Choice of Evaluation Imaging Technique for MAGAT Polymer Gel Dosimeter

N. N. Ashikin N. A. R.[1*], A. R. Azhar[2], S. M. Iskandar[3], M. R. Ramzun[4], Y. N. Zakiah[5], N. A. N. Zahirah [6], M. Amer al-Jarrah [7]

[1]School of Physics, Universiti Sains Malaysia, 18000, Pulau Pinang, Malaysia

[2]School of Physics, Universiti Sains Malaysia, 18000, Pulau Pinang, Malaysia

[3]School of Physics, Universiti Sains Malaysia, 18000, Pulau Pinang, Malaysia

[4]School of Physics, Universiti Sains Malaysia, 18000, Pulau Pinang, Malaysia

[5]School of Distance Education, Universiti Sains Malaysia, 18000, Pulau Pinang, Malaysia

[6]School of Physics, Universiti Sains Malaysia, 18000, Pulau Pinang, Malaysia

[7]School of Physics, Universiti Sains Malaysia, 18000, Pulau Pinang, Malaysia

[*]*Corresponding author's email: ohm_poisse [AT] yahoo.com*

ABSTRACT— ***The development of the polymer gel dosimeter evaluation focused mainly on magnetic resonance imaging (MRI) techniques. A new alternative imaging technique which is x-ray CT imaging has emerged from a current research. The study focused on the dose response, the dose sensitivity and the accuracy of the MAGAT gel dosimeter using two different imaging modalities. The MAGAT gel dosimeter was irradiated at 1, 5 and 10 Gy 24-h post-manufacturing. The imaging of MAGAT gel dosimeter by MRI and x-ray CT were done a day post-irradiation using an optimized protocol. The dose sensitivity of the gel obtained by the MRI technique was 0.7157 $s^{-1}Gy^{-1}$, whereas the dose sensitivity obtained by the x-ray CT technique was 0.6177 HGy^{-1}.***

Keywords— MAGAT gel dosimeter, dose response, MRI imaging, x-ray CT

1. INTRODUCTION

Complex radiotherapy techniques such as stereotactic radiosurgery, brachytherapy, conformal therapy and intensity modulated radiotherapy provide three-dimensional spatial dose distributions. One of the final steps in quality assurance of patient specific planning is to ensure close matching between the the dose delivered to the patient and the dose calculated by the treatment planning system (TPS). Tissue equivalent polymer gels are capable of recording three dimensional dose distributions. Polymer gel is fabricated from radiation sensitive chemicals such as aqueous gels. Upon irradiation polymerization occurs due to radiation-induced changes in the chemical species. The use of a radiation sensitive gel for radiation dosimetry was first suggested in the 1950s where radiation induced colour changes in dyes were related to the received radiation dose [1,2]. Polymer gel dosimeters were developed as an alternative to Fricke gels. Unlike the Fricke system diffusion complication is minimised in polymer gel hence can be used to verify the spatial dose distribution in complex radiotherapy [3,4].

The change in dose distribution can be recorded in three dimensions (3D) by various methods such as magnetic resonance imaging (MRI), x-ray computed tomography (x-CT), ultrasound, optical CT and vibrational spectroscopy [5]. To date, magnetic resonance imaging (MRI) is the commonly used technique for recording 3D dose information in a polymer gel [3,4,6]. MRI can non-invasively and non-destructively measure the magnetization of hydrogen atoms in water molecules with high spatial resolution in three dimensions.

The development of the polymer gel dosimeter evaluation focused mainly on MRI techniques. A new alternative imaging technique which is x-ray CT imaging has emerged from a current research. Both of these techniques are able to image 3D dose distribution polymer gel dosimeters with high resolution. However, each technique has technical problems and implementation challenges. The present study evaluated the dose response of the polymer gel dosimeter

using the MRI and x-ray CT techniques in order to discover which technique is the best imaging modality for polymer gel dosimeter.

2. METHODOLOGY

2.1Fabrication of MAGAT gel dosimeter

The gel formulation consisted of methacrylic acid (Acros, Organics), gelatin (250 bloom, Bovine) (Sigma Aldrich), de-ionised water, ascorbic acid (Sigma Aldrich) and THPC (Sigma Aldrich). The MAGAT polymer gels were manufactured under normal atmospheric conditions. The gelatin was mixed with de-ionised water in a mixing vessel and was continuously stirred at approximately 48˚C until the gel was completely dissolved and a clear solution was obtained. The solution was cooled to 40˚C then the methacrylic acid monomer was added and continuously stirred until the monomer was completely dissolved. For manufacturing the normoxic polymer gel, an anti-oxidant was finally added to minimise the oxygen exposed to the solution [7]. The fabrication procedures of gel solution are shown as Figure 1. The MAGAT gels were then poured into 4 ml tissue equivalent polystyrene cuvettes of inner dimensions 1 cm x 1 cm x 4.5 cm (width x length x height) with the top sealed by a parafilm tape. Finally they were wrapped in aluminium foils to avoid any preliminary polymerisation from the ambient light. The sample vials were stored at 4˚C before irradiation. In this study, MAGAT polymer gel used the concentration of MAA 6% (w/w), gelatin 5% (w/w) and at 10 mM THPC. These concentrations were obtained from our previous study where optimisation of MAA, gelatin and THPC has been done and the optimised values of the compositions are shown in the Table 1.

Table 1: MAGAT gel compositions

Composition	MAGAT concentration
Gelatin	5% (w/w)
Methacrylic Acid	6% (w/w)
THPC	10 mM
De-ionised water	89% (w/w)
Dose range	0-10 Gy

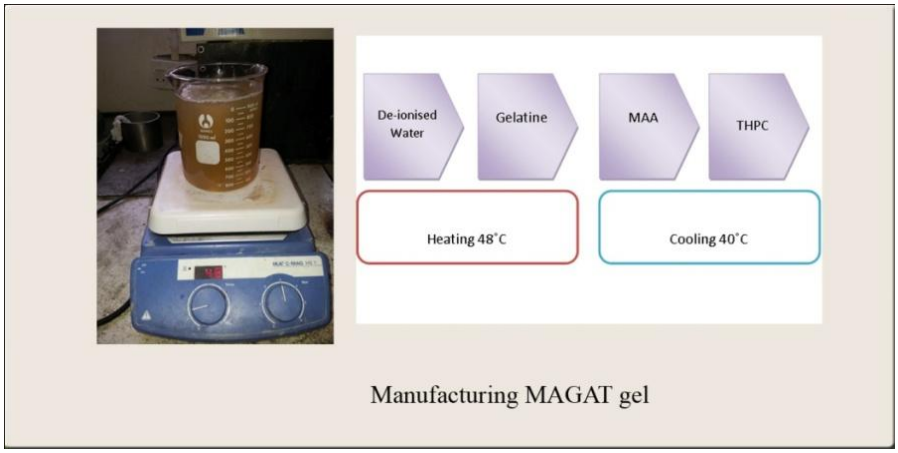

Figure 1: Fabrication of MAGAT gel dosimeter

2.2 Irradiation of gel dosimeter

Irradiations were performed using a 6-MV photon beam by a linear accelerator (Primus LINAC, Siemens), with a field size of 10 cm x 10 cm at the isocentre and at 100 cm source axis distance (SAD). The dose rate was 3 Gy min^{-1}. The samples were irradiated from 0, 5 and 10 Gy by parallel opposed beams so that the gels received a uniform dose at 5 cm depth. One sample of each batch is left unirradiated for background measurement. Solid water phantom slabs were placed above and below the Perspex cuvette holder and the samples were placed at the midregion of the phantom as shown in Figure 2. The irradiation were done a day post-manufacturing.

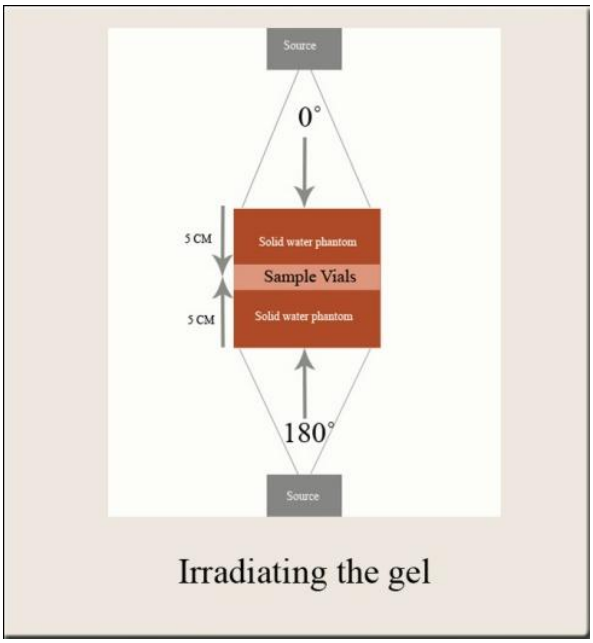

Figure 2: The irradiation of MAGAT gel dosimeter using 6-MV photon beam

2.3 MRI imaging technique

All the sample vials were inserted in a dedicated styrofoam holder and placed in a MRI Signa HDxt 1.5 T whole body scanner using a head coil as shown in Figure 3. All of the samples were imaged a day post-irradiation.The imaging sequence applied was a single spin-echo sequence with time echoes of TE1=20 ms and TE2= 300 ms and a relaxation time (TR) of 3500 ms. The other scanning parameters used such as NEX = 3, slice thickness = 5 mm, slice spacing = 0 mm, FOV = 22 mm and flip angle = 90˚. The T2 dicom images were transferred to a personal computer and analyzed using MATLAB 7.1 (Math Works, Inc.) software. From the time series of T2-weighted images (TE=20 ms, and TE=300 ms), R2-maps were calculated from these images for each sequence pixel by pixel basis using pixel signal intensities and applying the two-point method [8].

$$R2 = \frac{\ln S1 - \ln S2}{TE2 - TE1}$$

The two-point method; where S_1, S_2 is the measured MR signal intensity at a given echo time, TE and R2 is the transverse relaxation rate.

R2 maps can be converted to dose maps using a linear dose response equation that has been reported by several independent investigators [9,10,11].

$$R2 = \alpha D + Ro$$

Linear dose response equation: where α is the slope of the dose–R2 curve, R_o is R2 background and R2 is R2 value of the irradiated gel.

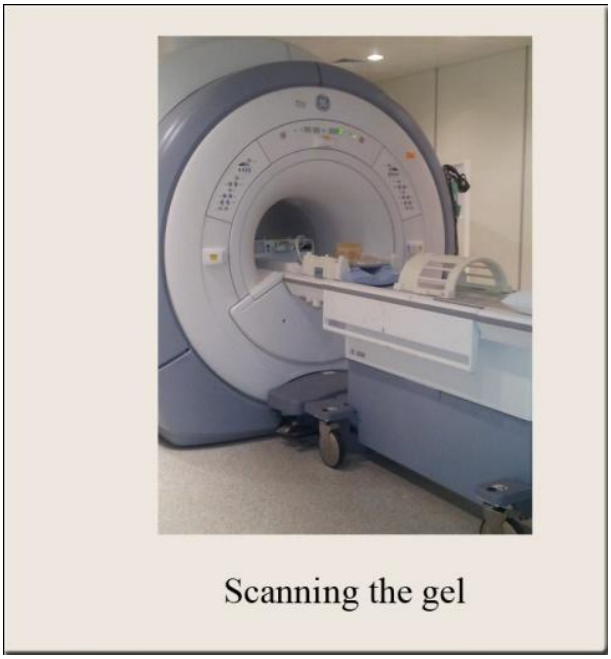

Figure 3: The scanning of the gel samples by 1.5T MRI

2.4 X-ray CT scanning

All the MAGAT gel dosimeters were kept in the scanner room for at least an hour to ensure temperature equilibrium. X-ray CT imaging (Siemens Somatom Definition AS+ 128-Slice) was performed using a standard protocol from Hospital Universiti Sains Malaysia, Malaysia. The MAGAT gel dosimeters were imaged a day post-irradiation using a Siemens CT scanner with 130 kV, 200 mA, 1.5 s exposure time and 2 mm slice thickness. This protocol allows a maximum number of photons to reach the detectors, thereby reducing noise. The ROI of 3 mm^2 area was plotted at the centre of each sample to extract the mean CT number. The imaging time for complete scanning was approximately 15 minutes. The dose sensitivity of the gel was determined by the following equation:

$$H = \alpha D + Ho$$

Where H is the CT number, α is the slope (sensitivity), D is the absorbed dose within the gel, and Ho is the intercept [12].

3. RESULT AND DISCUSSION

3.1 Dose response and dose sensitivity of the MAGAT gel dosimeter using MRI and x-ray CT imaging

The aim of the investigation was to compare the dose response sensitivity of the polymer gel dosimeter and the accuracy of the MRI and x-ray CT imaging techniques. As illustrated in Figure 4 and Figure 5, the dose response of the MAGAT gel dosimeter in both imaging modalities showed a similar trend in the case of a linear dose response of up to 10 Gy, with linear regression values of 0.9989 for the MRI technique and 0.9921 for the x-ray CT technique. The dose sensitivity of the gel obtained by the MRI technique was 0.7157 $s^{-}Gy^{-1}$, whereas the dose sensitivity obtained by the x-ray CT technique was 0.6177 HGy^{-1}.

However, the sensitivity from the x-ray CT technique was lower compared to that from the MRI. This may have been due to the additional dose imparted to the gel from the x-ray CT imaging at 130 kV. As shown in the results presented in Table 2, the percentage deviation (%) of the dose from the MRI technique is within 5% for the dose range of 10 Gy while for the x-ray CT technique, the percentage deviation was as high as 13%. Therefore, the MRI technique provided better accuracy and was selected as the imaging modality for the whole study.

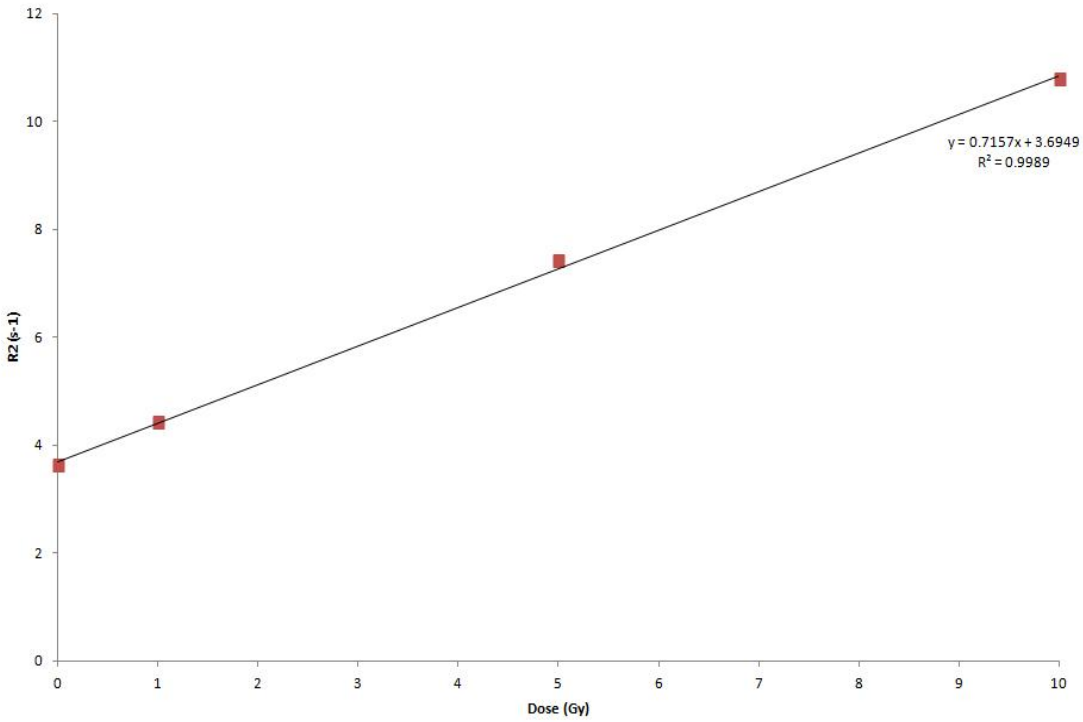

Figure 4: Transverse relaxation rate (R2) as a function of absorbed dose (D) for MAGAT gel dosimeter scanned by MRI irradiated from 1 to 10 Gy.

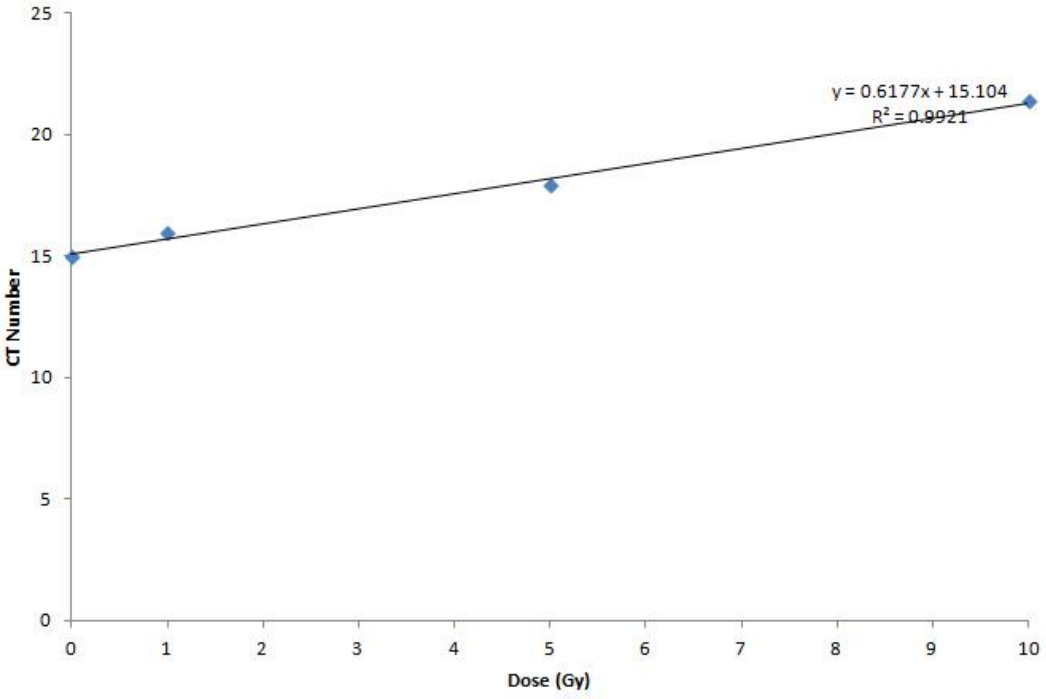

Figure 5: The CT-number as a function of absorbed dose for MAGAT gel dosimeter scanned by x-ray CT irradiated from 1 to 10 Gy

Table 2: The % deviation of dose obtained from MRI and x-ray CT compared to true dose value

True Dose (Gy)	MRI		X-ray CT	
	Dose (Gy)	% Deviation	Dose (Gy)	% Deviation
0	0	0	0	0
1	1.06	-5.09	0.87	13.12
5	5.20	-4.01	4.53	9.47
10	9.57	4.33	11.07	-10.66

4. CONCLUSION

The sensitivity of the MAGAT gel dosimeter imaged by MRI showed a slightly higher sensitivity compared to the x-ray CT imaging, and the dose accuracy was within 5% for the MRI technique and 13% for the x-ray CT imaging technique. Hence, MRI was found to be a more suitable evaluation technique than x-ray CT imaging.

5. ACKNOWLEDGEMENT

We are indebted to Universiti Sains Malaysia for providing us a short term grant. We would like to thank to Mount Miriam Cancer Hospital, Penang and Pantai Hospital, Penang for giving us the opportunity to use the linear accelerator unit. We also grateful to Institut Perubatan dan Pergigian Termaju (Advanced Medical & Dental Institute), Penang for the use of the Magnetic Resonance Imaging unit.

6. REFERENCES

1. Day, M.J. and G. Stein, Chemical effects of ionising radiation in some gels. Nature, 1950. 166:146–147.

2. Day, M.J., et al., Gel dosimeter for depth dose measurements. . Review of scientific instruments, 1957. 28:329–332.

3. Maryanski, M.J., J.C. Gore, and R.J. Schulz, 3D radiation dosimetry by MRI: solvent proton relaxation enhancements by radiation-controlled polymerisation and crosslinking in gels. . proc. Soc. Magn. Reson. Med., 1992:1325.

4. Maryanski, M.J., et al., NMR relaxation enhancement in gels polymerized and cross-linked by ionizing radiation: a new approach to 3D dosimetry by MRI Magn. Reson. Imaging 1993. 11: 253–258.

5. Baldock, C., et al., Polymer gel dosimetry Phys. Med. Biol. , 2010. 55:R1–R63 505.

6. Hiraoka, T., N. Fukuda, H. Ikehira, K. Hoshino, K. Nakazawa, Y. Tatemo, and K. Kawashima. 1986. Digital imaging of dose distributins by magnetic resonance. *Nippon Igaku Hoshasen Gakkai Zasshi- Nippon Acta Radiologica* 46:503-505.

7. De Deene, Y., Hurley, C., Venning, A., Vergote, K., Mather, M., Healy, B.J., and Baldock, C. 2002a. A basic study of some normoxic polymer gel dosimeters Phys. Med. Biol. 47:3441–3463.

8. De Deene, Y., and C. Baldock. 2002b. Optimization of multiple spin-echo sequences for 3D polymer gel dosimetry. *Phys. Med.Biol* 47:3117-3141.

9. Maryanski, M.J., Ibbott, G.S., Eastman, P. Schulz, R.J., and Gore, J.C. 1996. Radiation therapy dosimetry using resonance imaging of polymer gels Med. Phys. 23:699–705.

10. Ibbott, G.S., Maryanski, M.J., Eastman, P., Holcomb, S.D., Zhang, Y.S., Avison, R.G., Sanders, M., and Gore, J.C. 1997. 3D visualization and measurement of conformal dose-distributions using MRI of BANG-gel dosimeters Int.J. Radiat. Oncol. Biol. Phys. 38:1097–1103.

11. Oldham, M., Baustert, I.B., Lord, C., Smith, T.A.R., McJury, M., Leach, M., Warrington, A.P., and Webb, S. 1998. An investigation into the dosimetry of a 9 field tomotherapy irradiation using BANG-gel dosimetry Phys. Med. Biol. 43:1113–1132.

12. Trapp, J.V., S.A.J. Back, M. Lepage, G. Michael, and C. Baldock. 2001. An experimental study of the dose response of polymer gel dosimeters imaged with x-ray computed tomography. *Phys. Med. Biol.* 46:2939-2951.