ELSEVIER

Brachytherapy 12 (2013) 645–653

BRACHYTHERAPY

Commissioning of a grid-based Boltzmann solver for cervical cancer brachytherapy treatment planning with shielded colpostats

Justin K. Mikell[1,2], Ann H. Klopp[3], Michael Price[4], Firas Mourtada[2,5,*]

[1]*The University of Texas Graduate School of Biomedical Sciences at Houston, Houston, TX*
[2]*Department of Radiation Physics, The University of Texas MD Anderson Cancer, Houston, TX*
[3]*Department of Radiation Oncology, The University of Texas MD Anderson Cancer, Houston, TX*
[4]*The University of North Carolina at Chapel Hill, Chapel Hill, NC*
[5]*Radiation Oncology, Christiana Care Health System, Newark, DE*

ABSTRACT

PURPOSE: We sought to commission a gynecologic shielded colpostat analytic model provided from a treatment planning system (TPS) library. We have reported retrospectively the dosimetric impact of this applicator model in a cohort of patients.

METHODS AND MATERIALS: A commercial TPS with a grid-based Boltzmann solver (GBBS) was commissioned for ^{192}Ir high-dose-rate (HDR) brachytherapy for cervical cancer with stainless steel–shielded colpostats. Verification of the colpostat analytic model was verified using a radiograph and vendor schematics. MCNPX v2.6 Monte Carlo simulations were performed to compare dose distributions around the applicator in water with the TPS GBBS dose predictions. Retrospectively, the dosimetric impact was assessed over 24 cervical cancer patients' HDR plans.

RESULTS: Applicator (TPS ID #AL13122005) shield dimensions were within 0.4 mm of the independent shield dimensions verification. GBBS profiles in planes bisecting the cap around the applicator agreed with Monte Carlo simulations within 2% at most locations; differing screw representations resulted in differences of up to 9%. For the retrospective study, the GBBS doses differed from TG-43 as follows (mean value ± standard deviation [min, max]): International Commission on Radiation units $[ICRU]_{rectum}$ (−8.4 ± 2.5% [−14.1, −4.1%]), $ICRU_{bladder}$ (−7.2 ± 3.6% [−15.7, −2.1%]), $D_{2cc\text{-}rectum}$ (−6.2 ± 2.6% [−11.9, −0.8%]), $D_{2cc\text{-}sigmoid}$ (−5.6 ± 2.6% [−9.3, −2.0%]), and $D_{2cc\text{-}bladder}$ (−3.4 ± 1.9% [−7.2, −1.1%]).

CONCLUSIONS: As brachytherapy TPSs implement advanced model-based dose calculations, the analytic applicator models stored in TPSs should be independently validated before clinical use. For this cohort, clinically meaningful differences (>5%) from TG-43 were observed. Accurate dosimetric modeling of shielded applicators may help to refine organ toxicity studies.

Keywords: ^{192}Ir; Shielded applicator; Cervical cancer; Dose calculation; Acuros

Shielded gynecologic applicators can be used when treating cervical cancer to spare critical organs such as the rectum and bladder (1). Properly positioned, shielded applicators have been shown to significantly impact dosimetry to critical structures (2, 3). Traditional brachytherapy treatment planning systems (TPS) rely on modeling the source in finite water following the American Association of Physicists in Medicine (AAPM) formalism from TG 43 (4). To account for attenuation of a shielded applicator, a first-order approximation (1-D) has been included in the TPS, accounting for primary attenuation but not for full scatter in 3-D (5). Recently, sophisticated model-based dose calculations (MBDC) have been implemented in clinical TPS (6–8). Unlike TG-43 which, models a single source in an effectively infinite water phantom, these MBDCs model sources, applicators, patient heterogeneities, and patient boundaries (scatter conditions). There are several methods to model these factors including Monte Carlo (MC) simulations, analytical approximations, convolutions, and deterministic solvers (6–8). This work focuses

Received 14 February 2013; received in revised form 2 April 2013; accepted 5 April 2013.

* Corresponding author. Helen F. Graham Cancer Center, Rm 1152, Newark, DE 19713. Tel.: +1-302-623-4691.

E-mail address: Fmourtada@ChristianaCare.org (F. Mourtada).

1538-4721/$ - see front matter
http://dx.doi.org/10.1016/j.brachy.2013.04.007

on following the AAPM TG-186 (6) guideline to commission an MBDC available for clinical use in TPS BrachyVision v10.0.26 (Varian Medical Systems Inc., Palo Alto, CA). The licensed MBDC in the TPS is Acuros v1.4.0 (Transpire Inc., Gig Harbor, WA); it is a grid-based Boltzmann solver (GBBS) that deterministically solves the linear Boltzmann transport equation and has been studied in the literature (9–12).

The use of MBDCs is expected to provide more accurate dose calculations for brachytherapy treatment planning—particularly when using applicators with shields. However, this assumes that (*1*) radioactive sources are sufficiently modeled, (*2*) applicator models in TPS libraries are correct, (*3*) CTs or MRIs are properly converted to materials and densities, (*4*) radiation transport sufficiently approximates a solution to the linear Boltzmann transport equation, and (*5*) the temporal and spatial aspects (applicator position, dwell positions, dwell times, anatomy) of the treatment plan match the actual treatment delivery. We studied assumptions one through four previously for unshielded applicators (9, 10). The purpose of this work was to (*1*) commission the TPS's shielded applicator analytic model and (*2*) report the dosimetric impact for a cohort of cervical cancer patients accounting for the ^{192}Ir source, shielded applicator, tissue heterogeneities, and patient boundaries.

Methods and materials

Shielded applicator model validation

An MC model of the shielded colpostat was independently derived from design schematics obtained from the vendor. MCNPX 2.6 was used for the MC simulations (13). Cross-sections were based on MCPLIB04. Photon transport included coherent scattering, and the photon cutoff was set at 1 keV. Electron transport was not simulated. The scoring tallies were *pedep* (equivalent to MCNP F6 tally) in rectangular meshes for two orthogonal planes. Figure 1a–c show the independent MC model created using the vendor's proprietary computer-aided drawings. Briefly, the shielded applicator main structure is composed of a stainless steel source channel with a density of 8.02 g/cc and composition as a percent of weight as follows: Si, 1%; Cr, 19%; Mn, 25%; Fe, 68%; and Ni, 10%. The shields are also composed of stainless steel. The 2.5-cm diameter Acetal caps are 1.42 g/cm^3 with a composition as a percent of weight as follows: H, 5.0%; C, 73.3%; O, 14.5%; and S, 7.2%. Within the TPS, the dimensions of the shielded applicator (library ID #AL13122005) were measured using TPS tools (Fig. 1d–f) and compared with the independent MC model and vendor computer-aided drawings. All TPS calculations were performed in the TPS BrachyVision 10.0.26 (Varian Medical Systems) with Acuros 1.4.0. As an additional check, consistent with commissioning applicators, a radiograph of the applicator (Fig. 1g) was acquired and dimensions were measured and compared with the vendor's specifications.

For a dosimetric comparison, the colpostat model was placed at the center of a 30-cm diameter sphere of water. A single ^{192}Ir source VS2000 (Varian Medical Systems) was then centered in the colpostat and dose calculated by the GBBS using the TPS's applicator model was compared with MC simulations using our independent applicator model. The comparisons were for two orthogonal planes bisecting the applicator with a dose grid resolution of 1 mm; a circular (R = 3.25 cm) line profile was then taken around the colpostat. The accuracy of our VS2000 (Varian Medical Systems) MC model was previously verified (9).

Retrospective clinical study

Treatment planning images for 24 patients were selected from a database at the Mary Bird Cancer Center. The images were CT datasets acquired with unshielded, CT/MR-compatible applicators (tandem and colpostats) inserted. The unshielded applicators have a similar overall dimension to the shielded applicators with the advantage of having no CT image artifacts. Using the unshielded datasets allowed better delineation of rectum and bladder. This retrospective dosimetric analysis was conducted under the University of Texas MD Anderson Cancer Center Institutional Review Board–approved chart review protocol.

It should be noted that GEC-ESTRO recommends the use of T2 MRI instead of CT for planning (14, 15). Unfortunately, this cohort of patients did not undergo MRI; however, the organ delineation coupled with doses from the GBBS accounting for the shielded applicators should still be useful to the brachytherapy community as an example of validating MBDC.

The TPS has a library of applicator analytic models that can be rigidly transformed and registered to the CT in 3D space. Stainless steel shielded applicators (library ID #AL13122005) with the same diameter colpostats as the unshielded applicators were selected from the library and manually moved to coincide with the applicators visible on CT.

The VS2000 (Varian Medical System) HDR ^{192}Ir source dwell times were based on AAPM TG-43 dose calculations delivering 6 Gy to Manchester point A. Dwell weights were not optimized; they were set to mimic a standard 15-10-10 mgRaEq tandem and 15 mgRaEq in each colpostat.

The following clinical dosimetric parameters were recorded for both TG-43 and GBBS calculations: Manchester points A and B, International Commission on Radiation units (ICRU) report #38 rectal and bladder points, 3 and 9 o'clock, doses for the most exposed 2 cm^3 of the bladder (D_{2cc} bladder), rectum (D_{2cc} rectum), and sigmoid colon (D_{2cc} sigmoid) (16). The 3 and 9 o'clock positions are located on the lateral colpostat surface and represent the patient's left and right vaginal mucosa, respectively.