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The validity of Acuros BV and TG-43 for high-dose-rate brachytherapy superficial mold treatments

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ABSTRACT

PURPOSE: The purpose of this work is to validate the Acuros BV dose calculation algorithm for high-dose-rate (HDR) brachytherapy superficial mold treatments in the absence of full scatter conditions and compare this with TG-43 dose calculations. We also investigate the impact of additional back scatter material (bolus) applied above surface molds to the dose distributions under the mold.

METHODS AND MATERIALS: The absorbed dose at various depths was compared for simulations performed using either TG-43 or Acuros BV dose calculations. Parameter variations included treatment area, thickness of the bolus, and surface shape (flat or spherical). Film measurements were carried out in a flat phantom.

RESULTS: Acuros BV calculations and film measurements agreed within 1.5% but were up to 15% lower than TG-43 dose calculations when no bolus was applied above the treatment catheters. The difference in dose at the prescription depth (1 cm below the central catheter) increased with increasing treatment area: 3.3% difference for a 3 × 3.5 cm^2 source loading area, 7.4% for 8 × 9 cm^2, and 13.4% for 18 × 19 cm^2. The dose overestimation of the TG-43 model decreased when bolus was added above the treatment catheters.

CONCLUSIONS: The TG-43 dosimetry formalism cannot model surface mold treatments in the absence of full scatter conditions within 5% for loading areas larger than approximately 5 × 5 cm^2. The TG-43 model results in an overestimation of the delivered dose, which increases with treatment area. This confirms the need for model-based dose calculation algorithms as discussed in TG-186.

Keywords: HDR brachytherapy; Surface mold; Skin treatment; Acuros BV; TG-43; Film dosimetry

Introduction

High-dose-rate (HDR) brachytherapy is a valuable treatment modality for treating skin malignancies (1, 2). The use of shielded cup-shaped applicators is limited to lesion sizes of less than 3 cm in diameter for Valencia and Leipzig applicators (Elekta, Stockholm, Sweden) and 4.5 cm for Varian applicators (Varian Medical Systems, CA) (2). For larger lesions, catheter flaps such as the Freiburg flap (Elekta), Catheter Flap Set (Varian Medical Systems), HAM (Mick Radio-Nuclear Instruments, NY) or custom made molds are widely used (2–6). In commercial flaps, the catheters are spaced parallel, typically 1 cm apart and 0.5 cm from the skin surface. Custom molds can be manufactured from thermoplastic or wax materials to fit the patient's skin. Plastic catheters are usually mounted with a spacing of 1 cm over the mold material, which should be at least 0.2–0.5 cm thick to avoid high local skin doses (2).

The AAPM TG-43 dose calculation formalism uses either vendor provided source data or more recent source data based on the AAPM working group report and associated consensus data set (7, 8). The TG-43 formalism assumes full scatter in water and does not take the actual scatter conditions of the patient or the surrounding environment into account (2, 9). Recently, model-based dose

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calculation algorithms (MBDCA) such as Acuros BV (Acuros BV™, Varian Medical Systems, Charlotte, NC) and ACE (Elekta, Stockholm, Sweden) have become available in most clinical treatment planning systems (10). In contrast to the TG-43 dosimetry formalism, these algorithms take heterogeneities and the actual scatter conditions into account and calculate either dose delivered to water or dose delivered to the actual medium. Acuros BV is based on the finite element solver of the linear Boltzmann transport equation, whereas ACE uses collapsed cone superposition algorithm (11). Both Acuros BV and ACE have been shown to largely agree within ±2% with MC calculations for single source models (12), and specifically near the skin for breast brachytherapy patient models (13). The improvement in calculation accuracy provided by these more sophisticated calculation models can potentially cause a considerable shift in clinical brachytherapy practice with unforeseen side effects. Therefore, the TG-186 working group recommended that clinical prescriptions should be based on the TG-43 model until more detailed clinical data using MBDCAs is available for different treatment sites (10).

The lack of back scatter material is a key factor that may pose limitations to the TG-43 calculation accuracy for skin treatments. Several authors demonstrated that dose calculations strongly depend on scatter conditions through studies of the dose dependency on phantom size (14–19). However, Pantelis et al. (20) and Lymperopoulou et al. (21) showed that the impact of this effect in a clinical setting such as superficial treatments cannot be straightforwardly assessed. A number of studies in literature using similar phantoms to investigate the dose calculation accuracy for superficial brachytherapy treatments showed differences that cannot be straightforwardly explained by the differences between the experimental setups. Furthermore, these studies issued different recommendations regarding the use of bolus for superficial treatments (2, 3, 4, 22). Granero et al. (3) reported that the difference in skin dose with and without scattering material above the surface mold was less than 3% in the region of interest (ROI) and concluded that bolus is not needed for the surface molds investigated. Similar findings were reported by Vijande et al. (4) who found differences less than 5% in the ROI and concluded that the TG-43 model is valid for skin brachytherapy using a Freiburg flap. Based on these findings, the American Brachytherapy Society (ABS) working group report (2) recommended that bolus is not required to improve the agreement between the delivered dose and TG-43–based dose calculations for skin HDR brachytherapy treatments. However, Raina et al. (22) advised using bolus for intraoperative treatments based on an experimental study which reported differences of up to 8.5% in delivered dose between measurements with and without additional bolus on top of a Freiburg flap.

This study was initiated because considerably larger surface molds are common in our department than those included in previous literature, and the fact that previous studies issued conflicting recommendations about the use of bolus. The aim of this study is to validate the Acuros BV dose calculation algorithm for HDR brachytherapy superficial mold treatments in the absence of full scatter conditions and compare this with TG-43 dose calculations. We also investigate the impact of additional back scatter material applied above surface molds to the dose distributions under the mold for different mold sizes and shapes. In addition, a clinical example is included to illustrate the potential clinical impact of TG-43 limitations.

Methods and materials

Film measurements

Dose verification measurements were performed using a VariSource iX (Varian Medical Systems) HDR brachytherapy treatment unit and Gafchromic EBT3 film (Ashland Inc, Covington, KY) in a 30 × 30 × 11 cm^3 phantom assembled of Plastic Water slabs (“The Original”, CIRS Inc, Norfolk, VA). Treatment plans were created in Brachytherapy planning (Varian Medical Systems). Two different loading areas were verified in the same phantom: five catheters with 10 cm loading length (20 source positions) each (8 × 10 cm^2) and eleven catheters with 20 cm loading (40 source positions) each (20 × 20 cm^2). The plastic catheters (Plastic Tipped Standard Catheter, 4.7Fr, Varian Medical Systems) were secured on top of the Plastic Water slab phantom using adhesive tape and with 2 cm parallel spacing between the catheters. The EBT3 film (8″ × 10″) was positioned in a coronal plane at 1 cm depth below the catheter surface (Fig 1). For each loading area, measurements were performed with none, 1 cm, and 2 cm bolus (Superflab, MedTec, Orange, IA) placed freely on the top of the catheters.

A CT scan of the phantom (Philips Brilliance Big Bore, Philips Medical Systems, Fitchburg, WI) with 0.4-mm slice thickness and 0.8-mm pixel size was acquired for the purpose of catheter reconstruction. The source to detector distance (SDD) was defined as the distance from the center of the HDR source to the active layer of the film. The SDD was calculated from

$$\mathrm{SDD} = \frac{t_{catheter}}{2} + t_{slab} + \frac{t_{film}}{2} = 1.10\,\mathrm{cm}, \quad (1)$$

in which $t_{catheter}$, t_{slab} and t_{film} are the measured thicknesses of the catheters, the build-up Plastic Water slab and the EBT3 film, respectively. This SDD was used to select the coronal plane within the TPS-calculated 3D dose distribution coinciding with the plane of the film measurements.

The Geometrical Optimisation tool (Brachytherapy Planning, Varian Medical Systems) was used for dwell time optimization to create a fairly homogenous (6 Gy) TG-43-calculated dose at the film plane. Acuros BV dose calculations were performed using the same dwell times and positions as those applied for TG-43-calculated plans. A calculation grid resolution of 0.1 cm was used.