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The use of normoxic polymer gel for measuring dose distributions of 1, 4 and 30 mm cones

C.C. Lee [a,b], J.F. Wu [a], K.P. Chang [c], C.H. Chu [d], S.P. Wey [a], H.L. Liu [a], C.J. Tung [a,d], S.W. Wu [d], T.C. Chao [a,e,*]

[a] Department of Medical Imaging and Radiological Sciences, College of Medicine, Chang Gung University, Kwei-Shan 333, Taiwan
[b] Department of Radiation Oncology, Chang Gung Memorial Hospital, Kwei-Shan 333, Taiwan
[c] Department of Medical Imaging and Radiological Sciences, Tzu Chi College of Technology, Hualien 970, Taiwan
[d] Department of Biomedical Engineering and Environmental Sciences, National Tsing Hua University, Hsinchu 300, Taiwan
[e] Institute for Radiological Research, Chang Gung University/Chang Gung Memorial Hospital, Kwei-Shan, Tao-Yuan 333, Taiwan

HIGHLIGHTS

- Normoxic polymer gels for small field measurements.
- Cone factors, PDDs, and profiles of 1-, 4-, 30-mm cones.
- DTAs in 30-mm cone were at most 1.2 mm.
- DTAs in 1- and 4-mm cones were at most 0.3 mm.
- Temperature affects gel response.

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ABSTRACT

This study demonstrates the use of normoxic polymer gel for measuring dose distributions of small fields that lack lateral electronic equilibrium. Two different types of normoxic polymer gel, MAGAT and PAGAT, are studied in a larger field (10 cm × 10 cm) and 1, 4 and 30 mm cones to obtain cone factors, dose profiles and percentage depth doses. These results were then compared to KODAK XV film measurements and BEAMnrc Monte Carlo simulations. The results show that the sensitivity of PAGAT gel is $0.090 \pm 0.074\ s^{-1}\ Gy^{-1}$, which may not be suitable for small-field dosimetry with a 0.3 mm resolution scanned using a 3 T MR imager in a dose range lower than 2.5 Gy. There are good agreements between cone factors estimated using KODAK XV film and MAGAT gel. In a dose profile comparison, good dose agreement among MAGAT gel, XV film and MC simulation can be seen in the central area for a 30 mm cone. In penumbra, the distance to agreement is at most 1.2 mm (4 pixel), and less than 0.3 mm (1 pixel) for 4 and 1 mm cones. In a percentage depth dose comparison, there were good agreements between MAGAT and MC up to a depth of 8 cm. Possible factors for gel uncertainty such as MRI magnetic field inhomogeneity and temperature were also investigated.

1. Introduction

Small-field dosimetry is critical in radiosurgery. Many researchers have reported the dose verification results for cones larger than 4 mm. Heydarian et al. (1996) carried out a comparison of dosimetry techniques, such as ion chamber, diamond detector, diode detector and EGS4 Monte Carlo (MC) simulation, in Stereotactic Radiosurgery (SRS) for cone size down to 5 mm. Calcina et al. (2007) used Fricke xylenol gel, TLD, film and ion chamber to determine dosimetric parameters for small fields. Khelashvili et al. (2012) used the Scanditronix 3D dosimetry system and MC simulation to study dosimetric characteristics of cones down to 5 mm. Cones smaller than 4 mm, although not commonly used in SRS, have potential in benign tumour radiosurgery and small-animal irradiation (Chao et al., 2009).

In recognition of the importance of small-field dosimetry, the American Association of Physicists in Medicine (AAPM) Task Group 155 (TG155) drafted a report on "Small Fields and Non-Equilibrium Condition Photon Beam Dosimetry" to provide guidelines for

* Corresponding author at: Department of Medical Imaging and Radiological Sciences, College of Medicine, Chang Gung University, Kwei-Shan 333, Taiwan.
E-mail address: chaot@mail.cgu.edu.tw (T.C. Chao).

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measuring and dosimetry for small fields (Das et al., 2013). Within a small field, there is a lack of charged particle equilibrium and the sizes of dose detectors or scoring volumes are commonly comparable to the field, leading to a partial volume effect. In addition, measurements or simulations in small-field dosimetry usually come with large signal-to-noise ratios. Accurately and precisely estimating doses in a small field should be carried out with more than one detector system.

Polymer gel has several advantages for measuring small-field dose distribution including its high spatial resolution, good tissue equivalence, 3D dose distribution, energy independence, and its ability to be prepared in different shapes. Gore et al. (1984) first developed the Fricke gel, which has most of the advantages of gel except for the poor spatial resolution owing to the diffusion of the ferric and ferrous ions. Maryanski et al. (1994) developed the first polymer gel, called BANG-1 gel, which consisted of gelatine and dissolved monomers. These monomers are polymerised by radiation, and the dosimetric position is more stable as the polymer structures remain fixed. Fong et al. (2001) developed a normoxic gel, MAGIC, which allows gel preparation at a normal oxygen level. Venning et al. (2005) investigated the PAGAT polymer gel dosimeter using magnetic resonance imaging and found that the R2-dose sensitivity is about $0.183 \pm 0.005\ s^{-1}\ Gy^{-1}$, and can be used in clinical radiotherapy. Watanabe et al. (2005) used BANG gel and Natanasabapathi et al. (2012) used MAGAT gel and EBT2 films to evaluate the dose delivery accuracy of Gamma Knife. This study demonstrated the use of PAGAT and MAGAT gels for measuring dose distributions of 1, 4, 30 mm cones. These results were then benchmarked using XV films and BEAMnrc simulations.

2. Materials and methods

Three major approaches including gel dosimetry, Monte Carlo simulation and film measurements were used. These measurements/simulations were taken in a 10 cm × 10 cm square field for calibration, and 1, 4 and 30 mm diameter circular fields to study small-field dosimetry. Because there is no 1 mm diameter conical collimator commercially available, we have customized a 1 mm diameter conical collimator made of tungsten carbide as shown in Fig. 1.

The gel dosimetry procedures included gel preparation, gel irradiation, (MRI) image acquisition and R2 signal processing. In this study, MAGAT was composed of 86% (by weight) water, 8% gelatine, 6% meth-acrylic acid (MAA) and 2 mM tetrakis (hydroxymethyl) phosphonium chloride (THPC); PAGAT was 89% water, 5% gelatine, 3% acrylamide, 3% *N*,*N*′ methylene bis-acrylamide and 5 mM THPC.

Both MAGAT and PAGAT gels were irradiated to specific doses for calibration (R2-dose response) using a Varian 2100 EX LINAC in 6MVX mode with 10 cm × 10 cm field and with a 95 cm SSD (100 cm SAD). The dose delivered to MAGAT was 0, 0.5, 1, 1.5, 2, 2.5 Gy, with 0, 0.5, 1, 2, 4 Gy to PAGAT.

The MRI parameters used in gel scanning were: (1) Siemens Magnetom Trio A Tim System (3T), (2) head coil, (3) multiple spin-echo sequence, (4) TR: 8555 ms, (5) TE: 20 ms with 16 echoes, (6) matrix size: 512 × 512, (7) 26 slices, (8) one excitation, (9) voxel size: 0.3 mm × 0.3 mm × 2 mm, and (10) scan time:73 min.

The resultant images were processed by our home-made R2code under Visual C++ 6.0 platform. This R2code first smoothed all pixels by using a 3D Gaussian filter ($\sigma = 1$ pixel) to suppress intrinsic MRI noises, and then generated T2 images by a least square fit on at most 16 non-zero pixels of a sequence of spin-echo images. Finally, R2 images were the reciprocals of T2 images.

For Monte Carlo simulation, a Varian Clinac 2100EX LINAC equipped with 1, 4 or 30 mm cones was modelled inside BEAMnrc06. This virtual accelerator was constructed with parameters such as material, size and geometry defining a primary collimator, an exit window, a flattening filter, an ion chamber, a mirror, secondary collimators, a light field reticle and a conic collimator according to the Monte Carlo Project—Confidential Information of Varian Oncology System. Moreover, several parameters of incident electrons before the exit window, such as incident electron energy, incident radius spread and cut-off energies, have to be optimised to obtain agreeable simulation results with measurements.

KODAK XV films were used to measure cone factors and lateral dose profiles. The exposed films were scanned by a Radlink LaserPro 16 scanner and the results were analysed by PTW MEPHYSTOmc^2.

3. Results and discussion

3.1. Gel sensitivity

The calibration curves for MAGAT and PAGAT are plotted in Fig. 2. As observed, the sensitivity of MAGAT ($3.54 \pm 0.16\ s^{-1}\ Gy^{-1}$) is much higher than that of PAGAT gel ($0.090 \pm 0.074\ s^{-1}\ Gy^{-1}$). In addition, the contrast-to-noise ratios (CNRs) for MAGAT gel were 10.5 (0.5 Gy), 22.4 (1 Gy), 18.9 (2 Gy) and 26.0 (2.5 Gy), which were much higher than the CNRs of PAGAT gel. The CNRs of PAGAT were 0.5 (0.5 Gy), 0.8 (1 Gy), 1.3 (2 Gy) and 2.5 (4 Gy). These indicate that PAGAT gel might not be suitable for

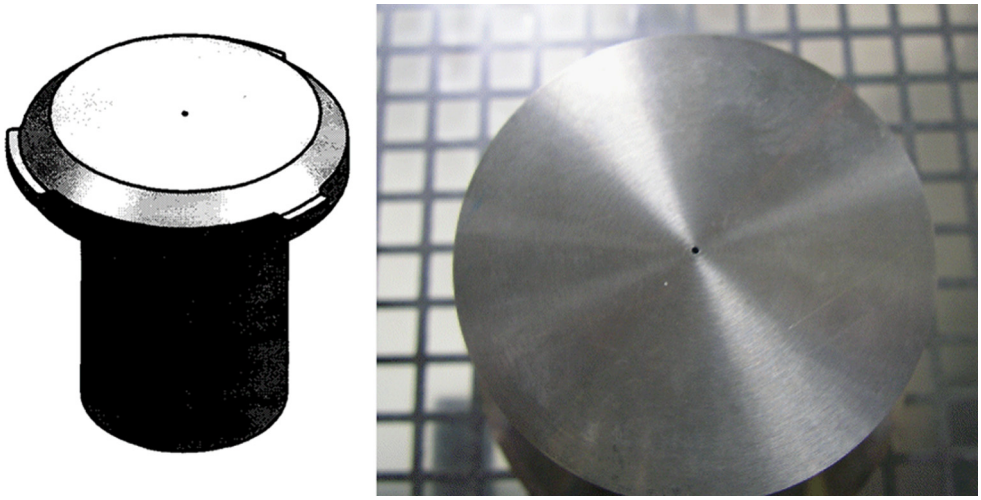

Fig. 1. A home-made 1 mm diameter conical collimator.