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Impact of source position on high-dose-rate skin surface applicator dosimetry

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ABSTRACT

PURPOSE: Skin surface dosimetric discrepancies between measured and treatment planning system predicted values were traced to source position sag inside the applicator and to source transit time. We quantified their dosimetric impact and propose corrections for clinical use.

METHODS AND MATERIALS: We measured the dose profiles from the Varian Leipzig-style high-dose-rate (HDR) skin applicator, using EBT3 film, photon diode, and optically stimulated luminescence dosimeter for three different GammaMedplus HDR afterloaders. The measured dose profiles at several depths were compared with BrachyVision Acuros calculated profiles. To assess the impact of the source sag, two different applicator orientations were considered. The dose contribution during source transit was assessed by comparing diode measurements using an HDR timer and an electrometer timer.

RESULTS: Depth doses measured using the three dosimeters were in good agreement, but were consistently higher than the Acuros dose calculations. Measurements with the applicator face up were significantly (exceeding 10%) lower than those in the face down position, due to source sag inside the applicator. Based on the inverse square law, the effective source sag was evaluated to be about 0.5 mm from the planned position. The additional dose during source transit was evaluated to be about 2.8% for 30 seconds of treatment with a 40700 U (10 Ci) source.

CONCLUSION: With a very short source-to-surface distance, the small source sag inside the applicator has a significant dosimetric impact. This effect is unaccounted for in the vendor's treatment planning template and should be considered before the clinical use of the applicator. Further investigation of other applicators with large source lumen diameter may be warranted.

Keywords: Skin cancer; Leipzig skin-applicator; HDR brachytherapy; Dosimetry; Dwell position uncertainty; Source transit dose

Introduction

Skin cancer is the most common type of malignancy in the United States. According to the American Cancer Society, there are more than 3.5 million skin cancer cases each year (1, 2). This is equivalent to a 1-in-5 overall lifetime risk for all Americans. Most skin cancers are basal cell carcinoma and squamous cell carcinoma and are relatively easy to treat when diagnosed early (3).

Skin cancer treatment options are determined by considering several factors including type and stage of the tumor, age and condition of the patient, and the cosmetic and functional impact of the treatment (4, 5). The standard of care is surgery; many skin cancers can be easily removed with good oncologic and cosmetic results. When surgery is not suitable, radiotherapy has been shown to be a good alternative, especially for lesions in areas where complete resection is difficult (6, 7).

Several radiotherapy modalities have been used. These include superficial x-ray with a typical peak energy range of 70–100 kV, electron beam of 6–12 MeV from a linear accelerator, electronic high-dose-rate (HDR) brachytherapy, and radioisotopic HDR brachytherapy with various skin applicators and custom molds (4,8–11).

We report on our experience in commissioning the Varian Leipzig-style (horizontal) applicator for clinical use; specifically, on discrepancies, we noticed between measured and

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treatment planning predicted dosimetry that, to our knowledge, have not been previously reported. Published data and manufacturer instructions refer to ‘‘in-phantom’’ measurements (12, 13), wherein treatment time calculations are typically done using a lookup table of depth-dose profiles along the applicator central axis and assume the applicator is face down, replicating phantom measurements.

For the skin surface applicators, Varian provides applicator templates for use in treatment planning with Acuros inhomogeneity corrections (14). We sought to compare the measured and treatment planning system (TPS) calculated data. The dosimetric discrepancy was traced to gravitational source sag inside the applicator source lumen. We also found that, for short treatment times used in commissioning measurements (as short as 30 seconds), extra dose, due to source transit, added to the dosimetric discrepancy. Here, we quantify the dosimetric impact of these two factors and propose corrections for clinical use.

Methods and materials

Leipzig-style skin applicator

In this work, we used the horizontal skin applicator (model #: GM11010080; Varian Medical Systems, Palo Alto, CA) shown in Fig. 1. The applicator is comprised of the Leipzig-style cone with a permanently mounted horizontal source transit tube and four apertures of 30−45 mm in 5 mm increments for various target sizes. The applicator and collimators are made of a stainless tungsten alloy, which provides directional treatment geometry and shields the nontreatment surface. The nominal source-to-surface distance (SSD) is 12.5 mm, and each collimator has a thin polycarbonate window at the distal end to ensure a flat target surface and consistent SSD. The integrated source lumen is positioned parallel to the polycarbonate window. Versions of this applicator are available for both GammaMedplus and VariSource afterloaders.

HDR afterloader

Varian GammaMedplus iX afterloaders (Varian Medical Systems) were used with the skin applicator. This afterloader uses an ^{192}Ir source (E_{avg} = 397 keV; $T_{1/2}$ = 74 d) with 0.9 mm diameter (source model: GMP ^{192}Ir HDR) (15, 16), which is soldered onto the tip of a flexible source cable. The afterloader treatment resolution is 1 mm in source positioning along the treatment lumen and 0.1 second in dwell time.

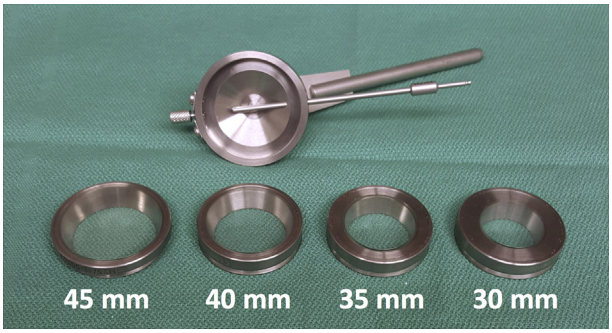

Fig. 1. Varian Leipzig-style HDR skin applicator (horizontal) with four apertures of different sizes. HDR = high dose rate.

EBT3 film measurement

The dose distribution from the skin applicator was measured with the EBT3 radiochromic film (Ashland Inc., Wayne, NJ) because it can provide a two-dimensional (2D) dose map of the whole field with high spatial resolution. The EBT3 is self-developing film in real time, almost energy independent, and near tissue-equivalent (17−20). Film calibration, to correlate the film’s optical density with the absorbed dose, was performed with a 6 MV beam from a linear accelerator in the reference conditions (field size of 10 x 10 cm^2 at the depth of maximum dose (d_{max}) of 1.4 cm) for 13 different dose levels ranging from 0 to 464 cGy. Considering the energy independent nature of the EBT3 film, energy correction was not carried out.

Films used were from the same lot, and care was taken to wait 24 hours between exposure and measurement. The films were scanned one at a time, keeping the same orientation, using EPSON expression 11000XL scanner (EPSON America Inc., Long Beach, CA). Scanner warm-up procedure was followed to ensure electronic stability of the scanner and ±1% scanning reproducibility. The scan resolution was set to 72 dpi for all films, which provides a pixel size of about 0.35 × 0.35 mm^2. For the calibration and further dose analysis, FilmQA Pro software (Ashland Inc., Wayne, NJ) was used. The red channel was chosen for both calibration and measurements for its wider dynamic range. The calibration curve was generated in the software as a reciprocal function between red channel color transmission and dose. Dose maps were measured at the surface, 2, 3, 5, and 10 mm depth. Figure 2a shows the dose measurement setup at the surface of the applicator.

Additional measurement with photon diode and optically stimulated luminescence dosimeter (OSLD)

To confirm the EBT3 film results, additional dose measurements were performed with a photon diode detector (IBA PFD^{3G}, IBA Dosimetry America, Bartlett, TN) and OSLDs (nanoDot, Landauer Inc., Glenwood, IL). The active volumes of photon diode detector and OSLDs are very small (0.2 mm^3 and 4 mm^3, respectively) and are thin enough (0.06 mm and 0.2 mm, respectively) to measure the depth-dose along the central axis of the applicator with the desired resolution (21, 22).

Each dosimeter was independently calibrated. The diode detector was mounted on a polystyrene phantom with a hole that fits the HDR source inside. The distance between the center of the source and the active volume of the