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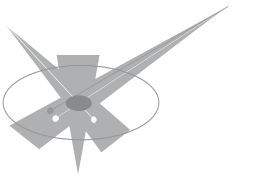

Preliminary Report

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Preliminary study on CT imaging of polymer gel radiation dosimetry

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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Summary

Background New radiotherapy techniques such as stereotactic radiotherapy (SRT) stereotactic radiosurgery (SRS), three dimensional conformal radiotherapy (3DCRT) and intensity modulated radiation therapy (IMRT) aim to deliver a high dose to the tumour while sparing the surrounding normal healthy tissues. As a result of these complicated treatment techniques there is a need for a 3-dimensional (3D) dose verification system. However, currently available dosimeters such as ion chambers, diodes, thermoluminescent dosimeters and films are limited to point (or) planar measurement. Multiple measurements are required to obtain the 3-dimensional dose distribution using the above dosimeters. Hence volumetric measurements are not feasible without multiple detectors (or) multiple measurements. Gel dosimetry attempts to meet the requirements of 3D radiation dose distribution. Gel dosimetry is tissue equivalent [1] and it acts as a phantom as well as dosimeter so there is no need for dose perturbation correction.

Aim Radiation-induced polymerization in polymer gel dosimeters gives rise to a change in CT number which can be measured with X-ray computed tomography (CT). The aim of this study is to assess the feasibility of using the X-ray CT scanner for the evaluation of dose distribution in polymer gel dosimetry.

Materials/Methods Polymer gel called PAGAT (**P**oly**a**crylamide **G**elatin **a**nd **T**etrakis hydroxymethyl phosphonium) consisting of 3.5% (w/w) BIS, 3.5% (w/w) acrylamide, 5% (w/w) gelatin, 10mM Tetrakis hydroxymethyl phosphonium (THP) and 88% (w/w) water was manufactured in normal atmospheric conditions. The gel was irradiated using a Siemens Primus linear accelerator. The radiation-induced change in CT number was evaluated using a Siemens Somatom Emotion CT scanner. The percentage depth doses and profiles were deduced. The same study was carried out using radiation field analyzer RFA-200 with RK-ion chamber and film and compared with polymer gel measurements.

Results Polymer gel dosimetry measurement was in agreement with ion chamber and film measurements except for a slight deviation in the build-up region. Discrepancies found were due to analysis of image without image averaging and background subtraction.

Conclusions This preliminary study was conducted to evaluate the feasibility of using X-ray CT-based polymer gel dosimetry for clinical use. The results of this study encourage further use of X-ray CT in conjunction with polymer gel for 3D radiation dose measurements.

Key words **polymer gel • 3D radiation dosimetry • gel dosimetry • X-ray CT • MRI**

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Background

New radiotherapy techniques such as stereotactic radiotherapy (SRT) stereotactic radiosurgery (SRS), three dimensional conformal radiotherapy (3DCRT) and intensity modulated radiation therapy (IMRT) aim to deliver a high dose to the tumour while sparing the surrounding normal healthy tissues. As a result of these complicated treatment techniques there is a need for a 3-dimensional (3D) dose verification system. However, currently available dosimeters such as ion chambers, diodes, thermoluminescent dosimeters and films are limited to point (or) planar measurement. Multiple measurements are required to obtain the 3-dimensional dose distribution using the above dosimeters. Hence volumetric measurements are not feasible without multiple detectors (or) multiple measurements. Gel dosimetry attempts to meet the requirements of 3D radiation dose distribution. Gel dosimetry is tissue equivalent [1] and it acts as a phantom as well as dosimeter so there is no need for dose perturbation correction.

Currently two types of gel dosimeters are used for 3D dose distribution measurement: the Fricke gel dosimeter and the polymer gel dosimeter. When irradiating the Fricke gel dosimeter, the ferrous ions (Fe^{2+}) are oxidized to ferric ions (Fe^{3+}) by radiolysis. So there is a change in spin-lattice relaxation time [2,3] (or) optical density [1,4]. These changes can be correlated with radiation dose. In polymer gel monomer is distributed in a water-based matrix. When irradiating, radiation-induced polymerization takes place in the gel. As a result of this polymerization, the physical properties of the gel are altered. This property can be studied using magnetic resonance imaging (MRI) [5,6], an optical CT scanner [1,7], Raman spectroscopy [8,9] and computed X-ray tomography (CT) [10,11].

In the MRI method, 90% of gel contains water and it is found in three different states in the gel: water protons attached with monomer, polymer and bulk water. Conversion of monomer to polymer changes the mobility of surrounding water protons and their relaxivity. Relaxation time for monomer and bulk water is large since these molecules are small in size, whereas relaxation time for polymer is low. Hence, change in relaxation time is proportional to radiation dose delivered to the patient.

In optical CT a light source is utilized. Study is based on absorption and scattering properties of monomer and polymer molecules. Absorbed dose is determined by measuring light transmission along a given path. Topographic data can be obtained through data obtained in multiples angles (translation and rotation).

Individual peaks in a Raman spectrum represent particular molecules in the sample. The shift in frequency of incident and scattered light gives the molecular information of the given sample [8,9]. Raman spectroscopy is intended to collect data for polymer gel using the frequency shift method.

In the CT method the increase in attenuation in polymerized regions in gel is related to an increase in density (CT Hounsfield number). Change of electron density (CT number) in gel is proportional to radiation dose [10,11]. Hence dose delivered to the actual patient can be obtained by gel dosimetry for wide ranges of radiation.

The advantages of the polymer gel dosimeter are 1) feasibility of volumetric measurements possible, 2) this dosimeter acts as phantom as well as detector, 3) it is independent of incident radiation direction, and 4) it integrates the dose from multiple beams.

Polymer gels like BANG-1 [5], BANG-2 [1], BANG-3 [12] and VIPAR [13] are more sensitive

to oxygen, because oxygen acts as an inhibitor of radiation-induced polymerization [6,14]. To remove oxygen from the gel, nitrogen gas is passed through the gel during preparation and the preparation is done in a nitrogen glove box facility. Due to this the process of preparing the polymer is laborious and it is very difficult to remove the oxygen completely. After several attempts, a new polymer gel dosimeter formulation was introduced by Fong et al. (2001) [15], which is sensitive to radiation in the presence of oxygen. This normoxic polymer called MAGIC gel consists of methacrylic acid (9% w/w), ascorbic acid (2mM), hydroquinone (18mM), copper II sulphate (0.08mM), gelatin (8% w/w) and water. In this formulation, the ascorbic acid acts as an anti-oxidant and copper acts as a catalyst in the oxygen scavenging by oxidation of ascorbic acid [14].

Aim

In this study we present our preliminary analysis of feasibility of CT imaging of PAGAT (new normoxic gel) polymer gel, response of PAGAT to radiation, comparison of dose distribution with ion chamber and film measurements.

Materials and Methods

Gel synthesis

Normoxic PAGAT gel was prepared on the bench top under normal atmospheric conditions. To prepare the PAGAT gel, 88% (w/w) triple distilled water and a magnetic stirrer were first placed in a glass flask and 5% (w/w) of gelatin was added. After the gelatin had swollen from soaking, the flask was heated to approximately 50°C to ensure that the gelatin was completely dissolved. At this point, 3.5% (w/w) BIS and 3.5% (w/w) acrylamide were added to the gelatin solution. Once the monomers were dissolved completely, 10 mM of anti-oxidant THP was added and the solution was stirred until the mixture was uniformly dissolved.

After manufacture, the polymer gel was poured into 10 small plastic cylindrical vials (diameter 2.5cm and length 4cm) for dose response study and also poured into two large plastic cylinders (diameter 10cm, length 16cm & 8cm and wall thickness 1mm) for percentage depth dose (PDD) and beam profile study. All vials and cylinders were kept in a refrigerator until they had gelled.

Gel irradiation

As soon as gellation was completed all irradiations were performed on a Siemens Primus linear accelerator. For dose response study, the calibration vials were placed in a purpose-built water equivalent wax phantom, and were irradiated with field size of 4×4cm, 6MV photon parallel opposed fields to doses of 1, 2, 3…10Gy and one vial was left unirradiated. The large cylinders were exposed to photon of 6MV and 12MeV electron of field size 5×5cm at SSD=100cm by keeping the gel cylinder inside the water phantom to provide sufficient scattering.

CT imaging

One day after irradiation the gels were imaged using a Siemens Somatom Emotion CT scanner with the following optimum scanning parameters: tube voltage 130kV, tube current 220mA, exposure time 1 second and field of view (FOV) 20×20cm. Axial sections of calibration vials were imaged at the centre of the irradiated regions. The large cylinders were imaged parallel (sagittal) and perpendicular (axial) to the flat surface of the cylinders.

Ion chamber and film dosimetry

Percentage depth dose and beam profile were also measured for both 6MV photon and 12MeV electron using radiation field analyzer RFA-200 (Scanditronix) and RK chamber (Scanditronix). Kodak film was placed in between the slab phantom parallel to the central axis of the beam and was exposed to 6MV photon and 12MeV electron. The film was scanned and the grey values were studied using Image J software.

Results and Discussion

Figure 1 shows the change in CT number as a function of absorbed dose. The response shows a linear region up to the dose of 750cGy and beyond 750cGy there is a decrease in dose response. Beyond 1000cGy the responses were not studied in this work.

Figures 2 and 3 show the comparison of PDD curve of 6MV photon and 12MeV electron obtained from ion chamber, polymer gel and film along the central axis of the beam. The polymer gel data varied ±2.5% to ±8.08% with the ion chamber measurements and ±2.5% to ±5.18% with the film measurements in the electronic

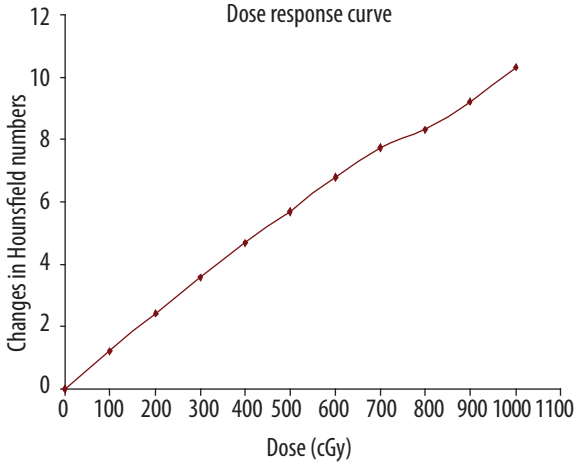

Figure 1. Dose response curve for 6MV photon beam.

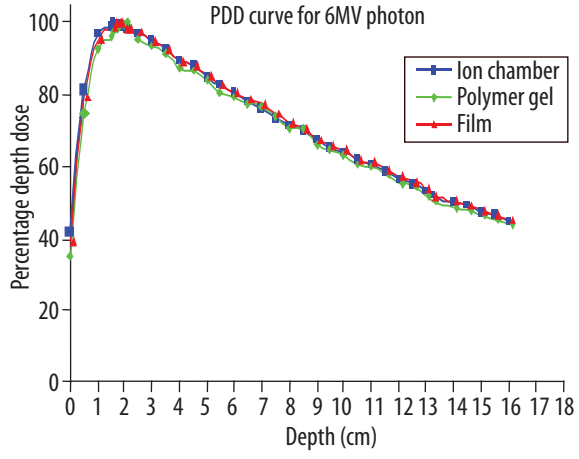

Figure 2. PDD curves for 6MV photon beam.

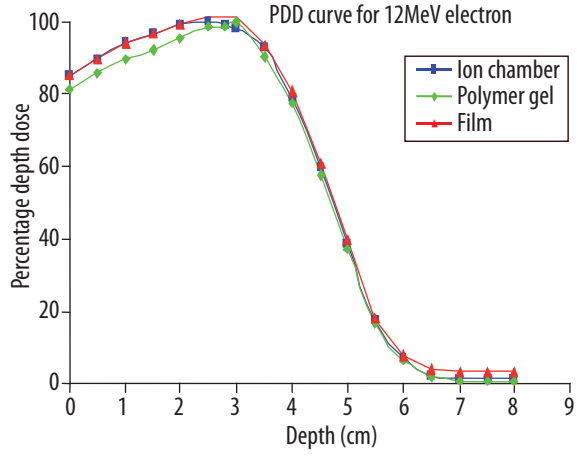

Figure 3. PDD curves for 12MeV electron beam.

equilibrium region of depth 1.6cm from the surface. This is due to the diffusion of oxygen into

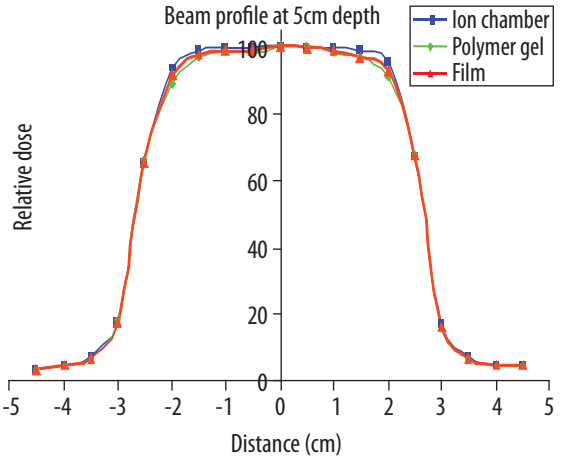

Figure 4. Cross beam profile for 6MV photon at 5cm depth.

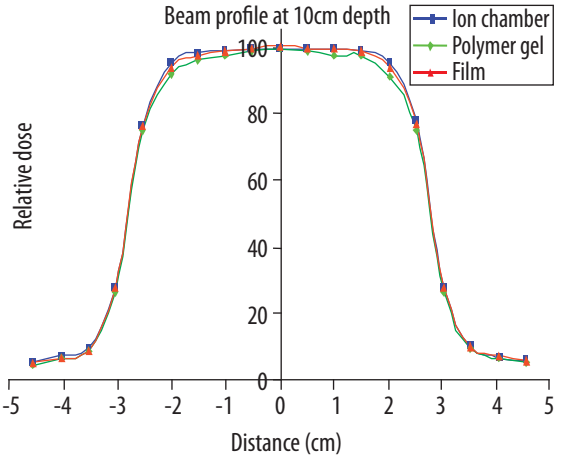

Figure 5. Cross beam profile for 6MV photon at 10cm depth.

the gel during the gellation process. Beyond the depth of maximum dose (dmax) the data show a maximum deviation of ±3%. From Figure 3 the variation of gel measurements is ±1.2% to ±4.5% from the ion chamber and film measurements. After dmax the variation gradually increases to a maximum of 9%. The cross beam profiles for 6MV photon at 5cm and 10cm depth are shown in Figures 4 and 5 respectively for gel dosimetry, film and ion chambers measurements, which show maximum deviation of ±5%.

Even though various measurement techniques are in very good agreement, there are some discrepancies. All data presented in this paper were obtained without background subtraction and image averaging [10,11,16,17]. By image averaging and background subtraction, the signal-to-noise ratio (SNR) can be increased. Also there are some artefacts such as beam hardening artifacts due to

the different/varying atomic number of wall material [10,11,16,17].

Conclusion

This preliminary study was conducted to evaluate the feasibility of using X-ray CT-based polymer gel dosimetry for clinical use. It does not have a complete set of characterization measurements. Future study should include the study of reproducibility, spatial resolution, temperature dependence and energy dependence. The quality of these images could be improved by image averaging, background subtractions and using an optimum scanning protocol. The results of this study encourage the use of X-ray CT in conjunction with polymer gel for 3D radiation dose measurements.

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