Problem 1: The Spin-Echo Sequence

The spin-echo sequence is a widely used MR imaging technique. It is characterized by a 90° pulse, followed by a 180° pulse, after which the signal is read out.

a) Draw a pulse sequence diagram of this pulse sequence, including the necessary gradients and characteristic timings. Describe briefly what the names and functions of the gradients are.

As seen in the course, the signal intensity S of a spin-echo image can be described as

$$s = \rho \cdot e^{-\frac{TE}{T_2}} \cdot (1 - e^{-\frac{TR}{T_1}}),$$

where ρ is the spin density, TR is the repetition time, TE is the echo time and T_1 and T_2 are the characteristic relaxation times.

b) Explain the difference between T_1 and T_2, both physically and in practice.

The differences in relaxation times are used to generate contrast in an image. In the brain, for example, white matter has T_1 = 800 ms and T_2 = 45 ms, while gray matter has T_1 = 1200 ms and T_2 = 70 ms (at 3T).

c) How does one have to adjust TE and TR in order to generate a T_1-weighted image (i.e. the yielded contrast is dominated by a difference of the tissues' T_1-values)? What has to be done to create a T_2-weighted image?

d) Suggest a TR and TE for a T1-weighted brain image, assuming that contrast is defined as the difference of two signals.

Problem 2: Contrast Agents

Contrast agents are often used in MRI to enhance the contrast between tissues by shortening the T_1 and T_2. The observed relaxation time ($T_{1/2,obs}$) depends on the concentration [CA] and relaxivity $r_{1/2}$ (the 'strength') of the contrast agent:

$$\frac{1}{T_{1/2,CA}} = \frac{1}{T_{1/2,initial}} + r_{1/2}[CA]$$

Every contrast has both an r_1 and an r_2. Depending on which of the two has a stronger effect at low concentrations, they are usually referred to as either a 'T_1 contrast agent' or a 'T_2 contrast agent', and subsequently the other effect is ignored.

a) Explain why a contrast agent that makes tissue appear lighter would be referred to as a T_1 contrast agent.

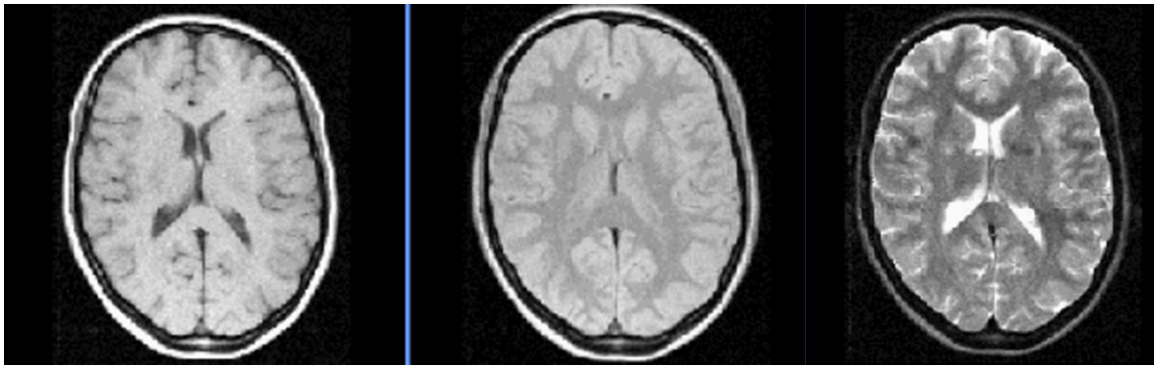
A recent trend has been to create macromolecules where thousands of contrast agents as well as a medicine are packed into one complex which has receptor-targeting ligands on its outside. The triple advantage is that this molecule targets whatever cell type is supposed to be targeted by the ligand, delivers the medicine to that cell type and generates strong MR contrast with only a few macromolecules.
One such target disease is arteriosclerosis. Assume that one component contrast agent has a relaxivity r_1=5 mM^{-1} s^{-1}, and that there are 50.000 contrast agent components as well as 2.000 medicine components per macromolecule. The required concentration of the medicine to have an effect on the arteriosclerosis is 20 µM. The T_1 and T_2 of an

arteriosclerotic plaque are 700 ms and 60 ms respectively. A spin echo sequence with TR=500 ms and TE=2 ms is used to generate an image of the plaque.

b) If the contrast *ratio* (the ratio of the signal from the plaque after and before the administration of the contrast agent) is 1.4, has sufficient medicine arrived at the plaque for the medicine to be effective? Support your answer with a calculation.

Problem 3: Image Contrast Optimisation

Here are three images of the same subject with three different type of contrast: T_1-W, T_2-W and proton density (ρ = density).



Tissue	T_1 [ms]	T_2 [ms]	ρ
White matter	800	45	0.8
Grey matter	1200	70	0.9
CSF	3000	100	1

a) From the value of T_1, T_2 and ρ of the three types of tissue present in the brain, sort the images by their type of contrast (e.g. T_1-W, T_2-W and proton density), justify your choice.

b) Describe the sequence type (gradient echo, spin echo,…) and parameters (long/short echo time, repetition time) to acquire these 3 types of image.

Problem 4: BOLD-Effect

The Bold effect is an effect used in functional MRI to detected activated areas of the brain. In this Problem you will investigate the link between physiological effects of brain activation and physical consequences that are measured by means of fMRI.

a) Describe the physical effect that influences the BOLD effect. Explain its physiological cause.

b) Calculate the arterial-venous (a-v) difference oxygen concentration during an increase of the cerebral blood flow (CBF) of 50%, assuming that the oxygen consumption is constant.

c) What is the effect of part b) on the concentration of the deoxyhaemoglobin in the veins?

d) What is the effect on MR images?

e) Explain why gradient echo sequences but not spin echo sequences are used to measure the BOLD signal.

f) Knowing that T_2* of deoxygenated blood is 35 ms while T_2* of oxygenated blood is 38 ms at 3T, what TE would you use in order to optimize the BOLD signal?