IBEHS 4D04: Introduction to Medical Imaging

Lab 5

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Part 1

Commented [TG1]: Changed diffusion gradient direction from x to y -> look tut 6

4.6
Then changed diffusion gradient direction to z

1. What was the calculated Larmor frequency of the water sample, given that the gyromagnetic ratio for a hydrogen nucleus is 42.577 MHz/T. The system has a 0.345T magnetic field. Does this match your experimental Larmor frequency?

$$\omega = \gamma\beta$$

$$\omega = 42.577 \times 0.345$$

$$\omega = 14.7\ MHz$$

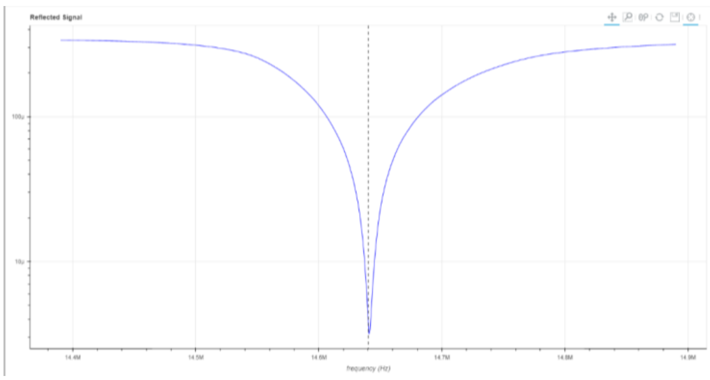

Figure 1: System Resonance Frequency from Wobble Test

The calculated Larmor frequency is $14.7\ MHz$ and the experimental Larmor frequency is approximately 14.64 MHz according to Figure 1. This is an error of approximately 0.06 MHz on a scale of over 14 MHz which is a very small percentage, hence we can conclude that the calculated Larmor frequency of the water sample does match the experimental Larmor frequency.

2. Compare the noise check between the ilumr and Terranova systems (Lab #4). Comment on the possible reasons as to why they are different/similar.

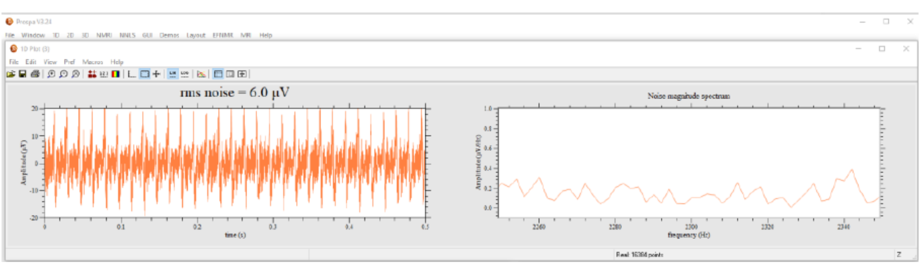

Figure 2: Terranova noise check (Lab 4)

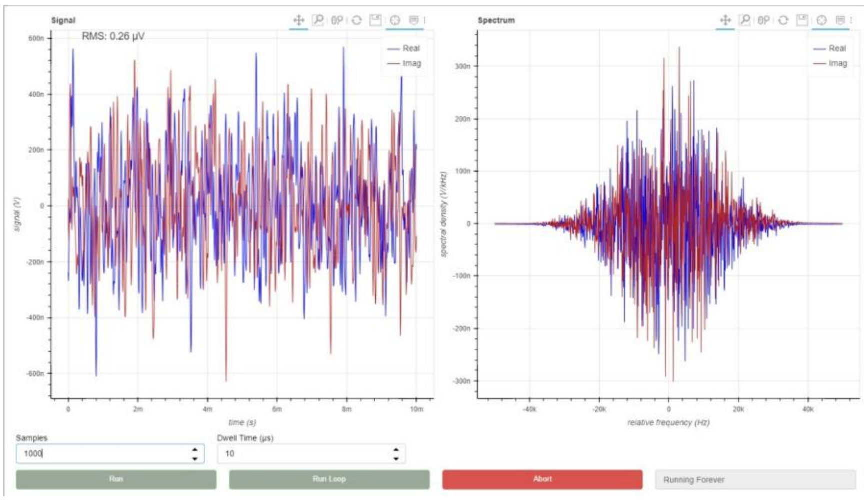

Figure 3: ilumr noise check (Lab 5)

As shown in Figures 2 and 3, the RMS noise of each system differs, the RMS noise for ilumr is 0.26 µV, while the RMS noise for Terranova is 6.0 µV. For both systems, the noise can be mostly attributed to white noise, which is always present in any imaging system. The difference in noise between the two systems is mostly likely due to differences in software and data acquisition, hardware, and different tuning of the RF coils.

3. Briefly describe what is happening during the shimming procedure. What does the shimming plot from step 7 represent?

Shimming is a process used to eliminate inhomogeneities in the magnetic field by applying weak magnetic fields that are position dependent across the sample. Small currents are passed through a group of coils corresponding to the x, y and z field gradients to create magnetic fields that cancel the inhomogeneties.

Figure 4 represents the degree of field homogeneity across the sample. A greater signal sum of squares implies that the magnetic field is more homogeneous. As the number of iterations increase, the signal sum of squares increases as expected. The autoshim process will increase the field homogeneity over the iterations.

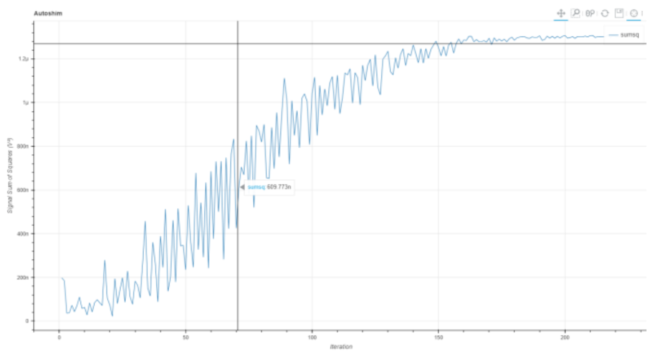

Figure 4: Autoshim Plot

4. Comment on the differences between the FID pre vs post shimming.

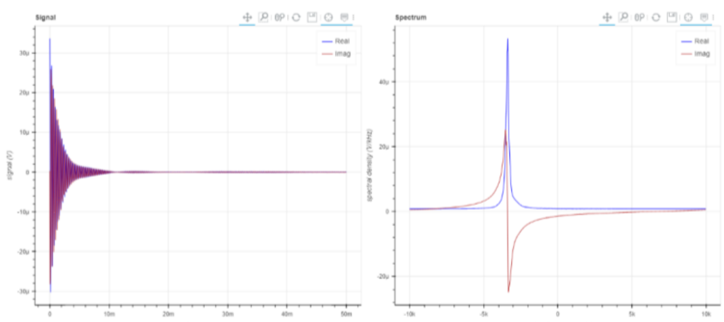

Figure 5: Unshimmed FID and Spectrum of an NMR Sample

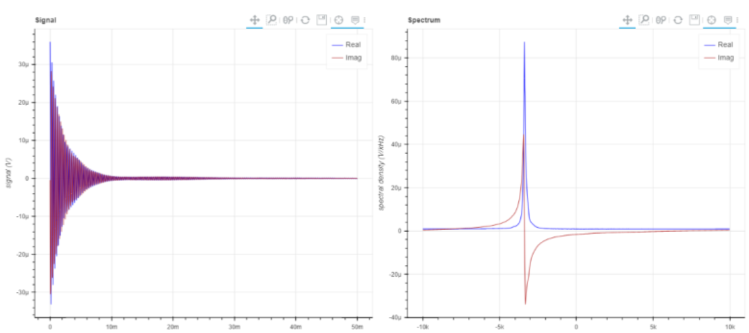

Figure 6: Shimmed FID and Spectrum of an NMR Sample

The shimmed FID seen in Figure 6 has more signal data over time. Shimming improves the resolution by eliminating inhomogeneities in the magnetic field which allows more signal. The shimmed FID has a slightly larger and narrow peak than the unshimmed FID peak which implies that the magnetic field is more uniform after shimming. The field inhomogeneities cause the magnetic moments to spin out of phase which leads to the faster decay seen in Figure 5 of the unshimmed FID.

Part 2

1. How do the 1D images generated by the 1D spin echo and 1D gradient echo pulse sequences compare in terms of contrast and resolution?

Spin echo sequences are typically used for T2-weighted imaging which is characterized by long TR and TE times, emphasizing differences in T2 relaxation times of. Meanwhile gradient echo is the go-to for T1-weighted imaging characterized by short TR and TE times that emphasize the differences in T1 relaxation times and is often used for T2*-weighted imaging. This difference means that spin echo imaging provides good contrast between different types of soft tissues (muscle, fat, organs, etc.) and for differentiating between tissues and fluids. Meanwhile, gradient echo imaging offers good contrast between tissues of different magnetic properties such as oxygenated and deoxygenated blood.

Resolution is determined by the number of points in each dimension of k-space and the field of view. Since in this case we are looking at the 1D images, we only need to look at the number of points in the 1D k-space images. Since spin echo imaging uses two RF pulses instead of the one pulse used my gradient echo imaging, it has longer TE and TR times. The longer signal can lead to a greater spatial resolution in the image compared to gradient echo, increasing the resolution of the 1D gradient echo image. On the other hand, the shorter TE and TR times of gradient echo imaging allows for the image to be developed quicker than with spin echo, at the cost of the resolution of the image [1].

2. How does varying the number of scans affect the image quality in the 1D SE sequence? Provide examples from your experiment to support your answer

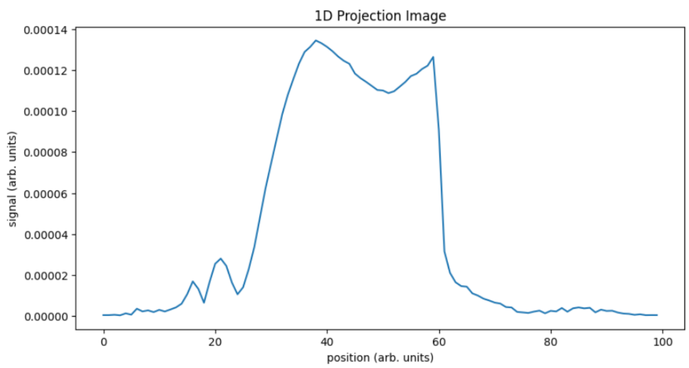

Figure 7: 1D Spin Echo Image Window for 5 Scans

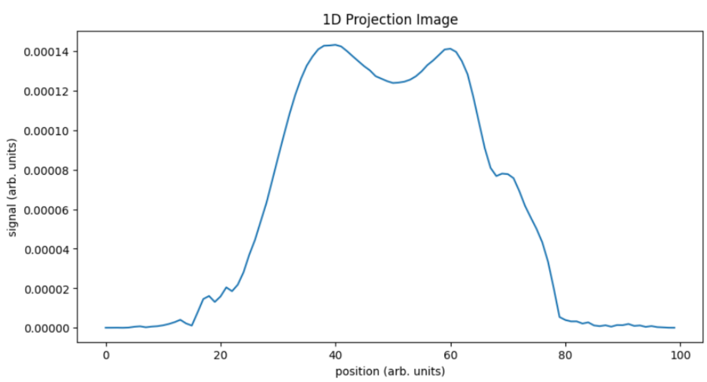

Figure 8: Spin Echo Image Window for 20 Scans

Figure 7 and 8 above show the same 1D projection image of the same sample, but just with different numbers of images. Figure 8 has 20 images vs Figure 7's 5 and this can be used to explain why the line of the graph in Figure 8 is much smoother than the line of the graph in Figure 7. This is apparent around the peaks in the graph, especially the large peak at approximately a position of 60. In Figure 7 it is a lot more of a sharp peak rather than the smooth peak that can be seen in the figure with more images. This increased number of images gives a better image quality, which makes sense as a greater number of scans gives more data points that can be plotted, to create a smoother graph. This can also be seen in the gradient echo images that can in Figures 9 and 10 below. Figure 9's plot was created with 20 scans while Figure 10's was created with 40 scans, with the resolution and all other parameters of the scans remaining the same.

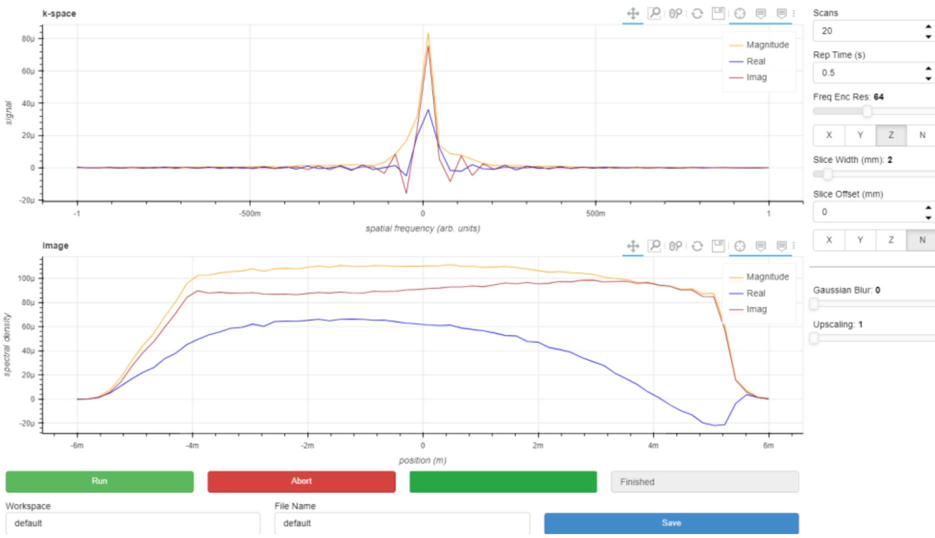

Figure 9: Gradient Echo image with 20 Scans

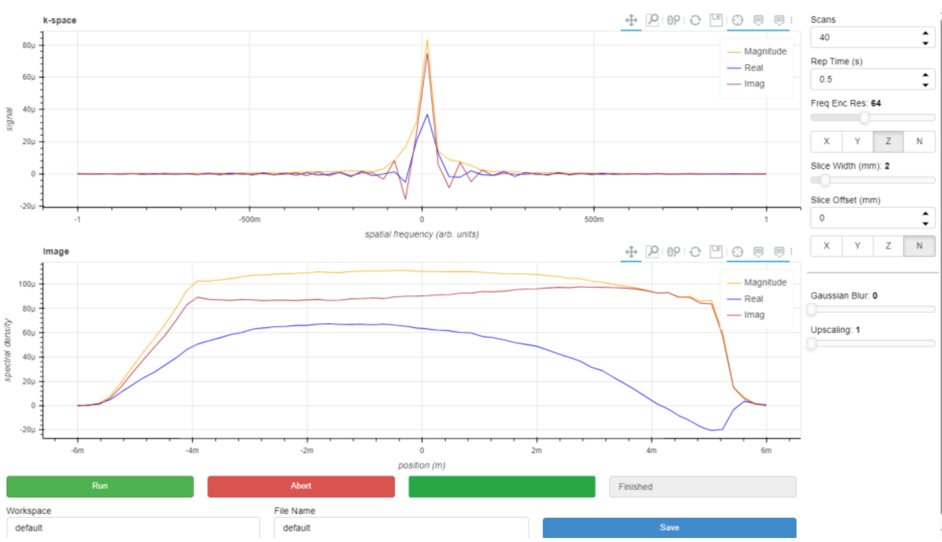

Figure 10: Gradient Echo image with 40 scans

The difference in the number of scans is especially visible in the magnitude plot in the image window. The yellow line is a lot smoother in the image plot that was created with a greater number of scans, once again demonstrating the difference of increasing the number of scans. However, as the number of scans increases, the returns of continuously increasing the number of scans taken on the smoothness of the graph does decrease. Hence why Figure A's 20 scan plots look very similar to Figure B's 40 scan plots. While there is a difference, it does get harder to notice as the number of scans increases.

Part 3

1. Comment on what is happening when you change the FE resolution axis from Z to X? What do you observe when swapping the PE and FE resolution axes?

The X, Y, Z axes are fixed directions with respect to the MRI. With this phantom orientation, the X axis is perpendicular to the frontal plane, the Y axis is perpendicular to sagittal plane, while the Z axis is perpendicular to the transverse plane of the brain. The way MRI images are formed is by frequency encoding in one direction and phase encoding in an orthogonal direction. In the displayed graphs, frequency encoding is always represented by the horizontal axis, while phase encoding is vertical. For that reason, switching the resolution axis from Z to X switches the view from frontal to transverse, while also changing the axis labels to reflect that. While switching one of PE and FE from one axis to the other changes the view plane, simply swapping the two axes uses the same plane but rotates the image.

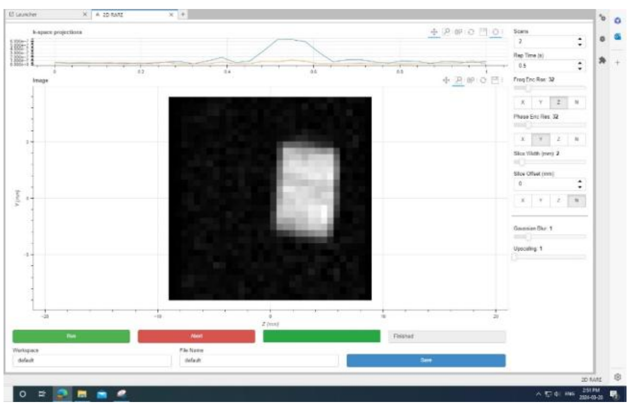

Figure 11: brain phantom with Z-axis FE and Y-axis PE

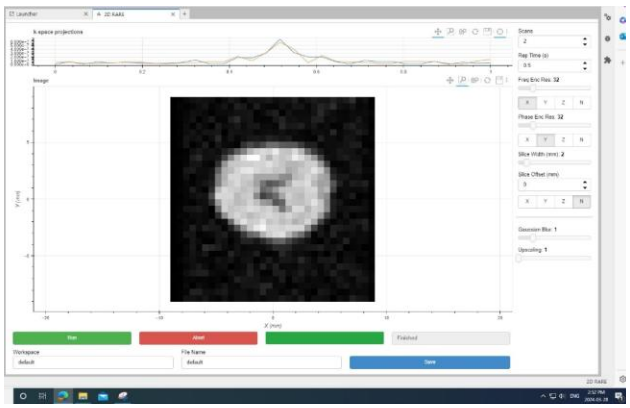

Figure 12: brain phantom with X-axis FE and Y-axis PE

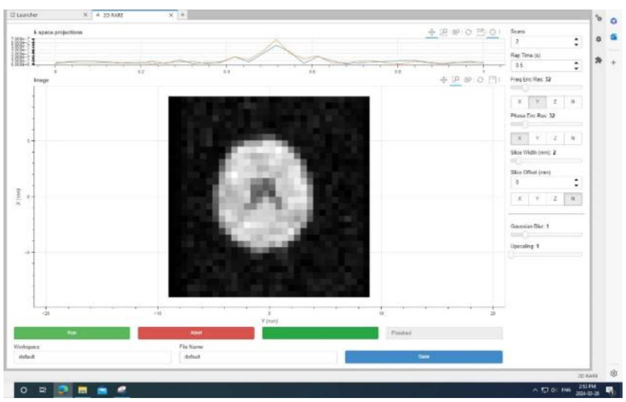

Figure 13: brain phantom after swapping encoding axes – Y-axis FE and X-axis PE

2. What did you notice about the images as you increase the Encoding Resolution? Was there a difference between changing the resolution of the phase encoding versus frequency encoding?

Increasing the encoding resolution in general increased the number of samples and therefore increased the resolution. However, it can be noted that increasing FE resolution alone made the voxels look rectangular rather than square. This is because the resolution was increased in one direction only, making the voxels narrower horizontally while keeping the same vertical height. Increasing both at the same rate maintained the voxel square dimensions, and setting them to their maximum limits makes the voxels small and precise, even though it made noise significantly more prominent.

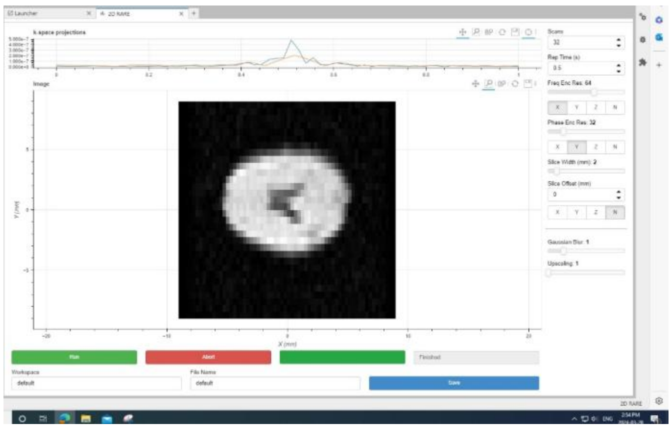

Figure 14: brain phantom after increasing FE resolution

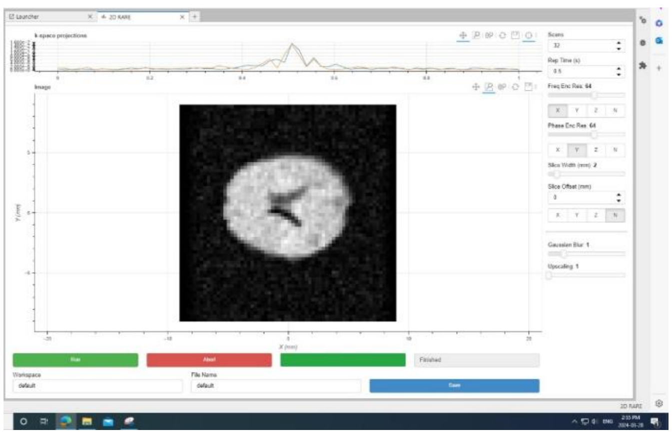

Figure 15: brain phantom after increasing both FE and PE resolutions

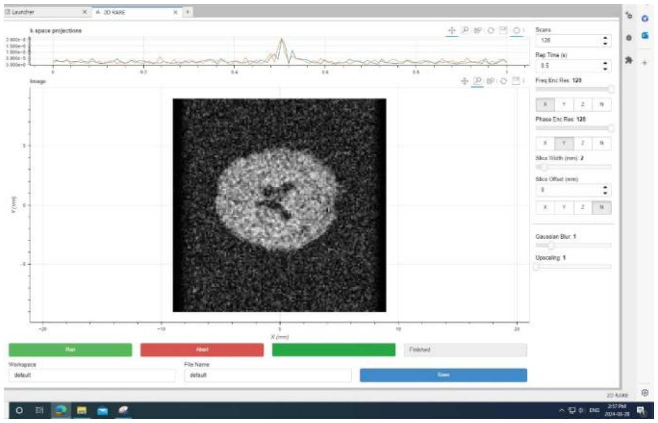

Figure 16: brain phantom after setting encoding resolutions to their max values

3. Given the Encoding Resolution is maxed, how would you further increase the resolution of the image?

By decreasing the slice width and reducing the gaussian blur.

Commented [NA2]: Ik TR prolly impacts SNR but idk if it impacts resolution. I also don't know if num of scans has effect on resolution specifically.

Part 4

1. Look at the diffusion phantom and the 3 subtraction images produced. Comment on the signal similarities and differences between the images, taking into consideration how the structure of the phantom affects the diffusion of water. Pay attention to the signal from the center of the test tube compared to the signal closer to the walls of the test tube.

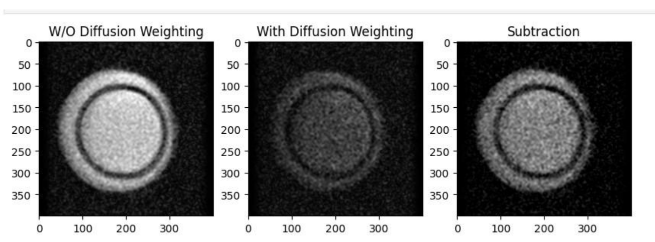

Figure 17: Diffusion Weighing in the X direction

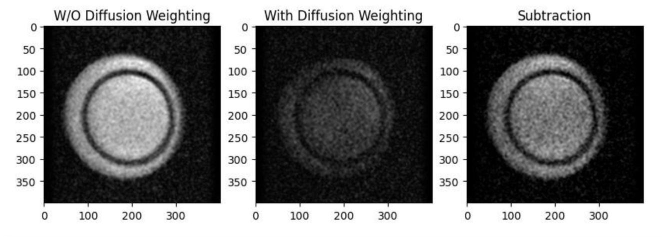

Figure 18: Diffusion Weighing in the Y direction

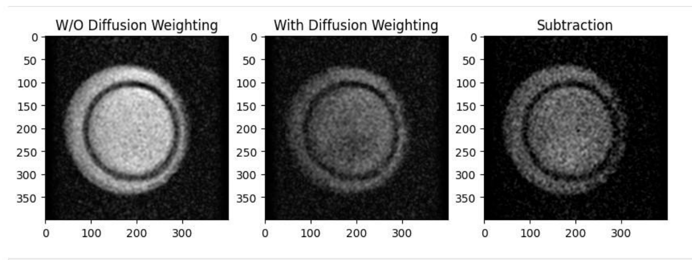

Figure 19: Diffusion Weighing in the Z direction

Water particles in the body are constantly moving or vibrating if their position allows them to. The movement of the water particles can be restricted by tissue or vessels. When the water particles move irregularly, this is called Brownian motion or diffusion. If the diffusion can occur in any direction with equal resistance, the diffusion is isotropic, but if the diffusion faces less resistance in one direction that the other two, this is anisotropic diffusion. When water molecules are restricted, they will be dephased and then rephased to the same degree, resulting in a stronger signal. Alternatively, when the water molecules aren't restricted, they will dephase but move before the next gradient and end up rephasing to a different degree, resulting in a weaker signal.

Areas where the water can diffuse easily will retain less signal, resulting in a darker image. Alternatively, areas of high restriction will retain a lot of the signal, resulting in a light image. There are three directions in which the diffusion gradient could be applied, X, Y, and Z. Due to the shape of our phantom being a tube, one direction will be the length of the tube, while the other two will be the width and the depth. Since the tube cross section is a perfect circle, the width and the depth should appear the same on the MRI since the protons are facing the same amount of resistance in both directions. In theory, the images of Diffusion Weighing in the X and Y directions should be the same shade since width and depth of the tube are the same, and they appear quite similar on the images to confirm this theory. Since the diffusion weighted MRI in the Z direction appears the lightest, it confirms that the Z direction is the length of the tube, since there is a large bundle of string at the bottom cause lots of resistance.

References:

1. Gre V SE. Questions and Answers in MRI. (n.d.). https://mriquestions.com/gre-vs-se.html
2. J. Yap, “Diffusion-weighted imaging: Radiology reference article,” Radiopaedia, https://radiopaedia.org/articles/diffusion-weighted-imaging-2 (accessed Apr. 3, 2024).