Mira Liu

Imaging Practicum 1: MRI 2

Due August 27th

**Overview of MRI k-space, sequences, artifacts, and quantitative T2**

**K-space:** Gradient coils are used to influence the Larmor frequency of spins in different physical locations and determine the physical location of different signals. This is done with a frequency encoding gradient, a phase encoding gradient, and a slice selection gradient. Frequency encoding is used for in-plane localization along the x-axis. If the main field is the field along the x-axis is then given by where is the frequency encoding gradient strength. A proton experiencing a lower gradient will precess at a slower frequency than one at the higher end of the gradient, . Phase encoding is used for in-plane localization along the y-axis. A gradient is applied along the y-axis adding different amounts of phase as a function of location, before being turned off such that they return to process at the original frequency. This shift in the sinusoid allows signal from different locations along the y-axis to be differentiated upon summation. The combination of the two gradients then presents a summed signal over all phase and frequency encoded signal, and after inverse Fourier transform the amplitudes of the varying frequency and phase components determine the brightness of an image pixel. Slice selection gradient is applied to change the Larmor frequency along the z-direction. The RF pulse is applied to only align with a narrow range of frequencies that matches those within a given slice.

K-space in turn represents a 2D map of spatial frequencies and phase information of an image. K-space is filled by different combinations of frequency encoding and phase encoding gradients, which determine and . How it is filled depends on which MR sequence is used and signal at the center is lower frequency and contains contrast information, while signal at the edges is higher frequency and contains detail information. However, each point in k-space represents the sum of signal from all image voxels for that specific combination of frequency encoding, phase encoding, and slice selection gradients. Finally, the information in k-space is redundant, so only a little more than half of k-space needs to be collected for a complete MR image.

**Sequences:** Common MR sequences include Spin Echo, Gradient Echo, Echo Planar Imaging, and Inversion Recovery. Spin echo involves a 90 pulse followed by a 180 pulse. TE is the time between those two pulses and TR is the time between successive 90 pulses. It has good SNR and minimizes artifacts but has high SAR and long TR times. Multi-echo SE can be used to get T2 with the first 90 pulse being followed by a sequence of N 180 pulses. This leads to N images in the same TR. Turbo spin echo uses a similar idea with N 180 pulses per TR, but with different phase encoding gradients set for each echo leading to N k-space lines collected in one TR. However, signal is lost throughout the TR due to both T1 and T2 decay, so there is more noise, more motion sensitivity, and blurring.

Gradient Echo is another form of sequence which uses a flip angle of and followed by a dephasing gradient and then a rephasing gradient at TE. This returns the T2\* decay, as there is no 180 pulse like the Spin Echo, and it is faster with lower SAR. This does mean it cannot be used to get T2, and there is signal loss at longer echo times and due to magnetic susceptibility. Echo planar sequence is a form of Gradient Echo in which after the pulse, all combinations of frequency and all phase gradients are turned on as the signal decays to get all of k-space in one TR. This means an entire image can be recorded in one TR, which is great for cardiac imaging, but leads to more artifacts and signal loss.

Lastly Inversion Recovery can be used for signal suppression in which a 180 pulse followed by a 90 pulse after TI is then followed by a 180 pulse at TE. Any spins that have a relaxation time T1 of TI will be suppressed as the signal will not exist for the second 180 pulse to flip into the transverse plane. Fluid attenuated IR is a commonly used IR sequence in which the TI is set to the T1 of free water such that free fluid is removed.

**Artifacts:** There are many types of MR artifacts. A few common ones are spike artifacts, inflow artifacts, motion artifacts, pulsation artifacts, respiratory, and cardiac artifacts. Spike artifacts involve an incorrectly high value in k space from external EM waves that leads to stripes of that frequency in the inverse Fourier transformed image. Inflow artifacts involve signal from blood vessels or fluid outside of the FOV, and motion artifacts involve distortion of images due to patient movement that influences frequency and phase encoding. Pulsation artifacts often lead to ghosting from arterial pulsation leading to tissue and fluid movement during the scan. Further respiratory and cardiac artifacts both occur from lung motion due to breathing or heart muscle contractions causing chest movement. These can be minimized by tracking breathing pressure, cardiac gated imaging, signal tracking of diaphragmatic movement, and breath holds. In addition, the effect of motion can be reduced with the use of fast imaging like EPI at the cost of decreased image quality.

**T2 Quantification:** An example of quantitative T2 of a knee from a multi-shot spin echo with TE of 20ms, flip angle of 90 is given below (left). Five TEs were taken (20, 40, 60, 80, 100ms) and fit voxel-wise to using least-squares Levenberg-Marquardt in Matlab (Matlab Release 2020b, The MathWorks, Inc., Natick, MA, USA). An image from the first TE is shown in the right. Signal was normalized and T2 starting value was set to 90ms to simplify fitting which may have influenced fitting. A ROI was applied to remove the ghosting artifact seen in the raw image on the right. As expected, tissue, cartilage, and bone are in the middle at around T2 = 40 – 90ms. For the T2 image, it’s expected that ligaments, cartilage, and fluid would produce brighter signal while bone marrow produces a darker signal. This can be seen in the T2-calculated image with the popliteal artery being bright, the patellar ligament being bright, and the ligaments surrounding the femur also being bright. Meanwhile muscle is darker while blood vessels and fat are lighter.

A picture containing text

Description automatically generatedA close-up of a human brain

Description automatically generated with medium confidence

SE at TE = 20ms T2 map (in ms)

Code used to produce the image on the left is provided below.

function [T2\_Map ] = T2(varargin)

%get all images

IM1 = dicomread('/Users/neuroimaging/Desktop/Imaging 1 Practicum/Sammet\_Lab/Lab\_4\_Scans/Volunteer 5/DICOM/IM\_0138');

IM2 = dicomread('/Users/neuroimaging/Desktop/Imaging 1 Practicum/Sammet\_Lab/Lab\_4\_Scans/Volunteer 5/DICOM/IM\_0139');

IM3 = dicomread('/Users/neuroimaging/Desktop/Imaging 1 Practicum/Sammet\_Lab/Lab\_4\_Scans/Volunteer 5/DICOM/IM\_0140');

IM4 = dicomread('/Users/neuroimaging/Desktop/Imaging 1 Practicum/Sammet\_Lab/Lab\_4\_Scans/Volunteer 5/DICOM/IM\_0141');

IM5 = dicomread('/Users/neuroimaging/Desktop/Imaging 1 Practicum/Sammet\_Lab/Lab\_4\_Scans/Volunteer 5/DICOM/IM\_0142');

header = dicominfo('/Users/neuroimaging/Desktop/Imaging 1 Practicum/Sammet\_Lab/Lab\_4\_Scans/Volunteer 5/DICOM/IM\_0138');

nx = header.Height;

ny = header.Width;

%brute force inelegant coding

%nx = 224

%ny = 224

Total\_Slices = 5;

Image\_stack=zeros(Total\_Slices, nx, ny);

%stack images

Image\_stack(1,:,:) = imresize(IM1,[nx ny],'bicubic');

Image\_stack(2,:,:) = imresize(IM2,[nx ny],'bicubic');

Image\_stack(3,:,:) = imresize(IM3,[nx ny],'bicubic');

Image\_stack(4,:,:) = imresize(IM4,[nx ny],'bicubic');

Image\_stack(5,:,:) = imresize(IM5,[nx ny],'bicubic');

T2\_Map = zeros(nx,ny);

%now fitting to T2 decay...

%for pixels in rectangular FOV chosen by eye

for i = 99:345

for j = 84:367

if Image\_stack(1, i, j)>0

T2\_Signal = double(Image\_stack(1:Total\_Slices, i,j)); %get signal from particular voxel for all images along z axis

[T2\_val, f0, TEs, Signal] = T2fit(T2\_Signal);

%plot(f0, TEs, Signal./Signal(1))

%title(strcat(string(i),string(j)));

T2\_Map(i,j) = T2\_val;

else

T2\_Map(i,j)=0;

end

end

counter = strcat(string(i),string(j)) %count/keep track of which voxel we're at.

end

figure,imshow(T2\_Map,[])

function [T2\_val, f0, TEs, Signal] = T2fit(Signal)

TEs = double([20, 40, 60, 80, 100]); %time in ms (as each TE is 20 ms??)

startpoints = [1, 90]; %starting normalized value of 1 or so, and a T2 of bone or cartilage of 90?

T2\_equation = 'a\*exp(-x/b)'; %normalized.... x = TE, b = T2, a = whatever constant

[f0, G0] = fit(TEs', Signal./Signal(1), T2\_equation, 'Start', startpoints); %fit normalized!

T2\_val = f0.b;

end

end