Fourier Space MR Imaging

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Introduction

Basic Fourier MRI

Magnetic Resonance Imaging (MRI) is a machine that uses magnetic fields to activate the atoms inside the body. Wounding coils inside the machine produce huge amount of magnetic field. These magnetic fields apply gradients through the body and nucleus and hydrogen atoms get energized. While the gradient is applied, atoms in body starts changing its gradients, phase, and frequency responses. When imaging the body, sampling resolution is very important. It is very critical where and how long the data is collected. Thickness of the collected data range can change the resolution. Also, number of data points can affect the results and these data acquisition parameters are adjusted depending on the application. MRI represents these data in k-space. MR Image is constructed from every data points in this k-space. In order to display these data point, data has to be evaluated using Inverse Fourier Transform. Inverse Fourier Transform reconstructs these data into the real image in the time domain.

Basic Theory on SNR

Noise signal represents the uncertainties such as outer interferences and extraneous information that will always exist in experiments. Signal-Noise Ratio represents the ratio of how much the noise exists in the data. This is very critical because these noises can interfere with the original signals and possibly change the result. SNR cannot be eliminated but only be reduced. There are many variables that affects the value of SNR; voxel size, slice thickness of the data, number of averages, and etc.

Objective of the Experiment

The main purpose of the lab is to achieve basic understandings of MR Imaging. The objective of this experiment is to observe changes in output of MRI depending on the changes in the variables. This experiment will demonstrate how the image acquisition parameters (resolution, number of averages (NAV), and slice thickness) affect the signal to noise ratio of the output.

Materials and Methods

In this lab, acquisition parameters are changed through out the lab in order to observe their effect on the SNR. In this experiment, an asparagus chunk and a tomato were used. Two subjects are placed inside the container. The container was filled up with water in order to eliminate any air that could possibly disturb the signal. The container was placed on the long plastic holder and inserted into the MRI horizontally. It is important to adjust edges of the container and the holder so that MRI can detect the container in correct position. Before activating the MRI, it is really important to check there are no metallic substances in the MRI room because the huge amount of magnetic fields can attract metals and cause damage.

Software named *Paravision* was used in this experiment. First of all, name of patient is set (EBME318 in this experiment). There are subcategories under the patient name and scans are saved in these subcategories. Before starting the actual experiment, standard adjustments are necessary. These includes shimming, adjusting the flip angle, and optimization process where optimum needs to be centered in the data points.

Scanning process starts after all the adjustments are made. Before starting the scanning process, paravision asks to set up acquisition parameters such as field of view, slice thickness, and the resolution. MRI starts the scanning process. Depending on the number of data points, it can takes up a long time to finish scanning and reconstructing the data. In order to reduce the time, previously scanned data has to be analyzed while the scanning process is going on.

When analyzing the data, it is necessary to place the cursor where data needs to be analyzed. Cursor will detect the signal and give the standard deviation values and mean values. Cursor has to be placed where signals are consistent in order to get pure value of target subject (asparagus, tomato, water, or air). In this experiment there were three parts, the number of data points (size of image matrix) was changed, the number of averages was changed and the slice thickness was changed.

Results

In this experiment, the SNR value was calculated by

$$\frac{Signal}{Noise} = \frac{MEAN(Signal)}{STD(Background)} \tag{1}$$

Changing the matrix size

64 x 64	Acquisition Time (s)	Repetition Time, TR (s)	Echo Time, TE (s)	
	9.6	0.15	0.008	
	Asparagus	Water	Tomatoes	Air (Noise)
Mean	1.59E+04	1.09E+05	1.06E+05	3.14E+05
STD	7.50E+05	3.02E+03	6.04E+03	1.62E+03
SNR	9.81E+00	6.73E+01	6.54E+01	

128 x 128	Acquisition Time (s)	Repetition Time, TR (s)	Echo Time, TE (s)	
	19.2	0.15	0.008	
	Asparagus	Water	Tomatoes	Air (Noise)
Mean	1.64E+04	1.09E+05	1.06E+05	3.65E+03
STD	4.96E+03	3.26E+03	4.24E+03	1.72E+03
SNR	9.53E+00	6.34E+01	6.16E+01	

256 x 256	Acquisition Time (s)	Repetition Time, TR (s)	Echo Time, TE (s)	
	38.4	0.15	0.008	
	Asparagus	Water	Tomatoes	Air (Noise)
Mean	1.87E+04	1.06E+05	1.03E+05	5.31E+03
STD	6.52E+03	4.50E+03	7.70E+03	2.81E+03
SNR	6.65E+00	3.77E+01	3.67E+01	

512 x 512	Acquisition Time (s)	Repetition Time, TR (s)	Echo Time, TE (s)	
	76.8	0.15	0.008	
	Asparagus	Water	Tomatoes	Air (Noise)
Mean	2.06E+04	1.09E+05	1.03E+05	1.14E+04
STD	9.71E+03	8.94E+03	5.05E+04	5.77E+03
SNR	3.57E+00	1.89E+01	1.79E+01	

Chart 1.

Note that acquisition time is increasing with the size of the matrix. In order to clearly observe the relationship between changing the matrix size and the SNR value, the data was plotted into a linear graph.

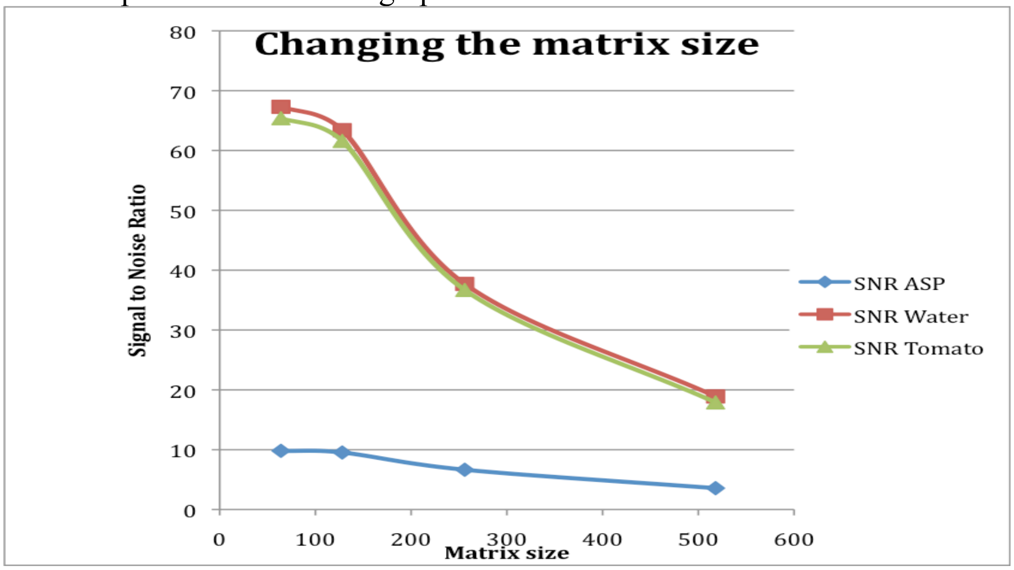

Figure 2.

<u>Changing the NAV</u>

256 x 256	Acquisition Time (s)	Repetition Time, TR (s)	Echo Time, TE (s)	
NAV = 1	38.4	0.15	0.008	
	Asparagus	Water	Tomatoes	Air (Noise)
Mean	1.87E+04	1.06E+05	1.03E+05	5.31E+03
STD	6.52E+03	4.50E+03	7.70E+03	2.81E+03
SNR	6.65E+00	3.77E+01	3.67E+01	

256 x 256	Acquisition Time (s)	Repetition Time, TR (s)	Echo Time, TE (s)	
NAV = 2	76.8	0.15	0.008	
	Asparagus	Water	Tomatoes	Air (Noise)
Mean	2.61E+04	1.58E+05	1.51E+05	7.78E+03
STD	9.73E+03	5.88E+03	6.90E+03	4.18E+03
SNR	6.24E+00	3.78E+01	3.61E+01	

256 x 256	Acquisition Time (s)	Repetition Time, TR (s)	Echo Time, TE (s)	
NAV = 4	153.6	0.15	0.008	
	Asparagus	Water	Tomatoes	Air (Noise)
Mean	6.11E+04	4.41E+05	4.22E+05	1.16E+04
STD	2.41E+04	1.04E+04	1.45E+04	5.71E+03
SNR	1.07E+01	7.72E-01	7.39E+01	

256 x 256	Acquisition Time (s)	Repetition Time, TR (s)	Echo Time, TE (s)	
NAV = 8	307.2	0.15	0.008	
	Asparagus	Water	Tomatoes	Air (Noise)
Mean	1.30E+05	8.78E+05	8.32E+05	1.65E+04
STD	4.80E+04	1.51E+04	8.19E+03	3.18E+04
SNR	4.09E+00	2.76E+01	2.62E+01	

Chart 2.

Note that acquisition time doubles as the number of averages (NAV) value doubles. This data was also plotted in order to observe the trend.

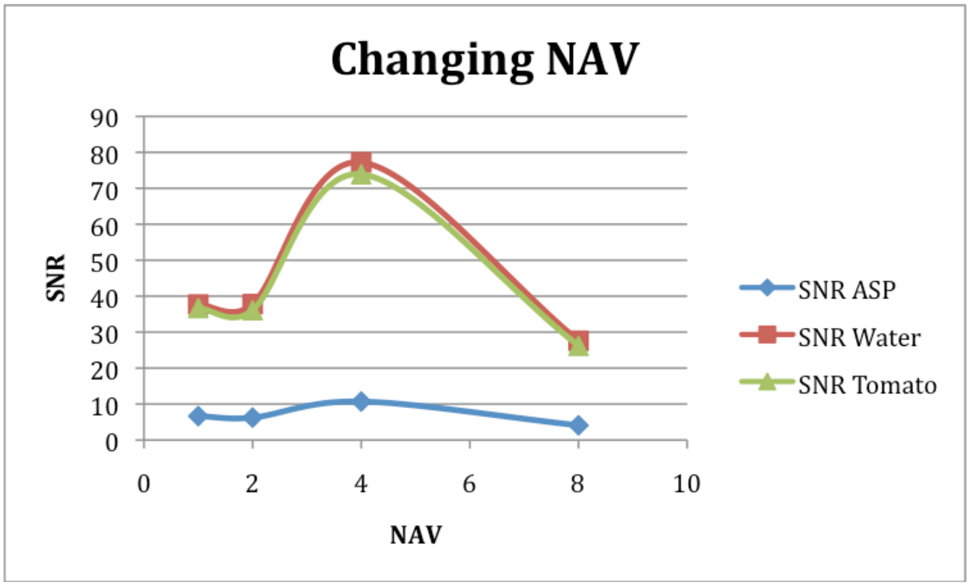

Figure 2.

Changing the slice thickness

256 x 256	Acquisition Time (s)	Repetition Time, TR (s)	Echo Time, TE (s)	
0.5 mm	38.4	0.15	0.008	
	Asparagus	Water	Tomatoes	Air (Noise)
Mean	6.76E+03	3.26E+04	2.49E+04	5.60E+03
STD	3.34E+03	4.31E+03	2.94E+03	4.43E+03
SNR	1.53E+00	7.36E+00	5.62E+00	

256 x 256	Acquisition Time (s)	Repetition Time, TR (s)	Echo Time, TE (s)	
1.0 mm	38.4	0.15	0.008	
	Asparagus	Water	Tomatoes	Air (Noise)
Mean	1.06E+04	5.65E+04	5.18E+04	6.01E+03
STD	5.51E+03	4.27E+03	5.11E+03	3.01E+03
SNR	3.52E+00	1.88E+01	1.72E+01	

256 x 256	Acquisition Time (s)	Repetition Time, TR (s)	Echo Time, TE (s)	
2.0 mm	38.4	0.15	0.008	
	Asparagus	Water	Tomatoes	Air (Noise)
Mean	1.87E+04	1.06E+05	1.03E+05	5.31E+03
STD	6.52E+03	4.50E+03	7.70E+03	2.81E+03
SNR	6.65E+00	3.77E+01	3.67E+01	

256 x 256	Acquisition Time (s)	Repetition Time, TR (s)	Echo Time, TE (s)	
4.0 mm	38.4	0.15	0.008	
	Asparagus	Water	Tomatoes	Air (Noise)
Mean	3.15E+04	2.21E+05	1.90E+05	5.84E+03
STD	1.09E+04	5.70E+03	1.55E+04	2.77E+03
SNR	1.14E+01	7.98E+01	6.86E+01	

Chart 3.

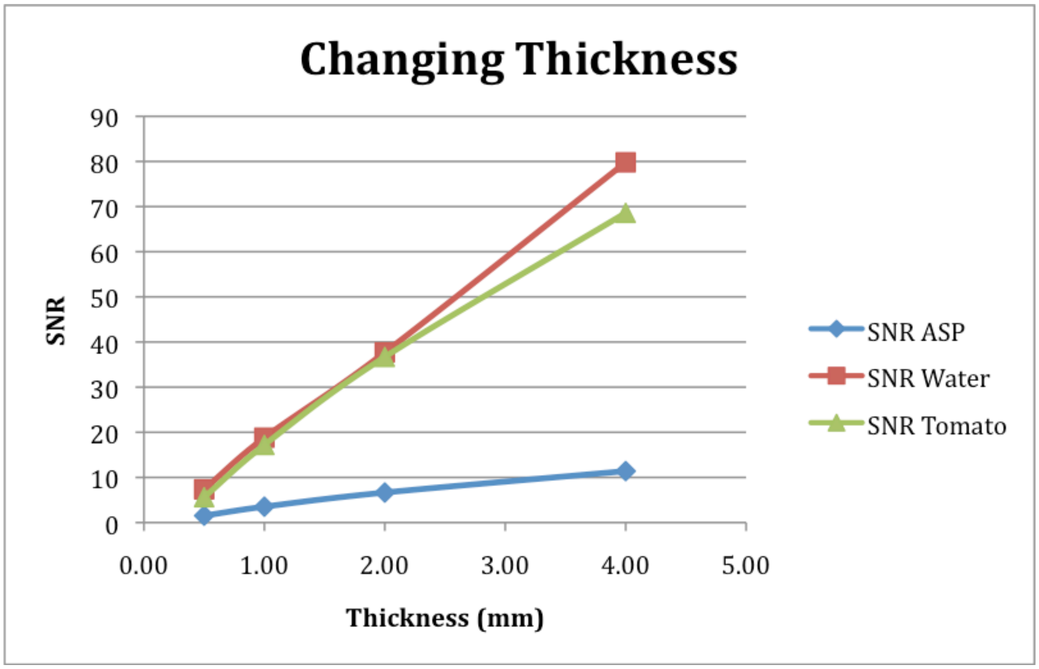

Figure 3.

MRI Data, Image reconstruction

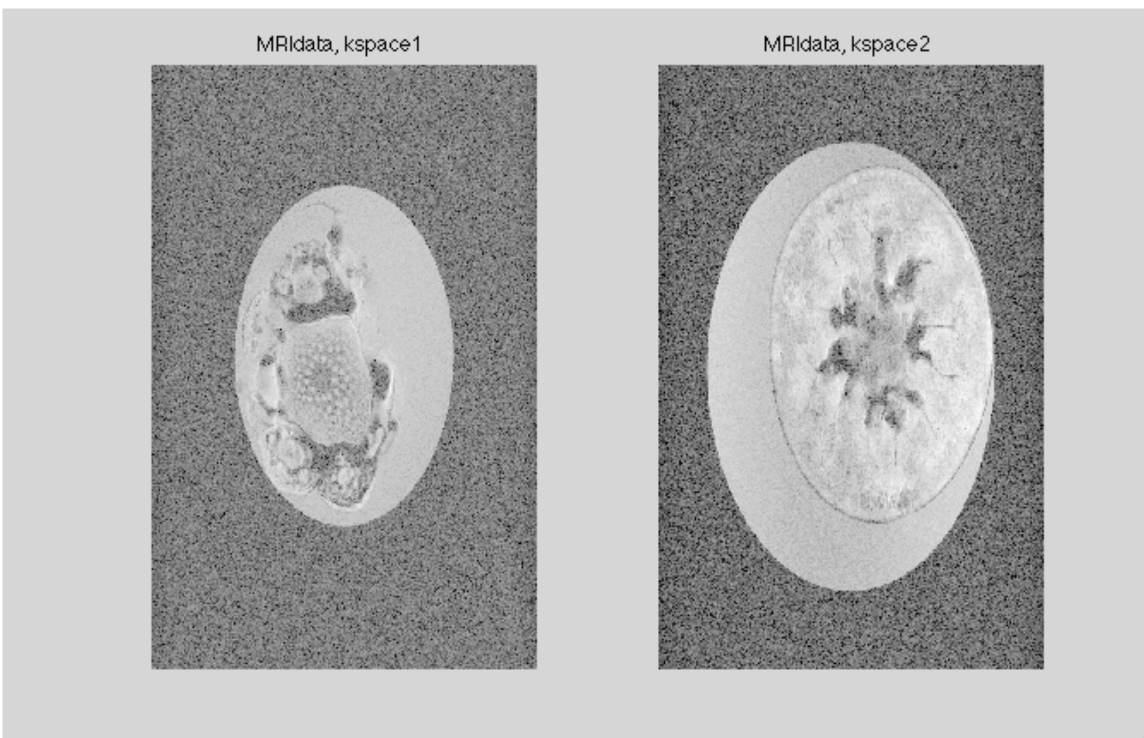

Image 1.

MRI data, alternative k-space lines

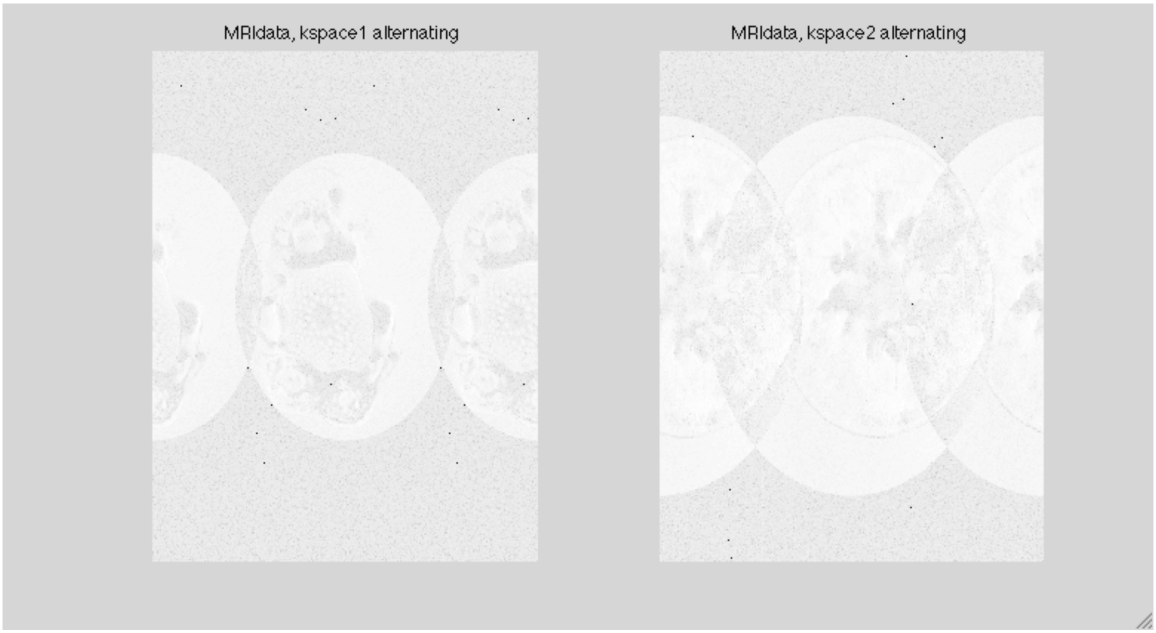

Image 2.

MRI data, central k-space lines 256

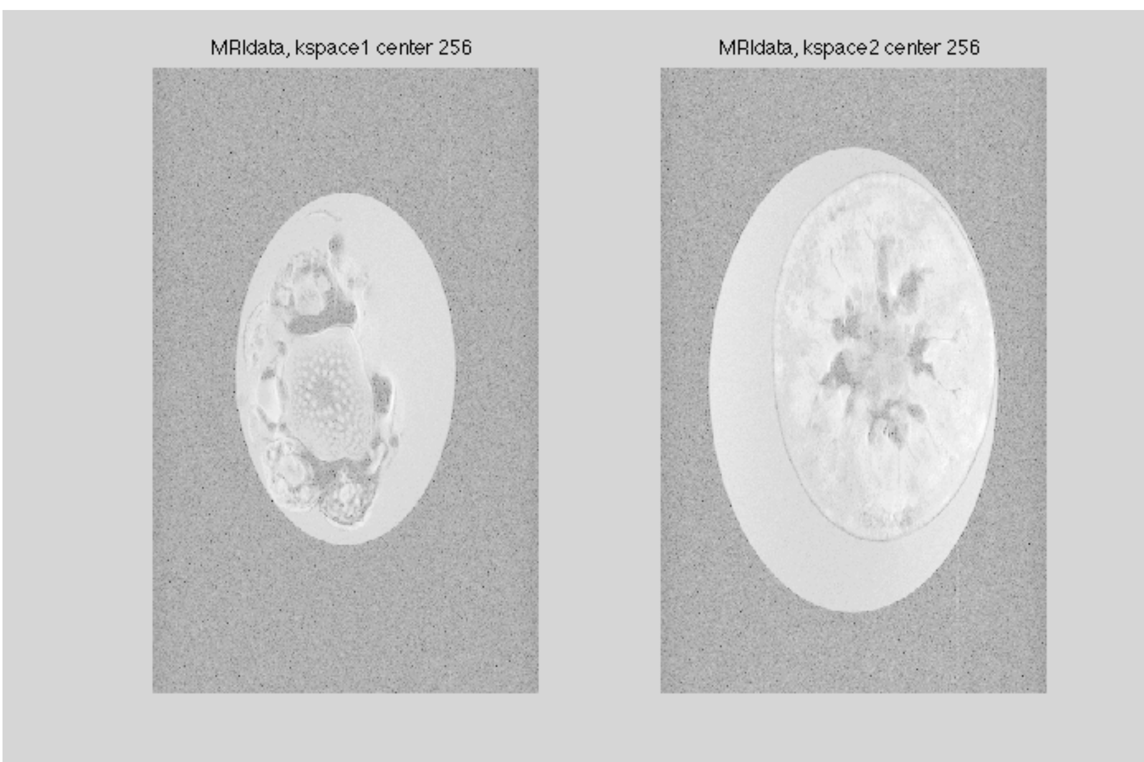

Image 3.

MRI data, central k-space lines 128

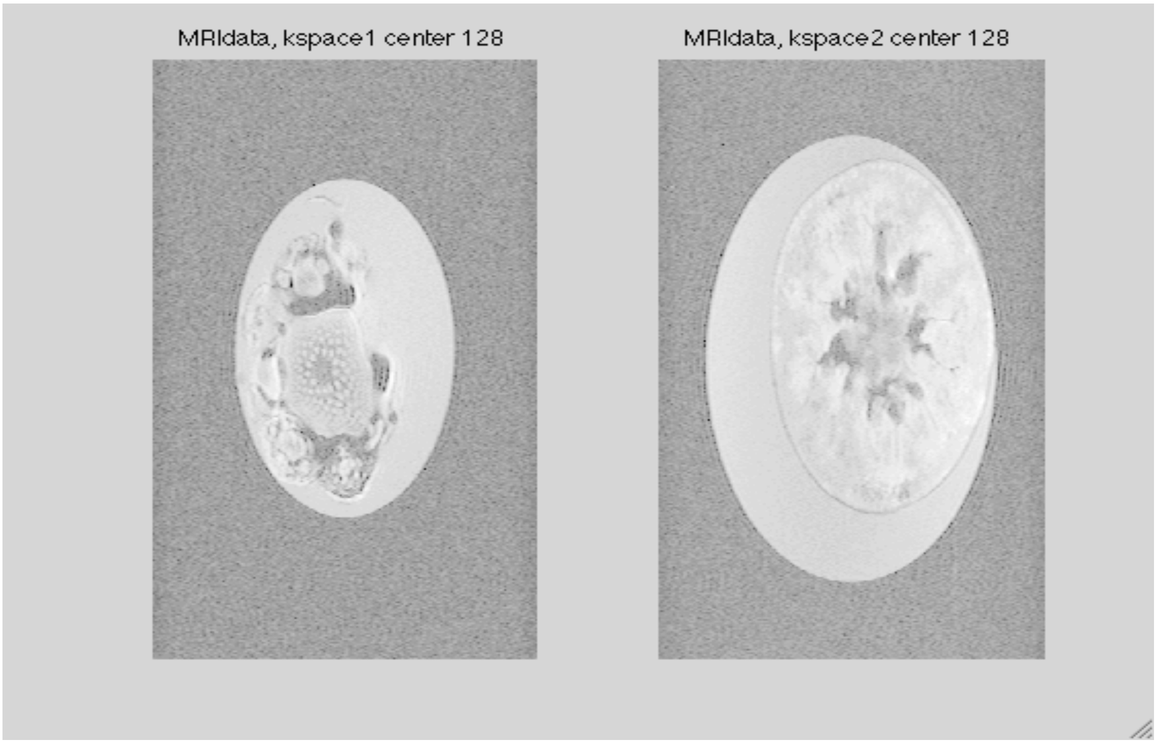

Image 4.

MRI data, central k-space lines 64

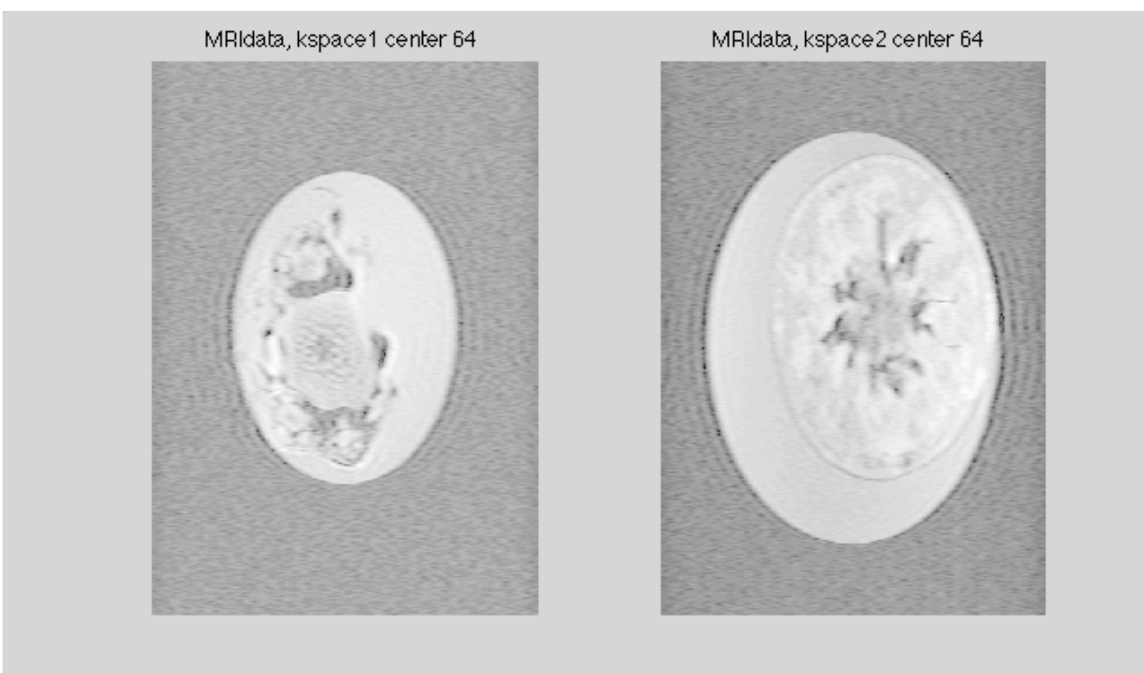

Image 5.

Discussion

From the results, it can be stated that Signal to noise ratio is dependent to the acquisition parameters (in this case, size of the matrix, number of averages, and thickness). The figure 1,2,3 shows their relationship with SNR. Signal to noise ratio in 2D imaging is represented by the equation.

$$SNR \sim \Delta x \Delta y TH \sqrt{\frac{NAV \cdot N_x N_y}{BW_{read}}} \qquad (2)$$

$$T_{acq} = N_y * TR * NAV \qquad (3)$$

In the first part of the experiment, N_x and N_y values were changed through out the trials. Acquisition time of each resolution increases by factor of two as the matrix size doubles. This relationship is clearly shown in equation (3). Since the N_y value doubled, acquisition time is also doubled. Observed from chart 1 and figure 1, SNR value decreases as the matrix size increases. Since the resolution of image has an inverse relationship with matrix size, increase in resolution eventually decreases SNR. As shown in the chart 1, STD value of background keeps on increasing and these results in decrease in SNR

Second part of the experiment deals with number of average values. In the equation (2), the NAV, number of averages, value has direct relationship with SNR value. If NAV value increases, the SNR value has to increase as well. However, shown in figure 2, the SNR value does not increase with the increasing NAV value. According to the equation (2), the SNR value is supposed to increase with the increasing NAV value. Looking at figure 2, when NAV is 8, the data seems to fluctuate. There are some possibilities that wrong data were collected during experiment since all of the subjects showed decreasing SNR behavior at the last point. Considering the acquisition timing, as the NAV value doubles, acquisition time has to double also and it is well shown in the chart (2). The result clearly followed the trend.

The last part of the experiment deals with the slice thickness. According to equation (2), SNR has direct relationship with slice thickness. Increasing slice thickness should also increase the SNR value. As shown in chart 3 and figure 3, the SNR value increases with increasing slice thickness. However, in equation (3), there are no relationship between acquisition time and the slice thickness. This is why changing in slice thickness does not affect the acquisition time.

This lab also demonstrated the effect of data selection in k-space data. image 1 ~ 5 shows how the data selection affects the image. Image 1 includes all the data points and it clearly displays all the data points. However, image 2 uses alternating k-space data points. Since alternating data points were selected, the image seems to duplicate. Clearly, it has lower intensity compared to the image 1. Alternating data points are effective in processing because it takes less time and effort. However, in this case, the alternating data points made to image unclear. Image 3 uses 256 lines of data in the center. All the lines outside of center 256 were set to zeroes. The image is very similar to the image 1 because it aims at the targeted area. Image 4 and 5 uses less data points. In image 4, only center 128 lines were included and in image 5, only center 64 lines were included. As observed from the images, they display the same image however as the data points decreases (number of lines to center decreases) the intensity of image gets low and edge of the image gets more rough. This happens because there are not as many data points to reconstruct the image.

In this experiment, MR Imaging was utilized to understand how MR Imaging works. Main focus was to understand how Signal to Noise ratio related to the acquisition parameters during the data processing. It was observed that number of averages; size of matrix, and slice thickness has direct relationship to the SNR value. These parameters changed SNR as well as the acquisition time. Also manipulating data reconstruction using different data lines showed how selection of data can change the image.

References

Yu, Xin. “Fourier Space MR Imaging: Pre-lab” pp 1-18 (Fall, 2011)

Yu, Xin. “Fourier Space MR Imaging: Post-lab” pp 1-15 (Fall, 2011)

Appendix

```
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%EMBE 318 - Xin Yu Lab

%% Normal
data1 = ifft2(kspace1);
data1 = log(abs(data1));
figure;
subplot(1,2,1)
imagesc(data1);colormap(gray); axis off; title('MRIdata, kspace1')

subplot(1,2,2)
data2 = ifft2(kspace2);
data2 = log(abs(data2));

imagesc(data2);colormap(gray); axis off; title('MRIdata, kspace2')
%% Alternating

altkspace1 = kspace1;
altkspace1(:, 1:2:512) = 0;
data1 = ifft2(altkspace1);
data1 = log(abs(data1));
figure;
subplot(1,2,1)
imagesc(data1);colormap(gray); axis off; title('MRIdata, kspace1
alternating')

altkspace2 = kspace2;
altkspace2(:, 1:2:512) = 0;
data2 = ifft2(altkspace2);
data2 = log(abs(data2));
subplot(1,2,2)
imagesc(data2);colormap(gray); axis off; title('MRIdata, kspace2
alternating')

%% central 256

c256kspace1 = kspace1;
c256kspace1(:, 1:128) = 0;
c256kspace1(:, 384:512) = 0;

data1 = ifft2(c256kspace1);
data1 = log(abs(data1));
figure;
subplot(1,2,1)
imagesc(data1);colormap(gray); axis off; title('MRIdata, kspace1 center
256')

c256kspace2 = kspace2;
c256kspace2(:, 1:128) = 0;
c256kspace2(:, 384:512) = 0;

data2 = ifft2(c256kspace2);
```

```
data2 = log(abs(data2));
subplot(1,2,2)
imagesc(data2);colormap(gray); axis off; title('MRIdata, kspace2 center
256')

%% central 128

c128kspace1 = kspace1;
c128kspace1(:, 1:256-64) = 0;
c128kspace1(:, 256+64:512) = 0;

data1 = ifft2(c128kspace1);
data1 = log(abs(data1));
figure;
subplot(1,2,1)
imagesc(data1);colormap(gray); axis off; title('MRIdata, kspace1 center
128')

c128kspace2 = kspace2;
c128kspace2(:, 1:256-64) = 0;
c128kspace2(:, 256+64:512) = 0;

data2 = ifft2(c128kspace2);
data2 = log(abs(data2));
subplot(1,2,2)
imagesc(data2);colormap(gray); axis off; title('MRIdata, kspace2 center
128')

%% central 64

c64kspace1 = kspace1;
c64kspace1(:, 1:256-32) = 0;
c64kspace1(:, 256+32:512) = 0;

data1 = ifft2(c64kspace1);
data1 = log(abs(data1));
figure;
subplot(1,2,1)
imagesc(data1);colormap(gray); axis off; title('MRIdata, kspace1 center
64')

c64kspace2 = kspace2;
c64kspace2(:, 1:256-32) = 0;
c64kspace2(:, 256+32:512) = 0;

data2 = ifft2(c64kspace2);
data2 = log(abs(data2));
subplot(1,2,2)
imagesc(data2);colormap(gray); axis off; title('MRIdata, kspace2 center
64')
```