Iran. J. Radiat. Res., 2008; 6 (1): 31-36

Verification of dose rate and energy dependence of MAGICA polymer gel dosimeter with electron beams

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Background: The purpose of this study was to evaluate the dependency of MAGICA polymer gel dosimeter response (R2) on different electron energies as well as on different mean dose rate for a standard clinically used linear accelerator. ***Materials and Methods:*** 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 12 dosimeters (11 irradiated and one blank) was obtained for 6 MeV electron beam. Dosimeter energy dependence was studied for electron energies of 4,6,12 and 18 MeV. Dose rate dependence was studied in 10 MeV electron beam with the use of dose rates 80,160,240,320,400 and 480 $cGymin^{-1}$. Evaluations of dosimeters were performed on Siemens Symphony, Germany, 1.5T Scanner in the head coil. A multiecho 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 4mm and FOV 256mm. ***Results:*** Polymer gel dosimeter response R2 was increased with increasing electron energy. No trend in polymer-gel dosimeter R2 dependence was found on mean dose rate for electron beams. ***Conclusion:*** In MAGICA polymer gel, the sensitivity is dependant on electron energy increase, but no dependence was observed on response to dose rate. The presence of antioxidant and oxygen scavengers in the MAGICA polymer gel is believed to cause different results. **Iran. J. Radiat. Res., 2008; 6 (1): 31-36**

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

INTRODUCTION

In 1984, magnetic resonance imaging (MRI) demonstrated great potential in visulazing 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)].

In 2001, the first normoxic gels were suggested that could be produced, stored and irradiated in a normal condition. The polymer gel dosimeter, known as MAGIC, was based on polymerization of Methacrylic Acid (MAA) infused with copper (II) sulphate and the anti oxidant ascorbic acid in a gel matrix [(5)]. Although MAGIC gel has found its place in gel dosimetry for its feasibility to be manufactured in normal condition in the presence of oxygen, it suffers lack of stability in the casts and molding. Subsequently, number of normoxic polymer gel dosimeters was investigated with adding some agarose to the MAGIC formulation known as

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MAGICA, to optimize the gel characteristics including stability, dynamic range, reproducibility and increasing stiffness [6]. 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 R2 are 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, 7-9]. 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 MAGICA polymer gel dosimeter response on different energies and dose rates in electron beams.

MATERIALS AND METHODS

Preparation of polymer gel dosimeter

A MAGICA polymer gel dosimeter was prepared. All chemicals (gelatin, ascorbic acid, CuSO4.5H2O, hydroquinone and methacrylic acid) were provided by Sigma Aldridge and Flucka with experimental grade. HPLC water was obtained from Novin Medical Radiation Institute in Tehran. The preparation of the gel was carried out in a similar procedure as described by Fong *et al.* (2001) with slight difference due to the presence of agarose in MAGICA formulation. First, water was divided into 5 flasks of varying sizes, ready for dissolving each substance. Gelatin was added in to about 60% of the total HPLC de-ionized water. Two electrical heating plates provided with magnetic stirring and thermostatic control were used to heat the solutions. Gelatin was allowed to swell for about an hour and then the solution was stirred and heated to about 50°C until a clear solution was obtained, ensuring all gelatin powder has been dissolved. When the temperature of gelatin solution reached near 40°C, agarose was added to about 30% of warm water which had been heated up to 50°C. Agarose solution was stirred and heated to about 90°C at which agarose was thoroughly dissolved. At this time gelatin solution should have reached near 50°C. Both solutions were allowed to cool. The gelatin solution was larger in volume compared to the agarose solution, thus agarose solution cools faster in spite of its higher temperature. However, the cooling rates can be adjusted with respect to each other by proper adjustment of the heating plates. When both solutions cooled to an equal temperature about 47°C, agarose solution was added to the gelatin solution and stirring continued. Stirring never stopped before the end of fabrication. At 45°C, Hydroquinone, which had been solved in about 5% of water, was added to the mixture. The remaining 5% of water were divided into two portions and in each portion Ascorbic Acid (AA) and Copper (II) sulphate were dissolved after being weighed. These two chemicals, which together play the role of oxygen scavenger, were added to the mixture when temperature declined to about 37°C. Methacrylic Acid (MAA) was added at the same temperature. The amount of MAA for all gel fabrications was 9% of the total weight of gel except in one experiment in which more MAA was used. The gel was then decanted into test tubes or poured into the phantoms and left in a typical refrigerator at about 4°C to set. Gel phantoms and calibration tubes were not irradiated in the first 24 hours after being manufactured. All irradiations were performed after that period [5, 6].

Irradiation of polymer gel dosimeter

Variation of transverse relaxation rate (R2) due to electron beam was studied for 4, 6, 12 and 18 MeV electron beams. Dose rate dependency was studied only in 10 MeV electron beam with dose rates of 80,160,240,320,400 and 480 $cGymin^{-1}$. To obtain calibration curves, 12 dosimeters were

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irradiated with doses in the range of 0-4000 cGy (0, 250, 500, 750, 1000, 1250, 1500, 1750, 2000, 2500, 3000, 4000cGy) for 6 MeV electron beam (24 hour) after gel preparation. To ensure homogeneous irradiation of the dosimeter, the gel phantom was fixed in the center of a water-filled cylindrical shape container. Four perpendicular fields (SSD=100 cm, field size = 20×20 cm^2) were used for polymer gel irradiation. All exposures were performed on the same date by the same repetition rate of 400 cGy/min.

Calibration curve in a polymer gel dosimeter

Polymer gel dosimeters in Perspex phantoms were homogeneously irradiated with 6 MeV electron beam with an Elekta linear accelerator located in Tehran. Delivered doses were from 0-4000 cGy. The calibration curve (R2 versus applied absorbed dose) was obtained and plotted.

MRI evaluation of polymer gel dosimeter

Evaluations of dosimeters were performed on a Siemens Symphony Germany, 1.5T scanner in the head coil one day after irradiation. All samples of the polymer gel dosimeter were left inside the MRI room for a sufficiently long time (2 hours) to become temperature equilibrated with the room temperature. A multiecho 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 20ms, Slice Thickness 4mm and FOV 256mm.

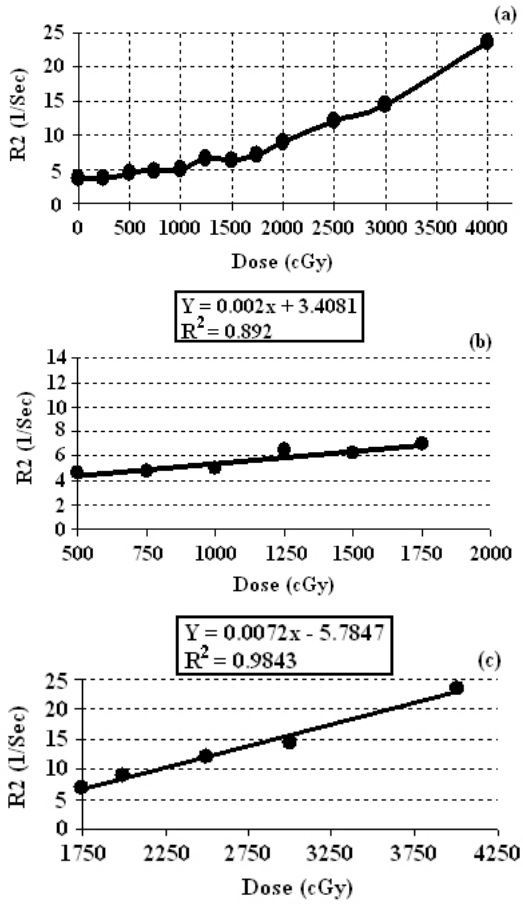

Figure 1. MAGICA polymer gel dosimeter R2 response on absorbed dose in range of 0-4000cGy.

RESULTS

1- Dependence of R2 response to the absorbed dose in the range of 0-4000 cGy is shown in figure 1. As it can be seen, the calibration curve is increasing with dose but 3 different regions are visible, (a) from zero to 250 cGy which no response is seen, (b) from 500 to 1750 cGy in which response is linear and a line with 89% correlation is fitted but the slope is low (0.002 $S^{-1}cGy^{-1}$), (c) from 1750 to 4000 cGy in which a good linear region with correlation of 98% and slope of 0.0072 $S^{-1}cGy^{-1}$ can be seen [10].

2- Response of the energy dependence was obtained for 4, 6, 12 and 18 MeV nominal electron energy and is shown in figure 2. A

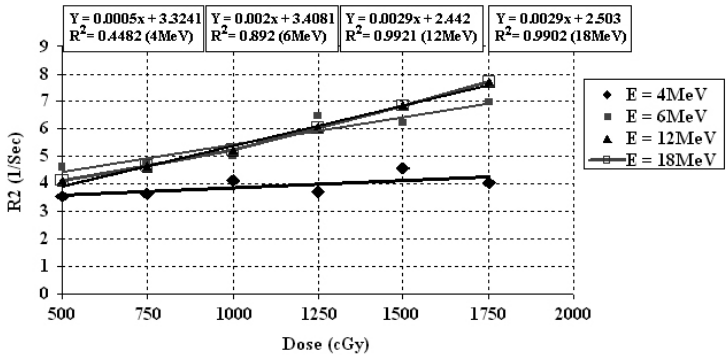

Figure 2. Dependence of MAGICA polymer gel dosimeter response to the energy of electron beam.

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linear function is fitted to each set of data and their slope and correlation were found. As it can be seen from figure 2, dependence of MAGICA polymer gel sensitivity to the energy of electron is shown. As the energy increases from 4 to 18 MeV the sensitivity increases from 0.001 to 0.003 $S^{-1}cGy^{-1}$: which is 66% variation in energy [10].

$$\left(\frac{0.003-0.001}{0.003}\right)\times 100 \cong 66\%$$

3- Dose rate dependence for MAGICA gel was verified in figure 3. With a 10 MeV electron beam 1000 cGy dose was delivered to the gel phantoms with dose rates varying from 80,160,240,320,400 and 480 $cGymin^{-1}$. A line was fitted to the data which shows no significant dependence of R2 to dose rate [10].

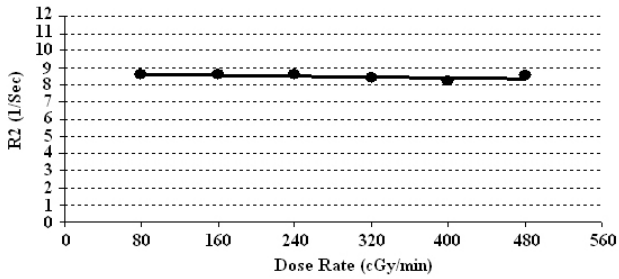

Figure 3. Verification of MAGICA gel dosimeter response to electron beam dose rates; a) calibration response from 0-4000cGy, b) linear response from 500-1750cGy, c) linear response from 1750-4000cGy.

DISCUSSION

According to the best knowledge of the authors, no published document was found on MAGICA gel dosimeter irradiated to electron beams. One researcher has used BANG-2 (gelatin, N-N-methylene-bis-acrylamide (BIS), acrylic acid. NaOH, dionized water) with electron beams (9, 12, 16 and 20 MeV) [11]. They found that BANG-2 response in dependent to electron energy but is independent to dose rate. This findings are consistent with our investigation in MAGICA gel, however the ingredient of the gels are very much different. It is believed that high energy electrons interact with material of polymer gel and produce secondary electrons. These electrons are absorbed in the dosimeter with simultaneous initialization induced polymerization and cross linking of acrylic monomers. Therefore electrons are responsible for chemical change in polymer gel.

Few other researching groups e.g. Ibbott *et al.* and Farajollahi *et al.* used BANG gel (Bis, gelatin, acrylamid and dionized water) with electron and photon beams [12, 13]. Baldock *et al.* [14] used PAG (poly acrylamid, gelatin) gel dosimeter with electron and photon beams. These researchers found that the response of polymer gels is independent to dose rate and energy. Energy independence of these gels could be justified with different types of gels and ingredient and possibly different values of accuracy.

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