Comparison of Maximum Signal Intensity of Magnevist Contrast Agent in Modified T_1 Weighted Spin Echo, T_1 Weighted Fast Spin Echo and T_1 Weighted Gradient Echo Sequences

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ABSTRACT

Background: Nowadays MRI examinations have been widely used in clinical applications for many diagnoses. The use of contrast agent in MRI improves lesion detection and characterization and causes more accurate diagnosis.

Objectives: The aim of this study was comparing to optimal dose of Magnevist contrast agent in modified T_1W SE (Spin Echo), T_1W FSE (Fast Spin Echo) and T_1W GRE (GRadient Echo) and effect of scan parameters of these sequences on the maximum SI of Magnevist contrast agent.

Material and Method: This study was done on a phantom that was containing test tubes. These test tubes were filled with 30ml saline mixed with different doses of Magnevist contrast agent. In this study, some scan parameters of T_1W pulse sequences were changed to achieve optimal parameters for maximum SI of contrast agent. In this study maximum signal intensity of each image was measured by ImageJ software.

Results: The results of this study show that there are differences in maximum SI in different T_1W pulse sequences with changing scan parameters. This study shows that 0.625 mmol/L of Magnevist has maximum SI in all of sequences. The maximum SI can be seen at GRE, SE and FSE sequences, respectively.

Conclusion: Using routine and changed scan parameters, each pulse sequence reaches different maximum SI in specific concentration , which is highest in 2D SPGR (SPoiled GRadient) with flip angle = 75˚ and least in T_1W SE with TE (Time of Echo) = 40ms.

Keywords

Gadolinium DT-PA , Contrast media, Magnetic Resonance Imaging, T_1 Weighted

Introduction

Contrast of MR images improves with contrast media. The alternation of signal intensity in diseased tissue forms the basis of MRI [1]. Some routine examinations are required to inject the contrast medium to the lesion to increase the accuracy of diagnosis [2-13]. When paramagnetic contrast agent passes throughout the tissue of body, it causes a local magnetic field inhomogeneity that leads to a decrease in T_1 and T_2 relaxation times of the tissues. Decrease in T_2 relaxation time

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causes a decrease in SI; while, any decrease in T_1 relaxation time causes an increase in signal intensity. The signal intensity of tissue observed in MR images is the result of a complex interaction of several factors, which can be classified as those reflecting inherent properties of biologic tissue, e.g. T_1 and T_2 relaxation times and PD (Proton Density), and those that are equipment related, e.g. field strength and pulse sequences. Although, due to a wide biologic variation, the relaxation times of normal and abnormal tissues often overlap. This limits the ability of plain MRI to detect and characterize abnormal tissue. By using very specialized pulse sequences, some of these limitations can be overcome, but not all. A solution is provided by MR contrast media altering the relaxation times of tissue into which they diffuse and therefore change the intrinsic tissue SI, enhancing contrast. The concentration of contrast media in MRI is measured indirectly from signal intensity [14-16]. It is important to know how much contrast agent should be injected to achieve a maximum SI in ROI (Region of Interest). The routinely used dose of contrast agents suggested by the documents only relies on the body weight of the patient [17-18]. Many studies have accepted the use of 0.1 mmol/kg of body weight injection in different T_1W pulse sequences with different image parameters and MRI scanner strength [19-25].

Objectives

The aim of this study was to evaluate the relationship between optimal dose of Magnevist contrast agent and maximum SI on different T_1W pulse sequences (T¬1 SE, T_1 FSE, 2D SPGR) with changing their parameters e.g. TE (Time of Echo), TR (Time Repetition), ETL (Echo Train Length) and Flip Angle (FA). Our objective in this study was obtaining the best parameters of T_1W sequences for achieving the maximum SI of Magnevist contrast agent.

Materials and Methods

This study was conducted using a 1.5T MR scanner (General Electric Health Care Corporation, SIGNA, USA). The contrast agent used in this study was Magnevist Gd-DTPA (gadopentetate dimeglumine, Bayer Schering Pharma AG, Berlin, Germany). In this study, we used a phantom which was MR compatible and the closest environment to the body tissues. The phantom consisted of six Falcon test tubes containing a mixture of saline and different contrast agent concentrations placed in a standard head coil at the center of the magnetic field. Falcon test tubes are made of polypropylene with a length of 12cm and inner diameter of 3cm. These tubes were filled with 30ml saline and different doses of contrast agent (0mmol/L, 0.625mmol/L, 1.25mmol/L, 2.5mmol/L, 5mmol/L and 10mmol/L). These doses are equivalent to these volumes of contrast agent (0cc, 1.25cc, 2.5cc, 5cc, 10cc and 20cc), respectively. Coronal image of this phantom is shown in Figure 1.

T_1W (SE, FSE, 2D SPGR) pulse sequences with types of changed scan parameters were used to achieve the correlation between optimal dose of Magnevist contrast agent and scan parameters for each pulse sequences. In this study, changed scan parameters were TR, TE, ETL and FA. We changed one scan parameter in each scan. Changed parameters of each pulse sequence are listed in Table 1. In this study, with changing TR (e.g. TR=500 in SE sequence), other scan parameters of sequence were unchanged to evaluate the effect of TR on the maximum SI of Magnevist contrast medium. The routine scan parameters were TR = 400 ms, TE = 14 ms, matrix size = 256×256, slice thickness = 5 mm, flip angle = 90˚, FOV (Field Of View) = 140 mm for SE sequence; TR = 500 ms, TE = 20 ms, matrix size = 256×256, slice thickness = 5 mm, flip angle = 90˚, FOV (Field Of View) = 140 mm, ETL (Echo Train Length) = 3 for FSE sequence; TR = 100 ms, TE = 3.2 ms, matrix size = 256×256, slice thickness = 5 mm, flip

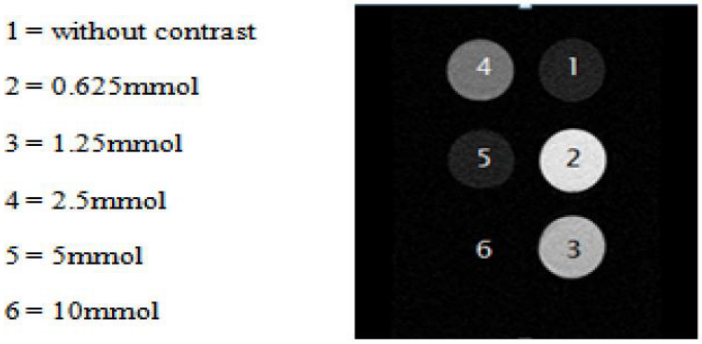

Figure 1: Coronal image of the phantom containing test tubes with different contrast concentrations. Positions of different doses of the contrast agent are determined in this image with numbers and other images in this paper have the same position.

Table 1: Altered parameters in SE T_1W, FSE T_1W and 2D SPGR pulse sequences

	T_1 W SE	T_1 W FSE	2D SPGR
TR (ms)	500, 600	600, 700	-
TE (ms)	10, 25, 40	-	-
ETL	-	2, 6	-
FA(α)	-	-	16˚, 30˚, 60˚, 75˚

angle = 45˚, FOV (Field Of View) = 140 mm for 2D SPGR sequence; and TR = 30 ms, TE = 8 ms, matrix size = 256×256, slice thickness = 5 mm, flip angle = 45˚, FOV (Field Of View) = 140 mm for 3D SPGR sequence. We only use 3D SPGR sequence for comparing with 2D SPGR.

Different settings of scan parameters were used for achieving the best parameters of each pulse sequence to obtain the maximum SI

One sagittal image was used as localizer. The scan plane was fixed throughout this study. Afterwards, the coronal images of phantom were achieved for all four T_1W pulse sequences. After transferring the images from MR scanner to a personal computer, the ImageJ software (Image Processing and Analysis in Java, www. http://imagej.nih.gov) was used for image processing. This software has the ability to display and process images. We drew ROI on each of test tube images by ImageJ software and achieved the maximum SI of each test tube. The size of ROI was fixed (15*15 pixels) and placed on each test tube image for the measurement of SI. SNR is calculated as follows:

SNR (c)=signal (c)/standard deviation of noise (1)

Signal (c) is the signal for a test tube with concentration c. The noise was obtained by the measuring the ROI outside the test tubes (26).

The equations of SI at different sequences:

$$S = PD.(1-e^{-TR/T1})e^{-TE/T2} \quad (2)$$

This is a formula for calculating the SI in SE and FSE sequences (27).

This one is SI formula for GRE sequence (28).

Results

The mean ± SD (standard deviation), mini-

$$S = PD\sin\alpha\{1-e(-TR/T_1)\}.\{e(-TE/T_2^*)\}/\{1-(\cos\alpha).(e(-TR/T_1))\} \quad (3)$$

mum and maximum SI of Magnevist for SE, FSE and 2D SPGR pulse sequences by changing their parameters is listed in Tables 2, 3 and 4. The mean, minimum and maximum SI with routine parameters in each of these pulse sequences is placed in Figure 3. In addition, some images of routine and modified pulse sequences are shown in Figures 2 and 3. In routine sequences, 0.625mmol/L of Magnevist shows maximum SI (Table 5). As these tables and figures show, there are differences in maximum SI between routine pulse sequences and the same sequences with changing scan parameters. For all sequences, the

Table 2: Maximum, minimum and mean SI of SE pulse sequence with changing TR and TE. 0.625 mmol/L of Magnevist shows maximum SI in TR = 500 ms, TR = 600 ms and TE = 10 ms. Test tube without contrast agent (only saline) shows maximum SI in TE = 25 ms and TE = 40 ms. Minimum and mean SI are listed too.

Altered parameters	Maximum SI	Minimum SI	Mean ±SD
TR = 500 ms	398 (0.625 mmol/L)	295 (0.625 mmol/L)	348.794 (0.625 mmol/L) ± 0.7
TR = 600 ms	407 (0.625 mmol/L)	288 (0.625 mmol/L)	347.356 (0.625 mmol/L) ± 0.6
TE = 10 ms	884 (0.625 mmol/L)	765 (0.625 mmol/L)	820.24 (0.625 mmol/L) ± 0.7
TE = 25 ms	266 (saline)	174 (saline)	223.955 (saline) ± 0.3
TE = 40 ms	273 (saline)	176 (saline)	220.909 (saline) ± 0.4

Table 3: Maximum, minimum and mean SI of FSE pulse sequence with changing TR and ETL. 0.625 mmol/L of Magnevist shows maximum SI in the changed scan parameters.

Altered parameters	Maximum SI	Minimum SI	Mean ±SD
TR = 600 ms	590 (0.625 mmol/L)	504 (0.625 mmol/L)	548.043 ± 0.6
TR = 700 ms	599 (0.625 mmol/L)	499 (0.625 mmol/L)	551.424 ± 0.9
ETL = 2	608 (0.625 mmol/L)	492 (0.625 mmol/L)	559.284 ± 0.5
ETL = 6	632 (0.625 mmol/L)	489 (0.625 mmol/L)	563.436 ± 0.8

Table 4: Maximum, minimum and mean SI of 2D SPGR pulse sequence with changing FA. 0.625 mmol/L of Magnevist shows maximum SI in all of FAs.

Altered parameter	Maximum SI	Minimum SI	Mean ± SD
FA = 16°	582 (0.625 mmol/L)	297 (0.625 mmol/L)	434.371 ± 0.8
FA = 30°	901 (0.625 mmol/L)	570 (0.625 mmol/L)	759.189 ± 0.4
FA = 60°	1545 (0.625 mmol/L)	1234 (0.625 mmol/L)	1401.067 ± 0.5
FA = 75°	1710 (0.625 mmol/L)	1462 (0.625 mmol/L)	1576.045 ± 0.3

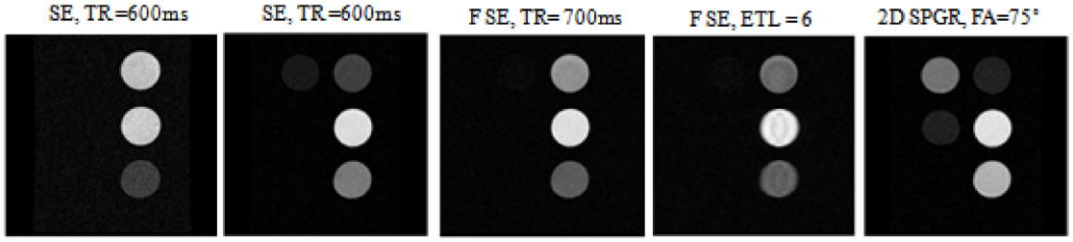

Figure 2: Some images of pulse sequences with changing parameters

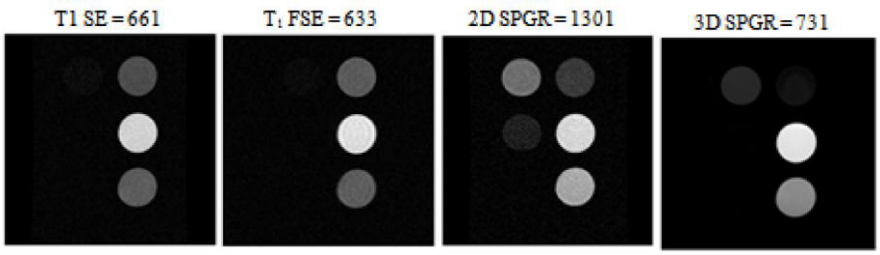

Figure 3: Maximum SI of SE, FSE, 2D SPGR and 3D SPGR pulse sequence with routine parameters, (In these sequences, the best dose that shows maximum SI was 0.625 mmol/L)

maximum SI was detected in test tube with dose 0.625mmol/L. In modified SE T_1W, TR= 600 ms and TE= 10 ms, in modified FSE T_1W, TR=700 ms and ETL=3 and in modified 2D SPGR pulse FA=75˚ were best parameters for achieving maximum SI of 0.625mmol/L.

Discussion

The concentration of Magnevist contrast agent demonstrated no linear correlation with the signal intensity [29]. Contrast agents have been used in NMR since the earliest days when Bloch added paramagnetic ferric ions in solution to shorten the longitudinal relaxation time (T_1) of protons in water [30]. Contrast-enhanced magnetic resonance imaging (MRI) offers the opportunity to quantitatively assess the physiologic properties of a tissue such as perfusion, blood volume and capillary permeability. Certain materials known as contrast agents can enhance MR image contrast by altering T_1, T_2 and T_2* relaxation times. Contrast agents are frequently used in diagnostic MRI in order to achieve a better assessment of local physiologic and anatomic conditions or to improve the detection of malignancy. Changing in MR image intensity after the administration of gadolinium chelates occur due to the effects

Table 5: Maximum, minimum and mean SI of routine T1W pulse sequences without changing scan parameters.

Routine sequences	Maximum SI	Minimum SI	Mean SI
SE	645 (0.625 mmol/L)	547 (0.625 mmol/L)	602.197 (0.625 mmol/L)
FSE	633 (0.625 mmol/L)	527 (0.625 mmol/L)	579.074 (0.625 mmol/L)
2D SPGR	1245 (0.625 mmol/L)	993 (0.625 mmol/L)	1119.945 (0.625 mmol/L)
3D SPGR	718 (0.625 mmol/L)	683 (0.625 mmol/L)	700.869 (0.625 mmol/L)

of T_1 and T_2 shortening. These two effects are competing; T_1 shortening leads to increased image intensity and T_2 shortening causes a decrease in intensity. The resulting image intensity is a nonlinear function of contrast agent concentration in tissue and is dependent on other parameters such as intrinsic tissue relaxation times, TR, TE and flip angle [31]. Melhem et al. compared CNR ratios between FSE and SE in T_1-weighted MR sequences of 32 enhancing brain lesions. MR images were obtained at 1.5T after administration of 0.10mmol/kg gadopentetate dimeglumine [21]. Hsiao C. et al. used various T_1W pulse sequences (SE, SPGR, 2D TOF and 3D TOF) and various coils (body coil and head coil) to achieve the optimal dose of two contrast agents (Magnevist and Omniscan). The results show that there are significant differences in optimal dose among various pulse sequences. However, there are no significant differences in optimal dose among various coils and these two contrast agents. The optimal dose for SE T_1W, SPGR, 2D Fast SPGR TOF and 3D Fast SPGR TOF are 1.25mmol/L, 2.5mmol/L, 2.5mmol/L and 20mmol/L, respectively. Images scanned by SE T_1W pulse sequence in this study had the largest CNRs and least optimal doses (26). Kakeda et al. compared SE (TR = 520 ms, TE = 9 ms), IR-FSE (TR = 2500 ms, TE = 9.1 ms, TI = 1000 ms, ETL = 7), and 3D-gradient echo sequences to detect brain metastases at 3T scanner. They administered 0.2mmol/kg gadoteridol for all patients. They reported that a 0.2mmol/L of contrast agent concentration gave the maximum SI in SE and IR-FSE sequences in a phantom study using a 3T MRI scanner [32].

As the results show, in our study 0.625mmol of Magnevist contrast agent has the maximum SI in types of T_1 W pulse sequences. The difference between the results of this study and previous studies might be due to the difference in field strength, used TR and TE. In our study, we investigated the effects of scan parameters such as ETL, TE, TR and FA in increasing maximum SI of Magnevist contrast agent. Our study shows that in SE T_1W pulse sequence with increasing TE (from 10 to 40), the maximum SI of 0.625mmol (1.25cc) decreased and vice versa. For T_1W sequences, increasing TE causes dephasing of signal so it would increase T_2 weighting of image and when we have a T_2 image, T_2 shortening effect would happen in test tubes with contrast agent so the saline tube which does not have any contrast agent, would not be affected by T_2 shortening effect. Accordingly, it would present the maximum signal intensity. As a result, we should not increase TE in T_1W SE sequence using the administration of contrast agent in MRI and TE in this sequence should be the least and in range of T¬1 weighted. Therefore, for maximum SI of contrast agent in T_1W SE sequences, the possible shortest TE is suggested (Figure 4). Also in this sequence, with the increase in TR (500 to 600) without altering of other parameters, maximum SI of contrast agent slightly increased. Although, it should be noted that more increasing TR leads to a decrease in T_1 weighting of image; it would decrease the SI of contrast agent because of T_2 shortening effect of gadolinium based contrast agents. Therefore, in order to increase the maximum SI of contrast agent in SE sequence, increasing TR is not a suitable option.

In this study, there is no significant change in SI with increasing ETL in FSE sequence (from 2 to 6). But the image was blurred due to the participation of other ETL in contrast of the image (Figures 2, 3 and 5). In FSE sequence, with increasing TR, SNR and maximum SI of 1.25cc (0.625mmol) slightly increased (equation1). Increasing TR leads to decreasing weight of T_1 and losing signal of Magnevist in T_1W sequences. As a result, for MRI studies with administration contrast agent, the shortest ETL and suitable TR for minimizing the blur and maximizing the SI are suggested.

In our study, in 2D gradient echo sequences such as 2D SPGR, with increasing FA (from 16˚ to 75˚) maximum SI increased significant-

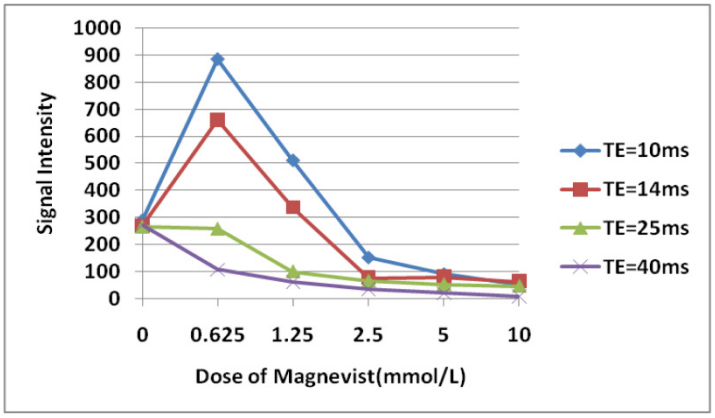

Figure 4: SI vs. Dose of Magnevist Gd-DTPA in SE pulse sequence with altering TE

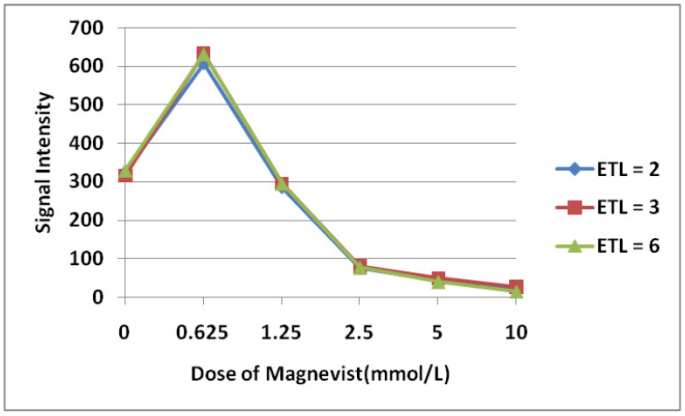

Figure 5: SI vs. Dose of Magnevist Gd-DTPA in FSE pulse sequence with altering ETL

ly (Figure 6). In these sequences with increasing FA, a larger longitudinal component would be placed in x-y plane and T_1 weighting of image and the SI increase. As a result, for achieving the maximum SI of contrast agent in 2D SPGR sequences, the possible maximum FA is suggested. But in 3D SPGR sequence to 2D SPGR sequence, the maximum SI of contrast agent decreased (Figure 3). In 3D sequences, imaging volume to contrast agent ratio (VOI/CM) is more than 2D sequences; therefore, 3D sequences compared with 2D sequences require more doses of contrast agent to create SI equal to SI of 2D sequences.

This study shows that the optimal dose of contrast agent is 0.625mmol/L in SE, FSE, 2D SPGR and 3D SPGR sequences which is different from previous studies. In previous studies, optimal dose for SE T_1w, FSE T_1w and 2D SPGR without any changed scan parameters were 1.25mmol/L, 4.96mmol/L and 2.5mmol/L, respectively [26, 29]. The difference between the results of this study and previous studies may be due to the difference in field strength and used TR and TE in routine T_1w sequences. The novelty of our study is the assessment of scan parameters on SI of Magnevist contrast agent which was not already

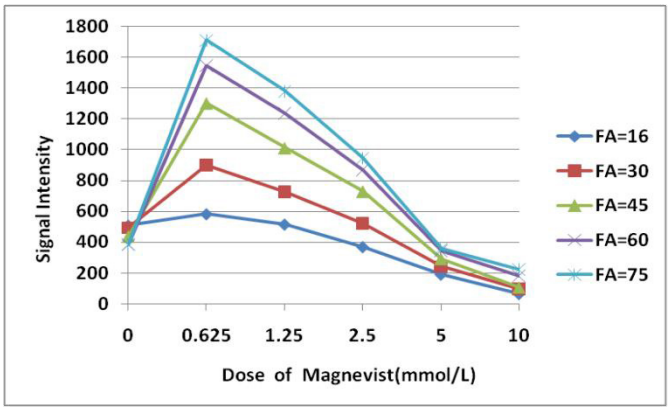

Figure 6: SI vs. Dose of Magnevist in 2D SPGR pulse sequence with altering FA. As the curve shows, with increasing FA, the larger longitudinal component would be placed in x-y plane and the maximum SI increases.

done. Our study showed that the maximum SI of optimal dose of Magnevist contrast agent depends on image sequence and its parameters. At higher doses of Magnevist contrast agent as mentioned in the results, there was not an increased SI, but a decreased SI (Figures 2 and 3). Changing scan parameters shows we can change scan parameters of routine sequences to achieve higher SI of contrast agent and decrease the received dose by patients. The highest maximum SI of 0.625mmol/L achieved in 2D SPGR with FA = 75˚. In FSE sequence, using shorter TR and optimal ETL in range of T_1 weighted result in higher SI. In addition, in SE sequence using shorter TE and TR than routine SE sequence causes higher maximum SI. For the comparison between conventional and modified T_1W pulse sequences, we find that SE sequence with the possible shortest TE, conventional FSE sequence and 2D SPGR with the possible maximum FA have maximum SI of Magmevist in ROI.

Conclusion

In this study, we have concluded that the maximum SI of Magnevist contrast agent is achieved by 2D SPGR sequence with routine and changed FA parameter. Maximum SI in 2D SPGR with increased FA (75˚) is higher than routine 2D SPGR sequence (FA=45˚), so we can use T_1W GRE sequence with optimized FA after the administration of Magnevist for achieving maximum SI in ROI. These can be suggested for clinical use in the future. This study was limited to phantom because we cannot administrate high doses of contrast agent to patients.

Conflict of Interest

None

References

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