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Dosimetry for ^{131}Cs and ^{125}I seeds in solid water phantom using radiochromic EBT film

Sou-Tung Chiu-Tsao [a,*], John J. Napoli [b], Stephen D. Davis [c], Joseph Hanley [d], Mark J. Rivard [e]

[a] Quality MediPhys LLC, Denville, NJ 07834, USA
[b] John Theurer Cancer Center at Hackensack University Medical Center, Hackensack, NJ 07601, USA
[c] Medical Physics, McGill University Health Centre, Montreal, QC, Canada H3G 1A4
[d] Princeton Radiation Oncology Center, Monroe, NJ 08831, USA
[e] Department of Radiation Oncology, Tufts University School of Medicine, Boston, MA 02111, USA

HIGHLIGHTS

- Measure the 2D dose distributions for ^{131}Cs and ^{125}I seeds using radiochromic film.
- For distances (0.06–5 cm) with submillimeter resolution in a Solid Water phantom.
- Generate Solid Water to liquid water correction factors from Monte Carlo simulations.
- Determine the TG-43 dosimetry parameters in water by applying the correction factors.

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ABSTRACT

Purpose: To measure the 2D dose distributions with submillimeter resolution for ^{131}Cs (model CS-1 Rev2) and ^{125}I (model 6711) seeds in a Solid Water phantom using radiochromic EBT film for radial distances from 0.06 cm to 5 cm. To determine the TG-43 dosimetry parameters in water by applying Solid Water to liquid water correction factors generated from Monte Carlo simulations.

Methods: Each film piece was positioned horizontally above and in close contact with a ^{131}Cs or ^{125}I seed oriented horizontally in a machined groove at the center of a Solid Water phantom, one film at a time. A total of 74 and 50 films were exposed to the ^{131}Cs and ^{125}I seeds, respectively. Different film sizes were utilized to gather data in different distance ranges. The exposure time varied according to the seed air-kerma strength and film size in order to deliver doses in the range covered by the film calibration curve. Small films were exposed for shorter times to assess the near field, while larger films were exposed for longer times in order to assess the far field. For calibration, films were exposed to either 40 kV (M40) or 50 kV (M50) x-rays in air at 100.0 cm SSD with doses ranging from 0.2 Gy to 40 Gy. All experimental, calibration and background films were scanned at a 0.02 cm pixel resolution using a CCD camera-based microdensitometer with a green light source. Data acquisition and scanner uniformity correction were achieved with Microd3 software. Data analysis was performed using ImageJ, FV, IDL and Excel software packages. 2D dose distributions were based on the calibration curve established for 50 kV x-rays. The Solid Water to liquid water medium correction was calculated using the MCNP5 Monte Carlo code. Subsequently, the TG-43 dosimetry parameters in liquid water medium were determined.

Results: Values for the dose-rate constants using EBT film were 1.069 ± 0.036 and 0.923 ± 0.031 cGy U^{-1} h^{-1} for ^{131}Cs and ^{125}I seed, respectively. The corresponding values determined using the Monte Carlo method were 1.053 ± 0.014 and 0.924 ± 0.016 cGy U^{-1} h^{-1} for ^{131}Cs and ^{125}I seed, respectively. The radial dose functions obtained with EBT film measurements and Monte Carlo simulations were plotted for radial distances up to 5 cm, and agreed within the uncertainty of the two methods. The 2D anisotropy functions obtained with both methods also agreed within their uncertainties.

Conclusion: EBT film dosimetry in a Solid Water phantom is a viable method for measuring ^{131}Cs (model CS-1 Rev2) and ^{125}I (model 6711) brachytherapy seed dose distributions with submillimeter resolution. With the Solid Water to liquid water correction factors generated from Monte Carlo simulations, the measured TG-43

* Corresponding author.
E-mail address: soutung@gmail.com (S.-T. Chiu-Tsao).

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dosimetry parameters in liquid water for these two seed models were found to be in good agreement with those in the literature.

1. Introduction

Accurate dosimetry for low-energy photon-emitting brachytherapy seeds is challenging in part due to the steep dose gradient, requiring detectors capable of fine spatial resolution and precision in distance determination. In the treatment of ocular melanomas using eye plaques, (Finger, 1997; Nag et al., 2003; Collaborative Ocular Melanoma Study Group, 2006; Chiu-Tsao et al., 2012) the distances between the radioactive sources and the points of interest in and around the tumor can be less than 0.1 cm. Thus, it is sometimes necessary to determine accurate radiation dose distributions at such close distances with submillimeter resolution.

The dosimetry parameters for the model 6711 ^{125}I seed (GE Healthcare, Arlington Heights, IL) have been extensively investigated and widely reported (Chiu-Tsao et al., 1990; Nath et al., 1995; Rivard et al., 2004, 2007a; Dolan et al., 2006; Nath and Chen, 2007; Taylor and Rogers, 2008a, 2008b; Melhus and Rivard, 2008; Thomson et al., 2008; Rivard, 2009; Furstoss et al., 2009; Kennedy et al., 2010). The model CS-1 Rev2 ^{131}Cs seed (IsoRay Medical, Inc., Richland, WA) was introduced to the brachytherapy community in the last decade, and several published reports have appeared in the literature (Murphy et al., 2004; Chen et al., 2005; Yue et al., 2005; Wittman and Fisher, 2007; Rivard, 2007b; Chen and Nath, 2007; Wang and Zhang, 2008; Tailor et al., 2008; Rivard et al., 2008; Nuttens and Lucas, 2008; Bice et al., 2008; Melhus and Rivard, 2008; Zhang et al., 2010; Ravi et al., 2011; Landry et al., 2011; Leonard et al., 2011). The radionuclide ^{131}Cs emits slightly higher energy photons (30.4 keV) and has a shorter half-life (9.7 days) compared with ^{125}I (28.4 keV and 59.4 days). The TG-43 dosimetry parameters for the model CS-1 Rev2 seed have been determined using Monte Carlo (MC) methods, thermoluminescence dosimetry (TLD), and gamma-ray spectroscopy (Murphy et al., 2004; Chen et al., 2005;Wittman and Fisher, 2007; Rivard, 2007b; Chen and Nath, 2007; Wang and Zhang, 2008; Melhus and Rivard, 2008; Tailor et al., 2008; Bice et al., 2008; Zhang et al., 2010; Landry et al., 2011). Both seed models are used in eye plaque brachytherapy (Chiu-Tsao et al., 2012).

MC simulations have been reported for the model 6711 ^{125}I seed (Chiu-Tsao et al., 1990; Nath et al., 1995; Rivard et al., 2004, 2007a; Dolan et al., 2006; Nath and Chen, 2007; Melhus and Rivard, 2008; Taylor and Rogers, 2008a, 2008b; Thomson et al., 2008; Rivard, 2009; Furstoss et al., 2009; Kennedy et al., 2010) and the model CS-1 Rev2 ^{131}Cs seed (Melhus and Rivard, 2008; Rivard, 2007b; Wang and Zhang, 2008; Zhang et al., 2010) at short distances. However, to verify the simulation results down to 0.1 cm from the seed center, accurate dose measurement with submillimeter spatial resolution is labor intensive and difficult to achieve with conventional dosimeters such as TLD (Chiu-Tsao et al., 1990; de la Zerda et al., 1996; Murphy et al., 2004; Dolan et al., 2006; Tailor et al., 2008; Kennedy et al., 2010) and diode (Knutsen et al., 2001) due to volume averaging effects and concerns for energy response corrections.

To meet such a challenge, radiochromic film has emerged as a viable detector for brachytherapy dosimetry (Taccini et al., 1997; Niroomand-Rad et al., 1998; Soares et al., 2001; Soares, 2002a, 2002b, 2006, 2007, 2009; Krintz et al., 2002; Piermattei et al., 2002, 2003; Mourtada et al., 2003; Chiu-Tsao et al., 2003a, 2004a, 2004b, 2005, 2007a, 2007b, 2008; Roa et al., 2004; Devic et al., 2004; Gifford et al., 2005; Price et al., 2005; Song et al., 2006; Alvarez et al., 2006, 2011; Furstoss et al., 2009; DeWerd et al., 2011; Acar et al., 2013; Han et al., 2013; Acar et al., 2013). In particular, Furstoss et al. (2009) reported on the verification of MC dose calculations for an ^{125}I seed (model 6711) by using EBT film in a water phantom. Acar et al. (2013) reported EBT film measurement in a polystyrene eye phantom for COMS eye plaques loaded with model I25.S16 ^{125}I seed(s), and verified the MC simulation results. In addition, GafChromic EBT film dosimetry for an ^{125}I seed (model 3500) in a Solid Water® phantom (Gammex, Inc., Middleton, WI) has been reported by Chiu-Tsao et al. (2008), demonstrating the capability of measuring 2D dose distributions and generating AAPM TG-43 brachytherapy dosimetry parameters in a Solid Water medium. However, the Solid Water to liquid water correction factors, i.e., $Q = D_{\text{water,water}}/D_{\text{water,SW}}$, were not applied in that study. The purpose of this study is to demonstrate the capability of (1) submillimeter resolution (0.02 cm) dosimetry at distances from 0.06 cm to 5 cm using radiochromic EBT film for ^{125}I (model 6711) and ^{131}Cs (model CS-1 Rev2) seeds in a Solid Water phantom, and (2) the generation of Q correction factors based on MC simulations.

The general methodology utilized in this work has been previously reported (Chiu-Tsao et al., 2008). Variations from that report in the current work are as follows:

(1) the same EBT film model was utilized, although it was of a different lot,
(2) film calibration was performed with the M50 x-ray beams at the University of Wisconsin Medical Radiation Research Center,
(3) film readout used only the green light box of the CCD100 microdensitometer, and
(4) data analysis used an Inverse Rodbard function (Abramoff et al., 2004; Ferreira and Rasband) to fit the calibration film data.

Before the high-end flatbed color CCD scanners such as Epson model 10000XL or equivalent became accepted by the radiation therapy community as a tool for radiochromic film dosimetry (Soares et al., 2009; Devic, 2010), the CCD100 microdensitometer and its predecessor model CMR-604 from Photoelectron Corporation (North Billerica, MA) (Niroomand-Rad et al., 1998; Devic et al., 2004) were popular 2D imaging type high resolution densitometers used mostly for brachytherapy dosimetry applications (Piermattei et al., 2002, 2003; Mourtada et al., 2003; Chiu-Tsao et al., 2003a, 2004b, 2005, 2007b; Roa et al., 2004; Devic et al., 2004; Gifford et al., 2005; Price et al., 2005; Song et al., 2006; Alvarez et al., 2006, 2011; Han et al., 2013). Although discontinued commercially, CCD100 microdensitometers remain robust and continue to be utilized in radiochromic film dosimetry (Piermattei et al., 2002, 2003; Mourtada et al., 2003; Chiu-Tsao et al., 2003a, 2004b, 2005, 2007a, 2007b, 2008; Roa et al., 2004; Gifford et al., 2005; Price et al., 2005; Song et al., 2006; Alvarez et al., 2006, 2011; Soares, 2006, 2007; Soares et al., 2009; Han et al., 2013).

In this paper, 2D dose distributions and the TG-43 dosimetry parameters for these two seed models were measured with fine resolution in a Solid Water phantom using radiochromic film and corrected using Q derived from MC methods (Meigooni et al., 2006). The TG-43 dosimetry parameters in liquid water were then determined and compared with those reported in the literature.