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3D MRI gel dosimetry based on image intensity (A new approach)

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ABSTRACT

Background: Since 1984 MRI gel dosimetry has been introduced as a potential technique for 3D dosimetry. Most of the studies have measured R_1 ($1/T_1$) or R_2 ($1/T_2$) properties of the gel depending on the gel type. We have studied image intensity change in the Fricke gel by different MRI protocols.

Materials and Methods: Gel Dosimeters contain 0.4 mM ferrous sulphate, 1 mM NaCl, 50 mM H2SO4 and 1% by weight agarose in distilled water. Prepared gels were poured in Plastic tube phantom and irradiated to a beam of Co-60 gamma rays. Imaging was performed by a 0.5T MRI system in the head coil with SE and GRE techniques.

Results: Our results showed that linear response exists between the variations of image intensity with absorbed dose (1-15 Gy). Optimal imaging parameters should be defined locally according to the type of MRI scanner and exact composition of the gel. Gradient echo (GRE) imaging technique also have been studied in comparison with classic spin echo (SE) imaging technique which will be discussed in detail.

Conclusions: Linearity of absorbed dose with intensity exists up to 15 Gy and can be used for MRI gel dosimetry. Reduction of imaging time is achievable in image intensity technique so that it's possible to image the gel in less than 20 minutes, which is critical to over-come the adverse ion-diffusion properties of the Fricke gel. *Iran. J. Radiat. Res., 2003; 1(1): 45 - 50.*

***Keywords**: Gel dosimetry, MRI dosimetry, image intensity, ferrous infused gels.*

INTRODUCTION

Three-dimensional dosimetry can be performed in two ways: 1- Automated water phantom, in which the, sensor either ion chamber or solid-state diode move automatically and dose distribution is measured in water tank, but the accurate dose measurement in complicated dose distribution is not possible. 2- Film dosimetry; in which dosimetry of complicated shapes is possible however, the film dosimetry is basically a two-dimensional dosimetry technique. Three- dimensional dosimetry is possible only with spatial combinations of the films. With introducing gel as a dosimeter, a new revolution in 3D dosimetry is happening. Since the gel used for dosimetry contains more than 99% of water therefore it can be considered as tissue equivalent. Application of the gel to make different phantoms is practical. It is also possible to measure dose in different planes up to 15 Gy, which means the response of the gel dosimeter is linear up to 15 Gy without being dependent to the type of radiation or energy. Two types of gels have been used, Fricke and polymer gels. In Fricke gel the Fe^{2+} ions oxidize to Fe^{+3} ions due to ionization (Gore *et al.* 1984, Olson *et al.* 1990 and Tarte *et al.* 1996).

In the polymer gels the construction of polymer changes due to irradiation. One difficulty with Fricke gel dosimeter is diffusion

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of Fe^{3+}ions with time. This problem has been investigated by several researchers (Baldock *et al.* 1996) and diffusion rate of Fricke gel dosimeters with different ingredients have been measured. Obtaining a faster technique results in reduction of measurement time, which in turn reduces the diffusion effect (Zahmatkesh *et al.* 1998). If the time between irradiation and final scanning is kept below one hour the diffusion effect is unimportant, which enables the user to avoid complicated calculation. So far dosimetry with Fricke gel had been performed either with optical scanning techniques or with magnetic resonance imaging (MRI) in which spin lattice relaxation rate (T_1, R_1) was measured. Application of signal intensity in MRI has been rear and only one work was found in the literature by Chue *et al.* (1988), who used signal intensity for dose calculation in gel dosimeter.

In this study, it has been tried to measure dose in Fricke gel dosimeter via image intensity for R_1 measurement.

MATERIALS AND METHODS

Gel preparation

Gel dosimeter contains 0.4 mM ferrous sulphate, 1mM sodium chloride, 50mM sulphuric acid, and 1% by weight agarose. All ingredients are laboratory grades and supplied by Sigma Aldridge Company. To make these Fricke gel dosimeters, the final volume of water required was divided into two equal portions. In one container sulphuric acid was poured and then, Fe^{2+} and NaCl were added and left to dissolve. The agarose powder was poured into the other container and stirred until it was dissolved. Agarose container was left in a microwave oven until it was boiling. The boiling agarose was removed from oven and cooled down to 62°C in a water bath. Stirring should be continued to cool the gel uniformly. In 62°C, two containers were mixed and poured in the phantoms. In this research Perspex phantoms with dimensions of $15 \times 10 \times 1cm^3$ and vial shaped plastic phantoms with inner diameter of 27mm and height of 115mm were used.

Irradiation procedures

Cobalt 60 unit (Theratron 780C, Canada) was used for irradiation. To verify the variation of signal intensity with adsorbed dose, vial shaped phantoms were fixed in a plastic water tank with dimensions of $22 \times 12 \times 11cm^3$ in vertical positions. The tank was filled with water up to the level of the gels to produce a homogenous environment and reduce the scatter effect. Source surface distance (SSD) and field size were fixed to 80cm and $15 \times 10cm^2$ respectively. In cases that wider phantoms were necessary to use, a $10 \times 10 \times 1cm^3$ Perspex phantom with 6mm wall thickness was used. In these cases SSD and field size were fixed to 80cm and $10 \times 10\ cm^2$ respectively.

MRI imaging

A 0.5 T commercial MR imaging system (Gyroscan T5/Philips) was used for imaging purposes. A special wooden mold was constructed to fix in the head coil. The water tank also was stuck to this wooden mold to prevent dislocation of the phantom in the head coil in scanning processes before and after irradiation. The scanning protocols were also identical for before and after irradiation. The data in the MRI console was transferred to the computer (Gyroview) work's station for analysis. For each image an average region of interest (ROI) was obtained and the value of noise was subtracted from this ROI. The data of the signal intensity for after irradiation was subtracted from before irradiation data to obtain the variation of signal intensity (ΔI) due to irradiation for each region.

In this work, two imaging protocols named spin echo (SE) and gradient echo (GRE) were used.

In SE technique scanning parameters were:

TE=11ms, TR=100, 120, 150, 200, 250, 350, 500, 1000, 2000, 4000ms.

Slice thickness =10mm, Gap thickness = 0 mm, NSA=2

In GRE technique imaging parameters were:

TE=11ms, TR=500ms. Flip angles =30, 60, 75, 90˚

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Slice thickness=10mm, Gap thickness = 0mm, NSA =2.
Total time for this kind of two stages GRE technique was 4 minutes.

RESULTS

In order to evaluate the effect of non-uniformity, Perspex phantom was placed in the head coil at X=40, X=0 and X= -40 positions and was imaged with SE technique with TE = 11 and TR =500.
The Results of non-uniformity in profiles perpendicular to Z-axis (axis along with head coil inward) is shown in figure 1-a. Non-uniformity of the field is also shown in profile perpendicular to Y-axis (axis perpendicular to treatment couch and upward) (figure 1-b).

Non-uniformity profiles in figure 1-b are comparable to the variation of signal intensity produced due to phantom irradiation. However, when the images of irradiated and un-irradiated gel was subtracted, for a certain position the related non-uniformity was cancelled out and had no effect in the final results. This is a sign of good reproducibility for this technique.

To find a proper SE protocol, it was assumed that TE<<TR and TE = 11 ms, for TR = 100, 120, 200, 250, 500, 2000 and 4000 ms, values of ΔI versus dose (D) was graphed in figure 2. An optimum TR must be selected so that these conditions are met: TE<<TR, images are T_1 weighted and have good variation of ΔI for unit of irradiation (ΔD). It was found that TR=500ms have the requirements and was accepted as spin echo imaging protocol. The slopes of the lines fitted to the curves correspond to TR=100, 500 and 2000 are 36.478, 39616 and 8.998 respectively.

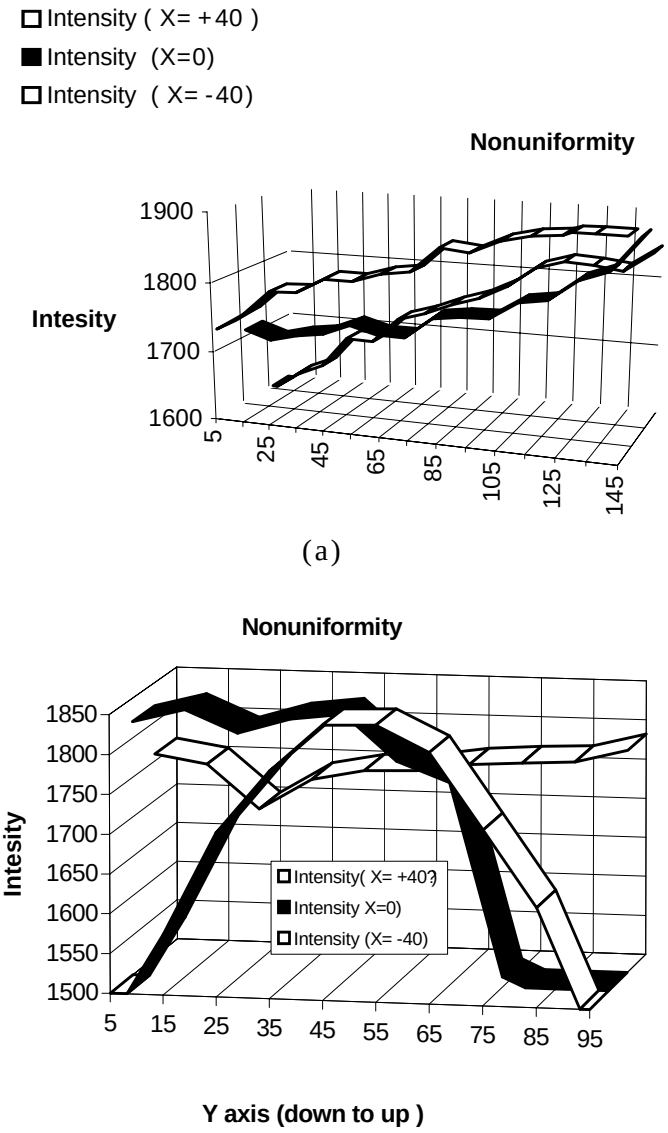

Figure 1. a) non-uniformity in magnetic field in head coil in image profile perpendicular to Z axis, b) non-uniformity in magnetic field in head coil in image profile perpendicular to Y axis.

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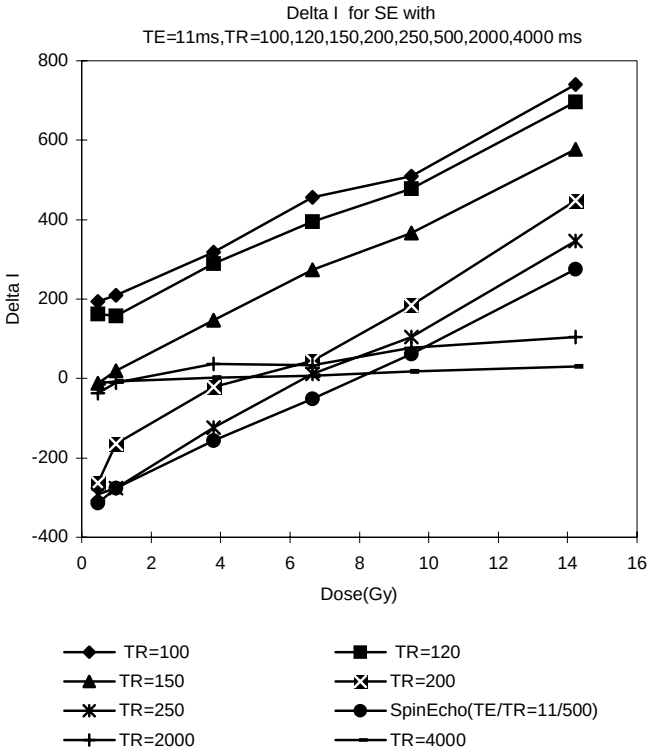

Figure 2. Signal intensity versus dose for TE=11ms and TRs=100,120,150,200,250,2000 and 4000ms in SE technique.

Results obtained for ΔI due to different angles indicate that flip angle =75º has higher sensitivity. Results for ΔI versus D was graphed for both SE and GRE techniques and their sensitivity are compared (figure 3). Results indicate that both graphs in dose interval of o.9-14.23 Gy are linear and relative sensitivity of SE to GRE is 1.5.

To determine reproducibility with SE technique, vial shaped phantoms were imaged for four times and values for ΔI versus D were graphed in figure 4.

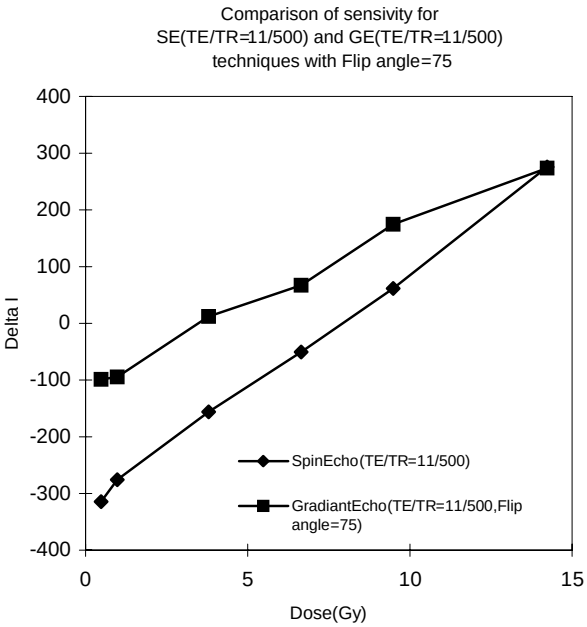

Figure 3. ΔI profiles for dose range of o.47 to 14.23 Gy, 1) SE technique with TE=11,TR=500 and 2) GRE technique with TE=11,TR=500 and flip angle 75. The sensitivity in (SE) is 39.9 Gy^{-1} while for (GRE) is 26.9 Gy^{-1}.

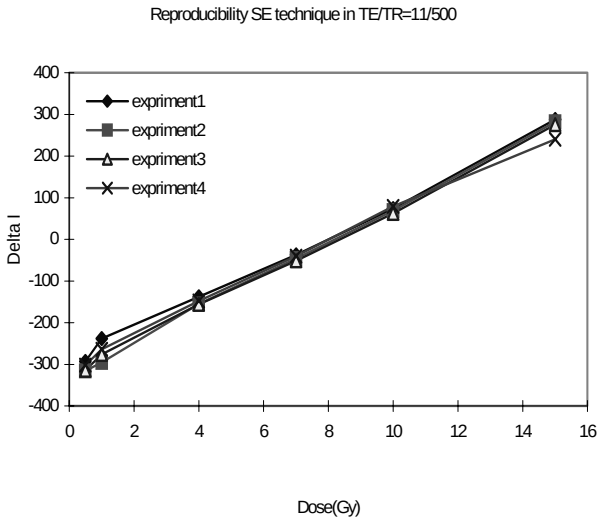

Figure 4. Reproducibility in SE imaging technique for gel dosimeter.

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DISCUSSION

Results shown in figure 2, prove that for T_1 weighted SE image, TE<<TR and doses lower than 15 Gy, signal intensity due to irradiation (ΔI) is increasing linearly with absorbed dose (D). Maximum sensitivity happens for TR=500ms. For TRs higher than 2000ms and up to 4000ms, sensitivity is reduced rapidly. This reduction in sensitivity is a sign that images are out of T_1 weighed area, and image is going towards a proton density weighted image; therefore, ΔI does not increase significantly and is independent of does (D).

In equation $\Delta I=C.N\,(H)\exp.(-TE/T_2)\,[(1/T'_1-1/T_1)\,(TR-TE)]$ (chu *et al.* 1998), from one side in very short TRs, (TR<100ms), Mcloren expansion can be used to obtain a linear relation between ΔI and various R_1 and in the other side the T_1 weighted condition will be on force, however for low signal to noise condition, the dose would be reduced. In dose evaluation, signal intensity is used directly in such a way that signal to noise ratio will increase which in turn will increase the sensitivity of the dose response. To achieve a higher signal to noise ratio, a scanner with stronger field, more averaged number and a gel with more ferrous ions in it can be used.

One drawback for increasing the number of averaging is the growth of the ferric ion diffusion. Error fraction due to T_2 variation in ΔI calculation is similar to R_1 calculation (Balcom *et al.* 1995, Kron *et al.* 1993, Maryanski *et al.* 1996) and for TE = 11 ms it has been estimated to be 3%.

In ΔI calculation, only one image of irradiated gel is needed, therefore in comparison with R_1 calculation that two or more irradiated gel is required, imaging time is reduced from one hour to 5 minutes. The reduction of imaging time will minimize the ferric ion diffusion and a three-dimensional (3D) dosimetry is easily achievable. In R_1 calculation also an error exists which is considerable in comparison with the error in the image intensity calculation. In GRE technique, because the $\alpha < 90°$ and in contrast to SE technique, the 180 pulse was not present, the imaging time shows 2 minutes reduction in comparison with SE technique when TE << TR. This reduction of time makes the ferric ion diffusion more unimportant. As it was shown in figure 5, as α angle is smaller, the sensitivity is also reduced. The reason is that in smaller α, images are leaving T_1 weighted state and go towards proton density or T_2 weighted. Of course the TR should be high enough to be able to have a T_1 weighted image in larger α. In this regard, the optimum values of TR and α were selected to be 500ms and 75° respectively as shown in figure 5. Although, in GRE technique, the variation of sensitivity of signal intensity to dose is 1.5 times less than SE, but for increase in imaging speed and also for 3D imaging, the GRE can be used as a proper imaging technique.
In ΔI technique, with changing the field power of MRI system, recalibration should be performed. This is also true for R_1 calculation technique, as with change of field, T_1 also would be different. Therefore from this point of view, these two techniques have no advantage to each other. In R_1 calculation technique, sensitivity (variation of R_1 in the unit of absorbed dose) is mentioned to be .0129 S^{-1} Gy^{-1} that is much lower than the sensitivity found in ΔI technique that is in the order of 10^{-3}.

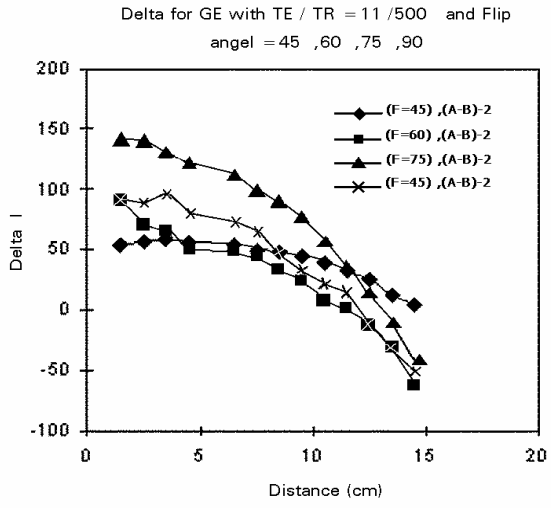

Figure 5. Curves obtained with GRE technique for TE=11ms, TR=500ms with flip angles of 45˚, 60˚, 75˚, and 90˚. phantoms were Plexiglas irradiated to a certain dose.

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