

## Investigation of the Post Time Dependence of PAGAT Gel Dosimeter by Electron Beams using MRI Technique

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**Abstract:** In this study investigation of the post time dependence of PAGAT gel dosimeter by electron beams using MRI technique has been undertaken. 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'-methylen-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 1 day. The  $R_2$ -dose response was linear up to 30 Gy. the response of the PAGAT gel is very similar in the lower dose region and The  $R_2$ -dose response for doses less than 3 Gy is not exact. The  $R_2$ -dose response of the PAGAT polymer gel dosimeter is linear between 10 to 30 Gy with  $R_2$ -dose sensitivities of 0.0525, 0.0471, 0.0497 and 0.0541  $S^{-1} \text{Gy}^{-1}$  when imaged at 1, 8, 15 and 29 days post-irradiation respectively. This study has shown that the normoxic PAGAT polymer gel has a properties of a dosimetric tool, which can be used in clinical radiotherapy.

**Key word:** Electron beams, MRI, post time, PAGAT gel

### INTRODUCTION

Gel dosimetry systems are the only true 3-D dosimeters. The dosimeter is at the same time a phantom that can measure absorbed dose distribution in a full 3-D geometry (Podgorsak, 2005; Veltoge, 2005; Venning *et al.*, 2004; Zahmatkesh *et al.*, 2004). 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 that 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 (Hilts *et al.*, 2005; Hill *et al.*, 2005).

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.*, 1993; (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 this study, investigation of the PAGAT polymer gel dosimeter such as calibration curve,  $R_2$ -dose response and time stability (post time dependence) by electron beams has been undertaken. In this communication, MRI 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% 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

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 mM
Hydroquinone (HQ)	0.01 mM
HPLC (water)	86%

Table 2: The protocol of Magnetic Resonance Imaging (MRI)

Parameters	
Field of view(FOV) (mm)	256
Matrix 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 width (Hz /pixel)	130

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 = 80 cm, field size of 20×20 cm<sup>2</sup> 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. Evaluation of dosimeters were performed on Siemens Symphony, Germany 1.5T Scanner in the head coil. A multi echo sequence with 32 equidistant echoes was used for the evaluation of irradiated polymer gel dosimeters. The parameters of the sequence were as follows: TR = 3000 ms, TE = 20 ms, Slice Thickness = 4 mm and FOV = 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 AND DISCUSSION

**Verification of R2-dose sensitivity of PAGAT polymer gel dosimeter:** PAGAT gels with optimum value of ingredient was manufactured and irradiated to different

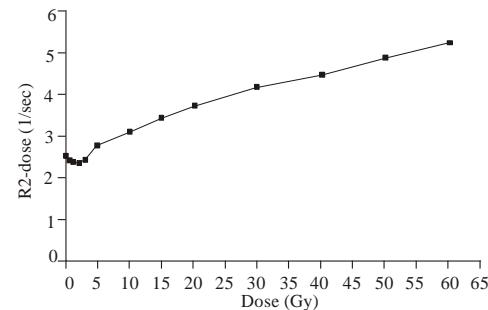


Fig. 1: Sensitivity of PAGAT with different range of doses (0-60 Gy)

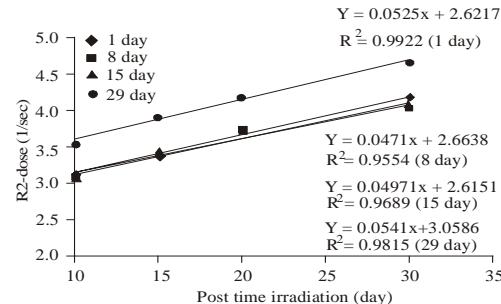


Fig. 2: R2-dose response curve of the PAGAT polymer gel dosimeter evaluated at 1, 8, 15 and 29 days post-irradiation

Table 3: Sensitivity of PAGAT with different range of doses

Dose (Gy)	R2- Dose sensitivity (S <sup>-1</sup> Gy <sup>-1</sup> )	Correlation coefficient
0-3	-0.0260	0.1997
3-10	0.8900	0.9421
10-30	0.0526	0.9921
30-60	0.0359	0.9975

doses. Polymer gel dosimeters in Perspex phantoms were homogeneously irradiated with 6 MeV electron beam with an electa linear accelerator located in Tehran. Delivered doses were from 0-6000 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 0-6000cGy 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 dose region and 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 s<sup>-1</sup> 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 response of PAGAT gel dosimeter with post irradiation time:** The R2-dose response of the PAGAT polymer gel dosimeter is linear between 10-30 Gy doses. Figure 2 shows the R2-dose

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

Imaging time post irradiation (day)	R2-Dose sensitivity ( $S^{-1}Gy^{-1}$ )	Correlation coefficient
1	0.0525	0.9922
8	0.0471	0.9554
15	0.0497	0.9689
29	0.0541	0.9815

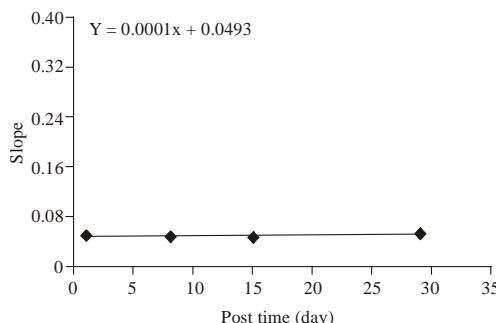


Fig. 3: The R2-dose sensitivities of 0.0525, 0.0471, 0.0497 and  $0.0541 S^{-1} Gy^{-1}$  when imaged at 1, 8, 15 and 29 days post-irradiation respectively

Response with Post Time (e.g., 1, 8, 15 and 29 days). In this study the R2-dose response was linear up to 30 Gy with R2-dose sensitivities of 0.0525, 0.0471, 0.0497 and  $0.0541 S^{-1} Gy^{-1}$  when imaged at 1, 8, 15 and 29 days post-irradiation, respectively. The R2-dose sensitivity showed stability with imaging post time after 29 days.

Table 4 lists the R2-dose sensitivity and correlation coefficients for the 4 post-irradiation imaging times. Table 4 indicate the PAGAT had reached steady-state by 29 days post-irradiation, therefore the R2-dose sensitivity of PAGAT polymer gel between 10 and 30 Gy wa 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.

Figure 3 shows the R2-dose sensitivities of 0.0525, 0.0471, 0.0497 and  $0.0541 S^{-1} Gy^{-1}$  when imaged at 1, 8, 15 and 29 days post-irradiation, respectively. Therefore , the R2-dose sensitivity of PAGAT polymer gel dosimeter had reached steady-state by 29 days Post-Irradiation.

## CONCLUSION

In this study, investigation of the PAGAT polymer gel dosimeter in electron beams has been undertaken. The well-known PAG polymer gel dosimeter has been combined with the anti-oxidant THPC the polymerization inhibitor HQ to form the normoxic PAGAT polymer gel dosimeter. the formulation which gives the maximum  $\Delta R_2$  has been determined to be 4.5% bis, 4.5% AA, 5% gelatine, 5 mM THPC, 0.01 mM HQ and 86% water (HPLC). The optimal post-manufacture irradiation and post-irradiation imaging times, which give the maximum  $\Delta R_2$ , were both determined to be 1 day.

The R2-dose response of the PAGAT formulation determined in this study was found to have a linear range 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 3 Gy is not exact. The R2-dose response of the PAGAT polymer gel dosimeter is linear between 10 to 30 Gy with R2-dose sensitivities of 0.0525, 0.0471, 0.0497 and  $0.0541 S^{-1} Gy^{-1}$ when imaged at 1, 8, 15 and 29 days post-irradiation respectively, therefore The R2-dose sensitivity showed stability with imaging post time after 29 days.

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 responses, which are important consideration when developing polymer gel dosimeters.

The PAGAT polymer gel dosimeter in this study exhibited the essential characteristics required for clinical radiotherapy dosimetry.

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