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Cervical MRI Image Quality Optimization based on Repetition Time (TR) and Echo Train Length (ETL) Settings

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Abstract

In radiodiagnostics, the MRI (Magnetic Resonance Imaging) modality is used to help establish a diagnosis, mainly by providing more accurate information about anatomical relationships and pathological abnormalities of the object being examined. This study was conducted at the Brain Clinic in Surabaya with a 3 Tesla MRI device. In addition, T2 weighting of the FSE (Fast Spin Echo) sequence was also used in the sagittal cervical MRI examination, with TR (Time Repetition) values of 3000 ms, 4000 ms, and ETLs (Echo Train Length) of 16, 20, and 24, respectively. This study used organ signals from the cerebrospinal fluid (CSF), spinal cord (SC), vertebral body (VB), disc intervertebral (DI), and bone edge boundary (BEB). Data analysis in this study by determining the ROI (Region Of Interest) value of the object and background to determine the effect of the sequence on the value of SNR (Signal to Noise Ratio), CNR (Contras to Noise Ratio), and time scanning in each organ. This study obtained the optimal SNR value for cervical MRI T2-FSE sequences at TR 4000 ms and ETL 20 variations. Meanwhile, the optimal CNR value in the CSF-SC and CSF-BEB is at TR 4000 ms and ETL 20, and the CNR in the VB-DI is at TR 4000 ms and ETL 16. Variations in the combination of TR and ETL have different effects. TR variation significantly affects SNR and CNR values in specific organs. Meanwhile, variations in ETL values do not considerably affect SNR and CNR values.

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KEY WORDS
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Introduction

Medical science and technology development is progressing rapidly and becoming more modern, especially in radiological medical services. In radiodiagnostics, the MRI (Magnetic Resonance Imaging) modality is used in helping to establish a diagnosis, especially in providing more accurate information about anatomical relationships and pathological abnormalities of the object being examined [1]. MRI is a non-ionizing scanning technique that can image the examined organ based on the principle of magnetic resonance of hydrogen atomic nuclei using RF (radio frequency) signals and magnetic fields on a specific scale [2]. MRI creates a better image quality that can be used to assess differences in soft organ anatomy in the body, especially the spine, compared to CT scans [3]. In the formation of MRI images, one must go through the image formation process, namely the provision of RF pulses, resonance phenomena, longitudinal (T1) and transverse (T2) relaxation times, FID (Free Induction Decay) signals, and image contrast mechanisms [4].

Vertebral is one of the many MRI examinations often encountered in the field, including the cervical MRI examination. The cervical vertebra is an organ that has a smaller size than the lumbar and thoracic vertebrae. The cervical vertebra is one of a series of vertebrae that are the vertebrae of the neck and form the nape area [6]. In the cervical MRI examination technique, T2 and T1 weighting are used, with the recommended protocol being Sagittal T1 SE / FSE, Sagittal T2 SE / FSE or GE, Coronal T1 SE / FSE, Coronal T2 SE / FSE or GE, Axial T1 SE / FSE, Axial T2 SE / FSE or GE [7]. In T2 weighting, according to Chong et al. (2016), using a fast spin echo pulse sequence is recommended because it can detect early pathological signs, such as edema, tumors, infections, fractures, and ligament injuries, and produce images with strong signals in the cerebrospinal fluid (CSF), including details of the nerve roots. Sagittal cuts are selected to provide a wider and more comprehensive image visualization [8].

FSE (Fast Spin Echo) is one of the sequences of SE (Spin Echo) pulses with a faster scan time than conventional SE MRI imaging [9]. In T2 FSE weighting, the scan time value is shorter, and using FSE sequences can increase the SNR (signal-to-noise ratio) value. This is because in the FSE sequence, the excitation angle of hydrogen protons is higher when given radiofrequency waves using a large flip angle (more than 90 degrees), so the energy given will be greater. This is to the concept of physics, the greater the energy, the greater the signal produced. When the signal is stronger, it will suppress the noise of signal interference. So that it will increase the value of the signal-to-noise ratio, or what is called the SNR. SNR is the signal amplitude ratio to the average noise amplitude [10]. Good MRI image quality can be determined by four characteristics, namely SNR, CNR (Contrast to Noise Ratio), spatial resolution, and scan time. Good image results are also influenced by several parameters, namely TR (time repetition), TE (time echo), ETL (echo train length), TI (time inversion), NEX (Number of excitations), FOV (field of view), and bandwidth [11]. The parameters that have the most significant influence on SNR, CNR, and examination time are TR and ETL. Giving a long TR can evaluate the organ in more slices and provide a good signal noise value, but it also causes the time required to be longer [12]. A fast TR can shorten the time in data retrieval, but fewer organ slices are evaluated so that the SNR value could be better.

Giving one 90-degree pulse followed by multiple 180-degree rephasing in one TR generates a series of echoes known as the ETL in FSE[13]. Each echo has a different phase encoded per TR and will fill other rows in the same k-space in image formation [2]. The TR parameter value for a sagittal section cervical T2 FSE examination is 2000–4000 ms [14]. High ETL in T2 FSE weighting can cause blurring, thus affecting image quality by reducing the SNR value and thus affecting CNR [15]. K-space is a frequency propagation space where signals in the form of frequencies originating

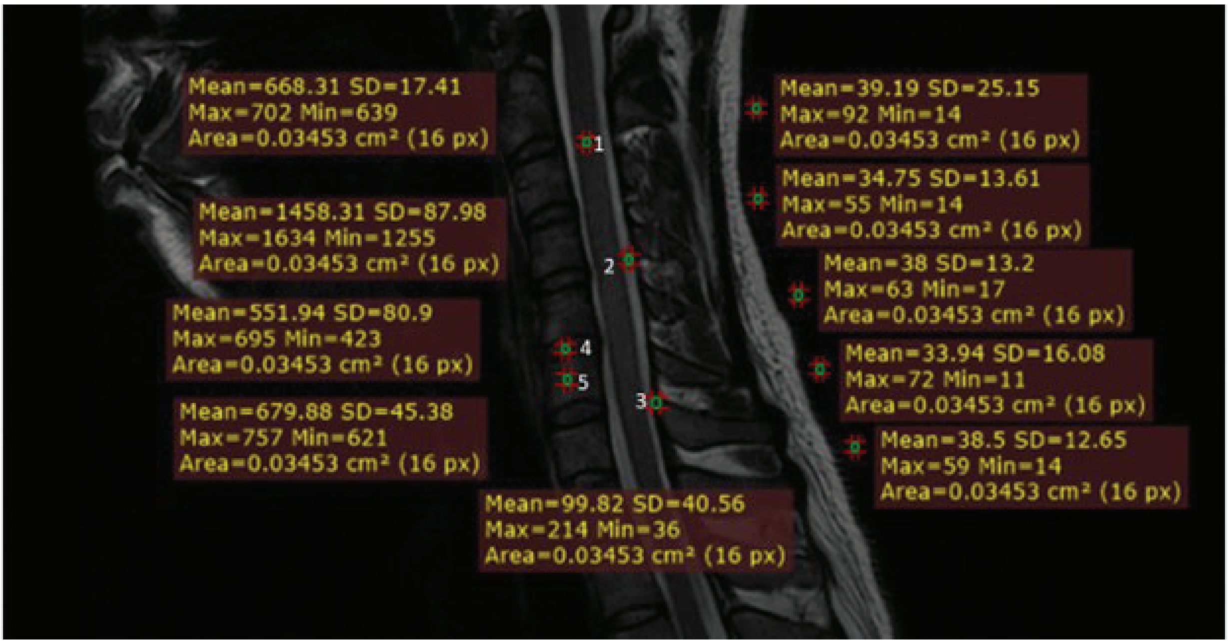

Figure 1. *ROI on objects and tissues, The ROI size is constant at 0.03453 cm2. Mean is the measured signal intensity of the object's anatomical region, and SD (standard deviation) is the noise intensity obtained from outside the anatomy of the object. Note : (1) SC, (2) CSF, (3) BEB, (4) DI, (5) VB.*

from patients are stored. In the FSE sequence, the k-space will be filled faster to shorten the scan time. Effective use of ETL can create strong signals and image more detailed nerve roots [2].

In MRI examinations with various cases of cervical vertebrae, movement in the patient's cervical must occur, both when the patient swallow's saliva, inhales, and circulates blood, and other movements due to the length of the examination, allowing motion artifacts due to these movements. Therefore, using FSE sequences is very helpful for patients and radiologists to perform faster examinations. However, the importance of proper TR and ETL settings must be recognized. Based on previous research, the ETL with the best image is ETL 16. However, this study did not consider the TR parameter [15]. In FSE imaging, the relationship between ETL and the number of slices allowed for a particular TR must be considered. Because if the ETL is too large, it has a negative impact on the SNR and CNR results, so if the TR is short and the echo circuit is too large, the resulting SNR is not good [2].

This study aimed to determine the role of FSE sequences as well as TR and ETL parameters in the diagnosis associated with various types of pathology in the cervical vertebrae. This study hypothesizes that an optimal image is obtained with a short scanning time for the TR and ETL variations used with the FSE sequence.

Material and Methods

The research was carried out at the Brain Clinic in Surabaya using a 3T MRI Merk GE (General Electric) on three young female participants (21,33 ± 0,58) years old. In addition, T2 weighting of the FSE sequence was also used in the sagittal cervical MRI examination, with TR values of 3000 ms, 4000 ms, and ETLs of 16, 20, and 24, respectively. Other parameters used in this study include RF Coil Cervical, TE (80 ms), Flip angel (180°), Slice Thickness (3 mm), FOV (270 mm), NEX (2), PE (512), and Time Scanning (192000; 153600; 128000; 256000; 204800; 170666.7 s). The organ signals taken in this study were from the CSF, spinal cord (SC), vertebral body (VB), disc intervertebral (DI), and bone edge boundary (BEB). Data analysis in this study was conducted by determining the ROI value of the object and background using the Radiant DICOM Viewer, as shown in Fig. 1. The ROI was manually determined with the same size of 0.03453 cm^2. After ROI, the SNR and CNR values can be calculated using equations 1 and 2. Data analysis is displayed using

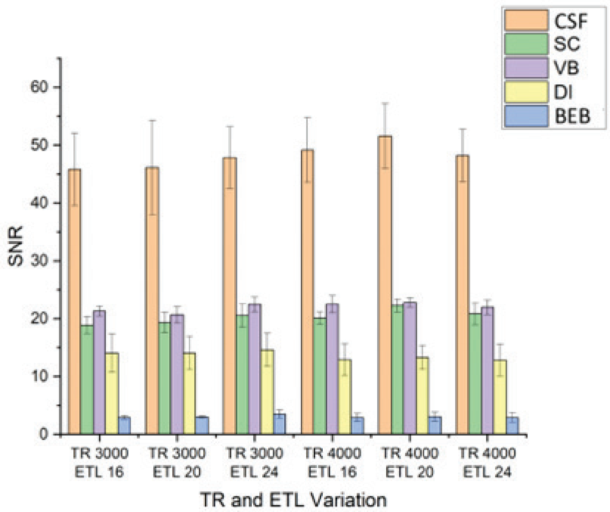

Figure 2. *Effect of changing TR and ETL on SNR*

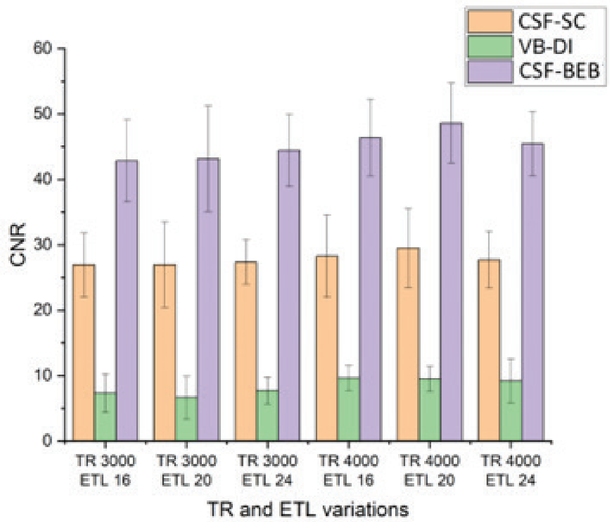

Figure 3. *Graph of the effect of TR and ETL Variations on CNR*

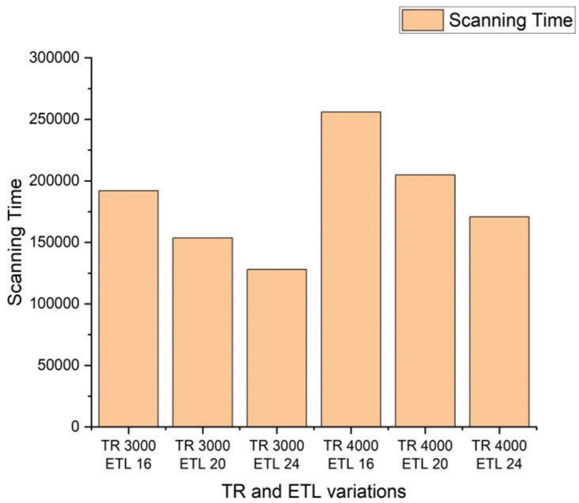

Figure 4. *Effect of TR and ETL changes on scan time*

graphs and statistical tests using SPSS One-Way ANOVA with a significance level of $p< 0.05$.

$$SNR = \frac{S\ (Signal)}{N\ (Noise)} = \frac{Mean\ Signal\ ROI}{Std.Deviation\ Bacground} \quad (1)$$

$$CNR = \frac{C\ (Contrast)}{N\ (Noise)} = \frac{Mean\ Signal\ ROI - Mean\ Background\ ROI}{Std.Deviation\ Bacground} \quad (2)$$

Results

According to Fig. 2, the organ's SNR, TR, and ETL values change. Based on statistical data analysis using SPSS in Table 1, it can be concluded that the value of TR on SNR in the spinal cord and vertebral body organs is significantly different from the change in the given TR value. At the same time, in the CSF, DI, and BEB, there is no significant difference in the change in the given TR value. Table 2 shows that between the ETL value and SNR in each organ, there is no significant difference in the change in the ETL value given.

Based on Fig. 3, it can be obtained that the CNR CSF-SC and CSF-BEB have the highest contrast values at TR 4000 ms and ETL 20, while the CNR VB-DI have the highest contrast at TR 4000 ms and ETL 16. Based on Table 3, TR variation does not give significant changes in CNR CSF-SC, while CNR VB-DI and CNR CSF-BEB considerably influence changes in TR values. Based on the comparison in Table 4 between the ETL value and CNR in each organ, there is a significant difference in the change in the ETL value given.

The scanning time of each combination is determined through calculation, namely by multiplying the TR value with the Phase Encode (PE) and NEX values, then dividing by ETL. From the results of the study of MRI images of the cervical sagittal section using the Fast Spin Echo sequence with ETL values of 16, 20, and 24, TR of 3000 ms and 4000 ms, and PE of 512, the results show that the scan time obtained is quite varied. The results of the calculation of the scan time of each variation of

Table 1. One Way Anova Test Results between SNR and TR

Organs	TR (ms)	Percentage of SNR Value (%)		Result	
		Mean	Standard Deviation	Significance	Conclusion
CSF	3000	46.59	6.51	0.06 (p< 0.05)	No significant difference
	4000	49.64	5.26		
SC	3000	19.57	1.84	0.00 (p< 0.05)	There is a significant difference
	4000	21.37	1.53		
VB	3000	21.48	1.39	0.01 (p< 0.05)	There is a significant difference
	4000	22.42	1.25		
DI	3000	14.25	2.89	0.1 (p< 0.05)	No significant difference
	4000	13.02	2.46		
BEB	3000	3.15	0.53	0.32 (p< 0.05)	No significant difference
	4000	2.97	0.78		

Table 2. One Way Anova Test Results between SNR and ETL

Organs	ETL	Percentage of SNR Value (%)		Result	
		Mean	Standard Deviation	Significance	Conclusion
CSF	16	47.49	5.99	0.81 (p> 0.05)	No significant difference
	20	48.83	7.36		
	24	48.02	4.83		
SC	16	19.94	1.67	0.35 (p> 0.05)	No significant difference
	20	20.79	2.11		
	24	20.67	1.90		
VB	16	21.90	1.34	0.58 (p> 0.05)	No significant difference
	20	21.72	1.58		
	24	22.21	1.27		
DI	16	13.49	3.00	0.96 (p> 0.05)	No significant difference
	20	13.68	2.46		
	24	13.74	2.87		
BEB	16	2.91	0.56	0.38 (p> 0.05)	No significant difference
	20	3.05	0.57		
	24	3.22	0.84		

Table 3. One Way Anova Test Results between CNR and TR

Organs	TR (ms)	Percentage of CNR Value (%)		Result	
		Mean	Standard Deviation	Significance	Conclusion
CSF-SC	3000	27.09	4.92	0.33 ($p < 0.05$)	No significant difference
	4000	28.48	5.49		
VB-DI	3000	7.20	2.73	0.00 ($p < 0.05$)	There is a significant difference
	4000	9.43	2.39		
CSF - BEB	3000	43.48	1.25	0.04 ($p < 0.05$)	There is a significant difference

Table 4. One Way Anova Test Results between ETL and CNR

Organs	ETL	Percentage of CNR Value (%)		Result	
		Mean	Standard Deviation	Significance	Conclusion
CSF -SC	16	27.61	5.52	0.91 ($p > 0.05$)	No significant difference
	20	28.23	6.27		
	24	27.54	3.80		
VB-DI	16	8.45	2.68	0.89 ($p > 0.05$)	No significant difference
	20	8.05	3.01		
	24	8.44	2.79		
CSF - BEB	16	44.61	6.19	0.82 ($p > 0.05$)	No significant difference
	20	45.89	7.48		
	24	44.95	5.11		

Table 5. Scanning time calculation results

TR (ms)	NEX	PE	ETL	Time Scanning (s)
3000	2	512	16	192000
3000	2	512	20	153600
3000	2	512	24	128000
4000	2	512	16	256000
4000	2	512	20	204800
4000	2	512	24	170666,7

the combination of TR 3000 ms and 4000 ms with ETL 16, 20, and 24 are presented in Table 5 and Fig. 4. Based on Table 5, when viewed based on the ETL value, the scan time decreases as the ETL value increases. When viewed based on the TR value, the time comparison for 3000 ms is smaller than the TR value of 4000 ms, so it can be concluded that changes in TR and ETL values have a considerable effect on the scan time, as indicated by the different time differences from each variation. These findings are consistent with previous research, which shows that the higher the TR, the longer the scan time. The higher the ETL, the shorter the scan time. Through the conventional relationship: scan time = (number of Phases encodes TR)/ETL, the imaging timings depended on the repetition time and echo train length [14].

Discussion

This study used three healthy young female participants (21,33 ± 0,58) years old, which include organ signals from the cerebrospinal fluid (CSF), spinal cord (SC), vertebral body (VB), disc intervertebral (DI), and bone edge boundary (BEB). In this study, the TR value was varied, namely 3000 ms and 4000 ms, and the variation of ETL values ranged from 16, 20, and 24. This variation is taken by the theory that to produce an image on T2, a long TR value of 2000 ms is required [16]. FSE is one of the sequences of Spin Echo pulses with a faster scan time than conventional Spin Echo. In T2 FSE weighting, the scan time value becomes shorter, and using FSE can increase the SNR value [2].

Based on the results of the TR and ETL combination, research data shows that the SNR and CNR values in each organ obtained different results. Then, it is also known that the higher the TR value, the greater the SNR value. This is consistent with the existing statement that a long TR allows full recovery, resulting in more transverse magnetization in the next RF [16]. Meanwhile, based on the analysis of ETL variations, there is no significant effect of each ETL variation given on the SNR value. The SNR value obtained increases as the ETL value increases, contrary to the existing theory that higher ETL can cause the image to blur due to decreased amplitude signal intensity [16]. That is because more late echoes with longer TE's contribute to the overall signal, and longer ETLs lead to higher T2-weighting. Because the subsequent echoes are weaker and the image is blurry, longer ETLs are also linked to worse overall signal-to-noise ratios (SNR) and contrast-to-noise ratios (CNR) [17]. However, the amount of signal intensity in FSE is determined by the ETL value and influenced by other parameters [14]. In FSE, the amount of signal intensity is also influenced by the amount of effective TE, which can affect the SNR value. It is also possible because there is an influence from the atomic structure of the hydrogen molecule in each organ and external influences such as patient movement.

So, the optimal SNR value for cervical T2 FSE MRI sequences is at TR 4000 ms and ETL 20. Meanwhile, the optimal CNR values for SF-SC and SF-BEB are at TR 4000 ms and ETL 20, and CNR VB-DI at TR 4000 ms and ETL 16. Furthermore, we analyzed the combination of TR and ETL on scanning time. The scanning time is the amount of time required to complete data acquisition. In the FSE technique, the scanning time is faster because there are ETL parameters [18]. Based on the research results from Rochmayanti et al. (2013), the time required to evaluate organ volume is a function of several parameters, namely TR and the phase encoding matrix [19]. Another study mentioned that a long TR would increase SNR, and a short TR would decrease SNR. The average per-organ SNR value increases as the TR value increases because the longer the TR, the more the signal increases. High CNR values can show differences in SNR values between two adjacent tissues or areas and show differences in pathological areas with healthy regions that affect the clarity of image information. The high and low value of SNR is influenced by the signal and standard deviation contained in an organ. The higher the SNR, the more signal there is in the organ [20]. This statement demonstrates a relationship between TR, ETL values, and scan time, such that the optimal examination time in this study is obtained at TR 3000 and TR and ETL 24. This is to previous research, which states that reducing the value of TR causes the examination time to be short, and as the ETL value increases, the scan time given will be shorter.

This study has limitations, namely the small number of participants. In addition, there is also a need for more variety in TRs and ETLs. Future research is expected to use other TR and ETL variations to obtain more significant differences in the increase or decrease in SNR values. Then, it is also likely to consider other parameters, such as the use of TE, FOV, NEX, and so on. In addition, it is also expected that there is an automatic ROI measurement software with the same size to get more accurate results.

Conclusion

Based on the results and discussion of this research, it can be concluded that the optimal image quality is located at TR 4000 ms and ETL 20 on CSF, SC, VB, DI, and BEB networks. This is based on the highest CNR value. Variations in TR and ETL combinations have different effects on SNR, CNR, and scan time values. In addition, it can also be seen that the higher the ETL value, the shorter the scan time, which will reduce noise caused by patient movement. **R**

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