An application of CT based MAGAT gel dosimetry to measure 3D dose distribution

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ABSTRACT: The aim of this project is to evaluate the CT (Computed Tomography) based MAGAT (methacrylic acid, gelatine and tetrakis phosphonium Chloride (THP)) gel dosimetry for measuring dose distribution in radiation treatment. A 2.7 L gel volume was irradiated based on typical treatment setup for prostate cancer patient. The measured dose distribution using gel dosimetry was compared with that obtained by treatment planning computer (TPS) and EBT2 film dosimetry. The qualitative and quantitative comparison of measured dose distribution agreed very well with that calculated using TPS and film dosimetry. The results showed that the MAGAT gel dosimetry with CT imaging can be considered as a valuable method for 3D dose distribution verification.

KEYWORDS: MAGAT gel dosimetry; EBT2 film dosimetry; CT imaging; 3D dose distribution.

I. INTRODUCTION

Polymer gel dosimetry showed an ability to measure three dimensional dose distribution of radiation treatment [1]. The earlier types of gel dosimeters have been limited in clinical use due to difficulty of avoiding of oxygen from penetrating the gel mixture. Oxygen acts as inhibitor of free radicals production and must be removed from gel dosimeters before irradiation otherwise the polymerization process will be inhibited [2,3]. A method was proposed to decrease the effect of oxygen in gel mixture by binding the oxygen with metallo-organic compounds [4]. The first gel dosimetry prepared in normal atmospheric conditions was named MAGIC (Methacrylic and Ascorbic acid in Gelatin Initiated by Copper) gel [4]. Because preparation of this gel can be performed under normal atmospheric conditions, the gel is called normoxic polymer gel. Subsequently, De Deene et al. (2002a) investigated various oxygen scavengers and it was found that tetrakis (hydroxymethyl) phosphonium chloride (THP) was effective at scavenging oxygen [5]. A new formulation consisting of methacrylic acid, gelatine and THP, named as MAGAT (methacrylic acid, gelatine and THP) gel was proposed [5]. Various normoxic gel formulations were also reported such as MAGAS (methacrylic acid gelatine and ascorbic acid) gel, PAGAS (polyacrylamide gel and ascorbic acid) gel [5,6] and PAGAT (polyacrylamide gel and THP) [7]. The different types of normoxic gel dosimeters have been reviewed by Baldock and colleagues [1]. The challenge in gel dosimetry is to extract dose information from the irradiated gel dosimeter. Number of methods have been proposed to extract dose information from gel dosimetry such as magnetic resonance imaging [8], Fourier-Transform Raman Spectroscopy [9], Ultrasound [10], Optical Computed Tomography [11,12], and X-ray Computed Tomography [13]. The most method of choice to extract dose information from gel dosimeter has been magnetic resonance imaging [14,15]. However, this technique showed some limitations such as the drifting in temperature of gel dosimeter during imaging process, which markedly affects the spin-spin relaxation time (T2) value [16]. Also, the lengthy imaging times is included in the current limitations of MRI imaging [17]. The advantages of CT scanner compare to other methods to extract dose information are: availability of CT to clinical radiation therapy for treatment planning purposes, simplicity & rapidity of image acquisition, and relatively insensitive to environmental factors. However, the limitation of X-ray CT gel dosimetry is the low-dose resolution of the scanned polymer gel which is due to the low-dose sensitivity of polymer gel formulations for X-ray CT imaging.

The CT based MAGAT gel dosimetry provides high dose resolution compare to other types of normoxic gel dosimetry with CT number-dose sensitivity of 0.85 ± 0.08 HU Gy^{-1} [18]. So far no study has been conducted to extract 3D dose distribution using CT scanner on irradiated MAGAT gel, which is a very important step for dose verification in radiotherapy treatment. The aim of this work is to evaluate the CT based MAGAT gel dosimetry system for measuring 3D dose distributions in radiation treatment. Also, to verify the dose distribution calculated by treatment planning system (TPS) using the established CT- based gel dosimetry and compare it with film dosimetry measurement.

II. MATERIALS AND METHODS

A 2.7 liter volume of MAGAT (Methacrylic Acid, Gelatin and Tetrakis (hydroxymethyl) phosphonium chloride) gel dosimeter was prepared and poured into a big plastic container (14 cm x 14 cm x 14 cm). The preparation process was based on a method proposed in the literature by De Deene et al. (2002a). The chemical materials used to produce the gel were 9% Methacrylic acid, 8% Gelatin type A (300 bloom), 0.19% Tetrakis (hydroxymethyl) phosphonium chloride (THP) and 83% deionised water.

Before the irradiation of the gel, the unirradiated gel was imaged using Computed Tomography and the images were transferred to Oncentra treatment planning computer to plan the treatment. The planning was based on typical treatment setup for prostate cancer patient with three irregular field sizes. The gel was then irradiated using 6 MV photon beam from linear accelerator (Siemens Primus, USA) to total dose of 12 Gy with three field sizes as shown in Fig. 1. The time between gel preparation and irradiation was about 24 hours.

Fig. 1. The polymer gel during irradiation process

To expose the EBT2 film dosimetry with three beams, the film was cut into 14 cm × 14 cm square to be matched with size of the gel phantom that was used previously in the experimental measurements. The film sheet was placed between the solid water phantom slabs and it was positioned perpendicular to the treatment table and parallel to the beam axis. The film was irradiated using a 6 MV photon beam linac (Siemens Primus, USA) with the same setup that has been done previously during gel dosimetry irradiation. The film was planned to receive a dose at isocenter of 12 Gy (Fig. 2).The film was scanned using Vidar scanner (Red LED Dosimetry Pro Advantage) and analysed using Radiation Analyser (RAY) software (Agila Radiological Technologies).

The irradiated sample inside cylindrical Perspex phantom filled with water was scanned using diagnostic CT scanner (Siemens Medical Solution, Malvern, USA), 48 hours after irradiation to ensure the polymerization process was completed. Scanning parameters chosen were: 140 kV, 400 mAs, and 3 mm slice thickness. The gel dosimeter was scanned 20 times for image averaging process. OsiriX imaging software was used to save the axial slices of the sample in DICOM format to be analyzed in personal computer using ImageJ (developed at the US National institutes of health) software. The measured dose distributions using gel dosimetry was compared with that obtained by treatment planning computer (TPS) and film dosimetry. The differences between the measured isodose lines using gel dosimetry with that calculated using TPS and measured using film dosimetry were investigated using ImageJ software.
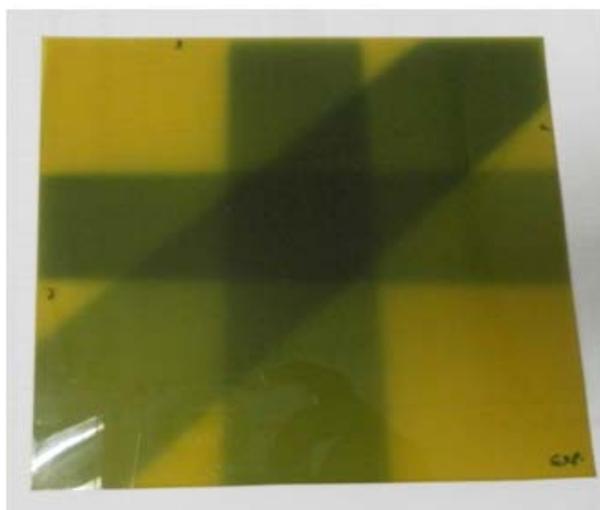

Fig. 2. The film dosimetry after irradiation to three fields

III. RESULTS AND DISCUSSION

The qualitative comparison of spatial distribution of dose for a prostate cancer treatment calculated by treatment planning system computer and measured using gel dosimetry measurement is shown in Figure 3. It is clear from the spectrum distribution for the irradiated gel dosimetry that each part in the exposed gel dosimetry is characterised with different pixel intensity. The degree of pixel intensity value was observed to be dose dependent, where the highest absorbed dose showed hyper intensity area (red color), and hence higher polymerization. The lowest absorbed dose showed hypo intensity area (blue color), and hence lower polymerization process. This shows the ability of the CT based gel dosimetry method to accurately localize the various dose regions in the exposed gel dosimetry. The shape of the absorbed dose for the exposed gel dosimetry was in very good agreement with that calculated using TPS. However, there was mismatching in some points between the measured and the calculated isodose lines. The difference in the spatial distribution of dose between the planned and measured isodoses $\geq 60\%$ was found to be 2 mm. For the low isodoses lines $\leq 40\%$, the margins of dose distribution matched very well with small differences in some parts. The differences could be attributed to uncertainties associated with digitising process in TPS calculation and inaccuracies in irradiation process including an error in positioning of gel dosimetry during irradiation process.

The comparison of dose distribution obtained by treatment planning system computer calculation and gel dosimetry measurement is shown in Figure 4. An overview for the matched isodose lines can be observed in the figure showing that there was a very good agreement in dose distribution between the TPS calculation and gel dosimetry measurement. For the verification of high isodoses (>50%), the maximum deviations observed between measured and calculated isodose lines was found to be 5 mm. This deviation between measured and calculated isodose lines could be due to the effect of uncertainty in pixel intensity measurements and uncertainties associated with digitising the TPS calculation. Also, inaccuracies associated with irradiation process including an error in positioning of gel dosimetry during irradiation process as mentioned previously. At 40% isodose line, the calculated and measured dose distribution matched excellently. A large individual point fluctuation can be observed at 20% isodose line due to the low dose gradient at this area and the effect of imaging filtering on CT gel images. The mean filter was used in the current study to reduce the artefact in CT gel images. The mean image filter provides the best noise reduction but an unacceptable degradation in spatial dose information [19], which can be seen clearly in the current study at 20% isodose lines, where the spatial information of the gel dosimetry image was effected significantly at low dose regions.
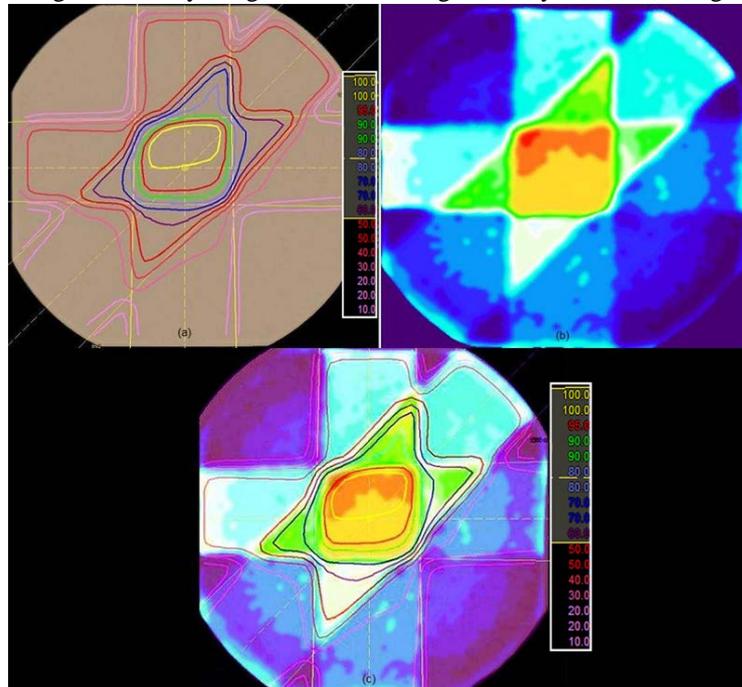

Fig. 3. The spatial distribution of absorbed dose by (a) TPS calculation, (b) spectrum distribution of absorbed dose using gel dosimetry, and (c) comparison of TPS calculation with spatial distribution of gel dosimetry.

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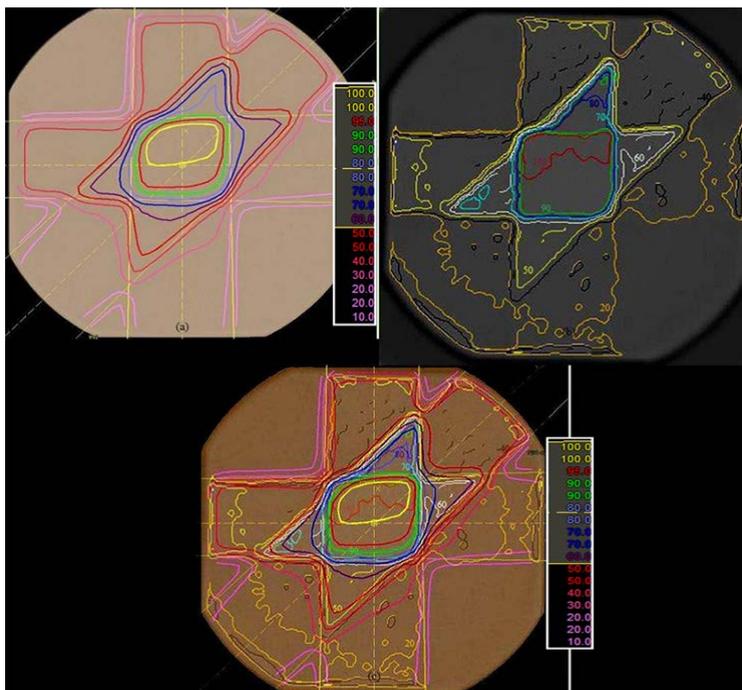
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Fig. 4. Comparison of 6 MV photon beam dose distribution for a prostate cancer treatment obtained by (a) TPS calculation, (b) gel dosimetry measurement, and (c) comparison between TPS and gel dosimetry dose distribution.

In the current study, the spatial distributions of dose obtained by film dosimetry and gel dosimetry measurements were compared as shown in Figure 5. It was found that the spatial distribution of dose between film dosimetry and gel dosimetry measurements was in close agreement, within 2 mm deviation for the 60% - 90% isodoses lines. For the 50% isodose line, the measurements agreed very well except at the upper region of 50% relative dose. The large deviation would probably be ascribed to non-uniformity within a sheet of film. The shape and location of 40% and 20% relative doses information between film dosimetry and gel dosimetry measurements are qualitatively comparable.

Comparisons of dose distributions obtained by film dosimetry and gel dosimetry measurements are shown in Figure 6. The dose distribution between film dosimetry and gel dosimetry measurements agreed very well. However, some deviation can be found at some points. At 90% and 80% isodose lines, the disagreement was within 1 mm. The 70% and 60% isodose lines agreed from 0–8 mm. At the 50% isodose line, the gel dosimetry measurement and film dosimetry measurement agreed within 0-4 mm. However, at the upper right region, the difference was larger. For the 40% isodose line, the measured dose distribution for the film and gel dosimetry agreed very well, within 3 mm difference. This difference could be ascribed to non-uniformity of polymer components distribution in the active layer within the sheet of the film dosimetry and thus increase the inaccuracy of the measured dose. For a single piece of EBT2 film uniformly exposed to a dose, the pixel value (dose) could vary by up to 3.7% [20]. Butson *et al.* reported that the polymer structures are not aligned completely with all axis of the film and they also noted that there were local variations within a sheet of film [21]. Another reason for the difference in isodose lines between the gel dosimetry and film dosimetry could be due to the resolution of the scanner used to measure the dose distribution from film dosimetry. The non-uniformity of the scanner light source has as a dramatic effect on dose accuracy.

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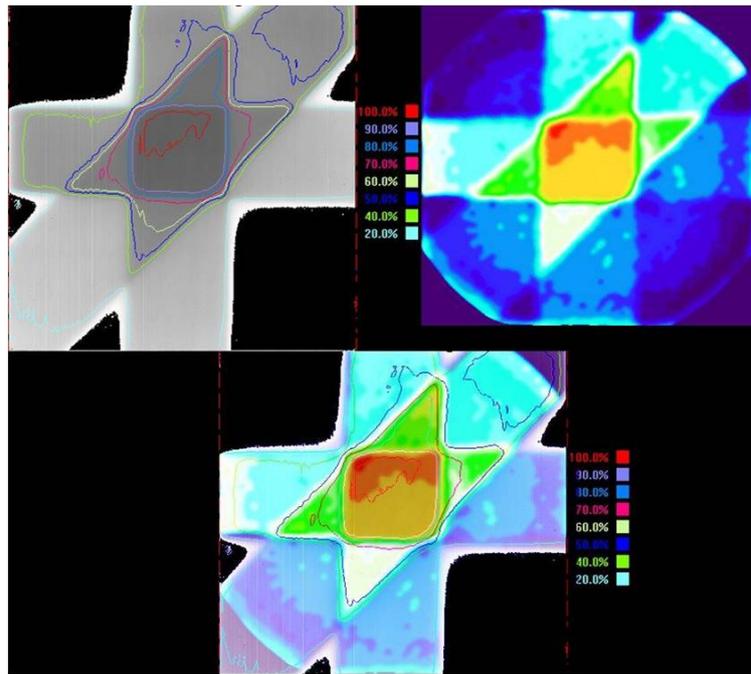
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Fig. 5. The spatial distribution of absorbed dose by (a) film dosimetry measurement, (b) spectrum distribution of absorbed dose using gel dosimetry, and (c) comparison of film dosimetry with gel dosimetry spatial distribution.
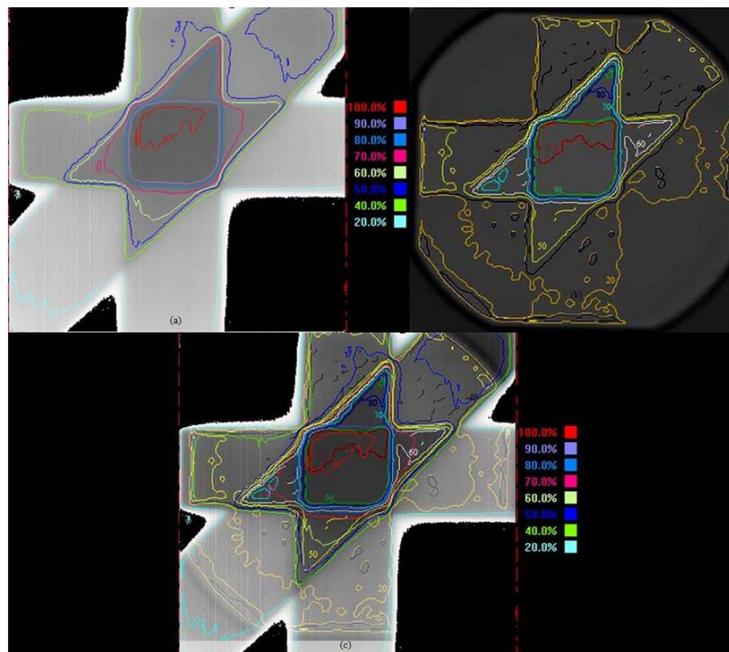

Fig. 6. The dose distribution by (a) film dosimetry measurement, (b) gel dosimetry measurement, and (c) comparison between film dosimetry and gel dosimetry dose distribution.

IV. CONCLUSION

This work was undertaken to evaluate the CT based MAGAT gel dosimetry for measuring 3D dose distributions in radiation treatment. The dose distribution measured from gel dosimetry was compared with TPS and film dosimetry. The qualitative and quantitative comparison of dose distribution for the prostate cancer treatment measured using gel dosimetry showed very good agreements with that calculated using TPS with maximum disagreement of 5 mm. However, the difference was found the highest at 20% isodose line due to the image filtering effect and low dose resolution. The spatial dose distribution measured using gel dosimetry was in good agreement with that measured using film dosimetry. Also, the dose distribution measured using gel dosimetry agreed well with that measured using film dosimetry, with maximum variation of 8 mm. The difference in the dose distribution between gel dosimetry and film

dosimetry measurements could be due to the non-uniformity of polymer components distribution in the active layer within the sheet of the film dosimetry. In conclusion, the CT based MAGAT gel dosimeter showed to be a great promising method for verifying three-dimensional dose distribution.

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