ORIGINAL ARTICLE

Choice of the pulse sequence and parameters for improved signal-to-noise ratio in T1-weighted study of MRI

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Abstract

Objective: To investigate the practical impact of alteration of imaging parameters on signal-to-noise ratio for the most commonly used T1-weighted magnetic resonance sequences.

Methods: The study was conducted in the Department of Medical Physics, Ninewells Hospital and Medical School, Dundee, UK, in 2007. Magnetic resonance images of a tissue-equivalent material were generated with a set of T1 and T2 values. Experimental variations in the imaging parameters were performed in echo time and repetition time. Quantitative analysis consisted of signal-to-noise ratio.

Results: Percentage inaccuracy in signal-to-noise ratio was the result of inappropriate choice of parameters. We have investigated conventional spin echo, fast spin echo and fast fluid attenuated inversion recovery with one of corresponding percentage errors 28.68%, -36.65% and -40.34%, respectively. Conventional spin echo presented moderately low percentage error with the choice of repetition time and echo time. Factual error in fast spin echo was slightly higher than conventional spin echo. Fast fluid attenuated inversion recovery could create outstanding signal-to-noise ratio of high T1/T2 value phantoms in T1-weighted images.

Conclusion: The role of repetition time and echo time in T1-weighted images was crucial to sustain the image quality.

Keywords: Magnetic resonance imaging, Pulse sequences, Signal-to-noise ratio, Imaging parameters, T1- weighted images. (JPMA 65: 512; 2015)

Introduction

Magnetic resonance imaging (MRI) is a non-invasive and highly flexible medical imaging technique that yields excellent image quality. The image quality and diagnostic value of MRI are primarily determined by the signal-to-noise ratio (SNR) and tissue contrast.[1] Since these entities are interdependent which are ruled by the basic laws of nuclear magnetic resonance (NMR) physics, their simultaneous improvement is not simple or straightforward.[2]

In MRI, the choice of the pulse sequence determines the weighting, quality of the image and their sensitivity to pathology. A number of pulse sequences are available at clinical level to create the MR image and each pulse sequence has individual characteristics with some benefits and drawbacks.[3] In recent years, diversity in MRI techniques and pulse sequences are available in clinical use with the potential of image worth and diagnostic correctness.[4-8] But the choice of a pulse sequence with optimised parameters for a specified body tissue with best image quality is still difficult on clinical settings.[9]

MR imaging involves a multitude of parameter decisions. Improper choice of parameters may give an impaired image quality and decreases the diagnostic efficacy.[10] Clinical MR imaging quality depends mainly on the SNR. Consequently the highest possible SNR is essential to avoid poor image quality.[11]

The improvement of MR image quality had been studied in the past with the help of different techniques. One study quantitatively evaluated the impact of alteration of imaging parameters on image quality and artifacts in fast T2-weighted MR sequences[10] Another study[12] developed recommendations and guidelines for a standardised MR imaging protocol for diagnosis and follow-up of multiple sclerosis (MS) patients. Yet another study improved motion-sensitised driven sequence to enhance the tissue SNR.[13] Recent developments in MRI technology have resulted in improving the image contrast and SNR by the optimisation of imaging parameters.[14,15]

The current study was planned to optimise the pulse sequence by applying a sequential range of imaging parameters, repetition time (TR) and echo time (TE). Key imaging parameters, TR and TE have a substantial effect on image quality.[16] Since TR and TE have different consequences on the image in different pulse sequences,

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therefore, the understanding about interaction of these parameters in each pulse sequence is indispensable to obtain the maximal image worth for diagnostic exactness.[17]

These parameters are used to analyse SNR for the most commonly used T1-weighted MRI sequences. Each pulse sequence has a tendency to give best outcome by an appropriate choice of parameters. These pulse sequences are conventional spin echo (CSE), fast spin echo (FSE) and fast fluid attenuated inversion recovery (FLAIR). This information will be supportive for the choice of MR pulse sequence with appropriate parameters to maintain the image excellence.

Material and Methods

The study was conducted in 2007. Atissue-equivalent material for MRI was produced from a polysaccharide gel and agarose containing gadolinium chloride chelated to ethylene diaminetetra-acetic acid (EDTA) in the Department of Medical Physics, Ninewells Hospital and Medical School, Dundee, UK. By varying the amounts of each constituent, longitudinal relaxation time (T1) and transversal relaxation time (T2) of the material of these phantoms varied independently.[18]

The chelation of the gadolinium ions to the macromolecule, EDTA used in the preparation of body tissue-equivalent material gives advantages in three ways. First, chelation removes the possibility of the ions undergoing any further chemical interaction with the gel matrix. Secondly, chelation may prevent the gadolinium ions from precipitating as a hydroxyl. Finally, and very importantly, the qualitative relaxation behaviour of the Gd-EDTA solution is slightly affected by the chelation and the effect can only become significant at the higher frequencies i.e. >30 MHz.[19]

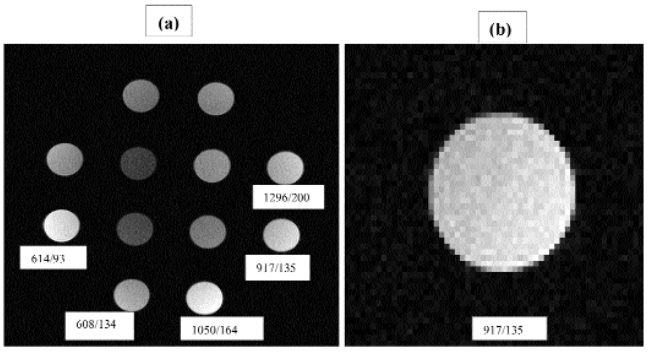
Five phantoms of 12mm diameter were used in this work. These phantoms have T1/T2 relaxation times 608/134, 614/93, 917/135, 1050/164, 1296/200ms. MR imaging was performed on 1.5 T unit (Siemens MAGNETOM Avanto, UK).

Signal intensities were measured by placing a region of interest (ROI) of area 1.5mm in the centre of gel and copy the ROI for the same measurement of background noise. We repeated this procedure in each pulse sequence for all parameters which changed during scanning. SNRs were calculated using the formula: SNR = SI/N, where SI was the mean signal intensity of the ROI within the central region of gel, and N was the standard deviation of the background. Image J software was used for the analysis of SNR.

Circularly polarised (CP) Head Coil of MRI was used during scanning of phantoms. Certain imaging parameters were held constant during the study for CSE, (field of view, 100×100 mm; number of acquisition,1; slice thickness,4mm; percentage sampling, 100; pixel per mm resolution, 1.280), FLAIR(inversion time, 860 ms; echo train length, 5) and FSE (echo train length, 7). We also compared the results with the standard data of Medicine and Healthcare Products Regulatory Agency (MHRA) Evaluation 04133 Siemens Magetom Avanto 1.5T (20). Percentage error represented the error between observed value and true value. Optimised value was approximated by curve fitting method using MATLAB version 7.7 (R2008b). The values of SNR were insufficient for complete analysis. Therefore, the standard curve fitting toolbox in MATLAB was used to find the required values from experimental data.

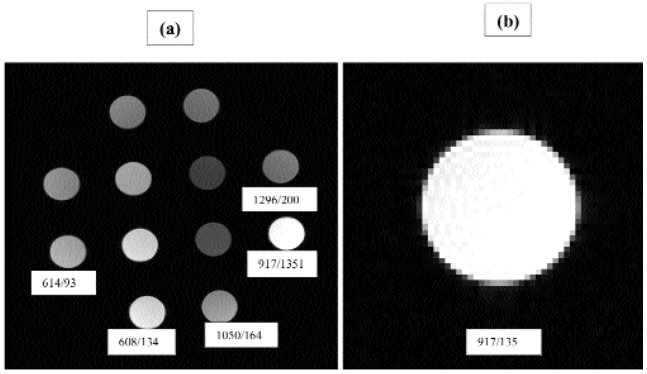
Results

In CSE, percentage error was the lowest compared to other pulse sequences at their selected TR values for



SNR: Signal-to-noise ratio. FSE: Fast spin echo. TR: Repetition time. TE: Echo time.

Figure-1: (a) SNR of Polysaccharide gel during scanning in FSE. (b) Magnified image of tissue equivalent phantom of T1/T2 917/135 ms. The values of TR/TE are 500/25 ms.



SNR: Signal-to-noise ratio. FSE: Fast spin echo. TR: Repetition time. TE: Echo time.

Figure-2: (a) SNR of Polysaccharide gel during scanning in FSE. (b) Magnified image of tissue equivalent phantom of T1/T2 917/135 ms. The values of TR/TE are 800/25 ms.

Table-1: Effect of TR in T1 weighted Images.

Sr. no.	Pulse Sequences	T1/T2 of phantom (ms)	TR (ms)	SNR	Percentage Error %	Optimized TR (ms)	Optimized SNR	T1/T2 of phantom (ms)	TR (ms)	SNR	Percentage Error %	Optimized TR (ms)	Optimized SNR
1	CSE	608/134	600	157.66				614/93	600	138.53	-5.76		
			700	184.50	18.71				700	149.87			
			800	191.49	21.97				800	151.33			
		900	202.04	28.68				900	159.89	1.84			
2	FSE	608/134	500	93.11	-36.65	900	149	614/93	500	153.35			
			600	107.30	-27.00				600	159.83	1.80		
			700	121.81	-17.13				700	163.26	3.98		
			800	134.60	-8.43				800	166.08	5.78		
3	FLAIR	608/134	2000	111.40	-24.217	1900	118	614/93	2000	199.461	27.045	2600	182
			2100	101.45	-30.982	1800	126		2100	197.082	25.530	2900	173
			2200	91.929	-37.462	1700	134		2200	195.013	24.212	3200	165
			2300	87.692	-40.345	1600	142		2300	190.568	21.381	3500	156
						1500	150						

Sr. no.	Pulse Sequences	T1/T2 of phantom (ms)	TR (ms)	SNR	Percentage Error %	Optimized TR (ms)	Optimized SNR	T1/T2 of phantom (ms)	TR (ms)	SNR	Percentage Error %	Optimized TR (ms)	Optimized SNR
1	CSE	917/135	600	160.08	1.96	500	153	1050/164	600	121.16	-17.57		
			700	163.47	4.12				700	137.96	-6.14		
			800	169.35	7.87				800	156.83			
			900	176.16	12.20				900	174.57	11.19		
2	FSE	917/135	500	111.76	-23.97			1050/164	500	136.46	-7.16		
			600	124.47	-15.32				600	153.28			
			700	139.90	-0.482				700	169.35	7.87		
			800	149.75					800	182.65	16.34		
3	FLAIR	917/135	2000	152.92				1050/164	2000	183.77	17.05	2400	167
			2100	149.83					2100	181.61	15.67	2500	163
			2200	146.86					2200	176.92	12.68	2600	158
			2300	144.87	-1.443				2300	170.91	8.86	2700	154

Sr. no.	Pulse Sequences	T1/T2 of phantom (ms)	TR (ms)	SNR	Percentage Error %	Optimized TR (ms)	Optimized SNR
1	CSE	1296/200	600	95.96	-34.71	1000	148
			700	110.26	-24.99		
			800	124.52	-15.29		
			900	134.26	-8.66		
2	FSE	1296/200	500	96.96	-34.04	900	145
			600	110.03	-25.14	1000	157
			700	123.04	-16.29		
			800	132.53	-9.84		
3	FLAIR	1296/200	2000	152.45	-6.70		
			2100	137.14	-9.81		
			2200	132.56	-12.63		
			2300	128.42	-6.70		

Comparison between CSE, FSE and FLAIR for the effect of TR on SNR in T1- weighted images for tissue equivalent gel of T1/T2 is 608/134, 614/93,917/135, 1050/164 and 1296/20 msec.
CSE: Conventional spin echo. FSE: Fast spin echo. FLAIR: Fast fluid attenuated inversion recovery. SNR: Signal-to-noise ratio. TR: Repetition time.

Table-2: Effect of TE in T1 weighted Images.

Sr. no.	Pulse Sequences	T1/T2 of phantom (ms)	TR (ms)	SNR	Percentage Error %	Optimized TR (ms)	Optimized SNR	T1/T2 of phantom (ms)	TE (ms)	SNR	Percentage Error %	Optimized TE (ms)	Optimized SNR
1	CSE	608/134	10	136.66	-7.03	8	142	614/93	10	170.40	8.53		
			12	128.27	-12.74	7	145		12	164.19	4.58		
			14	121.50	-17.36	6	149		14	154.33			
			16	116.57	-20.70				16	149.54			
2	FSE	608/134	12	193.40	23.18	40	156	614/93	12	167.94	6.97		
			25	179.43	14.29				25	164.37	4.69		
			37	159.14					37	151.26			
		608/134	12	199.46	27.04	31	157		12	138.40	-5.850	9	140
3	FLAIR		25	179.20	14.14			614/93	25	129.99	-11.571		
			37	140.12	-4.68				37	122.86	-16.421		
1	CSE	917/135	10	183.75	17.04			1050/164	10	136.66	-7.03	8	142
			12	170.92	8.86				12	128.27	-12.74	6	149
			14	157.12					14	121.50	-17.36		
			16	148.25					16	116.57	-20.70		
2	FSE	917/135	12	193.5	23.29	49	157	1050/164	12	135.99	-7.489	10	137
			25	178.1	13.44				25	129.47	-11.925		
			37	139.85	-4.86				37	121.59	-17.28		
		917/135	12	152.92					12	185.51	18.159	49	164
3	FLAIR		25	149.75				1050/164	25	183.77	17.050	62	157
			37	130.90	10.95				37	170.15	8.439		

Sr. no.	Pulse Sequences	T1/T2 of phantom (ms)	TE (ms)	SNR	Percentage Error %	Optimized TE (ms)	Optimized SNR
1	CSE	1296/200	10	112.09	-23.74	8	116
			12	110.46	-24.85	6	119
			14	107.98	-26.54		
			16	102.178	-30.49		
2	FSE	1296/200	12	115.62	-21.34	8	118
			25	113.93	-22.49		
			37	106.65	-27.44		
3	FLAIR	1296/200	12	152.45			
			25	147.01			
			37	134.09	8.77		

Comparison betweenCSE, FSE and FLAIR for the effect of TE on SNR in T1- weighted images for tissue equivalent gel of T1/T2 is 608/134, 614/93,917/135, 1050/16 and, 1296/200msec.

CSE: Conventional spin echo

FSE: Fast spin echo

FLAIR: Fast fluid attenuated inversion recovery

SNR: Signal-to-noise ratio

TE: Echo time.

phantom 608/134ms (Table-1). Shorter TR should be preferred for minimum error in favour of best SNR, while in FSE high value of TR is required to get good SNR. In FLAIR, percentage error was very high and the image quality was poor at given TRs. Hence, small value of TR was necessary for appropriate SNR. CSE was good in the choice of its TRs and SNRs for phantom 608/134ms.

FSE created best SNR and percentage error was the minimum in FSE at the given values of TRs for phantom 614/93ms. CSE was also good at specified values of TRs. Both pulse sequences were analogous in the results of SNR. SNR was the worst for FLAIR for phantom of T1/T2 614/93ms. Highest values of TR produced suitable SNR for FLAIR.

For phantom 917/135ms, FLAIR was creating good SNR with minimum percentage error. CSE was also good and as low as it could be. However, percentage error was not as high as it was in FSE. High value of TR was necessary for FSE to attain fine SNR. FLAIR was excellent in generating the required SNR and small value of TR was appropriate for good result.

In CSE, SNR of image was almost acceptable at all chosen values of TR for phantom 1050/164ms. Results were comparable with FSE. In both pulse sequences, SNR and percentage error were almost the same. For FLAIR, high value of TR was necessary for right and proper SNR. Percentage error was moderately acceptable at practical values of TR.

SNR was poor for phantom having T1/T2 value 1296/200ms in CSE. Lower values of TR produced very poor SNR, whereas SNR was rather acceptable for higher values of TR. For the phantom of high T1/T2, larger value of TR was required to initiate suitable SNR. FSE generated the worst SNR at selected values of TR. Higher values of TR could create good SNR in FSE. FLAIR created good SNR for selected values of TR. Although low values of TR were the most preferable for apposite SNR of the image.

For phantom 608/134ms, SNR of the images are high for smaller values of TE in all pulse sequences (Table-2). The smallest value of TE was the most appropriate for CSE to attain essential SNR of the image, since the image worth became poor with the increase of TE. Conversely, FSE gave suitable SNR at higher values of TE. However, percentage errors were almost same in both pulse sequences. In FLAIR, high value of TE was better for image quality, whereas lower values of TE gave high percentage error.

For the phantom 614/93ms, results of FSE and CSE were comparable. Small values of TE produced high SNR than the required, while desired SNR was attained at higher values of TR. Percentage error was acceptable at selected values of TE in both pulse sequences. In FLAIR, SNR was relatively poor and optimisation of parameters was indispensable for FLAIR to accomplish the essential SNR.

CSE produced suitable SNR for high values of TE, while percentage error was also acceptable at lower values of TE i.e. TE was 12ms for phantom 917/135ms. In FSE, percentage error was very high for smaller values of TE. However, higher TE values produced reasonable SNR in FSE. FLAIR produced image with moderately good SNR at chosen values of TE and acceptable percentage error at highest value of TE.

For Phantom of high T1/T2 value; 1050/164ms, SNR became poor with the increase of TE in CSE and FSE. Careful selection of parameters was necessary to achieve the required SNR. FLAIR gave images with acceptable percentage error at higher TE values. FLAIR was the pulse sequence which gave better SNR for phantoms of high T1/T2 values.

For high T1/T2 (1296/200ms) value phantoms CSE and FSE generated images with poorest SNR with high percentage error. FLAIR was quite suitable pulse sequence with the best image quality for this phantom. Appropriate SNR was attained at the lower value of TE in FLAIR.

Response of each tissue for TR and TE was according to its own T1/T2 TR. We had to choose TR and TE consistent with their relaxation times. Inappropriate selections of TR and TE in accordance with T1/T2 relaxation times produced a low image quality unacceptable for diagnostic accuracy (Figure-1), background noise was high and signal was very week at specific values of TR and TE for tissue T1/T2 917/135ms. Choice of TR and TE was very well suited for tissue of T1/T2 relaxation time 917/135ms (Figure-2). Tissue produced a strong signal and image quality was perfect for diagnostic precision.

Discussion

The results stress the need to be careful about the selection of pulse sequence and corresponding parameters to maintain SNR of the image. TR and TE usually consider factors that influence the SNR and therefore overall image quality. Moreover, they also affect the characteristics of the pulse sequence which are also imperative for the image excellence.

Suitable parameters of CSE, FSE and FLAIR applied on phantoms having different T1/T2 values and then evaluated SNR of images. High percentage error represents the poor image quality of MR images. This experimental study confirms how a pertinent pulse sequence, TR and TE are necessary to accomplish the MR images of the standard SNR.

SNR increases with the increase of TR in CSE and FSE. T1and T2 of a phantom or a tissue are vital for TR and TE response.[21] This is due to the fact that TR controls the amount of longitudinal magnetisation for a tissue to produce a maximum MR signal. Percentage errors in SNR are resulted due to the unsuitable TR for particular phantom. T1-weighted images are useful for demonstrating anatomy because they have a high SNR.[17] TE determines how much decay of the transverse magnetization is allowed to occur before the signal is read. As the TE increases, the signal intensity on the resulting image decreases due to the decay of the transverse magnetisation. This decay of the transverse magnetisation depends on the biological behaviour of the tissue. CSE is considered the gold standard for most of the imaging in MRI. The majority of sequences used in routine clinical MRI are based on concepts involving spin echo.[22] In general, CSE presents moderately low percentage error with the choice of TR and TE for almost all phantoms. However, optimised values of TR and TE suggest minimisation of errors and improvement in the image worth.

In FSE, the turbo factor is sensible to void the blurring of the image, but the percentage error is slightly higher compared to the percentage error in CSE. However, this increase in percentage error can simply be neglected with the appropriate choice of TR and TE which must be consistent with the nature of phantoms in FSE.

FLAIR is designed for high T1/T2 value tissues and is frequently used in T2-weighed images. FLAIR is also tested for low and high T1/T2 value phantoms in T1-weighted study to certify the availability of this pulse sequence for T1-weighted images. Here long Inversion Time (TI) is used in FLAIR to nullify the signal from any particular tissue. Results substantiate that FLAIR can create matchless SNR images of high T1/T2 value phantoms in T1-weighted images.

Conclusion

For diagnostic accuracy, choice of a pulse sequence and appropriate parameters should be compatible with the selection of the examined tissues. The selection of parameters is relatively simple in CSE in T1-weighted study. This maintains the image worth during the scanning for all phantoms of short and long T1/T2 value and this feature is moderately prevailing in FSE in T1-weighted imaging. Subsequently, the significance of the choice of the CSE pulse sequence for image excellence can't be denied. For T1-weighted images, FLAIR can also be used for diagnostic purposes with the fine image quality for high T1/T2 weighted tissues. The selection of TI should be compatible with T1 value of that tissue. Choice of the pulse sequence with accurate imagining parameters should be in accordance with the characteristics of a tissue to sustain image quality which is vital for diagnostic technique. Furthermore, optimal clinical applications of these pulse sequences require careful attention to these imaging parameters to their complex interactions.

Acknowledgement

We are grateful to the staff of the MRI Department of Ninewells Hospital and Medical School, Dundee, UK, for support in collecting data and facilitating this research. We are also grateful to the Higher Education Commission (HEC) of Pakistan for providing funds through its International Research Support Initiative Programme.

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