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PHYSICS CONTRIBUTION

A THREE-DIMENSIONAL COMPUTED TOMOGRAPHY–ASSISTED MONTE CARLO EVALUATION OF OVOID SHIELDING ON THE DOSE TO THE BLADDER AND RECTUM IN INTRACAVITARY RADIOTHERAPY FOR CERVICAL CANCER

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Purpose: To determine the effects of Fletcher Suit Delclos ovoid shielding on dose to the bladder and rectum during intracavitary radiotherapy for cervical cancer.

Methods and Materials: The Monte Carlo method was used to calculate the dose in 12 patients receiving low-dose-rate intracavitary radiotherapy with both shielded and unshielded ovoids. Cumulative dose-difference surface histograms were computed for the bladder and rectum. Doses to the 2-cm^3 and 5-cm^3 volumes of highest dose were computed for the bladder and rectum with and without shielding.

Results: Shielding affected dose to the 2-cm^3 and 5-cm^3 volumes of highest dose for the rectum (10.1% and 11.1% differences, respectively). Shielding did not have a major impact on the dose to the 2-cm^3 and 5-cm^3 volumes of highest dose for the bladder. The average dose reduction to 5% of the surface area of the bladder was 53 cGy. Reductions as large as 150 cGy were observed to 5% of the surface area of the bladder. The average dose reduction to 5% of the surface area of the rectum was 195 cGy. Reductions as large as 405 cGy were observed to 5% of the surface area of the rectum.

Conclusions: Our data suggest that the ovoid shields can greatly reduce the radiation dose delivered to the rectum. We did not find the same degree of effect on the dose to the bladder. To calculate the dose accurately, however, the ovoid shields must be included in the dose model. © **2005 Elsevier Inc.**

Intracavitary therapy, Brachytherapy, Monte Carlo, Ovoids, ^{137}Cs.

INTRODUCTION

A combination of intracavitary radiotherapy (ICRT) and external beam radiotherapy (EBRT) is quite successful in achieving local control of cervical cancer, but delivering a dose of radiation sufficient for tumor control while sparing nearby structures, particularly the bladder and rectum, remains challenging. One attempt to solve that problem was the development of the Fletcher Suit Delclos (FSD) ovoids, which include shields to protect those sensitive tissues. However, the effectiveness of the shields has not yet been well documented.

Several researchers have investigated computed tomography (CT)-based dosimetry for these gynecologic applicators (1–5). However, only two studies (2, 4) have included the effects of the shields. Gebara *et al.* (2) included the effect of the shields by using an effective water replacement attenuation coefficient (3). Steggerda *et al.* (4) used a shielding correction algorithm based on empiric data that was developed by Van der Laarse and Meertens (6). However, these correction algorithms do not model inter-applicator attenuation effects or model the ovoid shields explicitly. Weeks (7) calculated the perturbation effect of the shields for an FSD ovoid with MCNP4A (8) and obtained good agreement with an effective attenuation calculation algorithm. Markman *et al.* (9) calculated inter-applicator effects and modeled the ovoid shields explicitly with a Monte Carlo calculation. They found errors greater than 10% throughout the volume of the calculation in an idealized applicator system when only the sources were considered in the dose calculation.

Some have concluded that complications to the bladder or rectum might correlate with a surface area or volume of

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high dose instead of the traditional points outlined in International Commission on Radiation Units and Measurements (ICRU) Report 38 (2). Others have concluded that large dose reductions to the bladder and rectum cannot be achieved with the ovoid shields, so inclusion of the shields is not necessary (4). In an earlier study (10), we found a correlation between the minimum dose delivered to 2 cm^3 of rectum (D_{RV2}) and the ICRU 38 rectal point, but the dose calculations in that study did not include the effects of the ovoid shields.

The aim of the current study was to calculate the effect of including the ovoid shields on the 3D dose distributions in patient CT scans, using Monte Carlo–based dosimetry. Our calculation method was designed to model inter-applicator effects and the ovoid shields explicitly. More specifically, cumulative dose-difference surface histograms (DDSHs) of the bladder and rectum were calculated. These DDSHs provided insight into the effects of ovoid shielding on the dose delivered to the surface areas of the bladder and rectum. The minimum doses to 2 cm^3 and 5 cm^3 of rectum (D_{RV2} and D_{RV5}) and bladder (D_{BV2} and D_{BV5}) receiving the highest dose from dose–volume histograms (DVHs) were calculated with and without the inclusion of the ovoid shields.

METHODS AND MATERIALS

Patient selection

Between November 2001 and March 2003, 60 patients were prospectively enrolled in a pilot study of CT-based volumetric dosimetry. Patients were eligible if they had carcinoma of the uterine cervix and if their planned treatment was radical radiation therapy. The institutional review board at The University of Texas M. D. Anderson Cancer Center approved this protocol, and informed consent was obtained before the patient's first intracavitary insertion. Twelve patient cases that involved the use of FSD ovoids were randomly selected from this protocol.

Each patient receiving low-dose-rate ICRT for the treatment of cervical cancer typically undergoes two insertions. However, each of the 12 cases in this study had dose calculated for one insertion. Total doses from two ICRT implants and a course of EBRT are difficult to ascertain because of the deformation and displacement of structures irradiated by the two modalities (11), the differences in the biologic responses between ICRT and high-dose-rate EBRT, and the different fractionation schemes of ICRT and EBRT.

CT scanning

Computed tomography scans were performed on an AcQsim CT simulator (Phillips Medical Systems, Andover, MA). Scans were acquired in helical mode at 120 kVp and 250 mA, with a slice thickness of either 3 mm or 5 mm. Each image was 512 × 512 pixels, with a 12-bit pixel depth. A Foley bulb was filled with 7 mL of a solution that contained three parts Hypaque contrast medium (Amersham Health, Princeton, NJ) and 7 parts saline. Just before scanning, 20 mL of a more dilute solution containing 3 mL of Hypaque and 17 mL of saline was instilled into the bladder. Scans were performed with patients in a supine position immediately after placement of the tandem and ovoids. A specially fabricated insert marking the position of each pellet inside each applicator was placed in the tandem and ovoids before scanning. Images were transferred to the Brachyvision treatment-planning system (Varian Medical Systems, Concord, CA) for segmentation, source delineation, and planning.

Contouring

The entire bladder was contoured. The rectum was contoured from the bottom of the ischial tuberosities to the sigmoid flexure. Each slice of segmented image data was exported in bitmap format. The Pinnacle^3 treatment-planning system (version 6.2b; Phillips Medical Systems, Milpitas, CA) was used as a display device and to calculate the dose to points in the bladder and rectum. The exported bitmap files were imported to the Pinnacle^3 treatment-planning system. Because Pinnacle^3 did not have the coordinates of points on the contours from the exported bitmap files, the contours were traced in Pinnacle^3.

Patient treatment

At The University of Texas M. D. Anderson Cancer Center, the Selectron remote afterloading LDR unit (Nucletron Trading, Leersum, The Netherlands) coupled with the FSD tandem and ovoids is routinely used for most cervical cancer treatments. Three channels are used for patient treatment, one each for the tandem and the right and left ovoids. Each channel contains 48 pellets. The sources (active pellets) and inactive pellets are pneumatically loaded into the tandem and ovoids after the staff has left the room.

Intracavitary radiotherapy applicators are usually inserted while the patient is under spinal or general anesthesia. A tandem set to the length of the uterine cervix is inserted with the flange abutting the external cervical os. Vaginal applicators are selected according to the capacity of the upper vagina and the extent of vaginal involvement. Unless there is extensive vaginal involvement, small (2.0 cm), medium (2.5 cm), or large (3.0 cm) shielded ovoids are always used if they can be accommodated. After positioning of the ovoids, gauze packing containing a radio-opaque strand is positioned about the tandem and ovoid system. This limits movement of the system and, if it is correctly placed, displaces the bladder and rectum from the sources, reducing the dose of radiation delivered to these critical structures.

After placement of the intracavitary system, two orthogonal radiographs are taken, one lateral and one anteroposterior. The following guidelines govern the decision of whether to accept or reject the initial placement of the tandem and ovoid system (12): (*1*) the distance from the sacrum to tandem and from the sacrum to the pubis, (*2*) the position of the tandem with respect to the midline, (*3*) the distance between the centers of the radio-opaque cervical markers and the flange, (*4*) the distance between the centers of the radio-opaque cervical markers and the vaginal ovoids. (*5*) the distance from the axis of the tandem to the posterior edge of the ovoids, and (*6*) the maximum displacement of the radio-opaque packing from a line extending caudad from the posterior edge of the ovoids and parallel to the tandem.

Monte Carlo calculations

The Monte Carlo *N*-particle transport code MCNPX version 2.5.c (13), a general purpose Monte Carlo code for transporting neutrons, photons, electrons, and other particles in various geometries, was used for the simulations in this study. Photon and electron transport can be modeled at energies ranging from 1 keV to 1000 MeV. Greater detail concerning the code has been previously published (13).