Response Verification of Dose Rate and Time Dependence of PAGAT Polymer Gel Dosimeters By 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/T2 on different post time imaging as well as on different mean dose rates for a standard clinically used Co-60 therapy unit and an electa linear accelerator. Using MRI, the formulation to give the maximum change in the transverse relaxation rate R2 (1/T2) 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 sensitivity of the dosimeter was represented by the slope of calibration curve in the linear region measured for each modality. A calibration curve (in the linear region) based on 16 dosimeters (15 irradiated and one background) was obtained for 1.25 MV photon beam. To determine the calibration curve of the PAGAT polymer gel dosimeter, there are two linear responses between 2-10Gy and 10-30Gy and the R2-dose sensitivity showed stability with imaging post time after 38 days. Dose rate of dependence was studied in 6 MV photon beam with the use of dose rates 80, 160, 240, 320, 400 and 480 cGy/min. 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 3000ms, TE 20ms, Slice Thickness 4 mm and FOV 256mm. No trend in polymer-gel dosimeter 1/T2 dependence was found on mean dose rate for photon beams.

Key words: polymer gels, PAGAT gel ,dose rate, timestability, MRI.

1. Introduction

In 1984, magnetic resonance imaging (MRI) demonstrated great potential in visualizing three dimensional (3D) dose distributions of ferric or ferrous sulphate gel dosimeters [1]. Subsequently, studies were undertaken to investigate the feasibility of using Ferric gel as a 3D dosimetry system in radiation oncology [2]. The major limitation in Ferric gel dosimetry is that it suffers from blurness of dose with time which is due to the migration of ferrous and ferric ions in gel matrix, known as diffusion [3]. In 1993, a polymer gel dosimeter was developed that maintained spatial information following irradiation which could be visualized using MRI [4]. 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 [5-6]. 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 T2 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 [4-7-8-9]. 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. This study has been focused on evaluation of the dependence of PAGAT polymer gel dosimeter response on post time and dose rates of the photon beams in a Co-60 therapy unit and an electa linear accelerator.

2. Materials and methods

2.1. 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) [10]. 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 [10].

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

| Component                        | Percent Weight |
|----------------------------------|----------------|
| Gelatine(300Bloom)               | 5%             |
| N,N'-methylen-bis- acrylamide(bis)| 4.5%           |
| Acrylamide(AA)                   | 4.5%           |
| Tetrakis-phosphonium chloride(THPC)| 5mM            |
| Hydroquinone(HQ)                 | 0.01mM         |
| HPLC(Water)                      | 86%            |

2.2. 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 20x 20cm² 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 =80 cm, 
field size= 20x20 cm², dose 
cGy 
rate=400 ------- and the depth was selected at 5 cm. The optimal post-manufacture 
min 
irradiation was determined to be 1 day.

2.3. 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.

| 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          |
| mm Resolution               | 0.5            |
| Band With [Hz/Pixel]        | 130            |

3. Results

3.1. 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 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 1 shows that PAGAT polymer gel has a dynamic range of at least S.1 SSSS inl for doses up to 30 Gy compared with less than 2.55 inl for doses up to 30 Gy in the preliminary study of the PAGAT polymer gel dosimeter.
3.2. R2-dose Response of PAGAT polymer gel dosimeter with Post Time

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

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

| dose(Gy) | R2- dose sensitivity (S/Gy) | 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                 |

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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 lists the R2-dose sensitivity and correlation coefficients for the five post-irradiation imaging times. Table 4 indicate the PAGAT had reached steady-state by 38 days post-irradiation, therefore the R2-dose sensitivity of PAGAT polymer gel between 10Gy and 30Gy 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.

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 shows 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 therefore the R2-dose sensitivity of PAGAT polymer gel dosimeter had reached steady-state by 38 days post-irradiation.
3.3. Verification Dose rate dependence of PAGAT polymer gel dosimeter

Dose rate dependence for PAGAT gel was verified in figure (4) with a 6 MV photon beam 20Gy dose was delivered to the gel phantoms with dose rates varying from 80, 160, 240, 320, 400 and 480cGy/min. A line was fitted to the data which shows no significant dependence of R2 to dose rate.
figure (5) shows the PAGAT polymer gel dosimeter sensitivity with different dose rates, therefore no significant dose rate effects in PAGAT polymer gel have been observed using NMR evaluation when dose rate is changed from 80cGy/min to 480cGy/min.

4. Discussion

According to the best knowledge of the authors only a few studies were published to evaluate dose rate dependence for the polymer gel dosimeters. Ibbott et al. 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 [11]. Similarly De Wagter et al. which worked on polymer gel stated in their study that polymer gel responds practically independently of beam quality [12]. Maryanski et al., 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 as well as dose rate dependence of gel dosimeter for electron beams in the range 2-15MeV and dose rates in the range 20-400MU min⁻¹ [8]. They found that gel response is independent to the dose rate. This is similar to our work however the ingredients in BANG-2 and PAGAT are totally different.

5. Conclusions

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 PAG AT polymer gel dosimeter is linear 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, therefore The R2-dose sensitivity showed stability with imaging post time after 38 days. To verification of dose rate dependence, different phantom of PAGAT gels was irradiated to 20 Gy of doses by 6MV photons with different dose rates (e.g. 80, 160, 240, 320, 400 and 480 cGy/min). therefore no significant dose rate effects in PAGAT polymer gel have been observed using NMR evaluation when dose rate is changed from 80 cGy/min to 480 cGy/min.

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 dose rate and time stability 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. PAGAT polymer gel offers simplification in to the routine clinical radiotherapy environment.

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