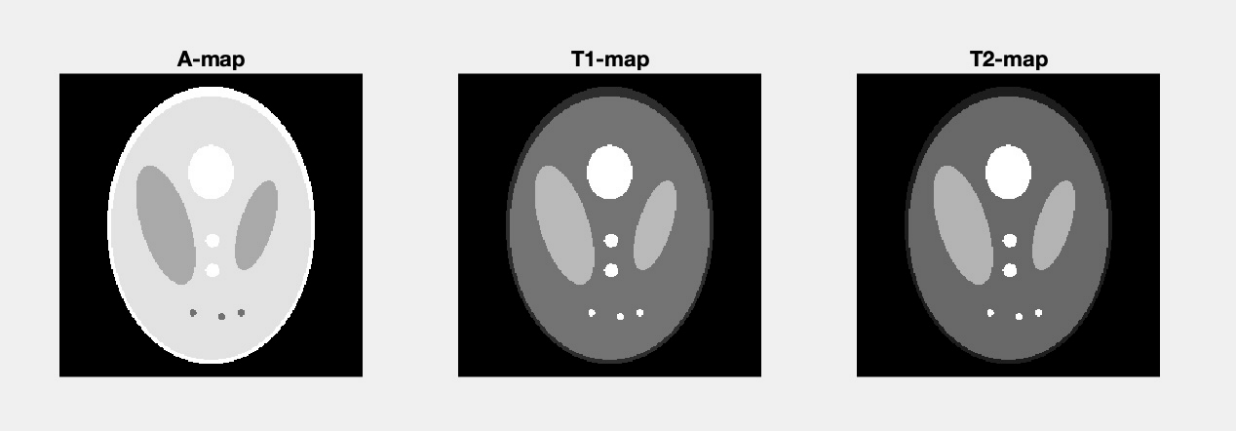
Assignment 2 Report - COSC 4372

Marwan Aridi - PSID 2156027

Introduction

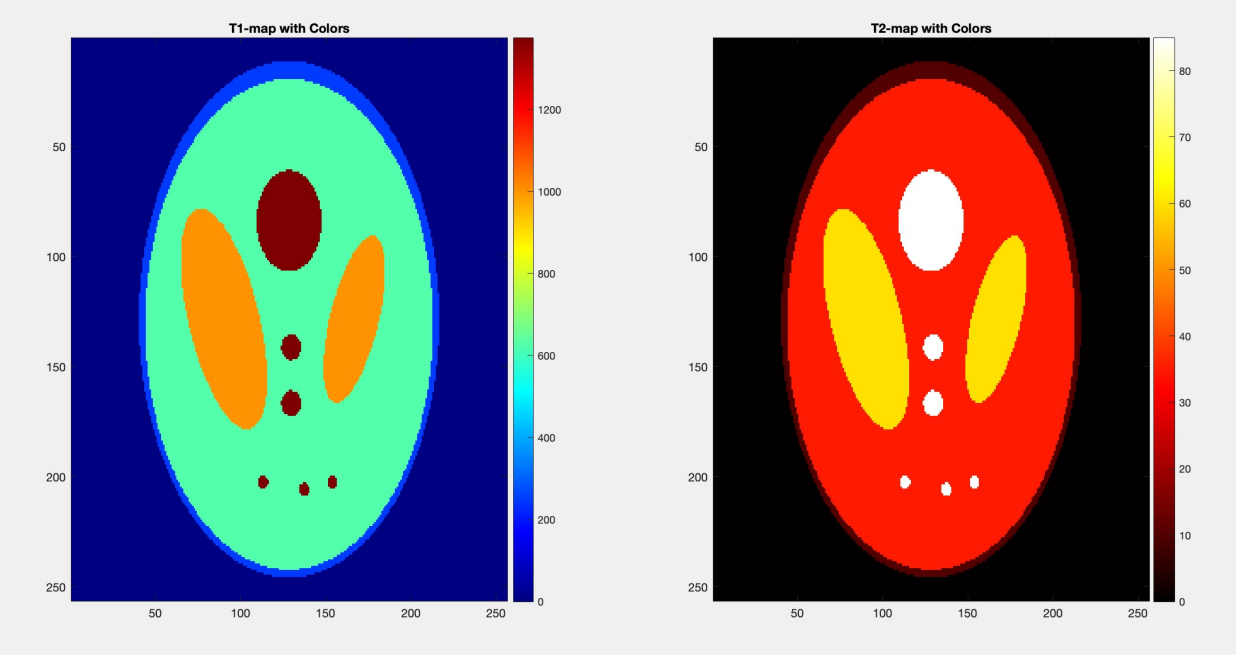
- In this assignment, we did the construction of a virtual MRI scanner based on the modified Shepp-Logan phantom that was made in the previous assignment. The goal was to provide a realistic simulation of an MRI machine by assigning different water content (A), longitudinal relaxation time (T1), and transverse relaxation time (T2) values to each voxel compartment. We calculated the signal intensity (SI) at different scanner parameters (TR and TE) and generated MRI images with these properties. The purpose of the assignment was to analyze the impact of these parameters on the resulting MRI images, allowing us to better understand how tissue properties and scanner settings influence image quality.

Q.1



- **A map**: The A map shows the distribution of water in all the compartments of the modified Shepp-Logan phantom. Each voxel in the phantom is assigned a value between 0.0 and 1.0, where 0.0 means no water and 1.0 corresponds to a voxel containing pure water. The usefulness of this technology is especially in simulating tissue contrasts in MRI images. The amount of water present in a voxel determines the signal intensity in an MRI scan. In the generated A-map, the various compartments are modeled with different A values to mimic different water contents, with the outer parts having greater values and the inner compartments having lower values in a progressive manner.
- **T1-map**: The T1-map describes T1 for each compartment that are calculated using the $T_1 = 250 + (j-1) \cdot 375$ formula where j is the compartment number. T1 is a vital parameter in an MRI scan as it tells the speed at which the protons in tissue align with the magnetic field after turning off the radiofrequency pulse. In the T1-map, the compartments have different T1 values with increasing grayscale intensities showing the long T1 times in various areas of the phantom. This map constitutes a simulation of the relaxation times which help explain the tissues' behavior during MRI scans.

- **T2-map**: T2-map is the output of the equation $T_2 = 10 + (j-1) \cdot 25$, with j being the number of the compartment, calculated for the transverse relaxation time (T2) for each of the compartments. T2 indicates the speed with which protons lose phase coherence and hence how strong the MRI signal is. T2-map also differentiates compartments with unique T2 values just like T1-map, those compartments with longer T2 times are represented by increasing grayscale intensities. This technique is the basis for producing T2-weighted MRI images, the differences of which are caused by the relaxation times of the transverse magnetic field.



- **T1-map (Color)**: The T1-map visualized using the `jet colormap` highlights the variations in longitudinal relaxation times across different compartments of the phantom. The color scheme effectively distinguishes between the regions, with deep blues representing shorter T1 values, progressing to bright reds for the longest T1 values. This range of colors creates an intuitive visual guide, where the cool tones (blues and greens) correspond to faster relaxation times, while the warmer tones (yellows, oranges, and reds) signify slower relaxation times. The central area, displayed in deep red, shows the highest T1 value, while the surrounding regions display a gradient of colors, indicating the gradual increase in T1 times. This colorful representation enhances the ability to quickly identify areas with different T1 properties, which is crucial in MRI analysis for differentiating tissue types based on their relaxation characteristics.

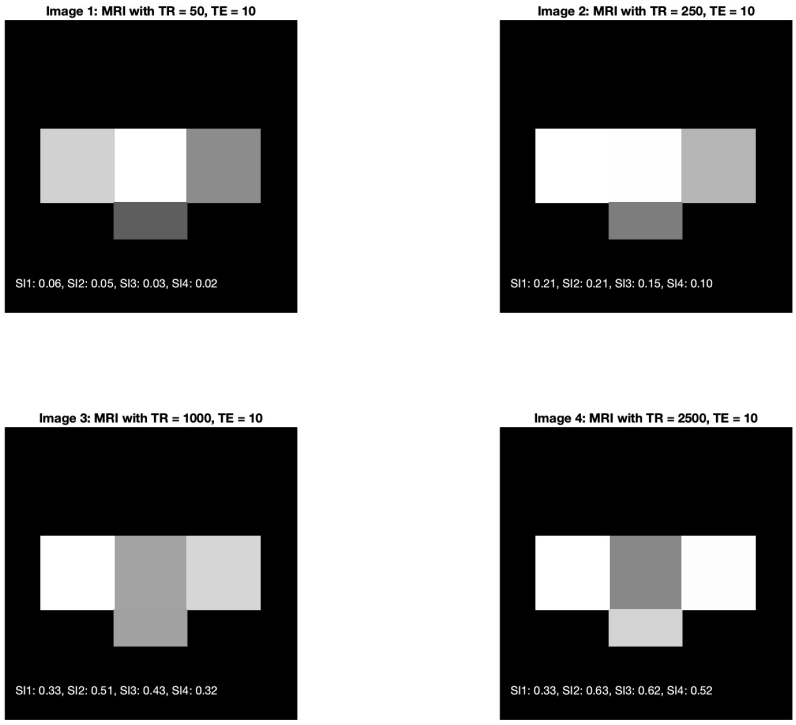
- **T2-map (Color)**: The T2-map uses a `hot colormap` to visualize the transverse relaxation times, in which the brilliant red-to-white scale graphically shows the differences between tissue compartments. The bright white areas are the areas with the largest T2 values, while the darker red and black regions are the places with the shortest T2 times. Through this sharp color differentiation, it is easily seen that partner arrangement is there in the phantom, with larger compartments showing a gradient of red-yellow shades, and the central and smaller regions appearing in bright whites and yellows. The hot colormap is the best for T2 representation, as it gives an immediate intuitive grasp of the relaxation dynamics by the transition of colors from dark to light. It serves to separate the tissues with faster decay from those with slower decay, which is a crucial aspect when analyzing T2-weighted MRI images.

Q.2.1

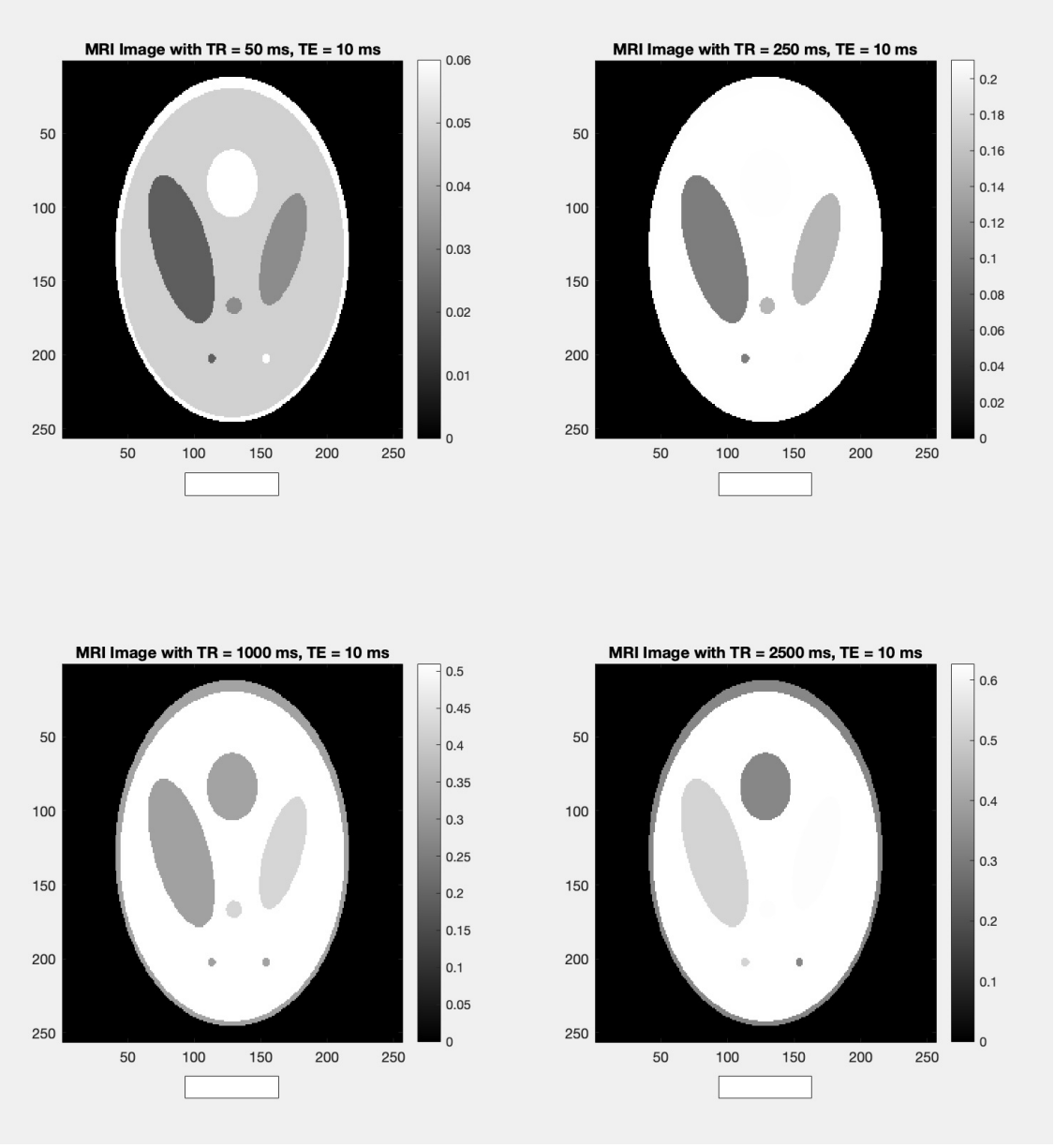
Table 1: Compartment Data

Compartment	A	T1	T2	SI1	SI2	SI3	SI4
1	0.90	250	10	0.0600167	0.2092897	0.3250273	0.3310765
2	0.85	625	35	0.0491099	0.2105849	0.5097931	0.6270565
3	0.80	1000	60	0.0330267	0.1497929	0.4280628	0.6215986
4	0.70	1375	85	0.0222228	0.1034567	0.3215926	0.5212936

Q.2.2

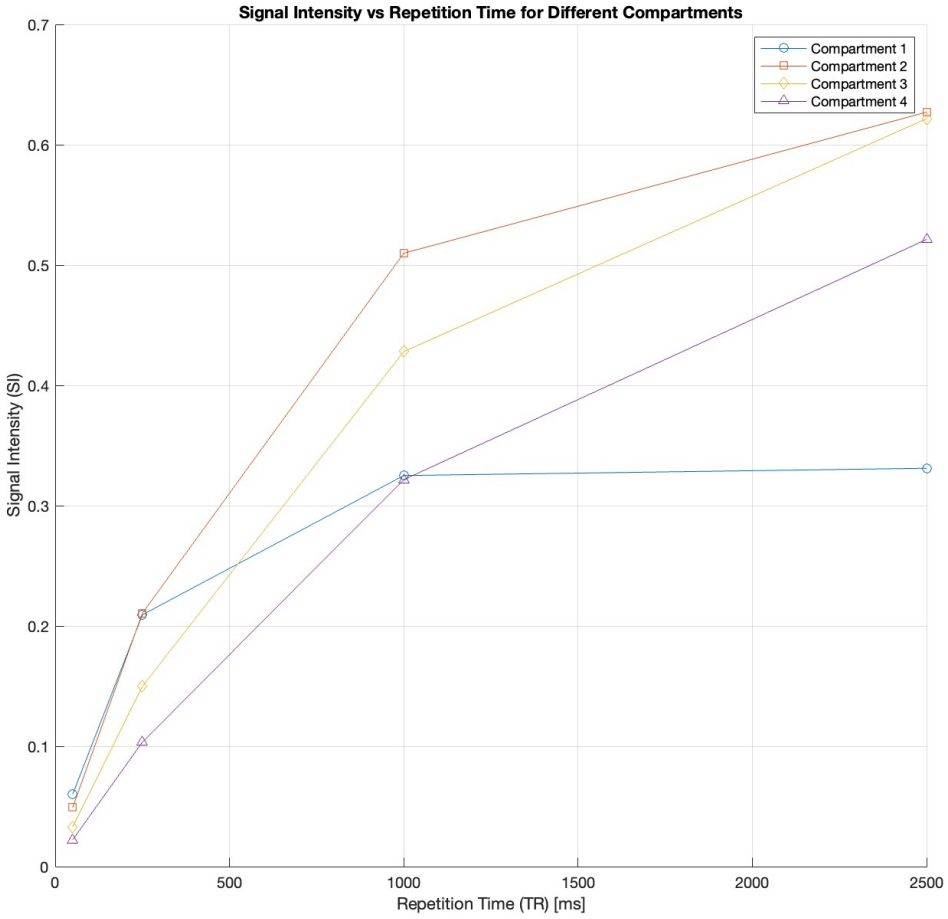


- The four MRI images generated show our observations on the effect of the TR (Repetition Time) variation and TE (Echo Time) constant 10. As TR increases from 50 to 2500, the signal intensity (SI) values for each compartment gradually increase, illustrating the influence of tissue relaxation time on MRI signal acquisition. In this case, compartments containing more water (A) signal a greater increase in diameter with TR increasing and show that these tissues decay at different rates. The first image, having the lowest TR, shows the faintest intensity, while the fourth image, with the highest TR, demonstrates the most evident contrast across compartments. These findings highlight the necessity of the adjusting TR parameter for the enhancing of the tissue contrast in MRI scans.
- Now, when we apply these parameters to the phantoms, this is what we get:



- This figure shows four different MRI images obtained through different acquisition parameters of TR (Repetition Time) and TE (Echo Time). The TR values for each of the images were (50 ms, 250 ms, 1000 ms, and 2500 ms) whereas TE was constant at 10 ms. The image color bars on the left are the grayscale ones and they show the signal intensity (SI) levels in the phantom compartments, with the brighter areas being the higher signal intensity. With TR going up, the image's signal intensity seemingly increases, especially in the midsections, which is a direct manifestation of longer TR values in signal acquisition in MRI. Through this, we see that the different properties of the tissue, which are defined by the relaxation times (T1 and T2) time constants, are responsible for the signal intensity variation under different scanning conditions. Here, you can see the effect of TR and TE values tuning on MRI scans, and the fact of different tissue contrast optimization.

Q.2.3



- **Observation**: The higher the value of TR (Repetition Time), the more the signal intensities (SI) for all compartments seems to be in the same direction. This is essentially in connection to a magnetization recovery which is a phenomenon in MRI. It describes there are not enough time intervals for the tissues to recover during a period of time and thus, the signal strength will be decreased. The situation is totally different at low TR values (like 50 ms) where the signal intensities are considerably lower all across the compartments. Thus, a situation of incomplete recovery of magnetization occurs which leads to decreased contrast and weaker signals. The situation is totally different at low TR values (like 50 ms) where the signal intensities are considerably lower all across the compartments. Thus, a situation of incomplete recovery of magnetization occurs which leads to decreased contrast and weakened signals. The property of TR is that it may start (to) increase (to) 50 ms, 1000 ms and finally TR 2500 ms. Signal intensity is greatly enhanced in this case with Compartment 2 and Compartment 3 being the cases which experience the greatest rises during TR = 50 ms and TR = 1000 ms. They displayed these features primarily due to tissue properties such as relaxation time T1 and hence increased benefits from the extended TR periods. On the contrary, Compartment 1 reached a nearly maximum signal intensity at TR = 250 ms and then experienced a plateau, which is a sign of the tissue in a compartment that is recovering its signal faster. There is a situation where if the TR increasing beyond a certain level the amount of SI will be gaining only decreases, such an effect is usually seen at most compartments particularly after TR = 1000 ms. Generally, the effect of higher TR is unambiguous: the higher

TR values provide more complete recovery of the tissue magnetization thereby increasing the signal intensities and the image contrast. But the effect during the time period is plateau as the tissues achieve their signal recovery maximum capability at longer TR values. This brings out clearly the need for proper TR values being chosen in correspondence to the desired contrast and the specific tissues that are being imaged in MRI.

Q.2.4

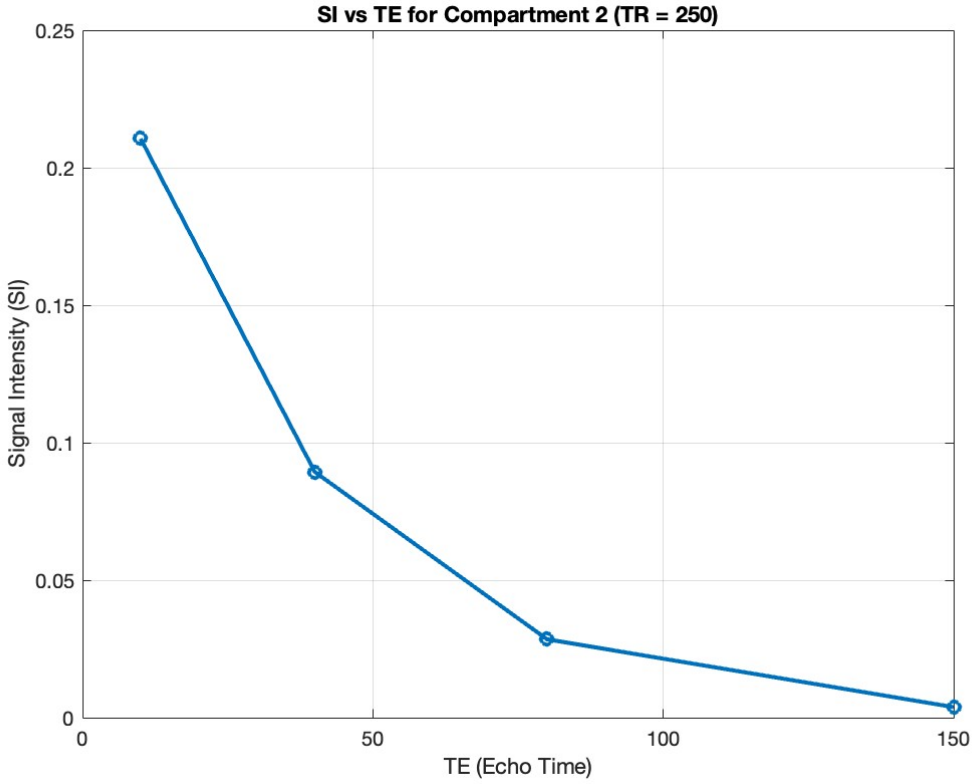


Table 2: Table of TE vs SI for Compartment 2 (TR = 250)

TE	SI
10	0.210580
40	0.089367
80	0.028500
150	0.003857

- As TE is increased, the signal intensity (SI) in the second compartment decreases as expected according to the T2 effect causing signal relaxation. The sharper variation in SI is mostly happened between TE = 10 and TE = 40, where the signal has the speed of early transverse relaxation decay which predominantly is responsible for small transverse signal. The SI fades generally slower after TE = 40, however, it still drops as TE progresses, to the point of very low signal at TE = 150. This behavior is in accord with the T2 relaxation feature of Compartment 2, where longer TE raster opens the scheme wider for signal decay. The T2 of 35 ms being exceeded leads to a reducing of signal intensity inducement quickly due to appropriate relaxation properties of the tissue which is exactly similar to

the case here. On the contrary, a linear decay is encountered, the latter of which is anticipated because less transverse magnetization remains for longer TE times as TE increases. In brief, the higher TE, the more SI reduction is obtained, and a shorter TE is the primary choice to secure the remaining signal, which highly depends on the imaging requirements.

Q.3.1

SSIM values that I got from MATLAB Command Window:

```
SSIM between Image 1 and Image 2: 0.6954
SSIM between Image 1 and Image 3: 0.5537
SSIM between Image 1 and Image 4: 0.5384
```

- To calculate the SSIM values, the code from Q.2.1 was modified to include the computing of the Structural Similarity Index (SSIM) between different pairs of generated MRI images. The generated images from Q.2.1, which are related to four different TR values (50 ms, 250 ms, 1000 ms, and 2500 ms), were used as the input images for the SSIM calculation. By using the built-in MATLAB function `ssim()`, the structural similarity was determined by comparing Image 1 with each of the subsequent images (Image 2, Image 3, and Image 4).
- The SSIM is the index by which two images' both similar and dissimilar features can be assessed - such as luminance, contrast, and structure. A value of 1 indicates two identical images while the value closer to 0 suggests images are not similar. In this case, the SSIM values of the images conformed to the trend of decreasing as the TR was increased, which means that with the increasing TR, the images' structures became more different. The reason is linked to the way the repetition time causes tissue relaxation to behave during MRI acquisition. Because of the longer TR values, the signal from the different tissue types changes with varying intensity distributions, and therefore, SSIM values are lower. Accordingly, with the signal Image 1, and Image 2 was the highest (0.6954), but it then dropped to 0.5537 (Image 3) and 0.5384 (Image 4) which shows the increasing TR value structural dissimilarity.

Conclusion

- In conclusion, the investigation of the influence of TR and TE on signal intensity (SI) points out the essential function of these parameters in MRI imaging. This is achieved by enabling more longitudinal magnetization recovery when TR is increased, leading to a gradual increase in SI, which after a while remains constant since complete recovery has been achieved. On the other hand, increasing TE results in a rapid fall of SI due to the T2 relaxation effect, where the signal intensity remains unaffected at the shorter TE values and is gradually reduced at the longer ones. The results highlight the need for a careful selection of TR and TE values to get the maximum contrast and the strongest signal in MRI images, which is dependent on the type of tissue examined. The option to adjust these parameters makes it possible to capture the needed contrasts of the tissue, thus, MRI is a versatile equipment in medical imaging. The right choice of these values is a prerequisite for the generation of high-quality images that are true to the actual tissue properties.