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# Dosimetric effect of tissue heterogeneity for $^{125}$I prostate implants

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ABSTRACT

*Aim:* To use Monte Carlo (MC) together with voxel phantoms to analyze the tissue heterogeneity effect in the dose distributions and equivalent uniform dose (EUD) for $^{125}$I prostate implants.

*Background:* Dose distribution calculations in low dose-rate brachytherapy are based on the dose deposition around a single source in a water phantom. This formalism does not take into account tissue heterogeneities, interseed attenuation, or finite patient dimensions effects. Tissue composition is especially important due to the photoelectric effect.

*Materials and methods:* The computed tomographies (CT) of two patients with prostate cancer were used to create voxel phantoms for the MC simulations. An elemental composition and density were assigned to each structure. Densities of the prostate, vesicles, rectum and bladder were determined through the CT electronic densities of 100 patients. The same simulations were performed considering the same phantom as pure water. Results were compared via dose–volume histograms and EUD for the prostate and rectum.

*Results:* The mean absorbed doses presented deviations of 3.3–4.0% for the prostate and of 2.3–4.9% for the rectum, when comparing calculations in water with calculations in the

*Abbreviations:* LDRBT, low dose-rate brachytherapy; AAPM TG, American Association of Physicists in Medicine Task Group; PS, planning system; MC, Monte Carlo; CT, computerized tomography; MBDCA, model-based dose calculation algorithm; DVH, dose–volume histogram; *d*DVH, differential dose–volume histogram; EUD, equivalent uniform dose; TCP, tumor control probability (TCP); NTCP, normal tissue complication probability; EBRT, external beam radiotherapy; OAR, organ at risk; HT, heterogeneous; W, water.

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heterogeneous phantom. In the calculations in water, the prostate $D_{90}$ was overestimated by 2.8–3.9% and the rectum $D_{0.1cc}$ resulted in dose differences of 6–8%. The EUD resulted in an overestimation of 3.5–3.7% for the prostate and of 7.7–8.3% for the rectum.

*Conclusions:* The deposited dose was consistently overestimated for the simulation in water. In order to increase the accuracy in the determination of dose distributions, especially around the rectum, the introduction of the model-based algorithms is recommended.



## 1. Background

Low dose-rate brachytherapy (LDRBT), using $^{125}$I and $^{103}$Pd permanent implants, has become very popular in the treatment of early stage prostate cancer. The American Association of Physicists in Medicine (AAPM) Task Group No. 43 (TG-43)[1] and the updated report (TG-43U1)[2] recommended a water-based dose calculation formalism for this low-energy emitting sources. The dose deposition is described around a single source in a spherical water phantom and then interpolated in order to obtain tables of absorbed dose to be used in the planning systems (PS). However, the influence of tissue and applicator heterogeneities, interseed attenuation, or finite patient dimensions can significantly change the absorbed dose values in the PS.[3] Moreover, for low-energy sources, the photoelectric effect predominates and differences in the mass-energy absorption coefficients between water and other tissues may result in significant differences in dose distributions.

Chibani et al.[4] investigated the effects of seed anisotropy and interseed attenuation for $^{103}$Pd and $^{125}$I prostate implants using Monte Carlo (MC) methods for two idealized and two real prostate implants. Absolute total dose differences between full MC simulations and point-source dose-kernel superposition were as high as 7.4% for the idealized model and 6.1% for the clinical model for the $^{103}$Pd implants and 4.4% for the idealized and 4.6% for the clinical for the $^{125}$I. Carrier et al.[5] found deviations of 6.8% for the prostate $D_{90}$ parameter (dose achieving 90% of the target volume) when comparing a clinical technique to a full MC simulation, of which 4.3% were due to the interseed attenuation and 2.5% to the tissue composition. Hanada et al.[6] compared the TG-43U1 parameters, $\Lambda$ and $gL(r)$, using MC simulations, for water and prostate tissue. The comparison of the $D_{90}$ prostate parameter showed a dose underestimation of 1.7% for the prostate tissue relative to water. CT-based studies comparing homogeneous water phantom with a heterogeneous phantom revealed a dose underestimation of 2.8 Gy in $D_{90}$[7] and a decrease of 5.6% in the tissue irradiated volume.[8]

In order to overcome these issues, new model-based dose calculation algorithms (MBDCA) are now available for brachytherapy. These algorithms account for heterogeneity corrections. The recently released AAPM report TG-186[3] provides guidance for the use of these algorithms in terms of the dose-specification medium, voxel-by-voxel interaction correction cross sections, and a commissioning process.

## 2. Aim

The purpose of this work was to understand the importance of these MDCAs in terms of the tissue heterogeneity correction. Dose distributions of LDRBT treatments of prostate cancer with $^{125}$I permanent implants using Monte Carlo methods were performed in a water medium and in a heterogeneous medium with the density and tissue composition of the prostate and surrounding tissues, and the values compared. For the simulations, we used two anthropomorphic voxel phantoms extracted from the computed tomography (CT) of two patients with prostate cancer. Dose deposition was evaluated on a voxel-by-voxel basis for the prostate and the rectum and compared via dose–volume histograms (DVH), equivalent uniform dose (EUD), tumor control probability (TCP) and normal tissues complication probability (NTCP).

## 3. Materials and methods

### 3.1. *Monte Carlo dose calculations*

The simulations were performed using the MCNPX code version 27a[9] and the default photon scattering cross section tables from the National Nuclear Data Center's ENDF/B-VI.8 library[10] based on EPDL97.[11] CT DICOM images of two patients with prostate cancer were segmented using the ImageJ version 1.44p[12] software and converted into the MCNPX code in order to create two voxel phantoms. A CT of a patient with a small prostate (prostate A: 31 cm$^3$) and a big prostate (prostate B: 109 cm$^3$) were chosen. The size of each voxel is the same as the CT voxel: 0.94 mm × 0.94 mm × 5 mm. To each structure of interest, a given density and elemental composition (Table 1) were assigned. The elemental composition of the skin, bladder, rectum, prostate, spinal cord, bones and muscle, as well as skin density, were taken from the ICRP publication 89.[13] Elemental compositions of the spinal cord and residual tissue, as well as the respective densities, and muscle and bone densities were taken from the ICRU 44 report.[14] Finally, the densities of the prostate, vesicles, rectum and bladder were determined through the CT electronic densities of 100 patients with prostate cancer. These patients had a median age of 68 years old, median of prostate volume of 58.2 cm$^3$, and a median Gleason score of 7. In order to evaluate the tissue heterogeneity influence in the dose distributions, a comparison