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Evaluation of MRI-based MAGIC polymer gel dosimeter in small photon fields

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► ***Technical note***

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ABSTRACT

Background: Accurate small radiation field dosimetry is essential in modern radiotherapy techniques such as stereotactic radiosurgery (SRS) and intensity modulated radiotherapy (IMRT). Precise measurement of dosimetric parameters such as beam profile, percentage depth doses and output factor of these beams are complicated due to the electron disequilibrium and the steep dose gradients. In the present work the MAGIC polymer gel was used for dosimetry of small circular photon beams. The results of MAGIC were compared with EBT2 measurements and Monte Carlo (MC) calculations. ***Materials and Methods:*** Experimental measurements were made by mentioned dosimeters in four small field sizes 5, 10, 20 and 30 mm. The BEAMnrc code based on EGSnrc was used for simulation to calculate dosimetric parameters at these small fields. The phantoms were irradiated in a 6 MV photon beam Varian 2100C linear accelerator at SSD=100 cm. gel readout performed by 3 Tesla MRI scanner. ***Results:*** The results showed that the Percent depth dose (PDD) values measured and calculated by EBT2 film and MC had maximum local differences 4% and 5% with PDD values measured by MAGIC for field size of 5mm respectively. These differences decreased for larger field sizes. The measurements of output factor and penumbra (80%-20%) and (90%-10%) showed good agreement between the measurements and MC calculation. ***Conclusion:*** This study showed that the MAGIC polymer gel based on high resolution MRI images is useful detector for small field dosimetry but its agreement with MC is less than agreement of EBT2 film with MC.

Keywords: *Small field, Monte Carlo, penumbra, MAGIC polymer gel.*

INTRODUCTION

Accurate small radiation field dosimetry is essential in modern radiotherapy techniques such as stereotactic radiosurgery (SRS), intensity modulated radiotherapy (IMRT) and VMAT [1, 2]. To improve accuracy of treatment planning systems (TPS), determining of exact dosimetry is essential [3]. The dosimetric parameters required for commissioning and quality assurance of treatment planning systems include output factor (OF), off-axis ratio (OAR), and percentage depth dose (PDD) [4, 5]. According to existence of lateral electronic disequilibrium and the sharp dose gradients in small field sizes, measurement of OFs, OARs and PDDs are difficult [4].

Therefore, accuracy and verity of dosimetry require using a good dosimeter. The required dosimeter for small field sizes should be energy and dose rate independent, reproducible and tissue equivalent. Also it should have stable dose response, adequate resolution and minimum radiation field perturbation [6-8]. Whereas, no single detector support all of these requirements for small field sizes, using several types of detectors has some benefit for stereotactic beam data acquisition [4].

Polymer gel dosimeters can measure the dose distribution in three dimensions (3D) [9]. These dosimeters don't perturb radiation field because the material phantom and these detector are the same [10]. Because of these benefits several studies in radiation small fields have been accomplished by using several types of polymer gel dosimeter [3, 7, 11-14] but the MRI-based on MAGIC polymer gel dosimeter has not been evaluated for small fields. It is well recognized that effect of a gel is different from others; even a change in component of a unique gel causes a different response to absorbed dose. We evaluated dosimetric parameters in small photon fields using Normoxic polymer gel dosimeter MAGIC 9%.

In this study MAGIC polymer gel dosimeter was used to acquire dosimetric data for small field sizes. These data were compared with Monte Carlo calculations and Gafchromic EBT2 film measurements for the same field sizes.

MATERIALS AND METHODS

Phantoms

Four Phantoms with dimension of 3×3×16, 3×3×16, 4×4×16 and 6×6×16 cm3 were made by Plexiglas sheets. They were used for field sizes of 5, 10, 20 and 30 mm respectively. The thickness of the phantoms walls was 2mm. Nine Pyrex glass vial with 15mm diameter and 100mm height were used for gel calibration. All vials are sealed by plastic screw cap.

Gel preparation

The polymer gel dosimeter used in this study was based on the MAGIC gel as proposed by Fong [15] and prepared under atmospheric (normoxic) conditions. This polymer gel is composed of gelatin (swine skin, 300 Bloom, Sigma Aldrich), methacrylic acid (purity grade approximately 99%, Merk), ascorbic acid (minimum 99%, Sigma Aldrich), copper sulfate (pentahydrate, 98%, Sigma Aldrich), hydroquinone (Sigma Aldrich) and deionized water. At first room tempered water and magnetic stir-bar were placed in a glass flask. Gelatin was added to water and left to soak for 15 minutes, and then mixture was heated to 50 ° C. The blend was kept at this temperature to ensure that the gelatin is completely dissolved. At this point the heat was turned off and hydroquinone was added to the mixture. After the mixture temperature fell to 37°C, the ascorbic acid, copper sulfate and methacrylic acid were added to solution. After filling calibration vials and phantoms with gel, they were sealed off airtight and kept in a refrigerator at 4 °C for one day.

Gel irradiation

Twenty-four hours after gel preparation, the gel containers were separately irradiated using a Varian 2100C linear accelerator in a 6 MV photon beam at a dose rate of 400 MU/min. To characterize the dose response of the MAGIC polymer gel dosimeter, calibration vials phantoms were located into big water phantom at source to surface distance (SSD) of 100 cm. For calibration, axis of vials was Perpendicular with the beam axis. The center of vials were placed at depth of 5cm.The different known doses 0 (control), 1, 2, 3, 4, 5, 6, 8 and 10 Gy were delivered at depth of 5cm by reference field sizes of 10×10 cm^2. Axis of gel phantoms were parallel with beam and their upper surface were tangent with water surface. Dose of 8Gy was delivered at depth of 1.5cm by small circular field's sizes of 5, 10, 20 and 30cm diameter.

Gel scanning

Three days after the irradiation, Gel samples were scanned using a 3Tesla (3T) magnetic resonance imaging (MRI) scanner (Siemens). Gels were placed in the clinical MR-scanner room for 12 hours before scanning in order to stabilize and homogenize temperature.

All gels were scanned in the head coil. We used a multiple spin-echo sequence with 32

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echoes [an initial echo time of 14ms, with further 14ms increments] for evaluation of irradiated polymer gel dosimeters. other imaging parameters were selected as follows: the repetition time (TR)=3000ms, field of view (FOV)=180mm×180mm, matrix size 384×384 pixels, slice thickness 2mm and number of acquisitions (NEX)=4. The calibration vials and gel phantoms were scanned together to elude calibration errors due to temperature deviations. Spin lattice relaxation rate (R2) values were calculated in MATLAB (The Math Works, Inc., Natick, Massachusetts, USA), a program was written to compute R2 values and create R2 maps.

EBT2 film dosimetry

Film measurements were accomplished by Gafchromic EBT2 films (ISP) to compare with gel data at the same condition. Films were located within solid water slabs that were used as scattering medium. Calibration data were measured for doses 0(control) to 300 cGy in 25 cGy increments at the SSD=100 cm, 10×10 cm^2 field size and depth 5cm. For measurements of Percent depth dose (PDD), films were placed in parallel with the beam axis, also output factors and beam profiles were measured in perpendicular with the beam at depth of 5cm [(16)]. All films were irradiated with nominal dose of 200cGy at depth of 1.5cm, SSD=100 cm and 24 hours after irradiation scanned with a MICROTEK 9800 XL (Microtek International Inc, USA) scanner. For analyzing the films, images obtained of scanner were read with Image J software and data was acquired in red channel.

Monte Carlo simulation

In this study, BEAMnrc and DOSXYZnrc user codes of EGSnrc were used for evaluation of small field photon dosimetry and comparing with gel and film measurements. First, we simulate geometry of certain linear accelerator head with using BEAMnrc code. The simulated linac was validated for field sizes 10×10 to 3×3cm by comparison with ion chamber measurements. The details of Monte Carlo (MC) validation incident electron beam have been explained in our previous work completely [(17)].

Voxel size considered for PDDs and OARs in DOSXYZnrc code were 0.2×0.2×0.2 and 0.05×0.05×0.2cm^3 respectively. The electron cut-off energies (ECUT) =0.512MeV and photon cut-off energies (PCUT) =0.01 MeV selected for codes. Global electron cutoff (ESAVE) =2 MeV was used for all modules of BEAMnrc except target. Directional bremsstrahlung splitting (DBS) was used and bremsstrahlung splitting number was determined 1000. Statistical uncertainty under 0.5% was acquired with addition number of initial particles in the simulation.

RESULTS

Gel calibration

Calibration data of spin-spin relaxation rate (R2) versus absorbed dose obtained from MAGIC polymer gel dosimeter has been shown in figure 1. Regression analysis illustrated this curve have the slopes 0.835 (±0.03), the offsets 5.83 (±0.05) and the coefficient of the determinant R2 were 0.998 for 0 to 10Gy which represented an excellent linear fit for the dose range used in this study. This is permissible due to the maximum dose that delivers to the phantoms for the dosimetric evaluation of photon small fields which did not exceed 8Gy. The standard deviation of the R2 values was smaller than 3%.

Percentage depth doses

Figure 2 shows PDD profiles for the 5, 10, 20, 30 mm circular field using EBT-2 film, MAGIC and Monte Carlo calculations. To obtain PDDs, all data were normalized to maximum dose. The dose differences between MAGIC and EBT2 film measurements were less than 3.1, 2.9, 2.4 and 2.1% for PDD values behind the buildup region for 5, 10, 20 and 30 mm field sizes respectively. These differences between MAGIC measurements and Monte Carlo calculation were less than 4.5, 3.3, 2.4 and 2.4%.

Off axis ratio

In figure 3 off-axis dose profiles measured by MAGIC and EBT2 and calculated by MC at 5cm

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depth and SSD=100 cm for 5, 10, 20 and 30 mm diameter field sizes are shown. The voxel resolution was 0.5 mm for MC calculations. All measurements were normalized to the central axis dose for each separate beam. The dose differences or distance to agreement (DTA) between MAGIC measurements with film measurements and MC calculation were less than 2% or 1 mm for field sizes of 5 and 10 mm .These differences were less than 1% and 1 mm for field sizes of 20 and 30mm.

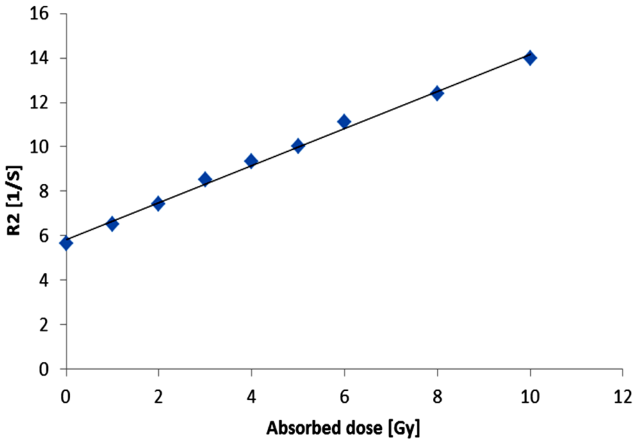

Figure 1. Dose response curve of MAGIC polymer gel.

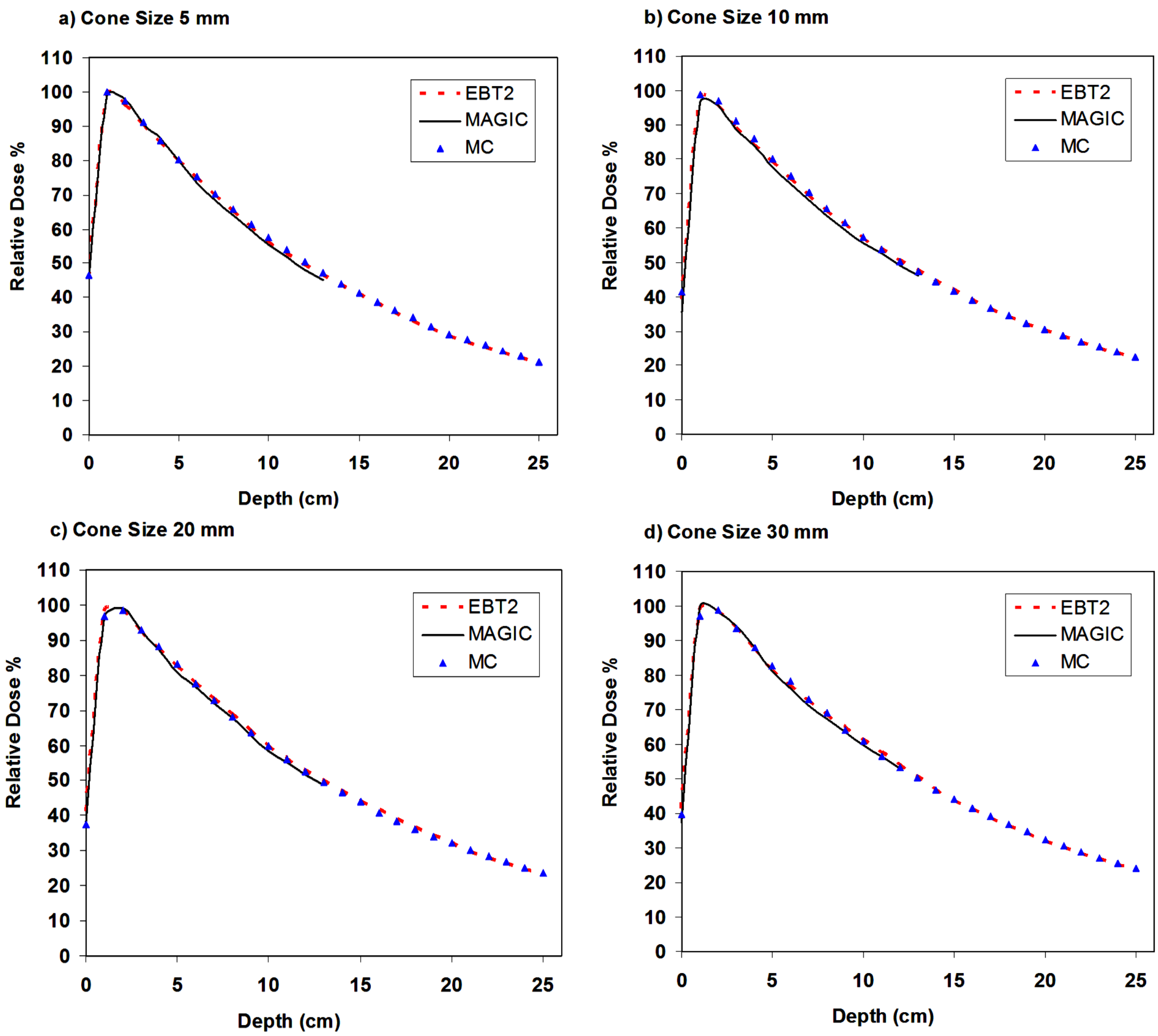

Figure 2. Measured and calculated Percent Depth Dose curves for circular field sizes. **a)** Cone Size 5 mm, **b)** Cone Size 10 mm, **c)** Cone Size 20mm and **d)** Cone Size 30mm.

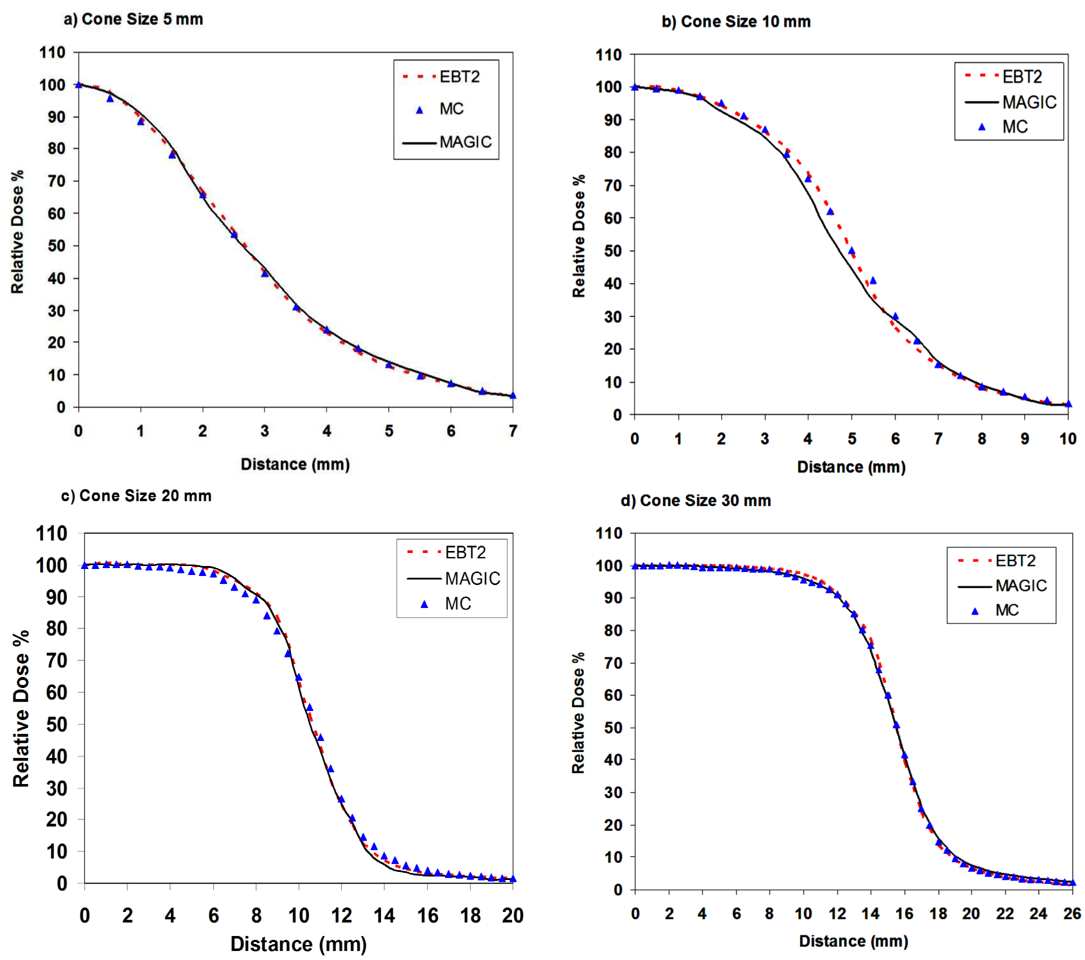

Figure 3. Measured and calculated relative beam profiles at 5cm depth and SSD=100 cm for small circular field sizes. a) Cone Size 5 mm, b) Cone Size 10 mm, c) Cone Size 20mm and d) Cone Size 30mm.

Output factor

Monte Carlo calculated and MAGIC and EBT2 measured output factors for 5, 10, 20, 30 mm circular field sizes are shown in table 1. All measurements and calculations performed at 5 cm depth and SSD=100 cm to avoid electron contamination.

Table 1. Output factors measured using MAGIC, EBT2 and calculated by Monte Carlo for 5, 10, 20, 30 mm circular cone sizes and 10 ×10 cm^2 square field at 5cm depth.

Cone size (mm)	Output factor		
	MAGIC	EBT2	MC
5	0.459	0.463	0.461
10	0.670	0.676	0.673
20	0.812	0.818	0.818
30	0.887	0.889	0.888
10×10 cm^2 Square field	1.0	1.0	1.0

DISCUSSION

In general a good agreement can be observed between the MAGIC and EBT2 film and Monte Carlo calculation. The difference between measurements and calculations is reduced by increasing field sizes due to decreasing of lateral electronic disequilibrium. The same result has been reported by Oliveira and Calcina for The Fricke Xylenol Gel dosimeter (FXG) compared with other dosimeters in small photon fields [5, 18].

High accuracy in penumbra measurement is important because from locational accuracy of ±1 to deliver dose in radiosurgery is essential [19]. Results obtained for off axis dose profiles show good agreement between measurements and Monte Carlo calculations in considered

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small fields. The penumbra values measured and calculated by MAGIC and Monte Carlo are slightly more than the actual value caused voxel dimension size used in the MRI and simulation that were relatively large. The EBT2 film results approximately show actual penumbra due to high spatial resolution and low energy dependence (16, 20). The spatial resolution in this study was 0.1678, 0.478 and 0.5mm for EBT2, MAGIC and Monte Carlo simulation, respectively.

Although other detectors such as Pinpoint chamber or Diode detector show underestimate or overestimate (4, 14), our results illustrate good agreement between MAGIC and EBT2 measurements as well as Monte Carlo calculation for small field output factors. This adaptation between MAGIC and EBT2 measurements and Monte Carlo calculation was within 1% for circular field sizes have been studied here.

CONCLUSION

MAGIC polymer gel is suitable for radiation dosimetry because this polymer gel acts as phantom and measures dose distribution in three dimensions with a high spatial resolution. Spatial resolution is an important parameter in dose distributions that have sharp gradient such as small field sizes. Spatial resolution of polymer gel depends on voxel sizes used in MRI. Increasing the power of magnetic fields and imaging time make smaller voxel size and better spatial resolution. The results of this study were shown MAGIC gel and EBT2 film is suitable detector for small field dosimetry but the agreement between MAGIC gel and MC is less than agreement of EBT2 film with MC. Also our results illustrated that increasing radiation field sizes can reduce differences between detectors.

Conflicts of interest: *none to declare.*

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