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Physics

Clinical transition to model-based dose calculation algorithm: A retrospective analysis of high-dose-rate tandem and ring brachytherapy of the cervix

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ABSTRACT

PURPOSE: To retrospectively compare clinical dosimetry of CT-based tandem–ring treatment plans using a model-based dose calculation algorithm (MBDCA) with the standard TG-43–based dose formalism.

METHODS AND MATERIALS: A cohort of 10 cervical cancer cohorts treated using the tandem and ring high-dose-rate applicators were evaluated. The original treatment plans were created using the department CT-based volume optimization clinical standards. All plans originally calculated with TG-43 dose calculation formalism were recalculated using the MBDCA algorithm. The gross target volume and organs at risk (OARs) were contoured on each data set along with significant heterogeneities like air in cavity and high-density plastic tandem and ring components. The patient tissue was modeled as homogenous liquid water. D_{90}, D_{95}, and D_{100} for gross target volume, $D_{0.1cm^3}$, $D_{1.0cm^3}$, and $D_{2.0cm^3}$ for bladder, rectum, and sigmoid were extracted from dose–volume histograms for TG-43 and MBDCA calculated plans. Mean absolute difference $\pm 2\sigma$ in the above metrics was calculated for each plan.

RESULTS: Using the manual applicator contouring method, MBDCA plans ($n = 10$) showed $2.1 \pm 1.1\%$ reduction in dose to Point A average, $2.6 \pm 0.9\%$ reduction in Target D_{90} dose, and $2.1 \pm 0.3\%$ dose reduction to OARs. Results from plans using vendor supplied solid applicator models ($n = 5$) showed $2.2 \pm 1.10\%$ reduction in dose to Point A average, $2.7 \pm 0.2\%$ reduction in Target D_{90} dose, and $2.7 \pm 1.0\%$ dose reduction on average to OARs.

CONCLUSION: For unshielded plastic gynecologic applicators, minimal dosimetric changes (<5%) were found using MBDCA relative to standard TG-43. Use of solid applicator model is more efficient than manual applicator contouring and also yielded similar MBDCA dosimetric results. Currently, TG-186 dose calculations should be reported along TG-43 until we obtain studies with larger cohorts to fully realize the potential of MBDCA dosimetry.

Keywords: HDR; Brachytherapy; MBDCA; Tandem–ring applicator; Cervical cancer

Introduction

Intracavitary high-dose-rate (HDR) brachytherapy using ^{192}Ir, combined with external beam radiation, plays an important role in the management of advanced cervical cancer by obtaining local control and high cure rates with minimal complications to organs at risk (OARs). The American Brachytherapy Society recommends including brachytherapy in definitive radiation therapy for cervical carcinoma based on the conclusion that reoccurrences and complications are reduced when brachytherapy is used in addition to external beam radiotherapy (1).

The CT/MR compatible tandem and ring applicator together with a smit sleeve is commonly used for volume-based intracavitary cervical HDR brachytherapy.

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The CT/MR ring and tandem applicator creates a pear-shaped isodose distribution matching the anatomy of the cervix and the endometrium (2–4). The applicator uses strong fiber composite tubing and can be used in combination with CT and MR imaging for volume-based treatment planning.

The dose calculation algorithm used in the planning of HDR brachytherapy plans is based on the AAPM TG-43 (5) dose formalism which has several limitations. TG-43 assumes homogenous water as the medium throughout an infinite treatment volume. The influence of tissue and applicator heterogeneities, intersource attenuation, air gaps, and finite patient dimensions are all ignored as well as the formalism fails to describe the scatter-dose component dependence on the full three-dimensional (3D) geometry.

Heterogeneity corrected calculations may significantly improve the accuracy of treatment planning systems (TPSs) because they can compensate for air in the bowel, applicator materials, and patient boundaries (6). The advanced collapsed cone engine (ACE) is a convolution algorithm that offers the possibility of departing from water-only geometries by modeling radiation transport in nonwater media (tissues, applicators, air–tissue interfaces), resulting in a much more physically accurate reconstruction of the dose distribution actually delivered to the patient. In this method, the dose deposited by primary, singly scattered, and multiple-scattered photons is calculated separately and summed. The fundamental principles of the collapsed cone superposition algorithm are described in TG-186 report (6). ACE is now fully integrated in the Oncentra Brachy treatment planning system (Elekta Inc, Stockholm, Sweden) (7). Model-based dose calculation algorithms (MBDCAs) explicitly simulate the transport of radiation in the actual media or employ multiple-dimensional scatter integration techniques to account for the dependence of scatter dose on the 3D geometry. The three methods of current interest to brachytherapy treatment planning are CC superposition/convolution, grid-based Boltzmann solver (GBBS), and Monte Carlo simulations (8). Mikell *et al.* (8) reported on the Acuros GBBS algorithm in BrachyVision treatment planning system (Varian, Palo Alto, CA) dose differences from TG-43 on a cohort of cervical cancer patients with the unshielded CT/MR tandem and ovoid system. Acuros differences from standard TG-43 dose estimates were found to be mainly due to source, boundary, and applicator model differences. Hofbauer *et al.* (9) evaluated retrospectively the dose heterogeneity using Acuros GBBS for nine cervix cancer patients with the plastic tandem–ring applicators with a few patients with additional interstitial needles. They found small dose reduction for up to 2% per fraction for OARs and up to 0.5% per fraction for high-risk CTV. For this study, the recently introduced ACE MBDCA is used to confirm the prior findings with Acuros. Furthermore, we compared the newly implemented solid applicator library in the Oncentra TPS to manually contoured T&R applicators.

Methods and materials

ACE MBDCA commissioning

Before the release of MBDCA for our clinic, ACE was commissioned according to the guidelines of the AAPM Working Group on Dose Calculation Algorithms in Brachytherapy and Elekta's published white paper (7). In Level 1 of the commissioning process, ACE was validated against a standard single-dwell dose distribution that is well established by the TG-43 formalism. The ACE dose distribution was calculated using a generic source model provided by the vendor, all material density assigned as water, full scatter conditions, and ACEs high accuracy calculation setting in Oncentra. This same standard dose distribution was compared to an average of MC dose simulations provided by the working group to confirm ACEs validation in Level 1. The results were satisfactory (not presented here), indicating agreement within 2% for all isodose lines >1 cm from the source. Level 2 testing consisted of calculating dose from a single-dwell position located 5 cm from a tissue boundary inside a shielded cylinder applicator model. The results from ACE were in good agreement with the average MC dose simulations (<5%) for isodose lines above 10% of the prescribed dose.

Patient cohort

Ten cervical cancer cases treated using the CT/MR tandem and ring HDR applicators were selected from the Christiana Care database. The retrospective study was conducted under our institutional Review Board approved chart review protocol. The cohort consisted of patients with locoregional advanced cancer of the cervix (FIGO Stage IB–IIIB) who received curative-intent concurrent chemoradiotherapy consisting of external beam pelvic radiotherapy and weekly cisplatin, with 5 fractions of HDR brachytherapy delivered near the completion of the treatment course.

All patients had a #14 Foley catheter placed into the bladder. The Foley balloon was inflated with a mixture of 5-mL of iodinated contrast and 5-mL sterile water, the catheter was temporarily clamped, and the bladder was instilled with a mix of 5-mL iodinated contrast and 55-mL sterile water for visualization of the bladder wall during imaging. For treatment, the bladder filling was reproduced by clamping the Foley once again and instilling 60-mL of sterile water. A rectal tube was placed in the rectum, and the rectum was instilled with a mix of 48-mL of sterile water and 2-mL iodinated contrast, after which the rectal tube was removed. All patients had a plastic smit sleeve inserted into the cervix os before the treatment. A rectal paddle was placed posteriorly to provide rectal shielding. Iodoform gauze packing was used to displace the posterior wall of the bladder from the high-dose region.

Contouring

Contours were delineated by a physician at CCHS per standard practice. The target was delineated to include