ORIGINAL ARTICLE

Comparison amongst pulse sequences for enhanced contrast to noise ratio in magnetic resonance imaging

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Abstract

Objective: To provide optimised pulse sequence and imaging protocols for contrast-to-noise ratio and for tissues that have different signal intensities in magnetic resonance imaging.

Methods: A tissue equivalent material, ferrous benzoic xylenol orange gel, was prepared using gelatine, ferrous ammonium sulfate, sulfuric acid, xylenol orange tetrasodium salt and benzoic acid. The gel was irradiated using 6MV photons from a Varian Clinac 600C linear accelerator, with a dose of 5, 10, 15, 20 and 25 gray. Experimental variations in imaging parameters were performed in echo time and repetition time. The quantitative analysis consisted of contrast-to-noise ratio.

Results: Conventional spin echo and fast spin echo were equivalent for the tissues of comparable signal intensities and for entities moderate difference between signal intensities. Conventional spin echo provided remarkable contrast for tissues where signal intensity difference was extremely high in T1, T2-weighted study. An appropriate inversion time of fast fluid attenuated inversion recovery made it significant to measure contrast between tissues where signal intensity difference was the smallest and ordinary.

Conclusion: Choice of pulse sequence and parameters played a vital role in developing fine image contrast.

Keywords: Contrast to noise ratio, Pulse sequences, Magnetic resonance imaging, Imaging parameters, T1-T2 weighted images. (JPMA 67: 225; 2017)

Introduction

The image quality and diagnostic value of magnetic resonance imaging (MRI) of human tissues are primarily determined by the signal-to-noise ratio (SNR) and the tissue contrast.[1,2] The contrast-to-noise (CNR) is the most critical factor affecting the image quality as it directly determines the eye's ability to distinguish areas of a high signal from areas of low signal.[3,4]

Excellent tissue contrast mainly depends on the best selection of suitable pulse sequences, each pulse sequence possessing different qualities.[1,3] The choice of the pulse sequences and the compatibility of appropriate parameters with the selection of examining tissues are the crucial concern for the contrast between tissues. Treatment of pathologies highly depends on the investigation correctness at the clinical stage.[5]

The improvement of the tissue contrast in MRI has been studied in the past with the help of different techniques. Wang et al. compared the traditional motion-sensitised driven-equilibrium (MSDE) and improved motion-sensitised driven-equilibrium (iMSDE) sequences for improved soft tissue SNR and CNR in carotid artery MRI.[6] Lee et al. proposed the application of balanced steady-state free precession (bSSP) for the significantly higher frequency for anatomy based resonance as compared to gradient echo (GE), which scarifies the certain amount of sensitivity and CNR as a result of spoiling of transverse magnetisation.[7] Blasiak et al. used iron oxide contrast agent in the pulse sequence spin echo (SE) and GE. GE with flow compensation (GEFC) as well as susceptibility weighted image (SWI) in T2 and T* contrast enhanced molecular MRI. They compared CNR in these pulse sequences for better molecular imaging.[8]

A variety of pulse sequences provide a tissue contrast that evaluates the size and spread of the disease.[9] The variety and complexity of pulse sequences and parameters make it impossible to reach the most appropriate diagnosis. If technologists and radiologists find it complicated to choose an appropriate pulse sequence and its parameters for T1-T2 weighting images due to the lack of understanding of their complicated correlation, they can diminish the MRI quality and make insignificant diagnosis which results in a deficiency of inherent difference between normal and pathologic tissues.

This research is particularly designed for the choice of perfect pulse sequence and its parameters for a specific lesion of the human body. It is also intended for

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excellent tissue contrast and image worth of T1-weighted and T2-weighted study. Comparison among conventional spin echo (CSE), fast spin echo (FSE) and fluid-attenuated inversion recovery (FLAIR) was made to investigate the performance of each pulse sequence with the variation of important pulse sequence parameters such as repetition time (TR) and echo time (TE). A sequential range of parameters (TR and TE) was used in each pulse sequence to find out a pulse sequence with excellent combination of TR and TE to produce good CNR between healthy and unhealthy tissues. This study was planned to show that how inappropriate choice of pulse sequences and its combination of parameters for a specific lesion can weaken the contrast between adjacent tissues.

Materials and Methods

A tissue equivalent material was made in the department of medical physics, Ninewells Hospital and Medical School, Dundee, the United Kingdom (UK) in 2007, expected to fulfil the requirement of the dose distribution measurements and optimisation of pulse sequences. Different types of gel systems have been proposed for the gel dosimetry, but gelatin (usually 300 BLOOM porcine) and agarose[10,11-15] are favourable for gel dosimetry. In our experiment, ferrous benzoic xylenol orange (FBX) gel was prepared using gelatine (from bovine skin, Type B), ferrous ammonium sulfate (Aldrich ammonium iron (II) sulfate hexahydrate, 99% American Chemical Society (ACS) reagent), sulfuric acid (Sigma-Aldrich), xylenol orange tetrasodium salt (Sigma-Aldrich) and benzoic acid (Sigma-Aldrich) formulated in 1998 by Kelly RG[16] and others.[13,14]

The stock solution was made by mixing 5mM of benzoic acid, 1mM of xylenol orange and 25mM of sulfuric acid in a one-litre volumetric container and set aside at room temperature. The production of gel started by adding 40gm of gelatin in 700ml of distilled water having 25mM of sulfuric acid and heated by a preheated hot plate of 40°C. The gelatin was liquefied in the gel by a continuous stirring for 30 minutes. Later on, 0.1mm of ferrous sulfate was dissolved in 100ml of benzoic acid and xylenol orange stock solution in a different beaker and then this mixture was added to liquid gelatin. Adding 25mM of sulfuric acid produced a final volume of one litre of gel. The response of Fricke gel dosimeter depended upon the preliminary concentrations of oxygen present in the solution. The gel was allowed to expose to air during its preparation and was poured in six test containers of 10ml capacity for the irradiation of separate doses. All gel phantoms were stored at 5°C.[17]

The gel was irradiated using 6MV photons from a Varian Clinac 600C linear accelerator to a dose of 5 gray (GY), 10GY, 15GYand 25GY with a 5×5cm2 field size at 95.5cm source to surface distance (SSD) (Table-1). MRI was performed on 1.5 T unit (Siemens MAGNETOM Avanto, UK). Circularly polarised (CP) body coil of MRI was used during scanning of phantoms. A phantom was imaged with a single slice using CSE, FSE, and FLAIR pulse sequences.

For quantitative image analysis, signal intensities were measured by placing a region of interest (ROI) of area 1.5 mm in the central region of the gel. The same area of ROI was taken for the measurement of background noise. This procedure was repeated in each pulse sequence for all parameters, which were varied during scanning.

CNRs were calculated by using the formula:

CNR = SNR-A - SNR-B

SNR-A was the contrast-to-noise ratio of the irradiated portion of the phantom and SNR-B was the non-radiated part.

Imaging parameters which were held constant during the study for CSE, FSE, FLAIR in T1-weighted study (field of view, 100×100 mm; number of acquisitions, 1; slice thickness, 4 mm), FLAIR (inversion time, 400 ms; echo train length, 7) and FSE (echo train length, 12). For T2-weighted study (inversion time of FLAIR, 2500MS; echo train length, 21) and for FSE (echo train length, 21).

T1/T2 calculation of FXG gel with variation of deliver dose was done.

T1/T2 calculations of FGX gel were done by employing the same techniques as used in the studies conducted by Afzal et al.[15,18] Bartusek et al.[19] and MATLAB version (R2008b).

Results

It was the CNR when signal intensity difference between the tissues was not consequently high (10-

Table-1: Varying doses.

Dose	T1 (ms)	T2 (ms)
0 Gray (No dose)	812	166
5 Gray	757	149
10 Gray	701	119
15 Gray	670	97
25 Gray	628	58

Table-2: Effect of TR and TE on CNR in T1-Weighted Images. Deliver Dose 10Gray & 5Gray. T1/T2 701/119 (ms) & 757/149 (ms).

Sr. No.	Pulse sequences	TR (ms)	TE (ms)	CNR	Percentage Increase in CNR/ TR %	Average Increase in CNR %	Total Increase In CNR %	TE (ms)	TR (ms)	CNR	Percentage Decrease in CNR/TE %	Average Decrease in CNR %	Total Decrease in CNR %
1	CSE	400	12	3.083				14	400	4.279			
		500	12	3.799	23%			16	400	4.172	3%	4%	11.55%
		600	12	3.851	1%	10%	45.9%	18	400	3.997	4%		
		700	12	3.970	3%			20	400	3.788	5%		
		800	12	4.498	13%								
2	FSE	400	14	3.671				25	500	4.312			
		500	14	3.856	5%		25.4%	37	500	4.267	1%	3%	9.5%
		600	14	4.009	4%	6%		49	500	4.140	3%		
		700	14	4.101	2%			62	500	3.904	6%		
		800	14	4.604	12%								
3	FLAIR	2000	16	6.283			27.5%	25	2000	7.379			
		2100	16	6.737	7%			37	2000	7.288	1%	5%	13.5%
		2200	16	7.253	8%	6%		49	2000	6.982	4%		
		2300	16	7.666	6%			62	2000	6.382	9%		
		2400	16	8.008	4%								

It is the first type, the contrast to noise ratio between tissues of signal intensity difference is not incredibly significant i.e. 10- 5Gray. T1/T2 701/119 (ms) & 757/149 (ms)
TR: Repetition time. TE: Echo time.
CNR: Contrast-to-noise
CSE: Conventional spin echo
FSE: Fast spin echo
FLAIR: Fluid-attenuated inversion recovery.

Table-3: Effect of TR and TE on CNR in T1-Weighted Images. Deliver Dose 15 Gray & 5Gray. T1/T2 670/97 (ms) & 757/149 (ms).

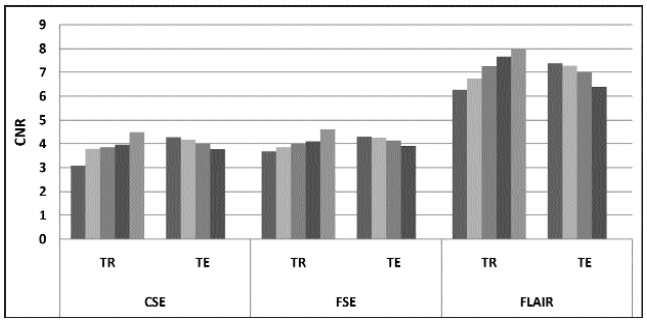
Sr. No.	Pulse sequences	TR (ms)	TE (ms)	CNR	Percentage Increase in CNR/ TR %	Average Increase in CNR %	Total Increase In CNR %	TE (ms)	TR (ms)	CNR	Percentage Decrease in CNR/TE %	Average Decrease in CNR %	Total Decrease in CNR %
1	CSE	400	12	8.088				14	400	8.916			
		500	12	8.952	11%			16	400	8.578	4%	4%	10.5%
		600	12	9.810	10%	8%	37.5%	18	400	8.332	3%		
		700	12	10.648	9%			20	400	7.977	4%		
		800	12	11.125	4%								
2	FSE	500	14	8.514	14%			25	500	8.933			
		600	14	9.587	13%	10%	45.8%	37	500	8.574	4%	6%	16.7%
		700	14	10.440	9%			49	500	7.953	7%		
		800	14	10.917	5%			62	500	7.435	7%		
3	FLAIR	2000	16	12.654				25	2000	13.892			
		2100	16	12.793	1%			37	2000	13.502	3%	2%	4.5%
		2200	16	13.140	3%	3%	66.4%	49	2000	13.417	1%		
		2300	16	13.987	6%			62	2000	13.256	1%		
		2400	16	14.130	1%								

It is the second type, the contrast between tissues of signal intensity difference is moderate i.e. 15-5Gray. T1/T2 670/97 (ms) & 757/149 (ms)
TR: Repetition time. TE: Echo time.
CNR: Contrast-to-noise
CSE: Conventional spin echo
FSE: Fast spin echo
FLAIR: Fluid-attenuated inversion recovery.

Table-4: Effect of TR and TE on CNR in T2-Weighted Images. Deliver Dose 25Gray & 0 Gray. T1/T2 628/58 (ms) & 812/166 (ms).

Sr. No.	Pulse sequences	TR (ms)	TE (ms)	CNR	Percentage Increase in CNR/ TR %	Average Increase in CNR %	Total Increase In CNR %	TE (ms)	TR (ms)	CNR	Percentage Decrease in CNR/TE %	Average Decrease in CNR %	Total Decrease in CNR %
1	CSE	1800	20	41.864				20	1800	47.157			
		2000	20	47.292	13%	9%	29.6%	30	1800	43.269	8%	6%	15.7%
		2200	20	50.687	7%			40	1800	41.742	4%		
		2400	20	54.267	7%			50	1800	39.743	5%		
2	FSE	3800	114	18.028				100	3800	18.028			
		4000	114	21.147	17%	8%	23.6%	113	3800	15.173	16%	9%	24.4%
		4200	114	21.567	2%			125	3800	14.515	4%		
		4400	114	22.283	3%			138	3800	13.618	6%		
3	FLAIR	3500	114	17.075				100	4000	26.424			
		4000	114	20.331	19%	18%	63.9%	113	4000	23.110	14%	13%	35.3
		4500	114	24.149	19%			125	4000	21.374	8%		
		5000	114	28.002	16%			138	4000	17.075	25%		

In the third type of tissues, the contrast along with tissues of signal intensity difference is extremely high i.e. 25-0Gray (T2-weighted study). T1/T2 628/58 (ms) & 812/166 (ms)
TR: Repetition time. TE: Echo time.
CNR: Contrast-to-noise
CSE: Conventional spin echo
FSE: Fast spin echo
FLAIR: Fluid-attenuated inversion recovery.



TR: Repetition time
TE: Echo time
CNR: Contrast-to-noise
CSE: Conventional spin echo
FSE: Fast spin echo
FLAIR: Fluid-attenuated inversion recovery.

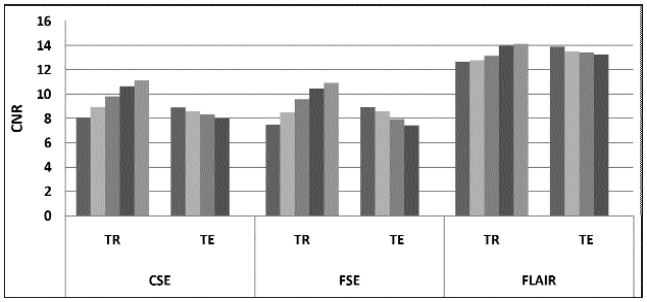
Figure-1: CNR between two tissues of delivering dose 10 and 5 Gray of T1/T2 relaxation time is 701/119 (ms) and 757/149 (ms) respectively, at the selected values of TR and TE in T1-weighted images.

5Gray). In CSE, CNR was 3.083 at TR 400 ms, the smallest among all the values as obtained from other pulse sequences. However, with the increase of TR, CNR increased between the tissues from 46% from 400 to 800 ms. In FSE, the contrast between tissues was high as TR moved from 700 to 800 ms though CNR moved up 25 % from TR 400 to 800 ms. FLAIR turned out higher CNR even at a less value of TR 2000 ms. CNR between tissues was almost the same at all values of TR and 27% increased CNR obtained from TR 2000 to 400 ms. The numerical difference between two small intensities could be well distinguished in FLAIR.

CSE created CNR with the variation of TE for tissues having trivial signal strength. Signal strength decreased with the rise of TE. An average 4% decrease was observed in the signal strength i.e. CNR. However, more appropriate TE is desirable to produce excellent contrast between tissues. Choice of TE in FSE is analogous to CSE to develop contrast among tissues. Signal intensity of 9% decreased from TE 25 to 62 ms.

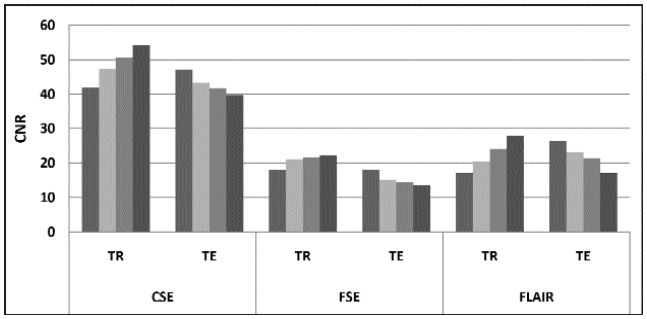
FLAIR created maximum contrast between tissues of minute signal intensity difference. There was a 5% average decrease in signal intensity with the selection of high value of TE (Table-2).

The moderate signal intensity difference amongst tissues (15-5 Gray), the contrast between signal strengths was evident even at small TR 400 ms in CSE. The disparity among signals turned out to be more visible, 11%, as TR got higher from 400 to 500 ms and CNR got 38% higher as TR increased from 400 to 800 ms. In FSE, Intensity difference was more obvious at smaller TR. CNR increased, though 46%, as TR increased from 400 to 800 ms. Within FLAIR, the signal strength of tissues was relatively higher



TR: Repetition time
TE: Echo time
CNR: Contrast-to-noise
CSE: Conventional spin echo
FSE: Fast spin echo
FLAIR: Fluid-attenuated inversion recovery.

Figure-2: CNR between two tissues of delivering dose 15 and 5 Gray of T1/T2 relaxation time is 670/97 (ms) and 757/149 (ms) respectively, at the selected values of TR and TE in T1-weighted images.



TR: Repetition time
TE: Echo time
CNR: Contrast-to-noise
CSE: Conventional spin echo
FSE: Fast spin echo
FLAIR: Fluid-attenuated inversion recovery

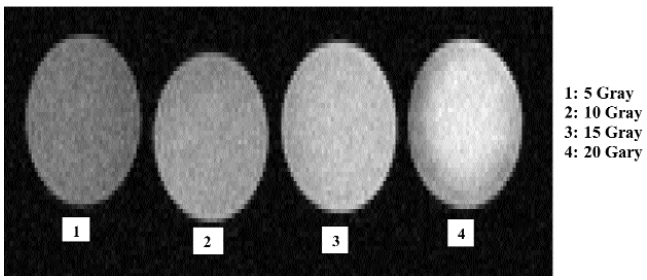
Figure-3: CNR between two tissues of delivering dose 25 and 0 Gray of T1/T2 relaxation time is 628/58 (ms) and 812/166 (ms) respectively, at the selected values of TR and TE in T2-weighted images.

than CSE and FSE at all values of TR. There was a 12% increase in CNR as TR increased from 2000 to 2400 ms.

CSE and FSE were parallel in their results; once 4% average decrease in signal intensity happened with CSE, there was 6% variation in the FSE. A higher value of TE reduced the signal intensity promptly.

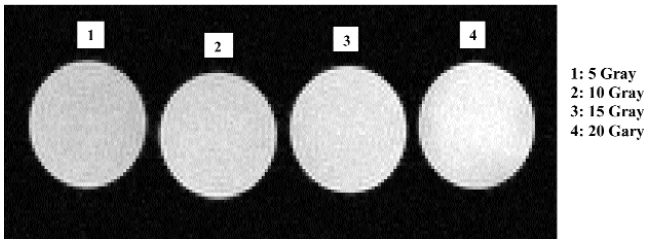
FLAIR produced again well contrast between tissues of moderate difference in signal strength with only 2% average decreased in signal intensity (Table-3).

In T2-weighted study, signal intensity difference was



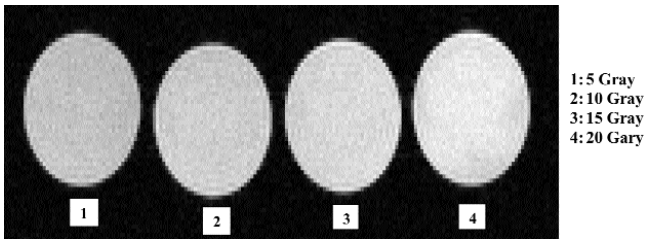
FLAIR: Fluid-attenuated inversion recovery
TR: Repetition time
CNR: Contrast-to-noise.

Image-1: Effect of TR on CNR in T1-Weighted Images. Deliver Dose 10Gray & 5Gray. T1/T2 701/119(ms) & 757/149(ms) in FLAIR.



FSE: Fast spin echo
TR: Repetition time
CNR: Contrast-to-noise

Image-2: Effect of TR on CNR in T1-Weighted Images. Deliver Dose 10Gray & 5Gray. T1/T2 701/119 (ms) & 757/149 (ms) in the FSE.



CSE: Conventional spin echo
TR: Repetition time
CNR: Contrast-to-noise

Image-3: Effect of TR on CNR in T1-Weighted Images. Deliver Dose 10Gray & 5Gray. T1/T2 701/119 (ms) & 757/149 (ms) in CSE.

extremely high i.e. 25-0Gray. CSE was a preferable pulse sequence for excellent tissue contrast. The signal intensity difference between tissues was greatly extended in CSE as compared to FSE and FLAIR. CNR increased 30% from TR 1800 to 2400 ms. CNR of FSE and FLAIR was almost comparable in the T2-weighted study, however, 24% CNR increased in FSE and 64% in FLAIR from the smallest to the

highest value of TR.

With the variation of TE in the T2-weighted study, CSE created a magnificent contrast between tissues. The lowest values of TE were most suitable for excellent CNR, however, 6% average decrease got into the choice of experimental parameters. In FSE, the contrast between tissues was the lowest as compared to CSE and FLAIR; a 9% average decrease was observed from TE 100 to 138 ms. In FLAIR, the image contrast between tissues was moderate, although the contrast was the highest at the least TE value; 13% average signal intensity decreased with the variation of TE (Table-4).

Discussion

The parameters TR and TE play an important role in MRI as they affect CNR of images. This is due to the fact that they provide varying levels of sensitivity to differences in relaxation time between tissues. The phantom analysis shows the contrast of each pulse sequence by using a variety of TR and TE to originate the numerical difference between two signal intensities. The confounding behaviour of each pulse sequence was observed with the different choice of TR and TE. Signal intensities in tissues differ predominantly due to the variation in the spin relaxation rates. The hydrogen density of the tissues also differs from each other and plays an important role in CNR. It is observed in MRI that the contrast between various tissues is possible, which is due to the T1 and T2 relaxation properties.[10,17] The magnitude of contrast depends on many substantial parameters of live tissues in MRI. The amounts of proton nuclei, T1/ T2 relaxation times and the kinetics of molecules of water, are the most important parameters.[18,20] The contrast of an MR image depends simultaneously on several considerations, e.g. the choice of a pulse sequence, its parameters such as TE, TR, the magnitude of flip angle, the time of nucleus inversion TI (the time that corresponds to the null point of certain tissues), etc. The contrast of the image (pathological areas of the tissue) can be improved by the selection of one of the above parameters, however, at the same time the effect of other parameters may also reduce MRI excellence.[21,22]

The CSE and the FSE pulse sequences are compared by varying TR and TE parameters among the tissues of T1/T2 as 757/149 (ms) and 701/119 (ms). The minute signal intensity difference between tissues reduces CNR which weakens the image quality at experimental values of TR and TE. The signal intensity improves with the higher value of TR by allowing maximum recovery of longitudinal magnetisation.[4]

In the current study, it was observed that the CNR turned out to be better at TR 800 ms, which resulted in 46% and 25% improvement of CNR in CSE and in FSE, respectively. The variation of TE did not improve CNR between the tissues. In CSE and FSE, most favourable TE is required to induce the maximum signal in the coil prior to the decay of transverse magnetisation. The FLAIR which is greatly inclined towards TI (the time that corresponds to the null point of certain tissues) nulls the signal of certain tissues to make the image contrast more visible (Figures 1-3, Images 1-3).[19]

In this study, TE for FLAIR produced the distinguishable contrast among tissues with comparable T1/T2 relaxation times by inverting 1800 pulse and considering 400 ms value of TI. It resulted in a significant gap between signal strength and the magnetisation vector recovered from the inversion. The extensive contrast between tissues was improved as TR increased, i.e. maximum longitudinal recovery. The practical selection of TE gave better CNR, while the lowest value of TE was optimised to minimise the transverse decay of the signal. In the comparison of pulse sequences, FLAIR measured the CNR amongst tissues of minute signal intensity difference. It was 78% better than CSE and 74% than FSE at the highest chosen value of TR and 42% better to CSE and FSE with the lowest value of TE.

In the next step of the analysis of CNR, we considered the second sort of moderate signal strength where the difference between the tissues of T1/T2 times were 757/149 (ms) and 670/97 (ms) with the variation of TR and TE in T1-weighted study. CSE and FSE produced almost similar CNR, however, CNR among tissues turned out to be better with larger difference of T1/T2 relaxation time as compared to the previous case (minute difference between T1/T2 relaxation times of tissues). Sine TR controlled the recovery of longitudinal magnetisation of tissues, at higher values of TR the difference between longitudinal magnetisation was more prominent among tissues. As a result, CNR improved by 38% in CSE and 46 % in the FSE.

Next, we investigated the dependence of CNR on parameter TE in each pulse sequence. It was found that CNR behaved in a similar way both in CSE and FSE by the variation of TE, i.e. the average decrease in CNR in CSE and FSE was 4% and 6%, respectively. FLAIR produced better contrast as compared to CSE and FSE between tissues of moderate difference signal intensities at the given values of TR and TE in the T1-weighted study by inverting 1800 pulse and TI 400 ms. The CNR of FLAIR was 27% in CSE and 29% in FSE which improved to 36% with the suitable

selection of TR and TE.

We also investigated the T2-weighted study for the case with the highest signal intensity difference between tissues. Here, the corresponding T1/T2 values were 628/48 ms (25 gray) and 812/166 ms (0 gray). The CSE at higher values of TR and TE produced a superlative contrast amongst tissues. The highest value of CNR is highly appreciable and desirable at diagnostic stage. The larger values of the parameters TR and TE in CSE are always preferable to differentiate the tissues having comparable signal intensities. The CNR increased 30% in CSE with the practical selection of TR and in FSE it could not approach the desired level of accuracy as obtained in CSE. In the T2-weighted study, the use of a long turbo factor made FSE less significant (contrast averaging) which is caused by the effect of averaging all the echoes into a single k-space.[23] The FSE is also influenced by the MT (magnetisation transfer) factor, which reduces the contrast between normal and abnormal tissues. However, the contrast of the tissues can be changed by altering the echo factor.[24] The optimum parameters are required to get better CNR in the T2-weighted study of FSE. The CSE was 144% and 192% better than FSE with the choice of TR and TE, respectively. It was also 94% and 133% superior to FLAIR in the T2-weighted study at the practical value of TR and TE (Figure-1-3).

Conclusion

Pulse sequences responded differently to specific values of TR and TE, designed for the same tissues. Inappropriate selection of parameters produced an insignificant image. This analysis showed that the role of parameters TR and TE in T1, T2-weighted images was very crucial to sustain the image quality.

The results of CNR for CSE and FSE were equivalent for the tissues of comparable signal intensities and for entities having a moderate signal intensity difference. It was found that CSE provided remarkable contrast between tissues due to extremely high signal intensity difference in T1, T2-weighted study.

The FLAIR was explicitly preferable for T2-weighted images, but we also analysed its importance in T1-weighted images. The results strongly suggested that it could also be used for diagnostic purpose with fine image quality of high T1/T2-weighted tissues in T1-weighted study as well, by choosing parameter in such a way that it should be compatible with T1 value of that tissue. An appropriate selection of the parameter TI of FLAIR made it significant to measure contrast between tissues where signal intensity difference was minute and moderate. The main outcome of this study was that the FLAIR could be highly advantageous to diagnose the abnormalities between the tissues of a minute signal intensity difference in T1-weighted study. The comparison among pulse sequences showed the appropriate pulse sequence for MRI. It also found that every pulse sequence showed a high accuracy at the perfect combination of parameters and the worst results at poor selection of parameters.

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