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Verification of Calibration Curve and Percentage Depth Dose (PDD) of PAGAT Polymer Gel Dosimeters By Photon Beams Using Magnetic Resonance Imaging

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Abstract: In this work, investigation of the normoxic PAGAT polymer gel dosimeter has been undertaken. 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% 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 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 2Gy is not exact. The R2-dose response of the PAGAT polymer gel dosimeter is linear between 10 to 30 Gy. In this study, the percentage depth dose (PDD) of PAGAT polymer gel dosimeter is determined and different phantoms of PAGAT gels was irradiated to 25Gy of doses by 1.25, 4, 6 and 18MV photons and the maximum percentage depth dose (PDD) is located at the depths of 0.5, 1.1, 1.5 and 3.4cm at depth of 21cm, the percentage depth dose for 1.25, 4, 6 and 18MV photons is determined, 48%, 52%, 57.3% and 59.73% respectively.

Key word: Polymer gels, PAGAT gel, R2-dose, PDD, MRI.

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. 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. Currently two types of gel dosimeters can be distinguished: Fricke gels, based on well established Fricke dosimetry and polymer gels. Both systems consist of 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 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 gel that restricts its usefulness and applicability. Polymer gels are an emerging new class of dosimeters which are being applied to the challenges of modern radiotherapy modalities. In PAGAT polymer gel dosimeter, the gel itself forms both a multi dimensional phantom and the detector. 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, 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. In this study, investigation of the PAGAT polymer gel dosimeter has been undertaken. In this communication, MRI was used to determined 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) (Venning *et al.*, 2005). 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 $48C^{\circ}$ 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 untile dissolved. Once the bis was completely dissolved the AA was added and stirred untile dissolved. Using pipettes,

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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 $4C^{\circ}$.

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

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

Components	Percent Weight
Gelatine (300 Bloom)	5%
N,N'-Methylen-bis-acrylamide(bis)	4.5%
Acrylanide (AA)	4.5%
Tetrakis-phosphonuim Choloride (THPC)	5mM
Hydroquinone (HQ)	0.01mM
HPLC (Water)	86%

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 $20\times 20cm^2$ and the depth was selected at 5cm. to determine the sensitivity of PAGAT polymer gel dosimeter with different energies (e.g. 4, 6 and 18 MV), irradiation of vials was performed using an electa linear accelerator with SSD =80cm, field size= $20\times 20cm^2$, dose rate= $400\frac{cGy}{\min}$ and the depth was selected at 5cm. 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.

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

Parameters	
Field of view (FOV){mm}	256
Marrix Size(MS)	512 x 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
$\{Hz/Pixel\}$ Band With	130

RESULTS AND DISCUSSIONS

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 has a linear response up to 30Gy. the response of the PAGAT gel is very similar in the lower dose region and The R2-dose response for doses less than 2Gy is not exact. The R2-dose response of the PAGAT polymer gel dosimeter is linear between 10-30Gy and 2-10Gy. Figure 1 shows that PAGAT polymer gel has a dynamic range of at least $3.188S^{-1}$ for doses up to 30Gy compared with less than $2.5S^{-1}$ for doses up to 30Gy in the preliminary study of the PAGAT polymer gel dosimeter.

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

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

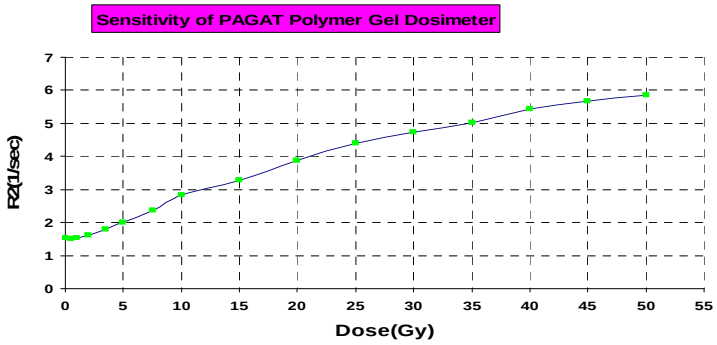

Fig. 1: Sensitivity of PAGAT with different range of doses.

Verification of Percentage Depth Dose in PAGAT Polymer Gel Dosimeter:

In this study, the percentage depth dose (PDD) of PAGAT polymer gel dosimeter is determined and different phantoms of PAGAT gels was irradiated to 25Gy of doses by 1.25, 4, 6 and 18MV photons and The maximum percentage depth dose (PDD) is located at the depths of 0.5, 1.1, 1.5and 3.4cm. figure 2 shows at depth of 21cm, the percentage depth dose for 1.25, 4, 6 and 18MV photons is determined, 48%, 52%, 57.3% and 59.73% respectively and figure 3 shows the percentage depth dose for 1.25, 4, 6 and 18MV photon beams. Thus, in the case of the higher energy photon beams, higher doses can be delivered to deep-seated tumors.

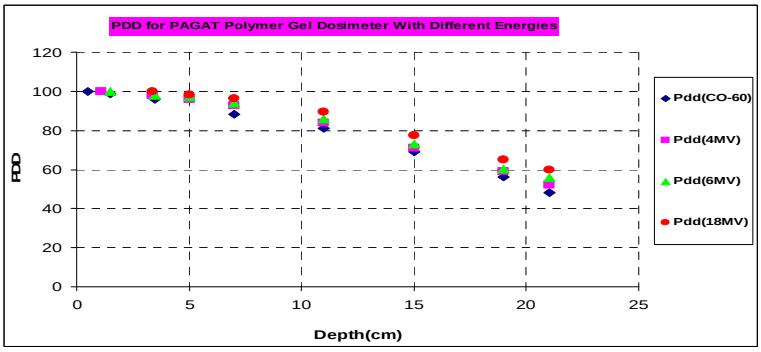

Fig. 2: Verification of Percent Depth Dose (PDD) in PAGAT polymer gel dosimeter.

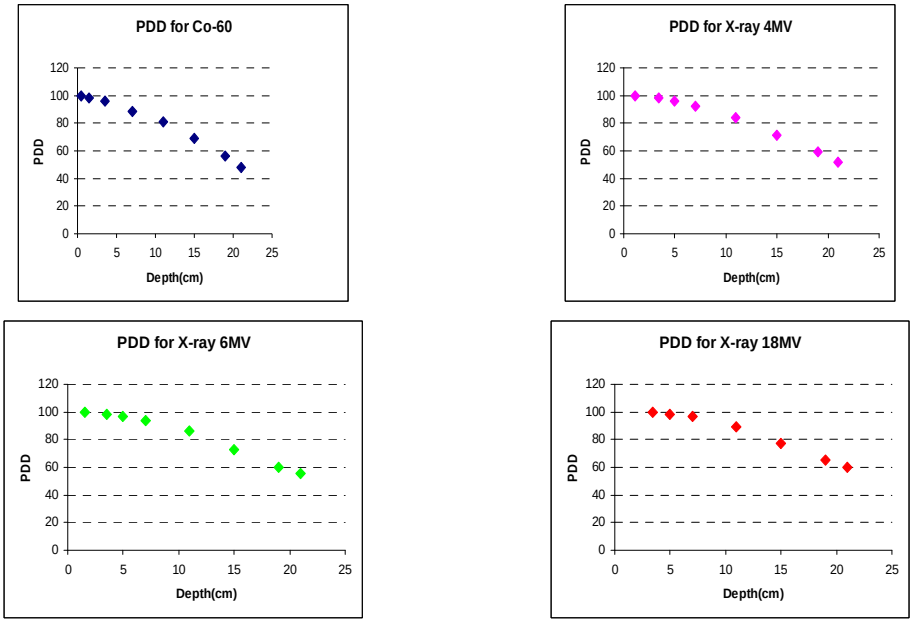

Fig. 3: the percentage depth dose of PAGAT polymer gel dosimeter for 1.25, 4, 6 and 18MV photon beams.

Conclusion:

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 $\Delta R2$ 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 $\Delta R2$, 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 30Gy. the response of the PAGAT gel is very similar in the lower dose region and The R2-dose response for doses less than 2Gy is not exact. The R2-dose response of the PAGAT polymer gel dosimeter is linear between 10 to 30 Gy. PAGAT gels were irradiated to 25Gy of doses by 1.25, 4, 6 and 18MV photon beams and the maximum percentage depth dose (PDD) is located at the depths of 0.5, 1.1, 1.5and 3.4cm. at depth of 21cm, the percentage depth dose for 1.25, 4, 6 and 18MV photons is determined, 48%, 52%, 57.3% and 59.73% respectively. Thus, in the case of the higher energy photon beams, higher doses can be delivered to deep-seated tumors.The PAGAT polymer gel dosimeter in this study exhibited the essential characteristics required for clinical radiotherapy dosimetry. PAGAT polymer gel offers simplification in to the routine clinical radiotherapy environment.

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