, pages 1045 and 1049 in the DeLaPaz paper, or the Cohen website.

Problem #2

An EPI scan using a trapezoidal readout gradient waveform is performed using the following parameters:

- Receiver bandwidth (?V) = ±62.5 kHz
- n_x = 128 points
- Readout FOV = 22 cm
- Slew rate = 120 T/m/sec

Assume no ramp sampling was used. What is ESP_{min}? If the bandwidth is increased to ±125 kHz, what is ESP_{min}?

Recalculate ESP_{min} for both receiver bandwidths (±62.5 kHz and ±125 kHz) using a reduced slew rate of 20 T/m/sec. Does increasing the bandwidth in this instance increase or decrease ESP_{min}? Why?

Hint: Think about the time necessary for ramping at this lower slew rate.

Answer

We know that:

$$T_{acq} = \frac{n_x}{2\Delta V}$$

$$G_x = \frac{4p\Delta V}{gL_x}$$

Using the parameters above, we can calculate T_{acq} and G_x:

$$T_{acq} = \frac{128}{2 \cdot 62.5} = 1.024\text{ms}$$

$$G_x = \frac{4p \cdot 62.5}{2p \cdot 4.257 \cdot 22} = 13.3\text{mT/m}$$

Now that we know T_{acq} and G_x, we can calculate ESP_{min} as follows:

$$ESP_{\min} = T_{acq} + \frac{2G_x}{S_R} = 1.024 + \frac{2 \cdot 13.3}{120} = 1.246\text{ms}$$

If the bandwidth is doubled, then T_{acq} is halved and G_x doubles. ESP_{min} therefore becomes:

$$ESP_{\min} = T_{acq} + \frac{2G_x}{S_R} = 0.512 + \frac{2 \cdot 26.6}{120} = 0.955\text{ms}$$

If the slew rate is reduced from 120 T/m/sec to 20 T/m/sec, then the ESP_{min} for receiver bandwidths of ±62.5 kHz and ±125 kHz, respectively, is:

$$ESP_{\min} = T_{acq} + \frac{2G_x}{S_R} = 1.024 + \frac{2 \cdot 13.3}{20} = 2.354\text{ms}$$

$$ESP_{\min} = T_{acq} + \frac{2G_x}{S_R} = 0.512 + \frac{2 \cdot 26.6}{20} = 3.172\text{ms}$$

If we compare the two ESP_{min} values with the larger slew rate of 120 T/m/sec, we can see that increasing the bandwidth ultimately decreases the minimum possible ESP. This can lead to a faster T_{seq}. If the slew rate is reduced, however, increasing the bandwidth does not lead to a shorter ESP_{min}; in fact, it increases. This is because much more time is needed to ramp up and down the gradient, negating any potential benefit of an increased bandwidth. For further explanation, see pages 710-711 of the textbook.