Instituto Tecnológico y de Estudios Superiores de Monterrey

Procesamiento de Imágenes Médicas para el Diagnóstico (Grupo 101)

MRI Exercises

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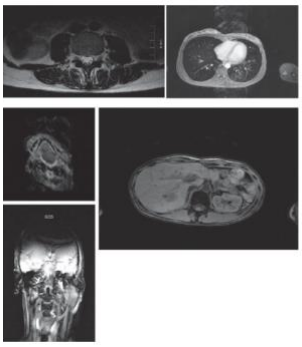
MRI Exercises

1. **Explain the artifacts in the images of Figure B.9**



By order from left to right and up to down:

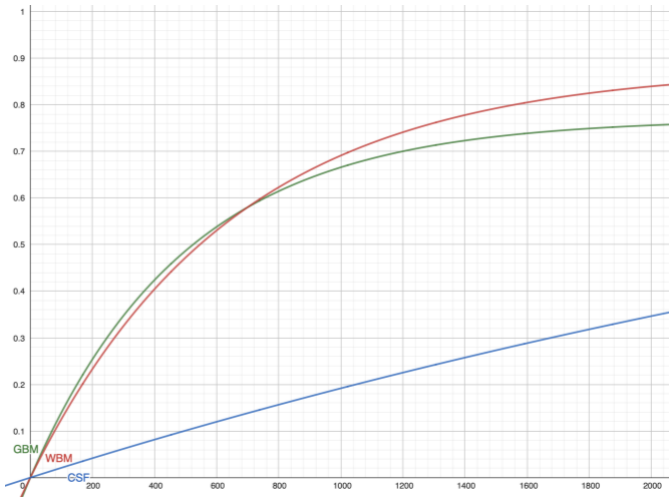
- Increased noise anterior (no coil active)
- Cardiac motion/pulsation (ghosting artefact)
- Bad shim/metal artefact (geometric distortion)
- Metal artefact (susceptibility artefact)
- Opposed (out-of)-phase imaging (phase cancellation artefact)

2. **Assume an MRI spin-echo (SE) sequence with $B_0 = 0.5\,T$. The following conditions are given.**
   - **In all the images TR = 2000 ms. From (a) to (d) TE = 25 ms, TE = 50 ms, TE = 100 ms, and TE = 200 ms respectively.**
   - **T_1 (white brain matter) ≈ 500 ms and T_1 (gray brain matter) ≈ 650 ms.**
   - **T_2 (white brain matter) ≈ 90 ms and T_2 (gray brain matter) ≈ 100 ms.**
   - **T_1 (CSF) > 3000 ms and T_2 (CSF) ≈ 2000 ms.**
   - **The proton density of gray matter is 14% higher than that of white matter.**

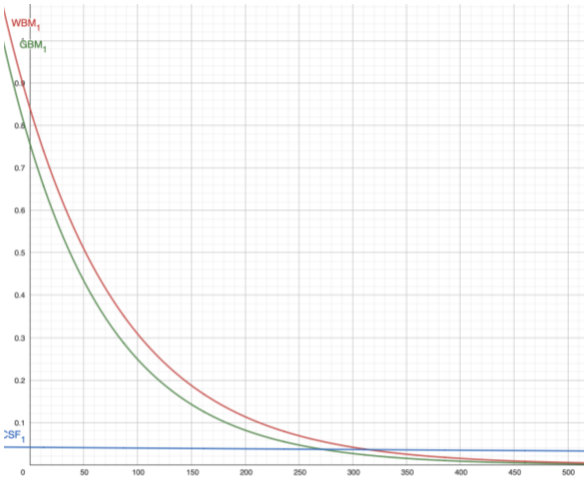
   The relative signal intensity can be expressed as:

$$s(t) = \rho e^{-\frac{TE}{T_2}}\left[1 - e^{-\frac{TR}{T_1}}\right]$$

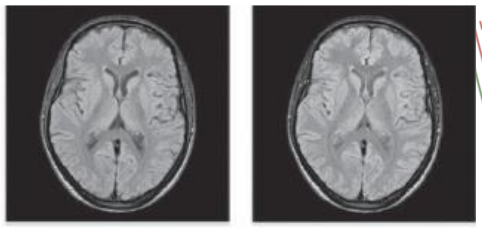
   a) **First, draw (schematically) the longitudinal magnetization (M_z) as a function of time after a 90º pulse for white and gray matter and for CSF (cerebrospinal fluid).**



b) Next, draw (schematically) the transverse magnetization (M_{xy}) as a function of time after a 90º pulse for white and gray matter and for CSF (note that TR = 2000 ms).

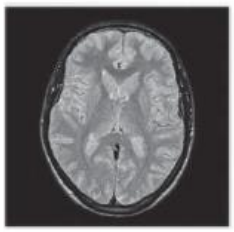


c) Explain now on this last diagram why the contrast between CSF and surrounding white brain and brain matter varies in Figure B.10.

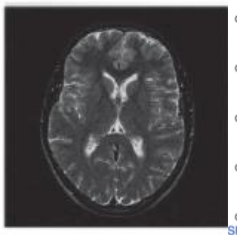


(a) SE: 2000/25

(b) SE: 2000/50

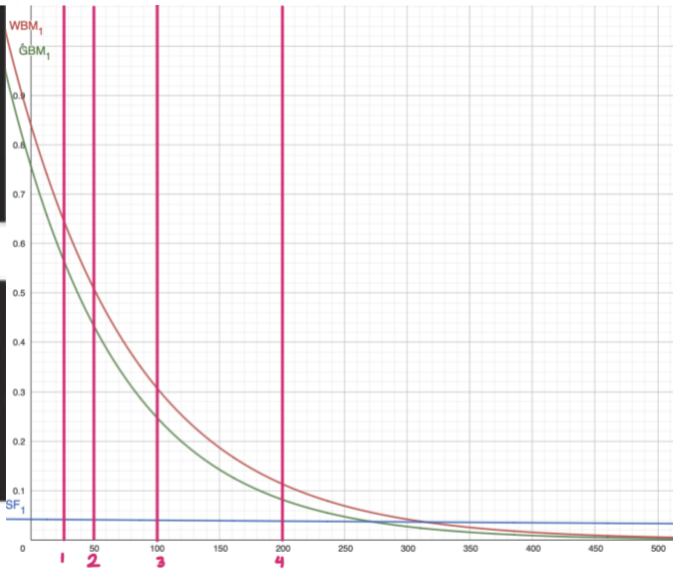


(c) SE: 2000/100



(d) SE: 2000/200

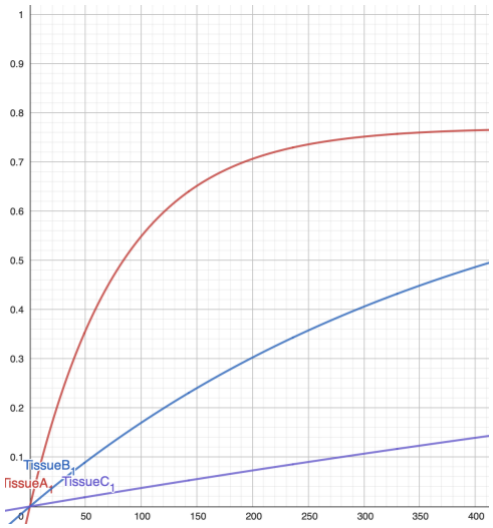
Figure B.10



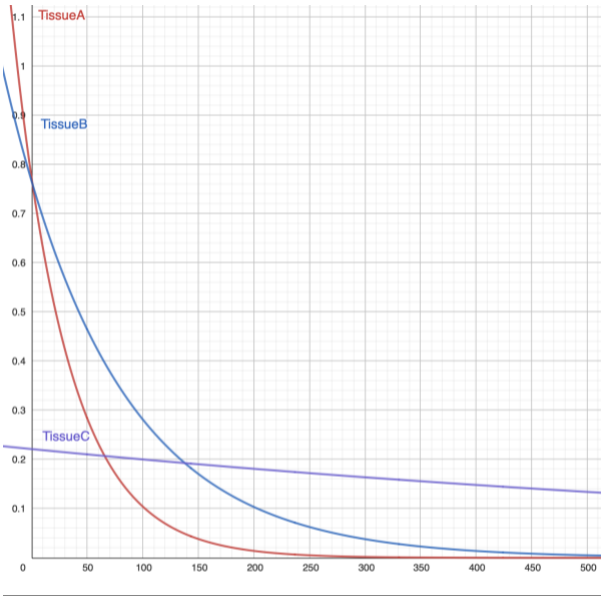
3. **T_1-weighted spin-echo sequences of one 2D slice of a phantom containing three different tissues are acquired. The repetition time (TR) is 400 ms. FOV 300x300 mm. Number of phase encoding steps 240. Slice thickness 8 mm.**
   - **Tissue A with T_1 = 80 ms and T_2 = 50 ms**
   - **Tissue B with T_1 = 400 ms and T_2 = 100 ms**
   - **Tissue C with T_1 = 2000 ms and T_2 = 1000 ms**

Assume that the tissues all have the same proton density.

a) Draw the T_1 - relaxation of each tissue as accurately as possible.



b) Draw the T_2 – relaxation of each tissue as accurately as possible, taking the T_1 -relaxation and the repetition time (TR = 400 ms) into account.



c) Assume an image with no T_2 – weighting.

– **On a gray scale from 0 (dark) to 100 (bright), specify the gray value of each of the three tissues.**

Tissue A	*Tissue B*	*Tissue C*
$\mathbf{0.99M_0}$	$\mathbf{0.63M_0}$	$\mathbf{0.18M_0}$

– **What is the acquisition time? Show the details of your calculations.**

$$T_A = \frac{N_{ph} * T_r}{ETL} = \frac{(240)(400\ ms)}{1} = 96\ s$$

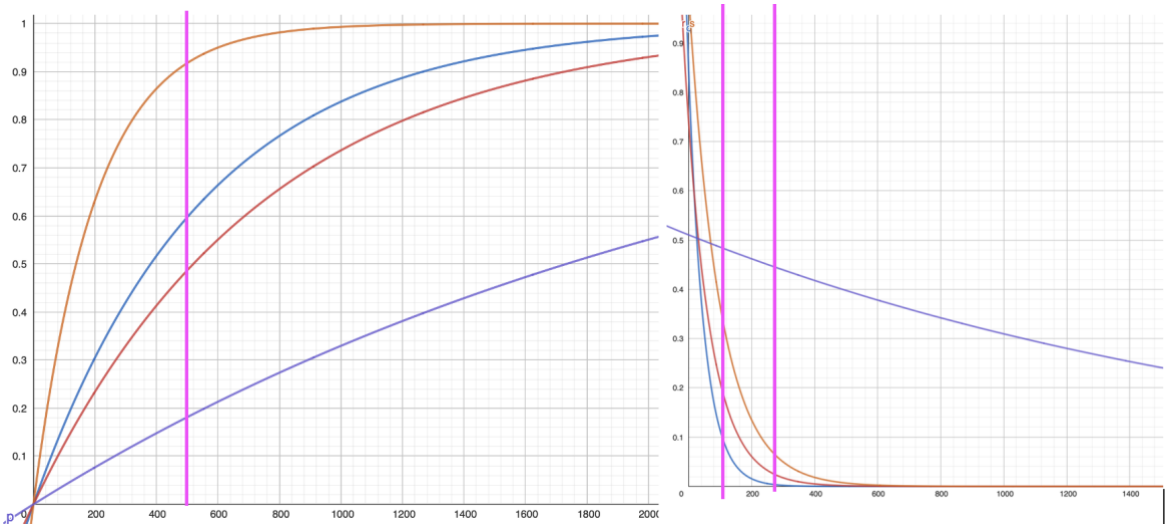
d) Te = 50 ms. Same questions as c).

Tissue A	*Tissue B*	*Tissue C*
$\mathbf{0.37M_0}$	$\mathbf{0.38M_0}$	$\mathbf{0.17M_0}$

$$\boldsymbol{T_A} = \frac{N_{ph} * T_r}{ETL} = \frac{(240)(400\ ms)}{1} = 96\ s$$

4.

a) See Figure B.11. If we assume that their proton densities are almost identical, draw the longitudinal and transverse relaxation curves for liver (star, T_1 550 ms, T_2 50 ms), spleen (circle, T_1 750 ms, T_2 80 ms), fat (square, T_1 200 ms, T_2 100 ms) and peritoneal water (triangle, T_1 3500 ms, T_2 2000 ms). Use an excitation RF pulse of 901 as start of the relaxation curves.



b) Draw for each image the spin-lattice and spin-spin relaxation curves and indicate TR and TE on thse curves.

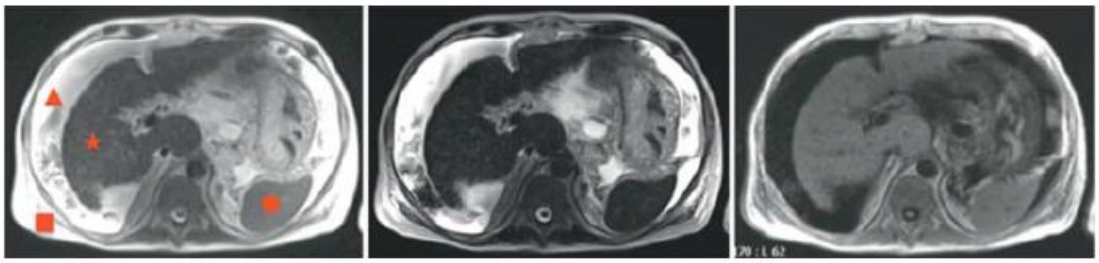
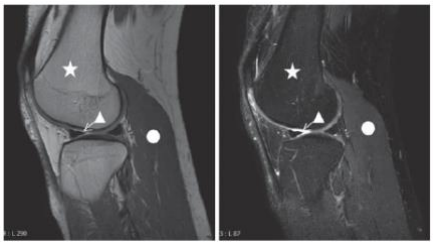


Figure B.11

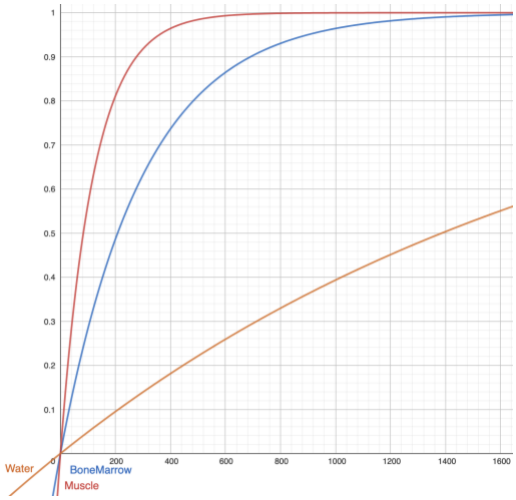
	Image A	*Image B*	*Image C*
TR	**2000 ms**	**2000 ms**	**450 ms**
TE	**120 ms**	**280 ms**	**10 ms**
Type	**Early T2-weighted**	**Late T2-weighted**	**T1-weighted**

5. **See Figure B.12.**
   - **Both images are obtained with a SE sequence (901 excitation pulse), TR = 1500 ms.**
   - **In the right image fat was suppressed with an inversion pulse (STIR = short TI inversion recovery).**
   - **Assume identical proton densities for all tissues.**

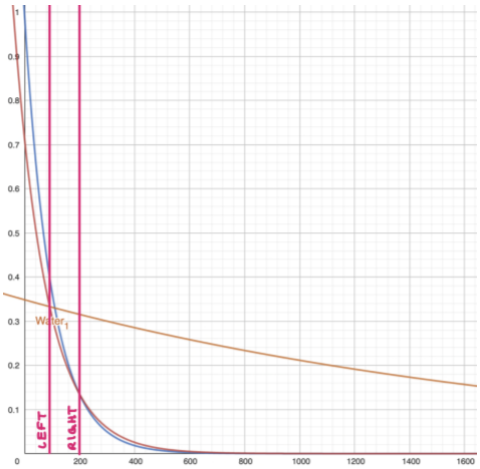


For both images:

a) **Draw the approximate longitudinal and transverse relaxation curves for fat-like behaving bone marrow (star, T_1 300 ms, T_2 100 ms), muscle (circle, T_1 1200 ms, T_2 120 ms), and water (triangle, T_1 3500 ms, T_2 2000 ms).**

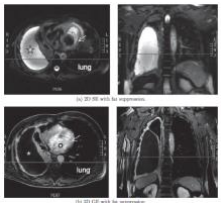


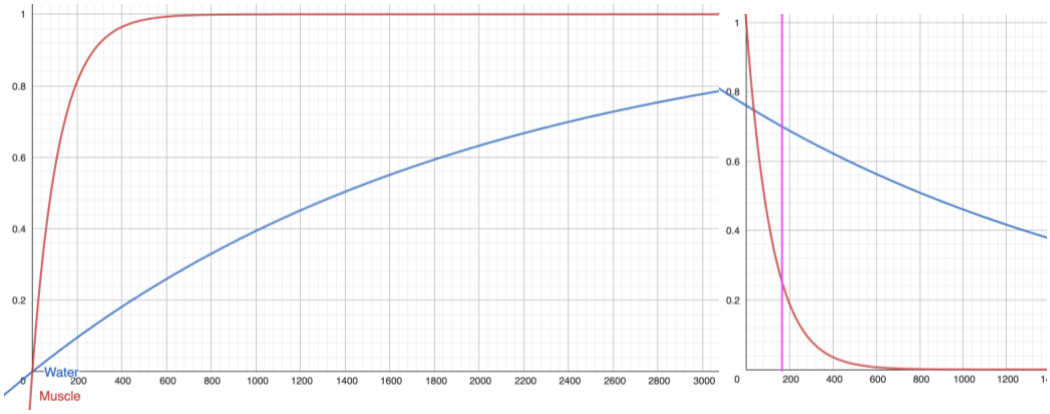
b) **Indicate TE on the transverse relaxation curves.**



6.

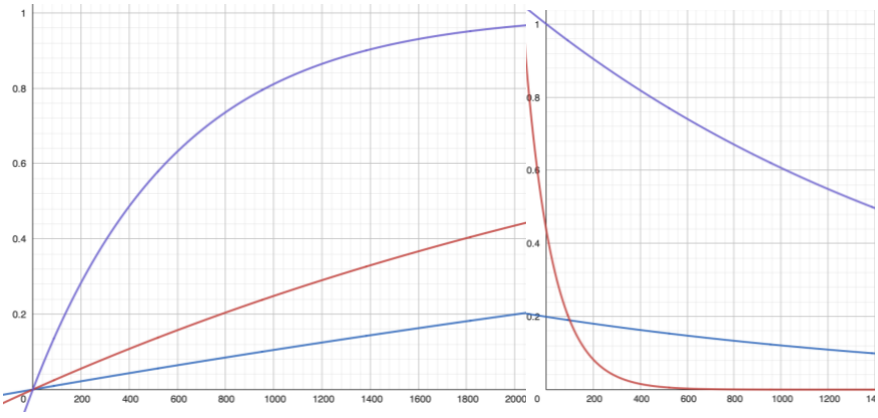
a) See Figure B.13(a). Assuming identical proton densities for muscle and water, draw the approximate longitudinal and transverse relaxation curves for water in the lungs (star, T_1 3500 ms, T_2 2000 ms) and muscle (arrow, T_1 1200 ms, T_2 120 ms). Indicate on these graphs the moment of the measurement. Explain why the healthy regions of the lungs appear dark in this image.





When the lungs are healthy, they are mostly air, thus there is no signal that can be detected. (Water is white and Muscle is gray)

b) See Figure B.13(b). Same assumption and questions as in (a). This image was acquired after injection of a gadolinium-base contrast agent. Draw also the longitudinal and transverse relazation curves of blood (with gadolinium) (circle) and explain why the signal of blood is bright.



Water is in dark color, and muscle is brigther because blood with gadolinium has a very short T1 and T2

7. **A 2-mm slice perpendicular to the z-axis at position z = 0.1 m is excited with a radiofrequency pulse at frequency f. Assume B_0 = 1.5 T and G_z = 10 mT/m. What is the frequency f (in Hz) of the RF pulse to exite this slice? And what is the bandwidth (in Hz)?**

$$\frac{\gamma}{2\pi} = 42.57\ MHz/T$$

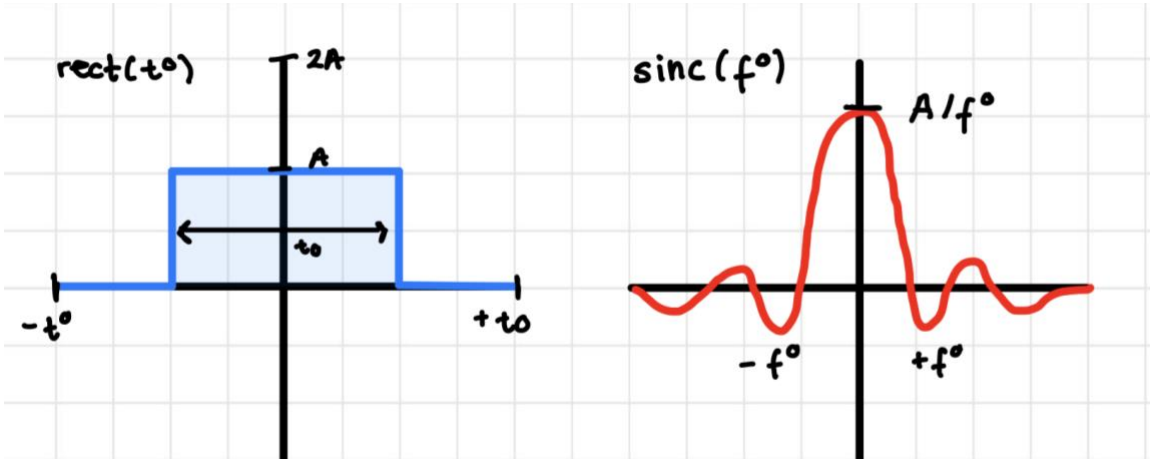
$$B = B_0 + (0.1\ m)\left(10\frac{mT}{m}\right) = 1.5T + 1mT = 1.501\ T$$

$$\omega = \gamma B = \left(42.57\frac{MHz}{T}\right)(1.501\ T) = 63.898\ MHz$$

$$BW = \gamma G_z \Delta z = (42.57\ MHz)\left(10\frac{mT}{m}\right)(2mm) = 851.4\ Hz$$

8. **In 2D MRI a rectangular SSP requires that the RF pulse is a sinc function.**

a) **Explain. Draw this sinc function for a rectangular SSP with a width of 1 mm. In practice, however, this is impossible because a sinc function has an infinite extent. Therefore the sinc function is truncated.**



b) **What is the effect on the resulting SSP?**

The SSP is multiplied by the original signal, the part that is not cover by this signal is multiplied by 0.

The function modification

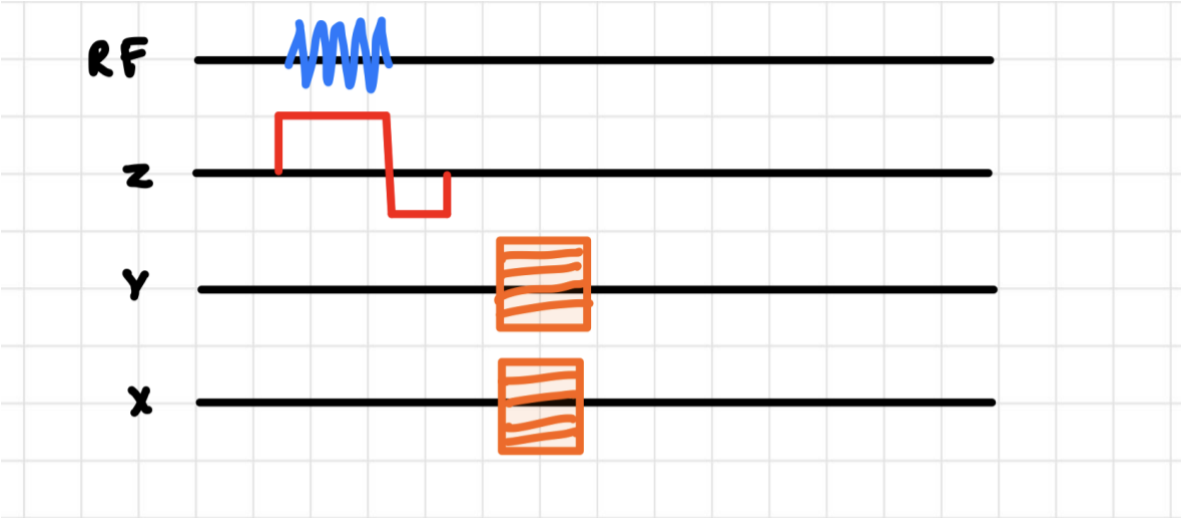
c) **What is the maximum distance (in mm) between two slices to minimize aliasing in the z-direction, i.e., perpendicular to the slices? Explain.**

The maximum distance is described by the formula:

$$d_{max} = \frac{w_{slice}}{2} = \frac{1mm}{2} = 0.5mm$$

This is used to prevent the superposition effects on the z-direction.

9. **Chechimal shift.**
    a. **Draw schematically a pulse sequence for 2D chemical shift imaging.**



    b. **What is the chemical shift artifact?**

Misregistrations caused by different speeds of rotation in different tissues

    c. **Calculate the acquisition time of this pulse sequence. (Choose acceptable values for the different parameters.)**

$$T_A = \frac{N_x N_y T_R}{ETL} = \frac{(16)(16)(2\ s)}{1} = 512\ s$$

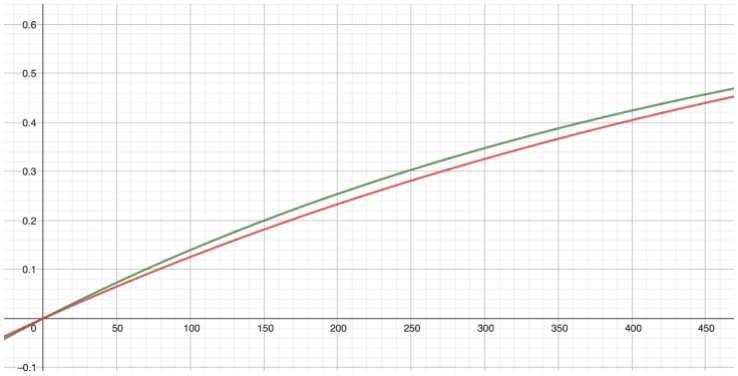
10. **For imaging of tumoral invasion in fat-like bone marrow a T_1 – weighted SE sequence is often used with the following parameters: field of view 200x150 mm, acquisition matrix 384x245, slice thickness 5 mm, TR 522 ms, TE 13 ms.**
    a. **What is the resulting voxel size (x, y, and z) and the acquisition time for this sequence?**

$$x = \frac{200}{384}\ ;\ \ y = \frac{150}{245}\ ;\ \ z = 5mm$$

$$T_A = (245)(0.522s) = 127.89\ s$$

    b. **Considering that tumoral invasion behaves like water, and bone marrow behaves like fat, which signal intensity will both tissues give in this sequence? Show this by drawing the longitudinal and transversal relaxation curves for water and fat, and indicate the moment of the measurement.**

T1-weighted sequence, water would be in a dark color while the fat would be in a bright one, in the next graph they are represented as red and green, respectively.

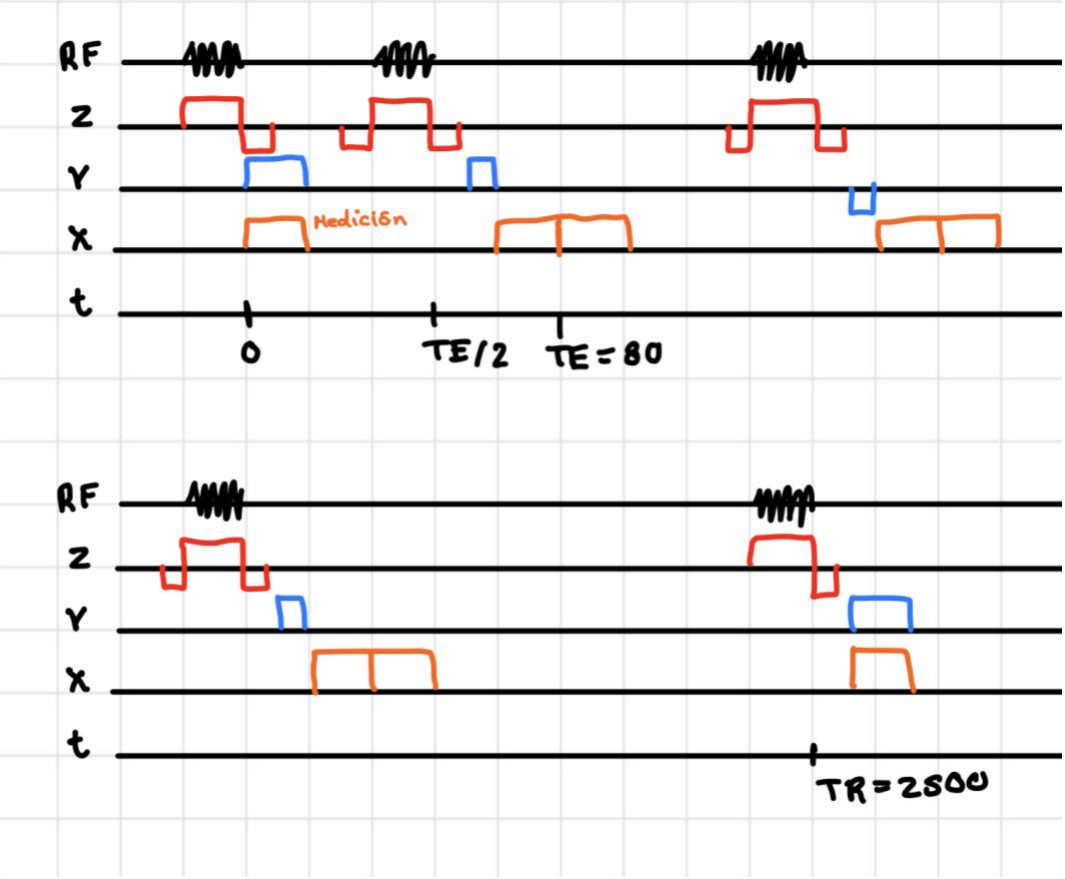


    c. **Knowing that the measurement of one line in k-space requires less than 20 ms, it is possible to acquire multiple slices during the same acquisition time as calculated in (a). Explain how this can be obtained.**

Is possible to acquire multiple slices while alternating slices within the same TR as the principle of concatenations stablishes.

11. Assume that a single slice of a T_2 – weighted turboSE sequence (30 echoes) is acquired with the following parameters: FOV 200x200 mm, matrix 128 (phase) x 256 (frequency), slice thickness 5 mm, TR 2500 ms, TE 80 ms.

a. Draw (schematically) the pulse sequence.



b. What is the pixel size and the acquisition time for this slice?

$$x = \frac{200}{128}\ ;\ \ y = \frac{200}{256}\ ;\ \ z = 5mm$$

$$T_A = \frac{(128)(2.5s)}{30} = 10.667\ s$$

12. A patient with thickness L is scanned using a coil with bandwidth BW (in Hz). Note that the different frequencies that are received by this coil are defined by the range of precession frequencies of the spins.

a. What are the conditions necessary to avoid aliasing artifacts in the read-out direction?

To avoid aliasing is a must to use Nyquist criteria, which stablish:

$$\Delta k \leq \frac{1}{2x_{max}} \; ; \quad x_{max} = \frac{FOV_x}{2} \; ; \quad \Delta k_x = \frac{\gamma}{2\pi} G_x \Delta t$$

$$G_x \Delta t \leq \frac{2\pi}{\gamma} \frac{1}{FOV_x}; \quad FOV_x = L$$

b. What is the maximal gradient amplitud as a function of BW and L that is necessary to avoid aliasing?

$$BW = \frac{\gamma}{2\pi} G_{x_{max}} L \; \rightarrow \; G_{x_{max}} = \frac{2\pi}{\gamma} \frac{BW}{L}$$

c. What is the relationship between BW and the sampling distance Δt?

$$\Delta t = \frac{1}{BW}$$