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Superficial dose evaluation of four dose calculation algorithms

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H I G H L I G H T S

- Four dose calculation algorithms were evaluated at the recommended skin depth 70 μm.
- Monte Carlo simulations were performed as the reference tool for evaluation.
- Multilayer film extrapolation method is feasible for measuring superficial dose.
- The rank of superficial dose calculation accuracy is AXB > CCC > AAA > PBC.
- Care should be taken when using AAA and PBC in the superficial dose calculation.

A R T I C L E I N F O

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A B S T R A C T

Accurate superficial dose calculation is of major importance because of the skin toxicity in radiotherapy, especially within the initial 2 mm depth being considered more clinically relevant. The aim of this study is to evaluate superficial dose calculation accuracy of four commonly used algorithms in commercially available treatment planning systems (TPS) by Monte Carlo (MC) simulation and film measurements. The superficial dose in a simple geometrical phantom with size of 30 cm × 30 cm × 30 cm was calculated by PBC (Pencil Beam Convolution), AAA (Analytical Anisotropic Algorithm), AXB (Acuros XB) in Eclipse system and CCC (Collapsed Cone Convolution) in Raystation system under the conditions of source to surface distance (SSD) of 100 cm and field size (FS) of 10 × 10 cm^2. EGSnrc (BEAMnrc/DOSXYZnrc) program was performed to simulate the central axis dose distribution of Varian Trilogy accelerator, combined with measurements of superficial dose distribution by an extrapolation method of multilayer radiochromic films, to estimate the dose calculation accuracy of four algorithms in the superficial region which was recommended in detail by the ICRU (International Commission on Radiation Units and Measurement) and the ICRP (International Commission on Radiological Protection). In superficial region, good agreement was achieved between MC simulation and film extrapolation method, with the mean differences less than 1%, 2% and 5% for 0°, 30° and 60°, respectively. The relative skin dose errors were 0.84%, 1.88% and 3.90%; the mean dose discrepancies (0°, 30° and 60°) between each of four algorithms and MC simulation were (2.41 ± 1.55%, 3.11 ± 2.40%, and 1.53 ± 1.05%), (3.09 ± 3.00%, 3.10 ± 3.01%, and 3.77 ± 3.59%), (3.16 ± 1.50%, 8.70 ± 2.84%, and 18.20 ± 4.10%) and (14.45 ± 4.66%, 10.74 ± 4.54%, and 3.34 ± 3.26%) for AXB, CCC, AAA and PBC respectively. Monte Carlo simulation verified the feasibility of the superficial dose measurements by multilayer Gafchromic films. And the rank of superficial dose calculation accuracy of four algorithms was AXB > CCC > AAA > PBC. Care should be taken when using the AAA and PBC algorithms in the superficial dose calculation.

1. Introduction

In radiotherapy, the accurate calculation of superficial dose is of major significance for clinical evaluation of the skin toxicity, especially for the breast or head and neck cancer treatment (Almberg et al., 2011; Chow and Grigorov, 2008; Lee et al., 2002). According to recommendations of the ICRP and the ICRU, the skin depth proposed for practical dose assessments is at 70 μm, generally corresponding to the interface of epidermis and dermis layers (ICRP, 1991; Johns, 1985; Stewart, 1977). Also, it's well known that the thickness of epidermis varies with different patients and locations on a given patient, thus the clinically relevant superficial depth for skin dose ranges from 0.05 to 1.5 mm (Devic

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et al., 2006; Kry et al., 2012). Such a superficial region makes skin dosimetry more complicated and challenging (Kry et al., 2012).

A variety of dosimeters can be used to obtain the superficial dose, such as fixed-separation parallel-plate chambers, TLD, diodes and MOSFET devices (Butson et al., 1996; Jornet et al., 2000; Kim et al., 1998; Stathakis et al., 2006). However, a substantial degree of variance can occur across a field particularly in the case of large fields for different incident angles (Buston et al., 1996; Devic et al., 2006). Another dosimeter, the extrapolation chamber, works well in the experimental environment and is usually referenced by other superficial dose measurements (Cora and Francescon, 1995). However, measuring with the extrapolation chamber is very time-consuming and impractical for clinical applications when the skin dose needs to be measured on a particular patient (Devic et al., 2006). With the development of dose calculation algorithms in commercial TPS, they have become a new way to predict superficial dosimetry and some researchers have studied the calculation accuracy of PBC and AAA algorithms (Almberg et al., 2011; Chakarova et al., 2012; Court et al., 2008; Panettieri et al., 2009). Vanessa et al. (Panettieri et al., 2009) have studied AAA and PBC calculation accuracy in the superficial 0–2 cm region with the Monte Carlo code PENELOPE and concluded that both algorithms underestimate the absorbed dose after the beginning 2 mm depth; Another research has also indicated that the error of superficial dose defined as the mean dose to the surface 2 mm thickness structure and calculated by PBC algorithm was within $\pm$20% for 95% of all measurement points compared with those measured by MOSFET in water phantom (Court et al., 2008). Whereas, to our knowledge, few literature has evaluated the calculation accuracy of various algorithms at that skin depth recommended at 70 μm by the ICRU and the ICRP, and the superficial depth defined by the reported literatures is too large to reveal any clinical relevance as the clinically relevant superficial depth for skin dose assessments is within 1.5 mm. Thus, more work is required to explore the characteristics of superficial dosimetry.

In this work, the calculation accuracy of four frequently-used algorithms AXB, AAA, CCC and PBC is evaluated and compared at the recommended skin depth of 70 μm and in the superficial region based on MC simulation, combined with the multilayer Gafchromic film extrapolation method.

2. Materials and methods

2.1. Phantom and irradiation procedures

RW3 solid water slab phantom (PTW) was used for film measurements in this work. The difference of the absorption and scattering properties between the PTW phantom and water phantom was within 1.0% and its physical density ranged from 1.039 to 1.049 g/cm^3. The dimension of this phantom was 30×30 cm^2 and the slab thickness varied from 0.1 to 1 cm. All experiments were carried out with Trilogy accelerator (Trilogy, Varian Medical Systems, Inc., Palo Alto, CA) for 6 MV with a source-surface distance (SSD) of 100 cm, and the incident angles were 0°, 30° and 60°.

2.2. Monte Carlo simulations

The Monte Carlo simulations were carried out in two steps. The first step consisted of the simulation of Varian Trilogy accelerator to obtain particle phase space information that was collected at 92.5 cm from the source target with a Field Size (FS) of 10×10 cm^2. In the second step, the phase space files obtained above were utilized in the Monte Carlo code, DOSXYZnrc, to calculate the dose distribution in a water phantom with the dimension of 30 cm $\times$ 30 cm $\times$ 30 cm, SSD equal to 100 cm and incident angles of 0°, 30° and 60°. To ensure the simulation accuracy, global photon and electron transport cutoff energy were respectively set to 0.01 MeV and 0.521 MeV for all calculations. Meanwhile, DOSXYZnrc was run with exact boundary crossing algorithm and opened relative spin effects in the modeling of multiple scattering. The scoring regions in the superficial depth chosen for accurate dose calculation were 0.001 g/cm^2 thick and centered at depths of 0.0189, 0.0567, 0.0945, 0.1323 and 0.1701 g/cm^2 which were also the effective measurement depths of the multilayer Gafchromic film detector. Directional Bremsstrahlung Splitting variance reduction technique was used and the resulting statistical uncertainty was less than 1.5% in the superficial region and 1.0% beyond. The simulated percent depth dose (PDD) normalized by the value of 1.5 cm depth dose is denoted as D_M.

2.3. Film measurements

In the present study, we used EBT3-1417 films (Ashland Inc. Covington, KY, USA) from the same batch whose mass thickness was 0.0378 g/cm^2 and effective measuring point was at the geometric center. All irradiated films were scanned with an EPSON 10000XL scanner after a 30 min warm-up. A consistent film orientation was maintained and all scans were performed 24 h after exposure. The central region of interest (ROI) was used for film reading to minimize non-uniform effect in the FilmQA Pro software. Precautions in the handling of radiochromic film outlined in TG-55 were used (Niroomand-Rad et al., 1998).

The calibration curve was acquired using Varian Trilogy accelerator. The films were irradiated at a depth of 10 cm and 100 cm SSD in the PTW phantom. Calibration film doses of 0, 20, 40, 80, 160, 240 and 320 cGy were calibrated against the ion chamber (Farmer, 0.6 cc) measurement at the same depth and location. After 24 h, all the films were scanned and read for three times to obtain the average scanner response and, then, draw the calibration curve.

The multilayer Gafchromic film detectors consisted of five layers of EBT3 film pieces with the size of 5×5 cm^2 that were placed in a stack. Much attention was taken to stick the film pieces together to minimize the air gap and movement between the films to ensure the experimental accuracy. The multilayer detector was placed on the surface of the 30 cm thick solid water and one EBT3 film at 1.5 cm depth in the phantom. After that, the detector was irradiated to 200 MU with SSD (Source to surface of films) equal to 100 cm and FS of 10×10 cm^2. The experimental procedure was repeated for 30° and 60° incident angles with the same radiation condition prescribed above. All of the exposed films were scanned to obtain the PDD normalized by the value of 1.5 cm depth dose, abbreviated as D_F. The effective measuring points of five layers in the multilayer Gafchromic film detector were 0.0189, 0.0567, 0.0945, 0.1323 and 0.1701 g/cm^2, respectively. Based on dose values of these points, the skin dose at 0.007 g/cm^2 was ascertained utilizing a second order polynomial extrapolation method because of the nonlinear nature of the superficial dosimetry (Buston et al., 1999).

2.4. TPS calculations

The TPS calculations were performed with Eclipse AXB, AAA and PBC and Raystation CCC. The water phantom was defined using volume contouring tools in TPS, with the same size of the PTW phantom used in multilayer Gafchromic film measurements as described in Section 2.3. The material within the contoured phantom was set as water and that surrounding the phantom as air. The calculation grid size of 1 mm was used for AAA, AXB and CCC and 1.25 mm for PBC, which is the finest calculation grid size

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