Int. J. Radiation Oncology Biol. Phys., Vol. 68, No. 4, pp. 1190–1198, 2007

0360-3016/07/$–see front matter

ELSEVIER

doi:10.1016/j.ijrobp.2007.02.036

PHYSICS CONTRIBUTION

POSTIMPLANT DOSIMETRY USING A MONTE CARLO DOSE CALCULATION ENGINE: A NEW CLINICAL STANDARD

Jean-François Carrier, Ph.D.,*† Michel D'Amours, M.Sc.,† Frank Verhaegen, Ph.D.,‡ Brigitte Reniers, Ph.D.,‡ André-Guy Martin, M.D., M.Sc.,† Éric Vigneault, M.D., M.Sc.,† and Luc Beaulieu, Ph.D.†

*Département de Radio-Oncologie, et Centre de Recherche du CHUM, Hôpital Notre-Dame du CHUM, Montréal, Québec, Canada; †Département de Radio-Oncologie et Centre de Recherche en Cancérologie de Université Laval, CHUQ Pavillon Hôtel-Dieu de Québec, Québec, Canada; and ‡Medical Physics Unit, McGill University, Montréal, Québec, Canada

Purpose: To use the Monte Carlo (MC) method as a dose calculation engine for postimplant dosimetry. To compare the results with clinically approved data for a sample of 28 patients. Two effects not taken into account by the clinical calculation, interseed attenuation and tissue composition, are being specifically investigated.
Methods and Materials: An automated MC program was developed. The dose distributions were calculated for the target volume and organs at risk (OAR) for 28 patients. Additional MC techniques were developed to focus specifically on the interseed attenuation and tissue effects.
Results: For the clinical target volume (CTV) D_{90} parameter, the mean difference between the clinical technique and the complete MC method is 10.7 Gy, with cases reaching up to 17 Gy. For all cases, the clinical technique overestimates the deposited dose in the CTV. This overestimation is mainly from a combination of two effects: the interseed attenuation (average, 6.8 Gy) and tissue composition (average, 4.1 Gy). The deposited dose in the OARs is also overestimated in the clinical calculation.
Conclusions: The clinical technique systematically overestimates the deposited dose in the prostate and in the OARs. To reduce this systematic inaccuracy, the MC method should be considered in establishing a new standard for clinical postimplant dosimetry and dose-outcome studies in a near future.

Prostate cancer, Low-dose-rate brachytherapy, Permanent seed implants, Iodine-125, Postimplant dosimetry, Monte Carlo.

INTRODUCTION

Permanent prostate brachytherapy is a procedure for treating early-stage prostate cancers (1, 2). The purpose is to implant radioactive seeds in the prostate under transrectal ultrasound guidance. The positions and number of seeds are selected using a treatment planning system to optimize the target-volume dose coverage and to minimize the dose to organs at risk (OARs).

The calculation formalism established by the AAPM Task Group No. 43 (3) (TG-43) is used in clinical practice and offers a fast method to evaluate the dose deposited for both the treatment planning and postimplant phases. Postimplant studies, usually performed about 1 month after the implantation procedure, assess the quality of the implant. A quantitative postimplant study is especially important, because permanent prostate implant is a treatment for which there is a dose-outcome correlation (4).

Recent studies from Chibani and Williamson (5, 6) and from Carrier *et al.* (7) showed differences in the calculated dose between the clinically approved TG-43 calculation technique and a more accurate Monte Carlo (MC) technique. The studies considered a few realistic anatomies and quantified the effect of two issues originally raised by the

Reprint requests to: Jean-François Carrier, Ph.D., Département de Radio-Oncologie, Hôpital Notre-Dame du CHUM, 1560 rue Sherbrooke Est, Montréal, Québec, Canada, H2L 4M1. Tel: (514) 890-8000, ext. 24682; Fax: (514) 412-7537; E-mail: jean-francois.carrier.chum@ssss.gouv.qc.ca

Selected for oral presentation at the Forty Eighth Annual Meeting of the American Society for Therapeutic Radiology and Oncology (ASTRO), November 5–9, Philadelphia, PA.

Supported by the National Cancer Institute of Canada (NCIC) with funds from the Canadian Cancer Society (CCS). JFC acknowledges financial support from the Fonds Québécois de la Recherche sur la Nature et les Technologies (FQRNT). FV is partially supported by the Fonds de Recherche en Santé du Québec (FRSQ).

L.B. and E.V. have an on going collaboration with Nucletron. No other conflict of interest.

Acknowledgment—The authors would like to acknowledge Nucletron for providing a DICOMRT export module to the SPOT planning system.

Received Dec 19, 2006, and in revised form Feb 14, 2007. Accepted for publication Feb 27, 2007.

AAPM Task Group No. 64 (8): interseed attenuation and tissue composition. These two effects are not taken into account by TG-43 based calculations. Earlier work by Mobit *et al.* (9) drew similar conclusions from a uniform seed distribution study.

The present article introduces an automated MC calculation system that allows for an extensive clinical study on many postimplant cases. For each patient, the clinical dosimetry calculation is compared to a more accurate MC calculation. The two specific effects, interseed attenuation and tissue composition, are studied independently and then combined for an overall comparison between a complete MC computation and the TG-43 based calculation.

The interseed attenuation, or mutual attenuation by neighboring seeds, is due to the proximity of neighboring seeds in a typical implant. The photons created in a seed A can interact with an adjacent seed B. In such a case, the energy deposited in seed B does not contribute to the treatment because it is not deposited in a tissue. The dose deposited in the seeds is not included in the dose–volume histograms or dose distributions. Globally, the calculated dose deposited in the prostate tissue is diminished if such an attenuation effect is considered. The dose to OARs is also modified. In the TG-43–based calculation, this decrease is not taken into account.

The clinical dose calculations assume a homogeneous tissue equivalent to water for all the organ and interorgan tissues. The tissue composition effect can be studied by comparing the dose calculated in water with that calculated in a realistic multitissue patient. This effect is potentially important for low-energy photon sources such as those used in low-energy prostate brachytherapy (^{125}I and ^{103}Pd). At such a low-energy regime, the photoelectric effect plays an important role and is very dependent on the atomic number of the irradiated tissue.

METHODS AND MATERIALS

This retrospective study focuses on postimplant dosimetry calculations for 28 patients treated with permanent brachytherapy between 2004 and 2005. The patient sample is presented in Table 1, which describes the state of the patients at the time of their postimplant study about 4 weeks after implantation. The choice of initial activity, 0.76 U (0.6 mCi), led to an average of 52 implanted seeds. For each patient, the clinical postimplant data (based on TG-43 formalism) is compared with new data obtained using MC-based techniques.

The implantation method and postimplant study

All patients were treated with intraoperative planning using the FIRST system with the ^{125}I selectSeed (Nucletron, Veenendaal, The Netherlands). A description of this system is readily available (10). In the operating room, the clinical target volume (CTV) (prostate gland) is contoured by the physician as is the urethra using transrectal ultrasound imaging. The planning target volume is the CTV plus a margin of 3–4 mm. An inverse planning dose optimization is then performed and aims at a dose to the planning target volume of 144 Gy, V_{100} of 100%, V_{150} between 60% and 70%, V_{200} less than 30%, whereas the V_{150} to the urethra is kept under 10% (target value of 0%).

For the postimplant dosimetry to be established, a computed tomography (CT) scan is performed on the patient about 4 weeks after implantation with slice thickness of 2.5 mm. The seeds are detected on the CT images and X-ray films for accurate seed counts. The organs are contoured by the treating physician on the CT dataset and a detailed postimplant dose distribution is obtained with a dose calculation engine.

For this study, the clinical dose calculation engine is from the SPOT PRO system (Nucletron). The engine manipulates dosimetry reference data (dose–rate constant, anisotropy function, and radial dose function) (11) taken from Karaiskos *et al.* (12) and Anagnostopoulos *et al.* (13). These data were evaluated by Rivard *et al.* (14).

The MC simulation method

A more accurate dose calculation can be achieved with the MC method. To sequentially study many patients, we developed a new MC program that automatically acquires the patient data, launches the simulation, and analyzes the dose distribution. Each step is automated and simple commands are needed to operate the system. The MC technique realistically reproduces the patient anatomy, seed geometry, and photon irradiation.

Patient anatomy: For a MC simulation, the three-dimensional (3D) patient is automatically built by stacking more than 200,000 voxels. The volume of a voxel is 0.0042 cm^3 (1.3 mm × 1.3 mm, with a 2.5-mm thickness). The voxelized region is a 10 × 10 × 10 cm^3 cube centered on the center-of-mass of the seed distribution. This region is inserted in a bigger water phantom with dimensions of 40 × 40 × 80 cm^3, representing the whole patient. This procedure is needed because the CT examination is zoomed in on the prostate region.

Each voxel is filled with one of more than 200 different available tissue combinations of variable densities and elemental compositions. The mixtures include combinations of five tissue types: muscle, adipose tissue, rectum tissue, bladder tissue, and prostate tissue (15). For each voxel, an automatic tissue-selection algorithm determines the elemental composition and the density of the voxel. If the voxel is inside a contoured organ (bladder, rectum, or prostate), the elemental composition of the corresponding tissue is selected. The density is then set according to the CT attenuation data. Interorgan tissue is modeled as a linear combination of

Table 1. Description of the patient sample (total, 28 cases)

	Average	Standard deviation	Maximum	Minimum
Clinical target volume	31 cm^3	9 cm^3	59 cm^3	17 cm^3
Urethra volume	0.56 cm^3	0.27 cm^3	1.3 cm^3	0.3 cm^3
Seed number	52	9	72	35
Initial source strength	0.77 $U_{(0.61\ mCi)}$	0.01 U	0.78 U	0.75 U