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Basic investigation on performance of low-density polymer gel dosimeter

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ABSTRACT

Background: In this study a series of basic dosimetric properties of a low-density (LD) gel dosimeter are investigated. The dose response is studied regarding to linearity, sensitivity, dose-rate and energy dependence as well as lung tissue equivalence. ***Materials and Methods:*** The LD gel was made by mixing the polymer gel with expanded polystyrene spheres. Energy dependence was studied at two different energies: 1.25 MeV and 6 MV photon beams which were produced by ^{60}Co and Linac machines. Investigation of dose rate dependence was performed in the low, medium, and high absorbed dose regions. Also reproducibility of dose response was studied in three sets of LD gel with identical preparation, irradiation and imaging procedure at three different days. Moreover the linearity and sensitivity were investigated up to 30Gy. ***Results:*** The results showed that the dose response was reproducible. The gel response was found linear up to 22Gy with r^2=0.981 and sensitivity of 0.814$S^{-1}Gy^{-1}$. In the measured ranges, the dose response of LD gel was independent of beam energy within less than ±0.02 and dose rate had no effect on the gel response. LD gel was nearly lung tissue equivalent with mass density 0.37 to 0.4g/cm3 and relative electron density 0.41. ***Conclusion:*** MAGAT LD gel dosimeter appears to be a promising dosimeter in all aspects of dosimetric properties evaluated in this study. In addition, its high linearity together with no dose rate dependence in different level of absorbed doses makes it a suitable dosimeter to measure 3D -dose distributions inside a non-homogeneous media.

Keywords: *Lung tissue dosimetry, polymer gel dosimeter, basic radiation properties, MAGAT.*

INTRODUCTION

Low-density (LD) gel dosimeters were introduced to extend potential application range of gel dosimeters in simulating tissues with different electron density. In preliminary study, the density of Fricke gel dosimeter was reduced [1, 2]. However, similar to Fricke gel dosimeters, its LD type also suffered from diffusion problem and it could not keep a stable dose distribution within the irradiated dosimeters [3].

With introduction of polymer gel dosimeters, LD Fricke gel was replaced by LD polymer gel dosimeters [4]. Among different polymer gel formulas, methacrylic acid (MAc) based gels showed higher sensitivity[5]. In LD polymer gel dosimeters, Mac based (MAGIC, MAGAT, etc.) gels are used to compensate expected loss in

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SNR as a result of the lower density [6].

MAGAT LD polymer gel dosimeters can be considered as a valuable tool for verification of dose distributions in lung during radiation treatments of lung or mediastinal tumors. Before application of a certain type of polymer gel in radiation dosimetry, a systematic study of the most important properties has to be implemented [7, 8]. Although the basic radiation properties of MAGAT gel with unit density (UD) had been studied before [5], recipe and structure of LD gel have some modifications compared to UD gel which can affect its performance in radiation dosimetry. Existence of styrofoam beads and also further amount of anti-oxidant in recipe of LD gel dosimeter are two main source of discrepancy between MAGAT gel and its LD type.

The present work explore some of the basic properties of LD MAGAT polymer gel including the effect of radiation beam energy, dose rate, linearity and reproducibility of dose response together with verification of its tissue equivalence which are important factors in their application radiation therapy.

MATERIALS AND METHODS

MAGAT gel is composed of 86% deionized water, 8% gelatin (300 Bloom, Sigma Aldrich), 6% methacrylic acid (purity grade approximately 99%, Sigma-Aldrich) and 50mM THPC (technical grade 80% in water, Sigma-Aldrich). The gel were fabricated according to a procedure as described by Haraldsson *et al.* [9].

Two sets of gel dosimeters with different densities were prepared. For UD polymer gel dosimeters, the prepared solution was poured into testing vials and for preparation of LD gels, the solution was injected into the vials filled with polystyrene spheres (StyrofoamTM spheres, Isopan, Regensburg, Germany). For further density reduction compared to Haraldsson study [9], the vials were completely filled with foam beads.

Samples were irradiated approximately 24 hour after manufacturing by a Varian 2100 C/D linear accelerator (Varian Medical systems, Palo Alto, CA, USA). The vials were irradiated with doses ranged 1 to 30Gy, using 6 MV photon beams. One sample was left un-irradiated for background measurement.

24 hours before imaging the vials were kept in MRI room to prevent any error by temperature fluctuation in the samples. MR images of the gel were obtained by a Siemens Magnetom Avanto 1.5T scanner (Siemens Medical Solutions, Erlangen, Germany). The transverse relaxation time (T2) was determined using a multi spin-echo sequence. For all measurements a time to repeat (TR) of 4000ms, 32 time echo (TE) ranging from 20 to 640ms with increment of 20 were used. To increase SNR, for each scan, data from two acquisitions were averaged (NEX=2) [10].

Lung tissue equivalence

In therapeutic energy ranges, relative electron and mass density are the most important parameters for radiological tissue equivalence of a dosimeter [7]. In order to investigate the lung equivalence of

LD gel dosimeter, its mass density, relative electron density to water and CT number were determined and compared with lung tissue.

Density of LD gel dosimeter was measured several times and each time a vial of the gel was weighted and its volume was determined.

The relative electron density of the LD gel was obtained from the CT number [11] using equation 1:

$$\rho_e^w = 1 + \frac{CT\ number}{1000} \qquad (1)$$

Computed tomography of the gel samples was carried out using a CT scanner (GE HiSpeed NX/iPro, GE Medical Systems). A pulmonary protocol with a slice thickness of 3 mm was applied.

Linearity and sensitivity

Linearity of LD polymer gel was described by a linear fit to the quasi-linear increase of R2 versus absorbed dose between 1Gy and the maximum detected dose [10]. For this purpose, the gel vials were irradiated to doses ranging from 1 to 30 Gy.

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Reproducibility

In order to investigate the dose response reproducibility, the LD gel was manufactured as described and the gel vials were irradiated to doses of 1 to 15 Gy. The experiment was repeated three times in different days, while keeping irradiation method and scanning parameters unchanged.

Dose rate dependence

For investigation of dose rate dependence of LD gel, irradiations were performed with three dose levels: low dose D=2 Gy, medium dose D=5 Gy, and high dose D=10 Gy and three different dose rates (100, 200 and 300 cGy/min).

Energy dependence

For assessing energy dependence, two sets of LD gel were prepared and irradiated to doses of 2, 5 and 10Gy. Irradiation carried out at two photon energies of 6 MV and 1.25 MeV X-ray produced by linear accelerator (dose rate=100 cGy/min) (Varian Medical systems, Palo Alto, CA, USA) and ^{60}Co machine (dose rate= 100 cGy/min) (Theraton 780, MDS/Nodion, Canada).

RESULTS

Lung tissue equivalence

LD gels had a mass density between 0.37 to 0.4g/cm^3 and the CT numbers varied from approximately −590 to −630 Hounsfield units. The relative electron density of LD gel dosimeter was 0.41.

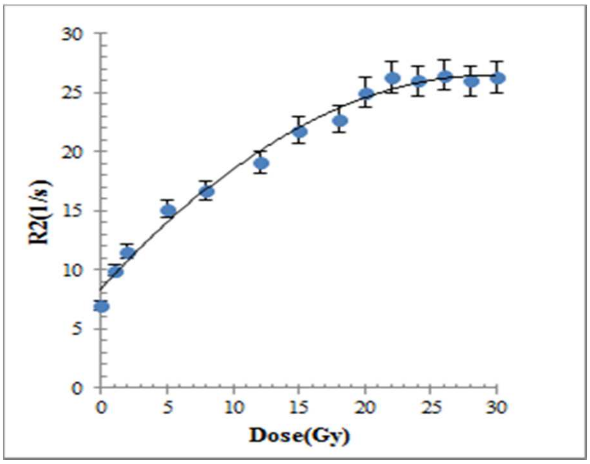

Figure 1. Linearity of R2 as a function of absorbed dose up to

Linearity and sensitivity

The results of R2 measurements as a function of dose, is shown in figure 1. It can be seen that the LD gel dose response is linear up to 22Gy with r^2=0.981. The R2-dose sensitivity of LD gel is 0.814S^{-1}Gy^{-1}.

Reproducibility

Figure 2 shows the results obtained from R2 in three sets of the samples. The data shows that the dose response is reproducible over the range of the measured dose with difference of 4% (r^2: exp1=0.967, exp2=0.927, exp3:0.937).

Energy dependence

In figure 3, the influence of the energy on dose response is visualized. It can be seen that the dose response of the LD gel is independent of the beam energy to within less than ±2% in the measured range (r^2: Co60= 0.963, 6MV=0.990).

Dose rate dependence

Figure 4 shows the R2 dose response of LD gel as a function of dose for three different dose rates and three different dose levels in LD gel. The results indicate that within the studied ranges, the dose rate did not significantly affect the response of the LD gel with SD = ±3% (r^2: DR100cGy/min=0.998, DR200cGy/min=0.997, DR300cGy=0.998).

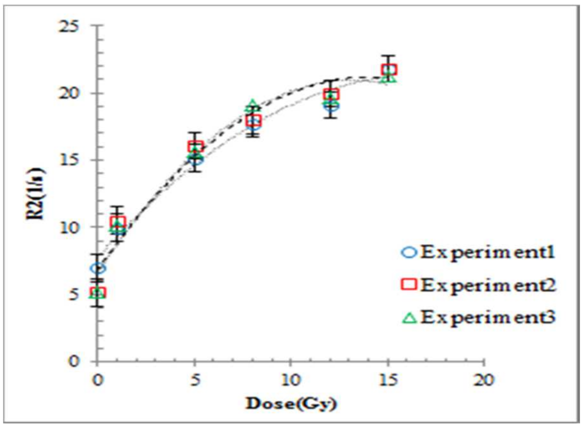

Figure 2. Reproducibility of low-density gel dose response in three different experiments with same preparation, irradiation and imaging methods.

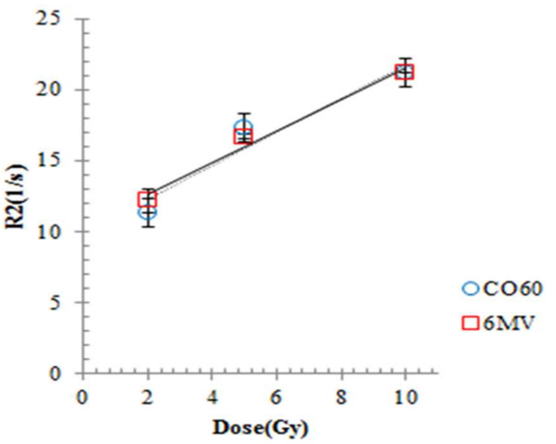

Figure 3. Energy dependence of low-density gel for two different energies (6MV and 1.25 MeV) and three different doses (2, 5, 10Gy).

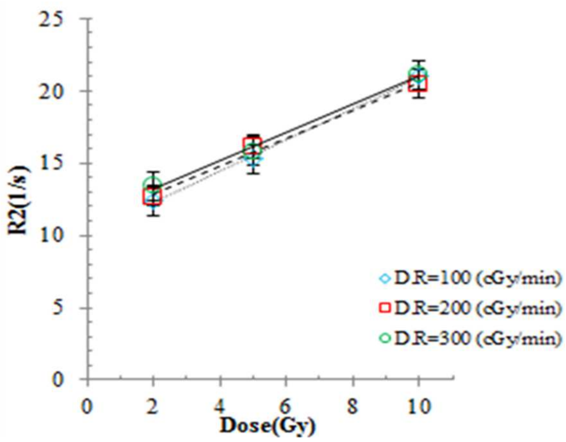

Figure 4. Dose rate dependence of low-density gel for three different dose rates and three different dose levels (2, 5,10Gy).

DISCUSSION

In this study a series of basic dosimetric properties of MAGAT LD gel dosimeter, such as linearity, sensitivity, dose rate, energy independence and tissue equivalence were studied.

The relative electron density values obtained for LD gel dosimeter comply well with De Deene *et al.* results which reported an electron density of 0.4g/ml [6]. While, compared to Haraldsson et al study [9], the gel density and CT number were decreased significantly with addition of more polystyrene spheres, still they were higher than the corresponding values for normal human lung tissue, which ranges from −770 to −875 Hounsfield units [12]. The gel density could potentially be further lowered by adding of smaller polystyrene spheres.

Dose-response of LD gel dosimeter, increased up to 22Gy. It is in accordance with De Deene et al results [13] but is in contrast with Haraldsson *et al.* [9], who reported a linear dose-response just for doses between 2 to 8Gy. The results of our experiment showed a sharp increase in R2 values from 0 to 2Gy, but Haraldsson reported inhibition of polymerization in the low-dose region (≤2Gy) [9]. Although gel preparation, irradiation and imaging were followed according to Haraldsson study, the differences can be due to different concentration of foam beads or fitting method and threshold application in data processing. Weak echo signals degrade R2 values significantly [14]. In their study, two point fit method with no report of thresholding was used for R2 extraction, while, we used many point fit method [15] and those echoes with SNR less than 3 were excluded from data analysis [16].

Dose rate may vary within the volume of interest in clinical irradiation pattern and it is expected that a dosimeter be independent of dose rate in the range of the applied dose during dosimetric investigations. In this study no dose rate dependence was observed in different levels of doses for LD MAGAT gel dosimeter, whereas, Bayreder *et al.* in 2006 [5] stated , dose response of MAGAT gel depends on dose rate in medium and high dose region. Bayreder used 2 mM of THPC as antioxidant, while, in Haraldson *et al.* study, 94mM of THP was recommended to remove any probability of oxygen contamination in LD gel. Sedaghat *et al.* claimed, oxygen and antioxidant both act as radical scavengers that affect the amount of polymer formed in the gel and modifying the radiation dose response of the dosimeter [17]. In LD gel, excess oxygen that is released by styrofoam beads, react with the extra antioxidant and somehow neutralize its inverse effect, but the amount of unreacted antioxidant left in the LD gel dosimeter can have an impact on the polymerization reaction. Although no hard evidence is available at the moment, we

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hypothesized, the extra concentration of THPC in LD gels, removed the dose rate dependence of MAGAT gel dosimeters, but further investigation is needed to explore the possibility of other sources.

No significant differences were found in dose response to 1.25MeV and 6MV photon beams in this study. Unfortunately there is no available data to compare the results. Looking at previous studies on Mac polymer gel dosimeters, De Deene *et al.* [18] found no significant effect of beam energy on the dose response of nMAG in 25MV.

CONCLUSION

MAGAT LD gel dosimeter appears to be a promising dosimeter in all aspects of dosimetric properties evaluated in this study. In addition, its' high linearity together with no dose rate dependence in different level of absorbed dose make it a suitable dosimeter to measure 3D-dose distributions insidea non-homogeneous media such as lung tissue.

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Conflict of interest: *Declared none.*

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