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Verification of the PAGAT polymer gel dosimeter by photon beams using magnetic resonance imaging

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Background: In this work investigation of the normoxic PAGAT polymer gel dosimeter such as sensitivity, the R2-dose response with post time and the percentage depth dose (PDD) of PAGAT polymer gel dosimeter have been undertaken. ***Materials and Methods:*** Using MRI, the formulation to give the maximum change in the transverse relaxation rate R2 was determined to be 4.5% N,N'-methylen-bis-acrylamide ©(bis), 4.5% acrylamid(AA), 5% gelatin, 5 mM tetrakis (hydroxymethyl)phosphonium chloride (THPC), 0.01 mM hydroquinone (HQ) and 86% HPLC (Water). Irradiation of vials was performed using photon beams by Co-60 therapy unit and an Electa linear accelerator. Gel dosimeters were imaged in a Siemens Symphony 1.5 Tesla clinical MRI scanner using a head coil. Gel dosimeters were irradiated 1 day post-manufacture, and imaged 1 day post irradiation. ***Results:*** The R2-dose response was linear 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 dosimeters varies between 10 to 30 Gy with R2-dose sensitivities of 0.0905, 0.1037, 0.1023, 0.0907 and 0.123 $S^{-1}Gy^{-1}$ when imaged at 1, 8, 15, 29 and 38 days post-irradiation respectively. The percentage depth dose (PDD) of PAGAT gel dosimeter was determined and at depth of 21cm, the percentage depth dose for 1.25, 4, 6 and 18 MV photons were determined to be, 48%, 52%, 57.3% and 59.73% respectively. ***Conclusion:*** Calibration curve of the PAGAT polymer gel dosimeter, were found to be linear between 2-10 Gy and 10-30 Gy with different slopes of the R2-dose sensitivity also showed stability with post time imaging after 38 days. In this study, the percentage depth dose (PDD) of the PAGAT gel dosimeter was measured. It can be concluded that in case of higher energy of photon beams, higher doses can be delivered to deep-seated tumors. **Iran. J. Radiat. Res., 2008; 6 (2): 83-87**

Keywords: *Polymer gels, PAGAT gel, magnetic resonance imaging (MRI).*

INTRODUCTION

Gel dosimetry systems are the only true 3-D dosimeters. The dosimeter is at the same time a phantom which can measure absorbed dose distribution in a full 3-D geometry [1-4]. Gel dosimeters are integrating dosimeters with the capability of capturing the whole dose distributions inside them and with versatility to be shaped in any humanoid form which makes them unique in their kind and potentially very suitable for the verification of complex dose distributions as they occur in clinical settings such as radiotherapy [2, 5, 6]. Currently, two types of gel dosimeters can be distinguished: Fricke gels, based on well established Fricke dosimetry, and polymer gels. Both systems consist a hydrogel matrix that preserves the spatial distribution of absorbed dose in the dosimeter. In Fricke gel dosimeters it is the concentration of ferric ions, and in polymer gel dosimeters the concentration of polymer aggregates that is correlated with the absorbed dose. Although, many researchers have contributed to the further development of Fricke gel dosimetry but nowadays, there is a trend towards polymer gels rather than Fricke gels which is due to the diffusion effects in the latter which restricts its usefulness and applicability [2]. Polymer gels are an emerging new class of dosimeters which are being applied to the

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challenges of modern radiotherapy modalities. In PAGAT polymer gel dosimeter, the gel itself forms both a multi dimensional phantom and the detector [3, 7]; therefore no corrections are needed to obtain the absorbed dose in PAGAT polymer gel using photon beams. 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, it is believed that PAGAT polymer gel dosimeter is the "closest to ideal" dosimetry method comparing with TLDs, ion chambers, film, Fricke and anoxic gels [7, 3]. In this study, investigation of the PAGAT polymer gel dosimeter (R2-dose response, post time, percentage depth dose) has been undertaken. In this study, MRI technique was used to determine the response of the normoxic PAGAT polymer gel dosimeter.

MATERIALS AND METHODS

PAGAT preparation

The PAGAT polymer gel formulation by % mass consisted of 4.5% N,N'-methylen-bis-acrylamide (bis), 4.5% acrylamid (AA), 5% gelatin, 5 mM tetrakis (hydroxymethyl) phosphonium chloride (THPC), 0.01 mM hydroquinone (HQ) and 86% HPLC (Water) [7]. All components were mixed under a fume hood. The gelatin 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 gelatin 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 the final polymer gel solution was completed, it was transferred into phantoms and allowed to set by storage in a refrigerator at about 47°C.

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

Table 1. Different chemicals and percent weight of PAGAT gel.

Component	Percent Weight
Gelatine (۳۰۰Bloom)	۵%
N,N'-methylen-bis-acrylamide (bis)	۴.۵%
Acrylamide (AA)	۴.۵%
Tetrakis-phosphonium chloride (THPC)	۵mM
Hydroquinone(HQ)	۰.۰۱mM
HPLC (Water)	۸۶%

Irradiation

Irradiation of vials was performed using photon beams by Co-60 therapy unit and an Electa linear accelerator with SSD = 80cm, field size of 20×20 cm^2 and the depth was selected at 5 cm to determine the sensitivity of PAGAT polymer gel dosimeter with different energies (e.g. 4, 6 and 18 MV). Irradiation of vials were performed using an Electa linear accelerator with SSD =100cm, field size= 20×20 cm^2, dose rate= 400 cGy/min and the depth was selected at 5 cm. The post-manufacturing times was selected to be 1 day.

Imaging

Before imaging, all gel dosimeters were transferred to a temperature controlled MRI scanning room to equilibrate to room temperature. The PAGAT 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 echo time (TE) of 20 ms, repetition time (TR) of 3000 ms, slice thickness of 4 mm, field of view (FOV) of 256 mm. The post imaging time was selected to be 24 hours. The images were

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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) which was used for PAGAT polymer gel imaging.

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
mm}{Resolution	0.5
Band With {Hz/Pixel}	130

Table 3. 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	0.0983	0.9939
30-50	0.0577	0.9825

RESULTS

R2-dose sensitivity of PAGAT polymer gel dosimeter

PAGAT gels with optimum value of ingredient was manufactured and irradiated to different doses. As it can be seen in figure 1, PAGAT had a linear response up to 30 Gy. The responses of the PAGAT gel were close to each other in the lower dose region (0-2 Gy) which meant the dosimeter was not accurate in doses less than 2 Gy. The response was linear between 2 - 10 Gy and 10-30 Gy respectively with different slope (0.1512 and 0.983 $s^{-1}Gy^{-1}$). Figure 1 shows that PAGAT polymer gel with a dynamic range of approximately 1.5 to 2.7 s^{-1} for 2-10 Gy 2.7 to 4.7 s^{-1} for 10-30 Gy and 4.7 to 5.9 s^{-1} for 30-50 Gy intervals.

Variation of R2-dose Response of PAGAT gel dosimeter with Post irradiation Time

The R2-dose response of the PAGAT polymer gel dosimeter was linear between 10-30 Gy doses. Figure 2 shows the R2-dose response with time (e.g. 1, 8, 15, 29 and 38 days). In this study the R2-dose response was linear up to 30 Gy with R2-dose sensitivities of 0.0905, 0.1037, 0.1023, 0.0907 and 0.123 $S^{-1}Gy^{-1}$ when imaged at 1, 8, 15, 29 and 38 days post-irradiation respectively. The R2-dose sensitivity showed stability with post time imaging

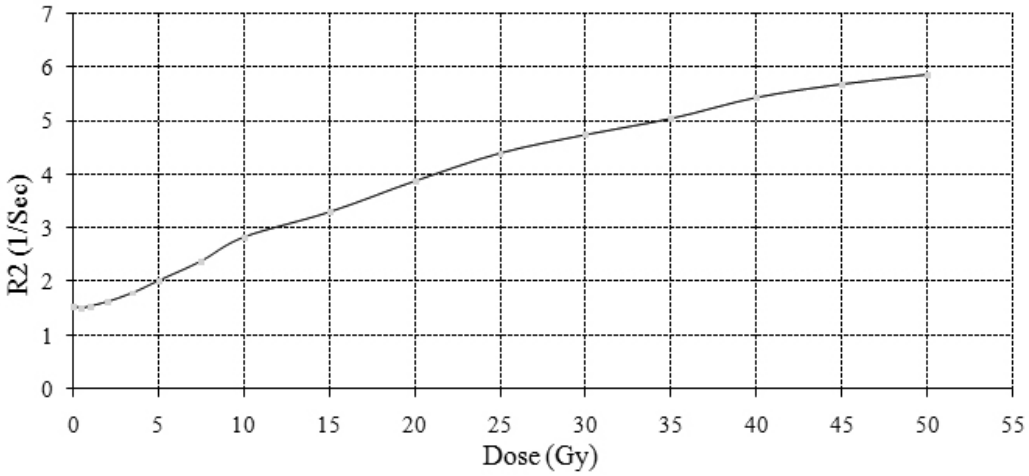

Figure 1. Sensitivity of PAGAT with different range of doses (0-50Gy).

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after 38 days.

Table 4 lists the R2-dose sensitivity and correlation coefficients for the five post-irradiation imaging times. This table indicates that PAGAT had reached the steady-state by 38 days post-irradiation, therefore, the R2-dose sensitivity of PAGAT polymer gel between 10 Gy and 30 Gy was not changing significantly and it was concluded that the response was stable. This study has shown that the normoxic PAGAT polymer gel dosimeter has the properties of a dosimetric tool, which can be used in clinical radiotherapy for a period of up to 30 days without changing the sensitivity (figure 3).

Verification of the percentage depth dose (PDD) of PAGAT gel dosimeter in different energies

In this study, the percentage depth dose (PDD) of PAGAT polymer gel dosimeter was measured for different phantoms of PAGAT gels irradiated to 25 Gy of doses of 1.25, 4, 6 and 18 MV photons. The maximum percentage depth dose (PDD) was located at the depths of 0.5, 1.1, 1.5and 3.4cm respectively. Figure 4 shows that for a maximum depth of 21cm, the percentage depth dose for 1.25, 4, 6 and 18MV photons have been 48%, 52%, 57.3% and 59.73%, respectively. Thus, in case of the higher energy photon beams, higher doses can be delivered to deep-seated tumors.

DISCUSSION

To the best knowledge of the authors, only one work was found in which PAGAT polymer gel was used as a dosimeter with photon beams [8]. In the study, the same ingredient of material was used and it was

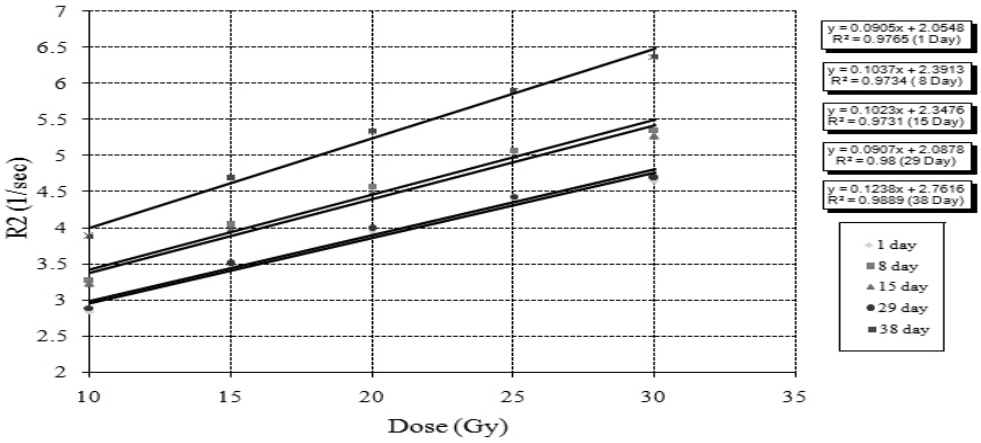

Figure 2. R2-dose response curve of the PAGAT polymer gel dosimeter evaluated at 1, 8, 15, 29 and 38 days post-irradiation.

Table 4. R2-dose sensitivity and correlation coefficient of PAGAT polymer gel between 10Gy and 30Gy.

Imaging time post Irradiation (day)	R2- dose sensitivity ($S^{-1}Gy^{-1}$)	Correlation coefficient
1	0.0905	0.9765
8	0.1037	0.9734
15	0.1023	0.9731
29	0.0907	0.98
38	0.123	0.9889

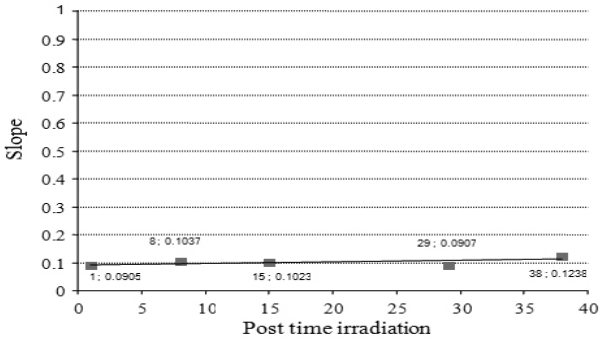

Figure 3. the R2-dose sensitivities of 0.0905, 0.1037, 0.1023, 0.0907 and 0.123$S^{-1}Gy^{-1}$ when imaged at 1, 8, 15, 29 and 38 days post-irradiation respectively.

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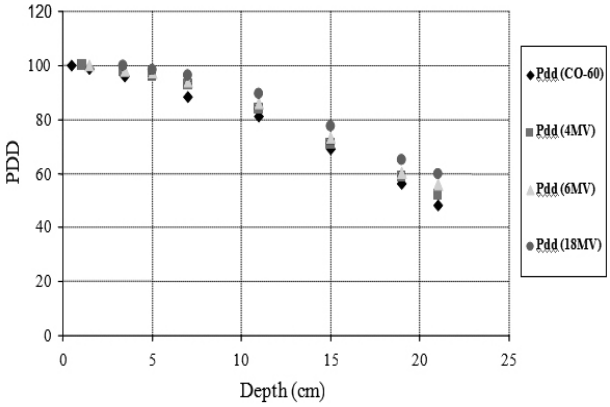

Figure 4. Verification of the percentage depth dose (PDD) of PAGAT polymer gel dosimeter when different phantoms of PAGAT gels was irradiated to 25Gy of doses by 1.25, 4, 6 and 18MV photons.

found that the linear part of the calibration curve has been between 0-7 Gy with a sensitivity of 0.182 $s^{-1}Gy^{-1}$ for a 6MV photon beam. In this study a sensitivity of 0.151 $s^{-1}Gy^{-1}$ was found for 60Co therapy beam for 2-10 Gy dose intervals which was compatible to the finding of Vennige's *et al.* [3]. For post irradiation time response, the obtained result of 0.0905, 0.1037, 0.1023, 0.0907 and 0.123 $s^{-1}Gy^{-1}$ for 1, 8, 15, 24, 38 day post irradiation times and dose interval of 10-30 Gy showed insignificant changes. These finding have also been consistant with those of Vennige's *et al.* [8] that found sensitivity of 0.183, 0.182 and 0.192 for 0.5, 7 and 24 day post irradiation with a 6 MV photon beam.

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