Verification of Percentage depth dose of MAGICA polymer gel dosimeter with electron beams

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Abstract: In this work investigation of the normoxic MAGICA 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 8% gelatin, 0.5% agarose, 9% methacrylic acid, 0.0352% ascorbic acid, 0.0015% CuSO4.5H2O, 0.002% hydroquinone and 82.3% 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 $4^\circ\text{C}$. The optimal post-manufacture irradiation and post imaging times were both determined to be 1 day. The R2-dose response was linear to 4000cGy. The response of the MAGICA gel is very similar in the lower dose region and The R2-dose response for doses less than 250cGy is not exact. The R2-dose response of the MAGICA polymer gel dosimeter is linear between 500 to 1750 cGy with R2-dose sensitivities of 0.0020 and 0.0023 when imaged at 1 and 8 days post-irradiation respectively. In this study, the percentage depth dose (PDD) of MAGICA polymer gel dosimeter is determined and different phantoms of MAGICA gels was irradiated to 1000cGy of doses by 6, 8, 12 and 18MeV electrons and The maximum percentage depth dose (PDD) is located at the depths of 0.5, 1, 2 and 3cm.

Key words: polymer gels, MAGICA gel, magnetic resonance imaging (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].

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 the 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 were investigated with adding some Agarose to the MAGIC formulation known as 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 T2 is a result of physical density changes of irradiated polymer gel dosimeters. This study has been focused on evaluation of the dependence of MAGICA polymer gel dosimeter Percentage depth dose on different energies of the electron beams in a Medical Linear accelerator.

2. Materials and methods

2.1. MAGICA preparation

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 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 beforehand, 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 has been dissolved. When the gelatin solution temperature reached near 40 °C, Agarose is added to about 30% of warm water which has been heated up to 50 °C beforehand. 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 stops before the end of fabrication. At 45 °C, Hydroquinone which has 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 and the stirring was continued. 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 this period [5-6].

2.2. Irradiation

Irradiation of vials was performed using electron beams by Elekta linear accelerator with SSD = 100cm, field size of $20 \times 20 \text{cm}^2$ and the depth was selected at 1cm. To determine the Percentage depth dose of MAGICAT polymer gel dosimeter with different energies 6, 8,12 and 18 MeV and dose rate= $\frac{400 \text{cGy}}{\text{min}}$. The optimal post-manufacture irradiation was determined to be 1 day [7].
2.3. Imaging
Before imaging, all polymer gel dosimeters were transferred to a temperature controlled MRI scanning room to equilibrate to room temperature. The MAGICA 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 1 lists the protocol of magnetic resonance imaging (MRI) was used in MAGICA polymer gel dosimeter [7].

3. Results

3.1. Calibration Curve of MAGICA polymer gel dosimeter
MAGICA gels with optimum value of ingredient was manufactured and irradiated to different doses. As it can be seen in figure 1, MAGICA has a linear response to 4000cGy. The response of the MAGICA gel is very similar in the lower dose region and the R2-dose response for doses less than 250cGy is not exact. The R2-dose response of the MAGICA polymer gel dosimeter is linear between 500-1750cGy and 1750-4000cGy. Figure 1 shows Calibration Curve of MAGICA polymer gel dosimeter. Table 2 lists the Sensitivity of MAGICA polymer gel dosimeter with different range of doses.

3.2. Percentage depth dose (PDD) of MAGICA polymer gel dosimeter
In this study, the percentage depth dose (PDD) of MAGICA polymer gel dosimeter is determined and different electrons of MAGICA gels was irradiated to 1000cGy of doses by 6, 8, 12, and 18MeV electrons and The maximum percentage depth dose (PDD) is located at the depths of 0.5, 1, 2 and 3 cm. Figure 2 shows at depth of 8cm, the percentage depth dose for 6, 8, 12 and 18MeV electrons is determined, 56.11%, 49.13%, 53.79% and 61.42% respectively.

Table 1. The protocol of magnetic resonance imaging (MRI)

| PARAMETERS                      | Values          |
|---------------------------------|-----------------|
| Field of View (FOV)             | 256             |
| Matrix Size (MS)                | 512 x 512       |
| Slice Thickness                 | 4               |
| Repetition Time (TR)            | 3000            |
| Echo Time (TE)                  | 20              |
| Number of Slices                | 1, 2, 3, 4      |
| Number of Echoes                | 32              |
| Total Measurement Time          | 25-30           |
| Resolution                      | 0.5             |
| Band With [ Hz / Pixel ]        | 130             |
Figure 1. Sensitivity of MAGICA with different range of doses

Table 2. Sensitivity of MAGICA with different range of doses

| dose (cGy)   | R2- dose sensitivity (S-1cGy-1) |
|--------------|----------------------------------|
| 500-1750     | 0.002                            |
| 1750-4000    | 0.0072                           |

Figure 2. Verification of Percent Depth Dose (PDD) in MAGICA polymer gel dosimeter.
4. Conclusion

For calibration curve of MAGICA polymer gel dosimeter formulation determined in this study was found to have a linear range to 4000cGy. the response of the MAGICA gel is very similar in the lower dose region and the R2-dose response for doses less than 250cGy is not exact. The R2-dose response of the MAGICA polymer gel dosimeter is linear between 500 to 1750 cGy with R2-dose sensitivities of 0.0020 and 0.0023 $S^{-1}cGy^{-1}$ when imaged at 1 and 8 days post-irradiation respectively, therefore the R2-dose sensitivity showed stability with imaging post time after 8 days.

MAGICA gels were irradiated to 1000cGy of doses by 6, 8, 12 and 18MeV electron beams and the maximum percentage depth dose (PDD) is located at the depths of 0.5, 1, 2 and 3cm. At depth of 8cm, the percentage depth dose for 6, 8, 12 and 18MeV electrons is determined, 56.11%, 49.13%, 53.79% and 61.42% respectively. The MAGICA polymer gel dosimeter in this study exhibited the essential characteristics required for clinical radiotherapy dosimetry. MAGICA polymer gel offers simplification in to the routine clinical radiotherapy environment.

References

[1] J.C. Gore, Y.S. Kang, and R.J. Schulz, “Measurement of radiation dose distributions by nuclear magnetic resonance (NMR) imaging”. Phys. Med. Biol. 29, 1189-97 (1984).

[2] L. E. Olsson, A. Fransson, A. Ericsson, and S. Mattsson, “MR imaging of absorbed dose distributions for radiotherapy using ferrous sulphate gels”. Phys. Med. Biol. 35, 1623-31 (1990).

[3] R. J. Schulz, and J. C. Gore, “Reported in Imaging of 3D dose Distributions by NMR National Cancer Institute Grant Application”. 2RO1CA46605-04. (1990).

[4] M. J. Maryanski, J. C. Gore, R. Kennan, and R. J. Schulz, “NMR relaxation enhancement in gels polymerized and cross linked by ionizing radiation: a new approach to 3D dosimetry by MRI (Magn. Reson. Imag.)”, 11, 253-8 (1993).

[5] P. M. Fong, D. C. Keil, M. Does, and C. J. Gore, “Polymer gels for magnetic resonance imaging of radiation dose distributions at normal room atmosphere”. Phys. Med. Biol. 46, 3105-3113 (2001).

[6] M. H Zahmatkesh, R. Kousari, Sh. Akhlaghpour, and S. A Bagheri, “MRI gel dosimetry with Methacrylic acid., Ascorbic acid., Hydroquinone and Copper in Agarose (MAGICA) gel”. Preliminary Proceeedings of DOSGEL 2004. Sep 13-16. 2004. Ghent. Belgium.(2004).

[7] Adinehvand K., “Verification Response of MAGICA Gel Dosimeter in Beams Electron with Technique MRI”. MS. Thesis. Department of Nuclear Engineering. Shahid Beheshti University. Tehran. Iran. (2007).