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A novel two-step optimization method for tandem and ovoid high-dose-rate brachytherapy treatment for locally advanced cervical cancer

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ABSTRACT

PURPOSE: To present a novel method allowing fast volumetric optimization of tandem and ovoid high-dose-rate treatments and to quantify its benefits.

METHODS AND MATERIALS: Twenty-seven CT-based treatment plans from 6 consecutive cervical cancer patients treated with four to five intracavitary tandem and ovoid insertions were used. Initial single-step optimized plans were manually optimized, approved, and delivered plans created with a goal to cover high-risk clinical target volume (HR-CTV) with D_{90} >90% and minimize rectum, bladder, and sigmoid D_{2cc}. For the two-step optimized (TSO) plan, each single-step optimized plan was replanned adding a structure created from prescription isodose line to the existent physician delineated HR-CTV, rectum, bladder, and sigmoid. New, more rigorous dose–volume histogram constraints for the critical organs at risks (OARs) were used for the optimization. HR-CTV D_{90} and OAR D_{2cc}s were evaluated in both plans.

RESULTS: TSO plans had consistently smaller D_{2cc}s for all three OARs while preserving HR-CTV D_{90}. On plans with "excellent" CTV coverage, average D_{90} of 96% (91–102%), sigmoid, bladder, and rectum D_{2cc}, respectively, reduced on average by 37% (16–73%), 28% (20–47%), and 27% (15–45%). Similar reductions were obtained on plans with "good" coverage, average D_{90} of 93% (90–99%). For plans with "inferior" coverage, average D_{90} of 81%, the coverage increased to 87% with concurrent D_{2cc} reductions of 31%, 18%, and 11% for sigmoid, bladder, and rectum, respectively.

CONCLUSIONS: The TSO can be added with minimal planning time increase but with the potential of dramatic and systematic reductions in OAR D_{2cc}s and in some cases with concurrent increase in target dose coverage. These single-fraction modifications would be magnified over the course of four to five intracavitary insertions and may have real clinical implications in terms of decreasing both acute and late toxicities.

Keywords: Cervical Cancer; HDR Brachytherapy; Tandem and ovoid; Volume optimization

Introduction

Intracavitary brachytherapy is an essential component of treatment for many cervical cancers. It may be used as monotherapy for Stage IA or in conjunction with external beam and chemotherapy for Stages IB–IVA cervical cancer treatments. The traditional treatments are designed to deliver a constant dose rate at Point A, irrespective of the size and shape of uterus and vagina. With the integration of three-dimensional CT and/or MRI into high-dose-rate (HDR) brachytherapy planning, it is possible to get detailed information regarding tumor dose coverage and dose to adjacent organs at risk (OAR) (1, 2). Ideally, this will result in better normal organ sparing and a custom adaptation/sculpting of the traditional pear-shaped isodose surface by tailoring dose to the shape and size of targets and OARs at the time of treatment delivery.

The success of an HDR procedure depends on all its elements. The proper applicator selection, image-guided insertion, and three-dimensional imaging for planning are fundamental aspects of the procedure. Although treatment planning is recognized as an important step in the procedure, the dose optimization is typically less emphasized. It is often perceived, particularly in gyn brachytherapy that

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dose optimization simply "involves manipulation of dwell positions and dwell times (3)."

Most optimization methods in clinical use rely on the principle of forward planning. With these conventional methods, the planner aims to achieve a dose distribution, which meets certain criteria, by iteratively adjusting the dwell times (4). Although experienced physicists and dosimetrists can produce decent (or esthetically pleasing) treatment plans, there is no guarantee of optimality. The difficulty in pursuing an exclusive dose/volume–based optimization stems from the fact that the structures involved explicitly in the planning (high-risk clinical target volume [HR-CTV], rectum, sigmoid, and bladder) and those involved implicitly (uterus, vagina, ureters, and connective tissue) are not enough to drive, by themselves, an optimizer toward a standard pear-shaped dose distribution. In other words, not all objectives can be easily quantified and translated into upper and lower bounds on the histogram, for structures clearly outlined/defined. A similar situation is true for evaluation of these plans: Although clear parameters are used to quantify certain parameters (e.g., D_{2cc} for bladder, rectum, and sigmoid), a physician may prefer one plan to another based on the general "look" and spatial extent of isodose lines (1, 2). There are probably as many nonquantifiable constraints as there are "brachytherapy schools" thus leading to a rather heterogeneous practice across institutions. This state of affairs is clearly reflected in the ABS guidelines "Optimization should be performed with caution by observing changes in the dose, dose/volume parameters, and the spatial dose distribution that results from the modified loading pattern. The exclusive use of dose–volume histogram (DVH)-based parameters to select a source loading is not recommended because substantial and perhaps undesirable changes in the spatial dose distribution may occur (5)."

One of the most difficult to quantify features of the plan is the general aspect and spatial extent of the pear (or squash) shape of the prescription isodose line. This classic isodose distribution models the low dose rate brachytherapy loading pattern with cesium sources, which allowed a fluid dose distribution between the tandem and ovoids (T&O)and minimized dose to the bladder and rectum. Theoretically, with the shrinkage caused by external beam radiation, this shape can encompass the residual disease in the cervix as well as residual gross and microscopic extension into the parametria. The shape can be varied to cover persistent clinically visible disease, and there is some variation in the shape of the dose distribution in relation to the uterine length, distortion of the anatomy by tumor, and applicator placement. The shape and size of the classic dose distribution is typically quite different from what is now defined as the HR-CTV, and this discrepancy has not been resolved. To optimize to the HR-CTV certainly loses the classic shape and veers from the standard distribution, potentially impairing previously reported rates of local control and survival.

However, the issue of optimization in cervical cancer brachytherapy is not new. The published literature on the subject is typically specific to either the treatment modalities—tandem and ring vs. T&O, interstitial implants or hybrid applicators—or the particular methods used for optimization—inverse planning simulated annealing (IPSA) or hybrid inverse planning and optimization (HIPO); the former is an in-house inverse planning software, whereas the latter is associated with the Oncentra Treatment Planning System (Nucletron B.V., Veenendaal, The Netherlands) (6–11). The two-step method we are presenting here, although developed in the context of the BrachyVision TPS platform (Varian Medical Systems, Inc.) and exemplified on T&O treatments, is general enough that it can be implemented on any available TPS (The only prerequisites are the ability to convert an isodose line into a structure and to perform a DVH (inverse/volumetric) optimization) and for any applicators.

A typical approach in planning, also used in the first step of our method, is to manually optimize dwell positions and dwell times trying to reasonably reduce dose to OARs while achieving good dose coverage of the HR-CTV and, most importantly, to achieve the general shape of the dose desired by the radiation oncologist. The novelty of our method is creating a pseudostructure from the prescription isodose surface of the manually optimized plan and then using that in conjunction with more stringent dose constraints for OARs and HR-CTV coverage. This second step guarantees the true minimization of dose received by OARs and the maximization of dose to the targets while preserving the general shape and extent of the pear-shaped prescription isodose surface.

Methods and materials

Twenty-seven CT planning data sets and treatment plans from 7 consecutive cervical cancer patients treated with four to five intracavitary T&O insertions were used in the study. The patients included had FIGO (International Federation of Gynecology and Obstetrics) Stage IIB–IVA disease and received 46–55 Gy with concurrent chemotherapy followed by a 28–30 Gy boost in four to five intracavitary insertions of 6–7 Gy/fraction. The average age of patients was 55 years, and 90% of them had squamous cell carcinoma.

Each HDR treatment involved insertion of Titanium Fletcher-Suit-Delclos-style tandem-and-ovoid applicators (Varian Medical Systems, Palo Alto, CA). The procedures were performed under anesthesia in dorsal lithotomy position. Appropriate length and size tandem-and-ovoid (T&O) applicators were used based on tumor size and shape, length of uterine canal, and vaginal length and width. Radiopaque packing was placed anteriorly and posteriorly to the applicator to increase distance between T&O from bladder and rectum. Each intracavitary insertion was followed by a CT simulation and contour delineation. The CT simulation was performed using Philips Brilliance Big