

Comparison of Energy Dependence of PAGAT Polymer Gel Dosimeter with Electron and Photon Beams using Magnetic Resonance Imaging

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Abstract: The purpose of this study was to evaluate dependence of PAGAT polymer gel dosimeter $1/T_2$ on different electron and photon energies for a standard clinically used ^{60}Co therapy unit and an electa linear accelerator. Using MRI, the formulation to give the maximum change in the transverse relaxation rate $R_2(1/T_2)$ was determined to be 4.5% N,N'-methylene-bis-acrylamide(bis), 4.5% acrylamid(AA), 5% gelatine, 5 mM tetrakis (hydroxymethyl) phosphonium chloride (THPC), 0.01 mM hydroquinone (HQ) and 86% HPLC(Water). When the preparation of final polymer gel solution is completed, it is transferred into phantoms and allowed to set by storage in a refrigerator at about 4°C . The optimal post-manufacture irradiation and post imaging times were both determined to be 24 h. The sensitivity of PAGAT polymer gel dosimeter with irradiation of photon and electron beams was represented by the slope of calibration curve in the linear region measured for each modality. The response of PAGAT gel with photon and electron beams is very similar in the lower dose region. The R_2 -dose response was linear up to 30 Gy and the R_2 -dose response of the PAGAT polymer gel dosimeter is linear between 10 to 30 Gy. In electron beams the R_2 -dose response for doses less than 3 Gy is not exact, but in photon beams the R_2 -dose response for doses less than 2Gy is not exact. Dosimeter energy dependence was studied for electron energies of 4, 12 and 18MeV and photon energies of 1.25, 4, 6 and 18 MV. Evaluation of dosimeters were performed on Siemens Symphony, Germany 1.5T Scanner in the head coil. In this study no trend in polymer-gel dosimeter $1/T_2$ dependence was found on mean energy for electron and photon beams.

Key words: Electron and photon beams, MRI, PAGAT gel, polymer gels

INTRODUCTION

In 1984, magnetic resonance imaging (MRI) demonstrated great potential in visualizing three dimensional (3D) dose distributions of ferric or ferrous sulphate gel dosimeters (Gore *et al.*, 1984).

Subsequently, studies were undertaken to investigate the feasibility of using Ferric gel as a 3D dosimetry system in radiation oncology (Olsson *et al.*, 1990). The major limitation in Ferric gel dosimetry is that it suffers from blurriness of dose with time which is due to the migration of ferrous and ferric ions in gel matrix, known as diffusion (Schulz and Gore, 1990). In 1993, a polymer gel dosimeter was developed that maintained spatial information following irradiation which could be visualized using MRI (Maryanski *et al.*, 1993). Polymer gel dosimetry is a technique that has the ability to map absorbed radiation dose distribution in three dimensions (3D) with high spatial resolution. Polymer gel dosimeters offer a number of advantages over traditional dosimeters such as ionization chambers, Thermoluminescent Dosimeter (TLD) and radiographic film. These advantages include independence of radiation direction,

radiological soft tissue equivalence, integration of dose for a number of sequential treatment fields, and perhaps most significantly, evaluation of a complete volume at once (De Deene, 2004) and (Brindha *et al.*, 2004). In 2001, the first normoxic gels were suggested that could be produced, stored and irradiated in a normal condition. Magnetic Resonance Imaging (MRI) has been most extensively used for the evaluation of absorbed dose distributions in polymer gel dosimeters. In the MRI evaluation of polymer gel dosimeters, changes in T_2 is a result of physical density changes of irradiated polymer gel dosimeters. Many factors such as polymer gel composition, temperature variation during irradiation, type and energy of radiation, dose rate, temperature during MRI evaluation, time between irradiation to MRI evaluation, and strength of magnetic field have been studied by different authors (Maryanski *et al.*, 1994); Maryanski *et al.*, 1996; Kennan *et al.*, 1996). All these factors can potentially affect polymer gel dosimeter response and significantly influence measured results. Consequently, it is important to evaluate and quantify each individual factor. In PAGAT polymer gel dosimeter, the gel itself forms both a multi dimensional phantom and

Table 1: Different chemicals and percent weight of PAGAT gel

Component	Percent weight
Gelatine (300 bloom)	5%
N,N'-methylene-bis- acrylamide (bis)	4.5%
Acrylamide (AA)	4.5%
Tetrakis-phosphonium chloride (THPC)	5 m M
Hydroquinone (HQ)	0.01 mM
HPL C (water)	86%

Table 2: The protocol of magnetic resonance imaging (MRI)

Parameters	
Field of view (FOV) (mm)	256
Marrix size (MS)	512×512
Slice thickness (d) (mm)	4
Repetition time (TR) (ms)	3000
Echo time (TE) (ms)	20
Number of slices	1,2,3,4
Number of echoes	32
Total measurement time (min)	25-30
Resolution (mm)	0.5
Band with (Hz/Pixel)	130

the detector (Venning *et al.*, 2005). The gel can be modified to be almost completely soft-tissue equivalent. Considering factors such as accuracy, sensitivity, the time needed for dosimetry, three-dimensional capabilities, energy independence, dose rate independence, and costs, we believe that PAGAT polymer gel dosimeter is the "closest to ideal" dosimetry method comparing with TLDs, ion chambers, film dosimetry, Fricke gels and anoxic gels.

MATERIALS AND METHODS

Preparation of PAGAT gel: The PAGAT polymer gel formulation by % mass consisted of 4.5% N,N'-methylene-bis-acrylamide (bis), 4.5% acrylamid (AA), 5% gelatine, 5 mM tetrakis (hydroxymethyl) phosphonium chloride (THPC), 0.01 mM hydroquinone (HQ) and 86% HPLC (Water) (16). All components were mixed on the bench top under a fume hood. The gelatine was added to the ultra-pure de-ionized water and left to soak for 12 min, followed by heating to 48°C using an electrical heating plate controlled by a thermostat. Once the gelatine completely dissolved the heat was turned off and the cross-linking agent, bis was added and stirred until dissolved. Once the bis was completely dissolved the AA was added and stirred until dissolved. Using pipettes, various concentration of the polymerization inhibitor HQ and the THPC anti-oxidant were combined with the polymer gel solution. When the preparation of final polymer gel solution is completed, it is transferred into phantoms and allowed to set by storage in a refrigerator at about 4°C (Venning *et al.*, 2005).

Table 1 lists the component with different percent weight in normoxic PAGAT polymer gel dosimeter.

Irradiation: Irradiation of vials was performed using electron beams by an electa linear accelerator with SSD

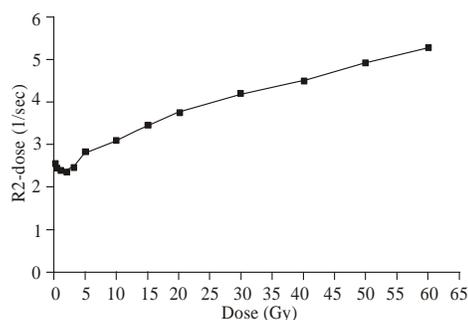


Fig. 1: Sensitivity of PAGAT gel with different range of doses (0-60Gy)

= 80 cm, field size of 20×20 cm² and the depth was selected at 5 cm. The optimal post-manufacture irradiation was determined to be 1 day.

Imaging: Before imaging, all polymer gel dosimeters were transferred to a temperature controlled MRI scanning room to equilibrate to room temperature. The PAGAT polymer gel dosimeters were imaged in a Siemens Symphony 1.5 Tesla clinical MRI scanner using a head coil. T2 weighted imaging was performed using a standard Siemens 32-echo pulse sequence with TE of 20 ms, TR of 3000 ms, slice thickness of 4 mm, FOV of 256 mm. The optimal post imaging times was determined to be 1 day. The images were transferred to a personnel computer where T2 and R2 maps were computed using modified radiotherapy gel dosimetry image processing software coded in MATLAB (The Math Works, Inc). The mean T2 value of each vial was plotted as a function of dose with the quasi-linear section being evaluated for R2-dose sensitivity. Table 2 lists the protocol of Magnetic Resonance Imaging (MRI) was used in PAGAT polymer gel dosimeter.

RESULTS

Verification of R2-dose sensitivity of PAGAT polymer gel dosimeter:

Verification of R2-dose sensitivity of PAGAT polymer gel dosimeter with electron beams: PAGAT gels with optimum value of ingredient was manufactured and irradiated to different doses. Polymer gel dosimeters in Perspex phantoms were homogeneously irradiated with 6MeV electron beam with an electa linear accelerator located in Tehran. Delivered doses were from 0-6000cGy. The calibration curve (transverse relaxation rate (1/T2) versus applied absorbed dose) was obtained and plotted. Dependence of 1/T2 response to the absorbed dose in the range of 0-6000cGy is shown in Fig. 1. As it can be seen in Fig. 1, PAGAT has a linear response up to 30 Gy. the response of the PAGAT gel is very similar in the lower

Table 3: Sensitivity of PAGAT gel with different range of doses

Dose (Gy)	R2- Dose sensitivity (S ⁻¹ Gy ⁻¹)	Correlation coefficient
0-3	-0.026	0.1997
3-10	0.89	0.9421
10-30	0.0526	0.9921
30-60	0.0359	0.9975

Table 4: Sensitivity of PAGAT with different range of doses

Dose (Gy)	R2- Dose sensitivity (S ⁻¹ GY ⁻¹)	Correlation coefficient
0-2	0.0456	0.6175
2-10	0.1512	0.9949
10-30	0.09831	0.9939
30-50	0.0577	0.9825

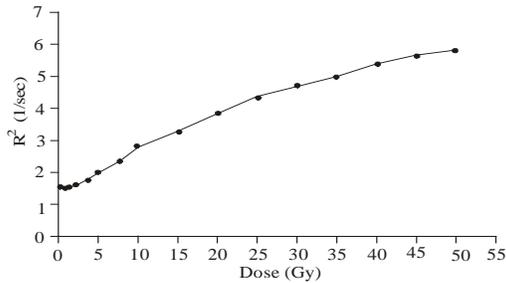


Fig. 2: PAGAT polymer gel dosimeter R2 (1/T2) calibration response in range of 0-50Gy

dose region and The R2-dose response for doses less than 3 Gy is not exact. The R2-dose response of the PAGAT polymer gel dosimeter is linear between 3-10 Gy and 10-30 Gy. Figure 1 shows that PAGAT polymer gel has a dynamic range of at least 1.6462 for doses up to 30 Gy.

Table 3 lists the Sensitivity of PAGAT polymer gel dosimeter with different range of doses.

Verification of R2-dose sensitivity of PAGAT polymer gel dosimeter with photon beams: Polymer gel dosimeters in Perspex phantoms were homogeneously irradiated with 1.25 MV photon beam with a Co-60 therapy unit located in Tehran. Delivered doses were from 0-5000 cGy. The calibration curve (transverse relaxation rate (1/T2) versus applied absorbed dose) was obtained and plotted. Dependence of 1/T2 response to the absorbed dose in the range of 0-5000 cGy is shown in Fig. 1. As it can be seen in Fig. 1, PAGAT has a linear response up to 30 Gy. the response of the PAGAT gel is very similar in the lower dose region and The R2-dose response for doses less than 2 Gy is not exact. The R2-dose response of the PAGAT polymer gel dosimeter is linear between 10-30 Gy and 2-10 Gy. Figure 2 shows that PAGAT polymer gel has a dynamic range of at least 3.188 S⁻¹ for doses up to 30 Gy compared with less than 2.5 S⁻¹ for doses up to 30 Gy in the preliminary study of the PAGAT polymer gel dosimeter (De Deene, 2004).

Table 4 lists the Sensitivity of PAGAT polymer gel dosimeter with different range of doses.

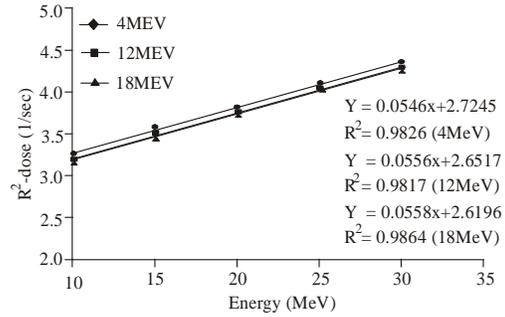


Fig. 3: Verification response of PAGAT polymer gel dosimeter with different energies (e.g 4, 12 and 18 MeV)

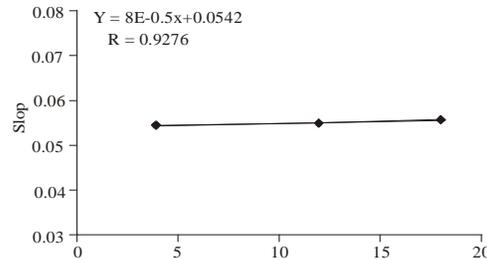


Fig. 4: Sensitivity of PAGAT polymer gel dosimeter with different energies (e.g, 4, 12 and 18 MeV)

Verification of R2-dose response of PAGAT gel dosimeter with different energies:

Verification of R2-dose response of PAGAT gel dosimeter with different electron energies: Response of the energy dependence was obtained for 4, 12 and 18 MeV nominal electron energy and is shown in Fig. 3. a linear function is fitted to each set of data and their slope and correlation were found. As it can be seen from Fig. 3, dependence of PAGAT polymer gel response to the energy of electron is shown. As the energy increases from 4 to 18 MeV the sensitivity is nearly stable:

$$\left(\frac{0.0558 - 0.0546}{0.0558} \right) \times 100 \approx 2\%$$

which is 2% variation energy.

Due to the large proportion of water (86%), the PAGAT polymer gel is nearly soft-tissue equivalent and no energy corrections are required for electron beams in radiotherapy.

Figure 4 Shows the sensitivity of PAGAT polymer gel dosimeter with different energies. The R2-dose sensitivity of PAGAT gel with energies (e.g, 4, 12 and 18 MeV) are 0.0546, 0.055 and 0.0558, respectively.

Verification of R2-dose response of PAGAT gel dosimeter with different photon energies: Response of

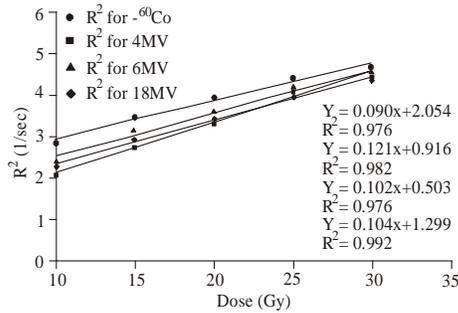


Fig. 5: Verification response of PAGAT polymer gel dosimeter with different energies (e.g., 1.25, 4, 6 and 18 MV)

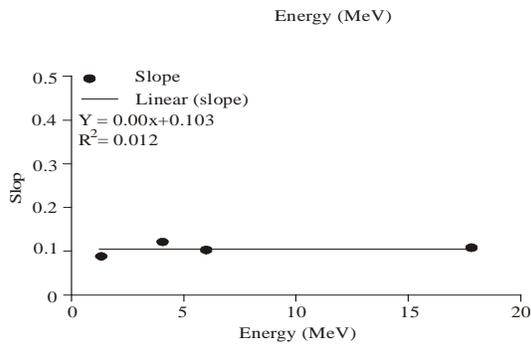


Fig. 6: Sensitivity of PAGAT polymer gel dosimeter with different energies (e.g., 1.25, 4, 6 and 18 MV)

the energy dependence was obtained for 1.25, 4, 6 and 18 MV nominal photon energy and is shown in Fig. 5. a linear function is fitted to each set of data and their slope and correlation were found. As it can be seen from Fig. 5, dependence of PAGAT polymer gel response to the energy of photon is shown. As the energy increases from 1.25 to 18 MV the sensitivity is nearly stable:

$$\left(\frac{0.1043 - 0.0905}{0.1043} \right) \times 100 \cong 13\%$$

which is 13% variation energy.

Due to the large proportion of water (86%), the PAGAT polymer gel is nearly soft-tissue equivalent and no energy corrections are required for photon beams in radiotherapy.

Figure 6 shows the sensitivity of PAGAT polymer gel dosimeter with different energies. The R2-dose sensitivity of PAGAT gel with energies (e.g. 1.25, 4, 6 and 18 MV) are 0.0905, 0.121, 0.1023 and 0.1043, respectively.

DISCUSSION AND CONCLUSION

According to the best knowledge of the authors only a few studies were published to evaluate energy and

dose rate dependence for the polymer gel dosimeters. Ibbott *et al.* (1997) which worked on BANG polymer gel, concluded that the polymer gel dose response is independent of both dose rate and beam modality and used the polymer gel calibration curve determined with 6 MV x rays for evaluation of the gel dosimeter irradiated with ⁶⁰Co without any limitations or approximations (Ibbott *et al.*, 1997). Similarly De Wagter *et al.* (1996) which worked on polymer gel stated in their study that polymer gel responds practically independently of beam quality (De Wagter *et al.*, 1996). Another study was also focused on the BANG polymer gel dosimeter response in different physical (Farajollahi *et al.*, 1999). They studied the dosimeter response for four different energies: 300 kV x rays, 1.25 MeV ⁶⁰Co gamma rays, 6MV x rays, and 8MV x rays. They homogeneously irradiated gel dosimeters with the same dose by four mentioned photon beams and compared the dosimeter response to conclude that there is no energy dependence (Farajollahi *et al.*, 1999; Farajollahi, 1999). Baldock *et al.* (1996) studied PAG (poly acrylamide gelatin) polymer gel dosimeter response for a range of electron and photon energies. They used incident nominal electron energies of 5, 7, 9, 12, 15, 17, and 20 MeV and photon energies of 660 keV from ¹³⁷Cs, 1.25 MeV from ⁶⁰Co, 6MV and 16MV to deliver the dose of 20 Gy in each sample. Based on measured polymer gel dosimeter response they concluded that the energy response of the polymer gel retains suitable characteristics for a range of commonly used electron and photon beams (Baldock *et al.*, 1996). Maryanski *et al.* (1996) used central axis percentage depth dose of 6 MV x-ray and 15 MeV electron beams measured in the BANG-2 gel dosimeter (composed of: 5% Gelatin, 3% N,N'-methylene-bis-acrylamide(BIS), 3% Acrylic acid, 1% NaOH & 88% Water) and compared them with diode measurements in water. They concluded that there is no energy dependence of gel dosimeter for electron beams in the range 2-15MeV (Maryanski *et al.*, 1996). This is similar to our work however the ingredients in BANG-2 and PAGAT are totally different. To avoid potential problems with different dosimeter response in different physical conditions one should perform calibration of polymer gel dosimeter and exposure of test phantom under the same or very similar physical conditions. PAGAT polymer gel dosimeter displayed good energy responses, which are important consideration when developing polymer gel dosimeters.

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