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The Silent Acoustic Noise Protocol of Magnetic Resonance Imaging Examination in the Case of Head Image

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ABSTRACT

Introduction: Health examinations are performed every six months. X-rays, magnetic resonance imaging (MRI), ECGs, and blood tests are all part of health examinations. In this investigation, the silent T2 Fast-Spin-Echo (FSE) and Gradient-Recalled Echo (GRE) MRI head examination sequences are compared. Noise is produced during an MRI test in addition to images.

Material and Methods: This research was conducted by adjusting the parameters on the MRI, such as time repeat (TR), time echo (TE), and echo train length (ETL). Then, the resulting silent sequence image is simulated with a simulation program.

Results: The variation of TR 440 with TE 24 in the GRE sequence for the white matter (WM) tissue has the highest signal to noise ratio (SNR) value. The cerebispinal fluid (CSF) tissue is also in the TR 560/TE 20 variant at the same time. Then, variations of TR 3360, TE 97, and ETL 33.6 have the highest peak signal to noise ratio (PSNR) measurement results in the WM or CSF tissue.

Conclusion: According to the study's findings, the average sound intensity level and mean square error (MSE) value produced by the GRE sequence protocol are less than those produced by the T2 FSE sequence protocol. While this is the case, the GRE sequence protocol generates an average PSNR value that is higher than the FSE T2 sequence protocol. The T2 FSE sequence with variations of TR 3360, TE 97, and ETL 33.6 may then be observed to be the best with the ideal noise level and SNR value.

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Introduction

Humans need to have good health. Without excellent health, humans cannot function adequately in their daily duties. Therefore, it is advised that health examinations be performed every six months. Human health security is the goal here. Blood tests, X-rays, ultrasounds, electrocardiograms, and MRI are all part of routine health examinations. Despite taking longer to image, MRI has much better imaging capabilities than CT. The magnetic resonance property of protons (H ions) is the foundation of MRI, which takes advantage of protons' pervasive presence throughout the human body, including the brain. The absence of radiation risks is another benefit of MRI, although it entails safety issues related to the use of an ultra-high-power magnetic field [1]. For some functional magnetic resonance imaging (fMRI) studies, especially those targeting the central auditory system, the high-level sound, or "acoustic noise," created by the imaging apparatus can be problematic. especially at high frequencies, where fMRI noise is most intense. Although it is well known that the ear canal, the head, and the body can all influence how sound is perceived [2]. The sound pressure on a logarithmic scale called the linear sound pressure level (SPL). SPL is expressed in decibels (dB) [3]. This loud knock noise can cause the gradient coil to move[4]. The movement of the magnetic coil is due to a modification of the parameters during imaging [5].

Clinical MRI pulse sequence noise levels can reach 100 to 120 dB. If not appropriately protected against, this can result in temporary or even permanent hearing damage [6]. In general, the way to reduce noise is to use earplugs, earmuffs, and a helmet during the scanning process. This is so that the sound produced by the MRI may be muffled by the ear protection material, which can also control vibration and pulse changes. The patient's comfort is still nevertheless disturbed by this acoustic noise [7].

Based on previous research [5-7], the parameters used in the MRI examination process affect acoustic noise, such as TR, TE, field of view (FOV), and section thickness [9]. In addition, there are also alleged temporary factors that cause noise, namely the influence of the TR, TE, Flip Angle (FA), and ETL

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parameters. Based on this preliminary assumption, an examination will be done using the GRE and T2-FSE sequences. This will be followed by an in-depth analysis of the effect of these parameters and making improvements through application to get the right parameter settings with low noise intensity for head examination. Yamashiro et al., have conducted research on reducing MRI acoustic noise on the human head using the ComforTone Scan with magnetic gradient waveform control [8]. In the study, it was found that the acoustic noise from MRI was significantly reduced by ComforTone Scan ($p < 0.01$).

This study differs from previous ones because fat suppression techniques or suppressing fat signals were employed to widen the gap between the fluid and fat signals so that the level of fluid collection and relief could be seen. This is due to the hyperintensity status of the fat and fluids in the T2 FSE image. In order to create an image with a superior signal-to-noise ratio than T2 fat saturation, this study applied a novel technique called the T2 multi-echo data image combination. This is because the system's flow compensation has been activated, which can lessen the impact of joint fluid and blood flow on scanned objects and limit the effect of image noise.

Additionally, compared to the new method using the T2 multi-echo data image combination, the T2 fat saturation is utilized to make images have a louder sound. This is so that the primary multi-data image combination T2 sequence can maximize the exposure of a single radiofrequency wave while utilizing a gradient field of strength. The magnitude of the energy is then reduced to less than 90 degrees as a result of the gradient field and excitation angle. Then, the T2-multi-echo data image combination's data collection pace will be faster to complete the generation of images.

The T2 sequence fat saturation, meanwhile, continually focuses on radio frequency so that the object being crawled's vibrating effect is more pronounced and can result in a louder sound. The excitation angle and Lorentz force, which cause the energy to be 180 degrees more significant, are to blame for this. In order to test the T2 fat saturation and T2 multi-echo data picture combination sequences in this work, the strongest parameters that can influence how loud the MRI loud noise is were identified. Use the MATLAB (Matrix Laboratory) program to mimic those input variables after that.

Materials and Methods

This research was conducted at the Brain Clinic Surabaya, which has obtained patient approval through informed consent The research protocol has also received ethical approval from the health research ethical clearance commission number (034/HRECC.FODM/I/2022). The investigation was carried out over the course of seven months, utilizing a GE Signa HD MRI field with a crucial field of 3 Tesla. Three patients' head pictures representing the examination findings were employed as the data source. As illustrated in Figure 1, each patient had a GRE and T2 FSE examination utilizing multiple variations of each patient-specific parameter. The TR varied in the sample with the T2 GRE, among other places, at 440 ms, 560 ms, and 660 ms. Each TR was conducted using different TEs, such as 16 ms, 20 ms, and 24 ms.

Additionally, each TR contains different FA values, such as 16, 20, and 24. Following that, the TR variation for the T2 FSE sequence sample is 3360 ms, 4200 ms, and 5040 ms. Each TR was carried out using different TEs, such as 77.6 ms, 97 ms, and 116.4 ms. Each TR was also subjected to ETL variants, including 22.4, 28, and 33.6.

Each variation's scan generates ten image slices. However, only one photograph was captured, and it amply demonstrated the network. The image was converted to determine its magnitude. The magnitude value is then used to calculate the sound intensity level. Then the MATLAB tool was used to calculate the MSE and PSNR values from the grayscale image. The findings served as a guide for the inspection process' utilization of acoustic noise. Equations (1) and (2) are used to calculate MSE and PSNR (2).

$$MSE=\frac{1}{m\times n}\sum_{i=0}^{n-1}\sum_{j=0}^{m-1}\left[f(i,j)-g(i,j)\right]^2 \tag{1}$$

$$PSNR=10\log\frac{255^2}{MSE} \tag{2}$$

The SNR value is also determined using the ROI (region of interest) technique [12]. Then, by using equation 3, the SNR value is obtained by measuring image quality. White matter and cerebrospinal fluid in the head are the two tissues to be examined.

$$SNR=\frac{S(Signal)}{N(Noise)} \tag{3}$$

In this study, the grayscale image matrix is directly transformed into a column vector form without first going through the segmentation stage.

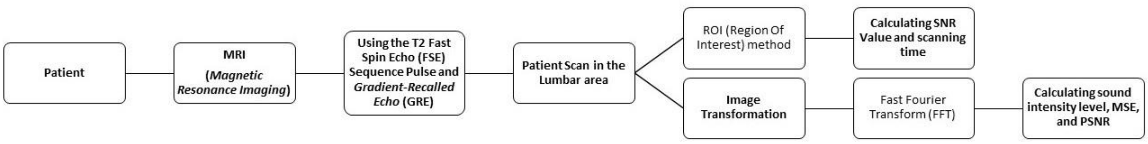

Figure 1. Block diagram of the research methodology

The fast fourier transform (FFT) is then used to transform. The grayscale picture matrix's entire pixel information is processed in order to improve the accuracy of the calculation of the sound intensity level, eliminating the need for the segmentation stage.

Results

Image Acquisition

One of three patient heads obtained by two sequence protocols GRE and T2 FSE was used to create the image. Ten images on the axial plane were produced during the image capture process for each patient. Head images from the GRE and T2 FSE sequences are shown in Figure 2.

Image Transformation

The FFT is used to transform the examined image into the frequency domain. At each frequency, a magnitude value is derived based on these adjustments. The sound intensity level is then calculated using logarithmic formulae in order to obtain the value of the sound intensity level in dB units.

A graph showing the magnitude of the imagery in the frequency domain on the GRE sequence can be known based on figure 3(a). Figure 3 (b) shows the sound intensity level generated by the GRE sequence to be 145.36 dB. The magnitude of the images in the frequency domain on the T2-FSE sequence can then be determined using figure 4(a). The T2-FSE sequence's generated sound intensity level is shown in figure 4(b) as 153.9938 dB.

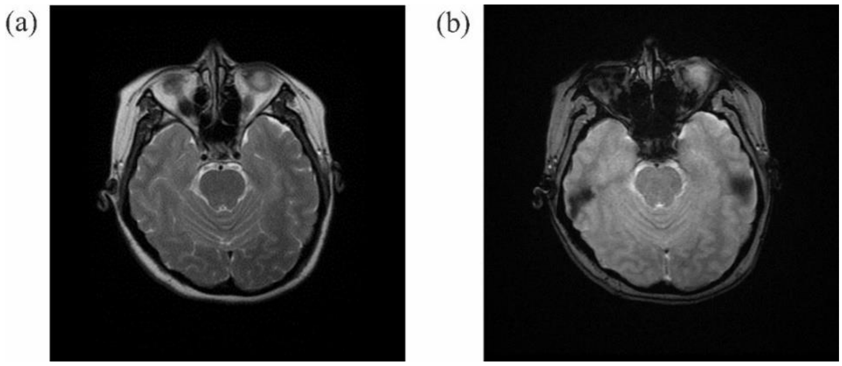

Figure 2. (a) Head image with GRE sequence protocol, (b) Head image with T2-FSE sequence protocol

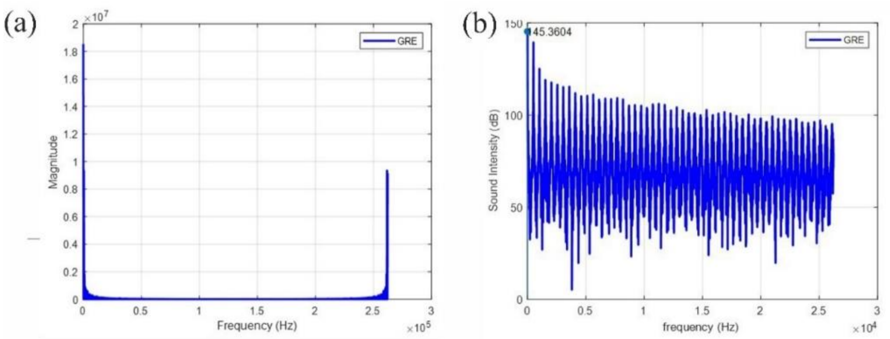

Figure 3. (a) Graph of image magnitude in frequency domain (GRE), (b) Graph of sound intensity level of head imagery with GRE sequence protocol

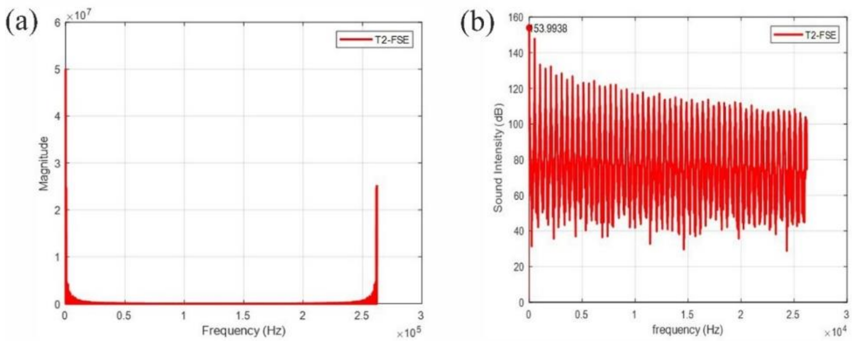

Figure 4. (a) Graph of image magnitude in frequency domain (T2-FSE), (b) Graph of sound intensity level of head imagery with T2-FSE sequence protocol

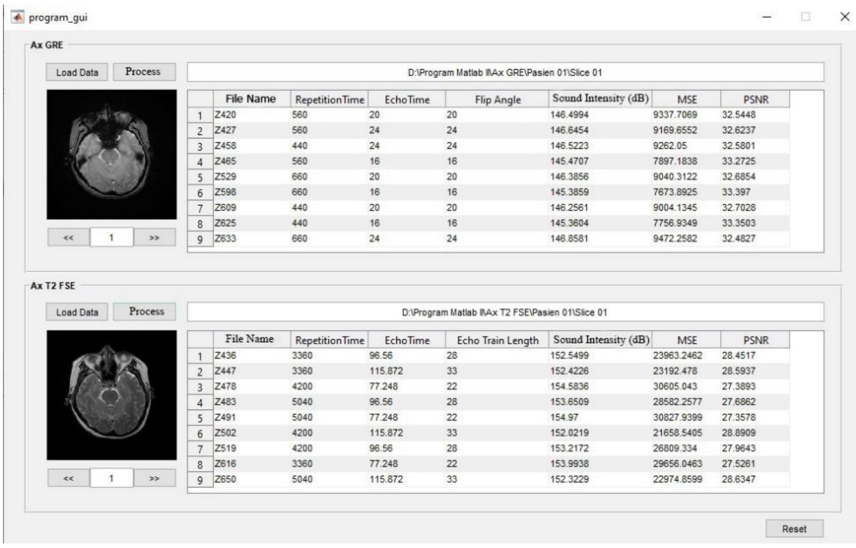

Figure 5. Program display of the application for calculating the level of sound intensity, MSE, and PSNR

Table 1. Average value of sound intensity, MSE, and PSNR in patient 1 (GRE)

Number	Time Repetition (ms)	Time Echo (ms)	Flip Angle	Sound Intensity Level (dB)	MSE	PSNR (dB)
1	440	16	16	146.50 ± 0.48	9784.81 ± 907.78	32.36 ± 0.43
2	440	20	20	147.63 ± 0.57	11766.13 ± 1203.28	31.56 ± 0.48
3	440	24	24	148.12 ± 0.65	12536.88 ± 1427.31	31.29 ± 0.54
4	560	16	16	146.74 ± 0.53	10182.04 ± 992.22	32.19± 0.46
5	560	20	20	147.97 ± 0.60	12339.36 ± 1299.05	31.36 ± 0.50
6	560	24	24	148.40 ± 0.71	12877.03 ± 1595.42	31.18 ± 0.60
7	660	16	16	146.61 ± 0.52	9859.47 ± 948.25	32.33 ± 0.45
8	660	20	20	147.78 ± 0.57	11900.82 ± 1213.25	31.51 ± 0.48
9	660	24	24	148.47 ± 0.65	13006.63 ± 1510.20	31.14 ± 0.55

Table 2. Average values of sound intensity, MSE, and PSNR in patient 1 (T2-FSE)

Number	Time Repetition	Time Echo	Echo Train Length	Sound Intensity Level (dB)	MSE	PSNR (dB)
1	3360	77.25	22	152.88 ± 0.80	25918.93 ± 2777.71	28.13 ± 0.46
2	3360	96.56	28	151.20 ± 0.94	19469.11 ± 2622.61	29.39 ± 0.57
3	3360	115.87	33	152.20 ± 0.86	22937.39 ± 2698.18	28.67 ± 0.50
4	4200	77.25	22	153.60 ± 0.80	28309.88 ± 2281.91	27.74 ± 0.36
5	4200	96.56	28	152.02 ± 0.93	22521.94 ± 2960.50	28.75 ± 0.56
6	4200	115.87	33	150.69 ± 1.02	17446.24 ± 2683.43	29.87 ± 0.65
7	5040	77.25	22	154.09 ± 0.78	29614.58 ± 1562.52	27.54 ± 0.23
8	5040	96.56	28	152.57 ± 0.89	24606.41 ± 3019.04	28.37 ± 0.53
9	5040	115.87	33	151.25 ± 0.97	19344.44 ± 2738.45	29.42 ± 0.61

The implementation of noise analysis through the use of MATLAB programming as a graphical user interface (GUI) display includes computations of sound intensity levels, MSE values, and PSNR values depending on the magnitude discovered through image transformations. So that a programming display, as seen in figure 4, is obtained. The GRE and T2-FSE sequencing methods for the MATLAB application are shown in Figure 5.

The program has been designed with buttons that may be used to run noise analysis on the head MRI scan. The program's interface is made to be straightforward for simple use. Tables 1 and 2 display the averages for each of the variants and sequences based on the outcomes of computing the MSE and PSNR values through programming.

According to table 1, the GRE sequence methodology produces an average sound intensity level that ranges from 146.50 to 148.47 dB. The average MSE value results fall between 9784.81 and 13006.63. The average PSNR value generated between 31.14 and 32.36 dB. The average sound intensity levels generated by the T2-FSE sequence technique are 150.69 to 154.09 dB, according to Table 2. The average MSE value results fall between 17446.24 and 29614.58. The average PSNR value generated at the same time varies from 27.54 to 29.87 dB.

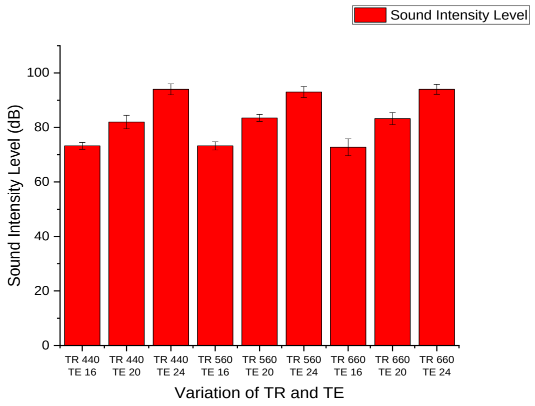

Figure 6. Diagram of measurement of sound intensity level on GRE sequence

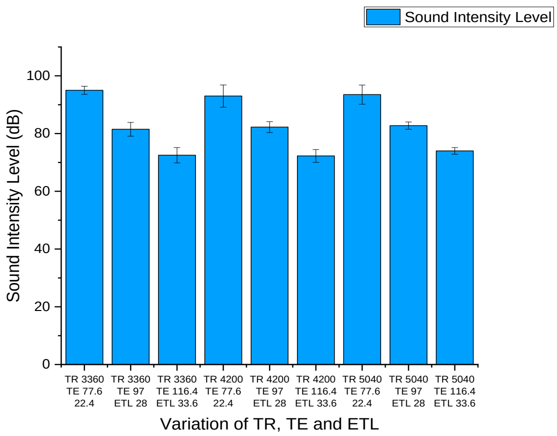

Figure 7. Diagram of measurement of sound intensity level on T2-FSE sequence

Figures 6 and 7 display the results of measuring the level of intensity with a sound level meter in addition to the results of estimating the level of sound intensity. The lowest intensity level in the GRE sequence was determined to be in the variation TR = 660 ms with TE = 16 ms based on the two diagrams in Figures 6 and 7. The lowest sound intensity level in the T2-FSE sequence was measured to be in the range TR = 4200 ms with TE = 116.4 ms and ETL = 33.6.

The difference in the measured sound intensity level for each sequence was then determined using a statistical test, along with the effects of the TR, TE, and ETL variables on the outcomes of measuring the level of sound intensity. As a result, the TE for the GRE sequence is significant at < 0.05, indicating that TE has an impact on determining the amount of sound intensity in the GRE sequence. However, there was a significant 0.05 in the TE ETL for the T2-FSE sequence, indicating that TE and ETL had an impact on the assessment of sound intensity levels in the T2-FSE sequence.

SNR Analysis

The SNR is calculated from the background noise value and the tissue means signal value. Table 3 and figure 8 both display the SNR calculation results for the GRE sequence. According to the graph in figure 8, the length of TR = 440 ms and TE = 24 ms results in the maximum SNR value for the WM organ.

The maximum SNR value for the CSF organ is discovered to occur when TR is 560 ms, and TE is 20 ms. The difference in SNR values between variations, which span from 500 to 700 values, can also be shown to not be sufficiently substantial. The computation results for the T2-FSE sequence are displayed in Table 4, and the diagram is presented in Figure 9.

Based on the graph in Figure 9, TR = 3360 ms with TE = 116.4 ms, and ETL = 33.6 has the highest SNR compared to other variations. Meanwhile, when TE and ETL rise, the SNR decreases, which can be indicated in TR = 440 ms and TR = 5040 ms for WM and CSF organs. Then, based on the results of statistical tests, it can be seen that the GRE sequences on the TE and TR variables do not have a significant influence on the SNR value. Meanwhile, the T2-FSE sequence shows that the TR variable significantly influences the SNR value, but the TE and ETL variables do not significantly influence the SNR value.

Table 3. SNR Analysis of GRE sequences

Number	Image	Variations	SNR Organ	
			WM	CSF
1	A	TR = 440 TE = 16	556.42 ± 32.27	571.50 ± 32.33
2	B	TR = 440 TE = 20	664.19 ± 24.25	651.13 ± 17.18
3	C	TR = 440 TE = 24	737.03 ± 92.07	665.89 ± 83.82
4	D	TR = 560 TE = 16	653.38 ± 33.22	689.54 ± 38.58
5	E	TR = 560 TE = 20	688.76 ± 34.48	761.57 ± 45.74
6	F	TR = 560 TE = 24	602.83 ± 120.92	613.20 ± 131.35
7	G	TR = 660 TE = 16	573.59 ± 79.45	631.44 ± 81.79
8	H	TR = 660 TE = 20	625.21 ± 81.86	697.03 ± 87.82
9	I	TR = 660 TE = 24	669.80 ± 118.16	662.92 ± 120.13

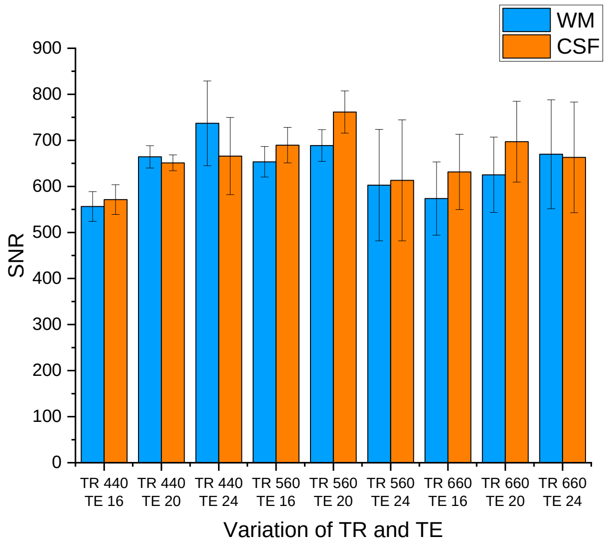

Figure 8. SNR values on GRE sequences for 9 Variations on WM and CSF organs

Table 4. SNR analysis of T2-FSE sequences

Number	Image	Variation	Organ	
			WM	CSF
1	A	TR = 3360 TE = 77,6 ETL = 22,4	1340.88 ± 108.86	1450.73 ± 116.74
2	B	TR = 3360 TE = 97 ETL = 28	1380.74 ± 152.57	1364.58 ± 153.91
3	C	TR = 3360 TE = 116,4 ETL = 33,6	1759.00 ± 192.44	1674.35 ± 178.27
4	D	TR = 4200 TE = 77,6 ETL = 22,4	1430.04 ± 192.10	1514.16 ± 184.18
5	E	TR = 4200 TE = 97 ETL = 28	1435.44 ± 4.11	1548.62 ± 8.33
6	F	TR = 4200 TE = 116,4 ETL = 33,6	1523.82 ± 237.21	1587.78 ± 249.74
7	G	TR = 5040 TE = 77,6 ETL = 22,4	1324.22 ± 234.31	1377.70 ± 297.07
8	H	TR = 5040 TE = 97 ETL = 28	1255.13 ± 238.56	1197.48 ± 230.05
9	I	TR = 5040 TE = 116,4 ETL = 33,6	1232.03 ± 31.97	1312.21 ± 24.81

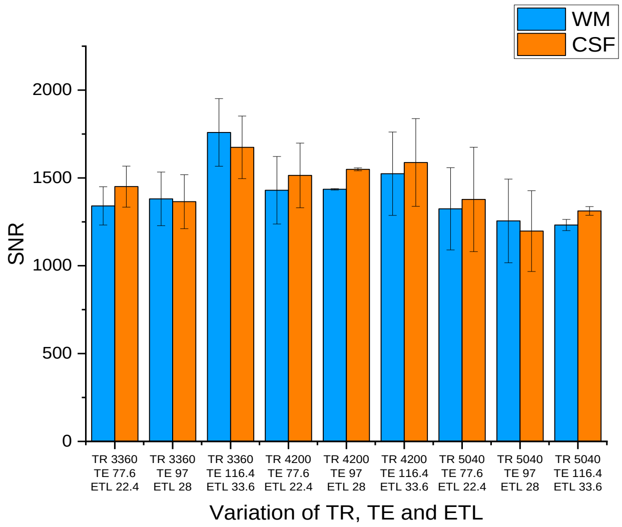

Figure 9. SNR values on T2-FSE sequences for 9 Variations on WM and CSF

Discussion

Based on calculations and statistical studies, it has been determined that the MRI parameter variables affect acoustic noise. The calculated findings demonstrate that the input variables at the moment of image acquisition have an impact on the volume of the sound that is generated. In the GRE sequence protocol, the sound intensity and MSE value tend to increase with increasing TR, TE, and FA values, but the PSNR value tends to decrease. This is in line with the hypothesis that the TR, TE, and FA values in the GRE sequence procedure are inversely proportional to the PSNR value but directly related to the sound intensity level and MSE value.

The sound intensity and MSE value in the T2-FSE sequence protocol tend to increase with the TR value, whereas the PSNR value tends to decrease. The sound intensity and MSE value produced then tend to be smaller as TE and ETL increase. However, the PSNR value tends to be more important. This is in accordance with the idea that the TR value in the T2 FSE sequence protocol is inversely proportional to the PSNR value and directly related to the sound intensity level and MSE value. At the same time, TE and ETL are directly proportional to the PSNR value and inversely proportional to the sound intensity level and MSE value, respectively.

According to the calculations, the MSE value and average sound intensity level created by the GRE sequence protocol is less than those generated by the T2 FSE sequence protocol. The GRE sequence protocol's average PSNR value, meanwhile, is higher than the T2 FSE sequence protocol's. Based on statistical studies, the impact of these factors on SNR demonstrates that the GRE sequence variables TE and TR have no appreciable influence on SNR. This is seen by the SNR value's negligible variation between the two variations. The TR variable, however, has a considerable impact on the SNR value in the T2 FSE sequence.

The results of the study show that the TR and TE lengths are 440 ms and 24 ms, respectively, the greatest SNR value in the GRE sequence for the WM organ is 737.03. The CSF organ's greatest SNR, with a value of 761.57, occurs when the TR and TE lengths are 560 ms and 20 ms, respectively. When TR = 3360 ms, TE = 116.4 ms, and ETL = 33.6 are used, the T2-FSE sequence has the highest SNR, with an SNR value at WM of 1759.00 and a CSF of 1674.35. As a result, the calculation's findings indicate that the SNR value between the T2-FSE sequence protocol and the GRE sequence protocol is higher.

When compared with the results of other studies, the method used in this study is a development of existing methods with significant results. The acoustic noise optimization diffusion-weighted imaging method achieved up to 20 dB of acoustic noise reduction with a 27–54% increase in scan time while maintaining image quality at the same level as a typical single-shot EPI sequence [4]. Verhappen (2012) compared the half fourier obtained with single shot turbo spin echo (TSE) and echo-planar imaging (EPI) techniques in head and neck cancer [10]. Meanwhile, Corcuera-Solano (2015) used the silent propeller MRI technique in brain imaging. Several of these studies used different methods to reduce noise in MRI. With sound levels of about 75 dB and a reduction in average sound pressure levels of up to 28.5 dB, quiet T2 and quiet T2 FLAIR had image quality that was comparable to that of conventional acquisitions, with the exception of longer scan time [6]. In the research of Heismann et al. (2015), researchers conducted noise reduction techniques using TSE and GRE protocols, resulting in a total acoustic noise reduction of up to 14.4 dB(A) for TSE and up to 16.8 dB(A) for GRE. The physical sound pressure reduction was 81% (TSE) and 86% (GRE) in MRI patients [11]. Other studies have shown that the FSE Protocol can clinically reduce noise during MRI examinations in the elderly and children [12] [13].

Based on the findings of this study, the average sound intensity level and MSE value produced by the

GRE sequence protocol were less than those produced by the FSE T2 sequence protocol. Nonetheless, the GRE sequence protocol resulted in a higher average PSNR value than the FSE T2 sequence protocol. The FSE T2 sequence with variations TR 3360, TE 97, and ETL 33.6 can then be observed as the best with ideal noise levels and SNR values. The limitation of this study is that the sound reduction resulting from the application of the silent T2 FSE and GRE sequences has not been able to make patients comfortable, so it is necessary to develop sound reduction methods without reducing image quality.

Conclusion

As a consequence of the study's findings, it can be said that the MSE value and average sound intensity level produced by the GRE sequence protocol are less than those created by the T2-FSE sequence protocol. The GRE sequence protocol's average PSNR value, meanwhile, is higher than the T2-FSE sequence protocols. Utilizing the MATLAB programming language as an intuitive user interface, the developed system has been integrated into the application software. The SNR value between the two sequences, namely the SNR value in the T2-FSE protocol rather than in the GRE sequence protocol, is then demonstrated by the calculation's results to be significantly more important. The T2-FSE sequence methodology with variations in TR 4200 ms, TE 116.4 ms, and ETL 33.6 was utilized to obtain the appropriate sequences and parameter variations to generate excellent imagery with a noise level that is not too high for head inspection.

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