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Calculation of Changes in Radiation Exposure due to Prostate Displacement in Permanent Prostate Brachytherapy

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Abstract

Background: Limited studies are available on the calculation of radiation exposure and its associated risks for people in contact with patients who have been treated with permanent prostate brachytherapy. In this study the changes in the radiation exposure were calculated in different stages of the bladder fullness in prostate seed brachytherapy.

Methods: Magnetic resonance images of three patients with full and empty bladders and different prostate sizes (32-71 mL; mean 54.6 mL) were used for Monte-Carlo dose calculations. Dose rate to skin for each patient was calculated using MCNP4c, MCNPX.

Results: There were no significant differences between dose distribution in the skin relative to the changes in the prostate position due to bladder filling (P=0.05).

Conclusion: Our results showed a negligible change in radiation exposure around the patient due to prostate displacement after bladder filling.

Keywords: Prostate displacement, Prostate brachytherapy, Radiation exposure, Monte-Carlo, MCNP

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Introduction

Currently, transrectal ultrasound guided prostate seed brachytherpy (TRUS) using Iodine-125 (1-125) or Palladium-103 (Pd-103) has become a well-recognized treatment for patients with localized prostate cancer.[1] It is well known that the anatomical position of the prostate gland can be affected by physiological displacements of surrounding pelvic organs such as the rectum and bladder.[2, 3] Lotfi et al. have reported that bladder filling as

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Table 1. Patient characteristics.

Characteristic	Mean (range)
Age (years)	54.0 (26-67)
Maximal anterior-posterior dimensions of the patients at the prostate level (mm)	44.6 (23.3-55.9)
Maximal lateral dimensions of the patients at the prostate level (mm)	47.2 (24.4-59.1)
Prostate volume (mL)	54.6 (32-71)

well as rectal distension result in prostate displacements, especially in the anterior and cranial directions.[4] These significant changes in prostate location, in brachytherapy, play a critical role in the total dose delivered to each organ. Because the risk of radiation exposure to human physiological systems is well known,[5-7] there is also a significant risk of radiation exposure to people in contact with patients who have undergone prostate brachytherapy.

Many studies have been done to quantify the effects of radiation exposure in this group of at-risk people.[8-17] Cattani et al.[11] have shown that a total of 7.7 days for I-125 and 21.6 days for Pd-103 at a 50-cm distance from the patient's skin are needed to reach the annual dose limit recommended by the National Radiation Commission (NRC). Smathers et al.[17] have suggested these times as 20 hours for I-125 and 500 hours for Pd-103. Daure et al.[15] have shown that only patients with I-125 implantation should avoid sleeping in the spoon position with other adults or carrying children in their arms for at least 20 days after the implant. Also, in accordance with "as low as reasonably achievable" (ALARA) recommendations, it would be safer to keep a distance of one meter with these patients for at least one half-life of the respective radioisotopes.[11] These findings suggest that there should be a period of concern for the safety of people in contact with patients treated by seed implants for their prostate cancer. However, no prior work has been done to calculate the changes in radiation exposure after seed implantation related to changes in the prostate location due to bladder filling. No previous studies calculated the radiation absorbed dose to the skin from the radioactive seeds in the prostate after changes in the geometry of the pelvic organs. The aim of this study was to calculate radiation exposure after prostate seed implantation in different stages of bladder fullness using two versions of Monte-Carlo (MC) codes; namely MCNP4c2 and MCNPX.

Materials and Methods

Three patients with different prostate sizes (32-71 mL; mean 54.6 mL) were selected to participate in this study. Participants gave written consent to the study and underwent diagnostic pelvic magnetic resonance imaging (MRI) in the supine position. Table 1 illustrates the patient characteristics. The study was approved by the Radiology Research Board at the Shiraz University of Medical Sciences, Shiraz, Iran.

A 1.5-tesla MRI system (Avanto, Siemens, Germany) was used to collect sequential axial and sagittal images of the patients' prostates. Routine T1- and T2-weighted sequences with a pelvic coil were used for MRI. Contrast agent was not used. For each patient, four sets of images in three stages were obtained in an axial T1-weighted (T1-w) turbo factor (spin echo) sequence; field of view [FOV]: 36 cm; matrix: 512×512; time repetition [TR]/time echo [TE]: 718/10 ms; slice thickness [ST]: 3 mm, T2-weighted (T2-w) turbo factor (spin echo) sequence; FOV: 36 cm; matrix: 512×512; TR/TE: 3200/73 ms; ST: 3 mm, and in a sagittal T1-w turbo factor spin echo sequence; FOV: 25 cm; TR/TE: 350/12 ms; ST: 4 mm with 0 mm gap. Patients were imaged in the supine position on a flat tabletop and set up using a set of triangulation lasers. Patients were instructed to drink one liter of water one hour before planning the first MRI, after which they were instructed to empty their bladders as completely as possible before planning the second MRI. This regimen was intended to ensure a comfortably full or empty bladder at the time of imaging. An expert radiologist in prostate

Table 2. Normalized dose rates.

Patient	Normalized dose rate	
	Bladder empty	Bladder full
Patient 1	0.092	0.089
Patient 2	0.094	0.092
Patient 3	0.098	0.097
Average (SD)	0.094 (0.003)	0.092 (0.004)

MRI interpretation reviewed all MRI sets and contoured the prostate and skin for each patient. Magnetic resonance images were initially acquired using a separate program and then imported into a software program (Scan to MCNP) to convert to MCNP codes (MCNP4c2 and MCNPX).[18] Scan to MCNP software enables one to accurately convert MRI geometry to the MCNP code. Monte-Carlo (MC) is a general N-particle transport code, which considers photoelectric, coherent, Compton and pair production interaction processes. In the MC codes the prostate was simulated using 70-110 (average 88) seeds (EchoSeed Model 6733 I-125 brachytherapy source)[19] depending on the size of the patient's prostate. The seeds were placed in a symmetric arrangement on the periphery of the prostate at a radius of 1.2 cm from the center to ensure a maximum distance from the urethra and 3 mm from the prostate border.[20] There are several tally types available in the MCNP4c2 and MCNPX codes for dose calculation.[21] In MCNP4c2 the F4 tally calculates the average photon energy fluence over the tally cell in the unit of MeV/cm^2/photon, which is then converted to the dose with the unit of MeV/g/photon by incorporating the updated mass-energy-absorption coefficients (cm^2/g). The energy-dependent mass energy absorption coefficient of the simulating medium was taken from the NIST-released library of Hubbell and Seltzer.[22] While in MCNPX, mesh tally directly calculates the dose at a given point per photon by determining the average energy deposition over a tally cell in the unit of MeV/g/particle. In this project, the F4 tally in MCNP4c2 was used to conform the seed with the published results by Meigooni et al.[19] Mesh tally in MCNPX was used to calculate skin dose around the multi-seed brachytherapy implant in a homogeneous water medium. The normalized dose rate (dose rate at skin surface relative to the prescribed dose rate) was calculated for each patient in two MRI stages with empty and full bladders. Mean values and standard deviations were calculated, and statistically significant differences between calculations were evaluated.

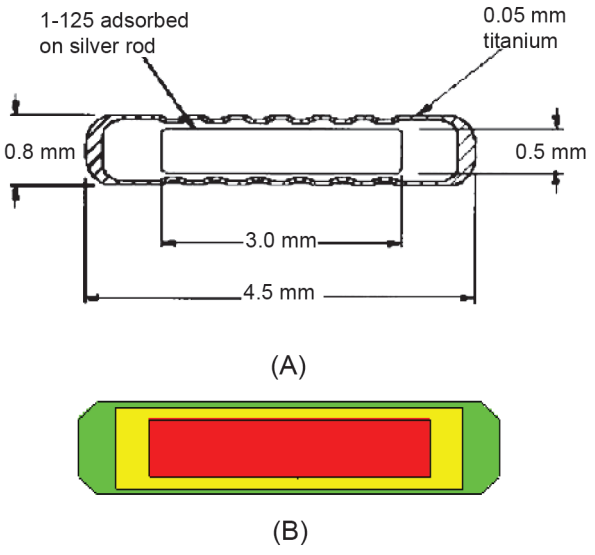

Figure 1. Schematic (A) and simulated (B) diagram of model 6733 seed in the MC codes.

Statistical analysis

Data were analyzed with SPSS version 10.0 and the Mann-Whitney U test. A P value of ≤ 0.05 was considered significant.

Results

Dose distributions in the skin that resulted from multi-seed implants of three patients in two different stages (full and empty bladders) using Model 6733 I-125 sources were calculated with the Monte-Carlo simulation technique. Table 2 shows the normalized dose rates.

Figure 1 shows the schematic and simulated diagram of the seed Model 6733 in MC codes and the implant pattern is shown in Figure 2.

Figure 3 illustrates the fused Monte-Carlo calculated isodose distribution of the multi-seed implant with the corresponding MRI in the mid-sagittal view using I-125 seeds. Figure 4 shows the corresponding 3D dose distribution on the middle slice (Z=0) for the prostate implant in patient

number 2, using Model 6733 seeds as the source. Statistical analysis showed no significant difference between dose distributions in the skin relative to the changes in the prostate position due to bladder filling in prostate seed brachytherapy (P=0.376).

Discussion

Since the introduction of brachytherapy as a treatment for prostate cancer in the 1980s, this treatment modality has remained under development. Many of its aspects, such as implant volume and dose distribution, have been studied. However, there are still major unsolved issues in radiation exposure for people in contact with patients who have been treated with permanent prostate brachytherapy. In this study, multi-seed treatment planning for prostate implants in three patients was performed using images of each patient in the supine position with full and empty bladders. These simulations were performed with 70-110 (average 88) seeds using EchoSeed Model 6733 I-125 as the brachytherapy source with a peripheral loading scheme in the MCNP4c2 and MCNPX Monte-Carlo codes. The images used for modeling were from patients with different prostate sizes ranging from 32 mL to 71 mL (mean 54.6 mL). We have focused on the calculations of skin dose relative to changes in prostate location due to bladder filling. Using the Mann-Whitney U test, we found no significant difference between dose distributions in the skin due to bladder filling (P=0.05). This may be due to the distance from the skin to the prostate and the rapid decrease in dose gradient between the prostate and healthy surrounding organs. Even though dose distributions were calculated using actual cases with different prostate sizes, slight differences in the values for the absorbed dose to the skin can be expected due to the varying pelvic and prostate volumes.

Our results are in agreement with those reported by Dauer et al.[15] and Smathers et al.[17] In both of these studies, the radiation dose rates were measured both at the anterior skin surface and some distances from it, whereas we used MC

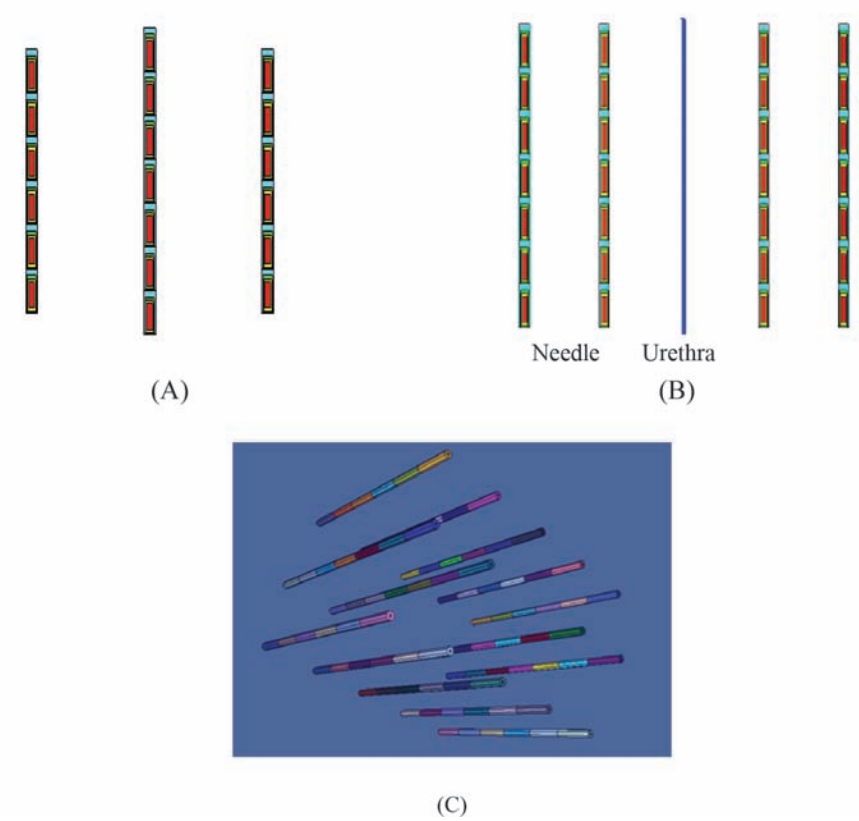

Figure 2. Schematic diagram of seed arrangement in the prostate of patient 2 for implant using the Model 6733 seeds, sagittal (A), anterior (B), isometric view (C).

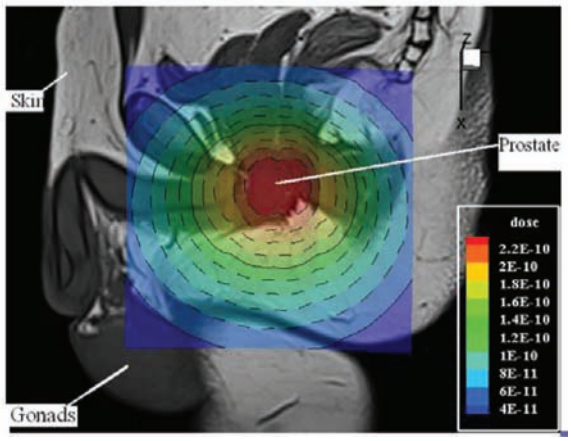

Figure 3. Fused image of the dose distribution with MRI, sagittal view for patient 2 (dose/particle).

simulations to calculate dose rate to skin. Additionally, these studies did not consider the movement of the prostate due to bladder filling and its effect on the dose distribution. Therefore, the amount of radiation dose to the skin and to any individuals who come into contact with the implanted patients relative to different stages of bladder fullness can be considered a negligible and irrelevant factor in the therapeutic decision. However, it is important to evaluate the influence of the changes in the shape and location of the prostate due to bladder filling and rectal distension in the dosimetry of the prostate's neighboring organs.

The results of this study support the use of the MC simulation technique in future treatment-planning systems to achieve accurate dose distributions throughout the implant volume. The only disadvantage of the Monte-Carlo simulation in this study was the running time. The required calculation time was 93.5 hours (in a Pentium IV processor) for a patient with a 110 seed implant, a history number of 4×10^8 Particle, which provides a statistical uncertainty of less than 5%. This exceeds the time available in a clinical practice. Thus, increased processing power along with more efficient algorithms and optimization techniques will be necessary to incorporate the MC

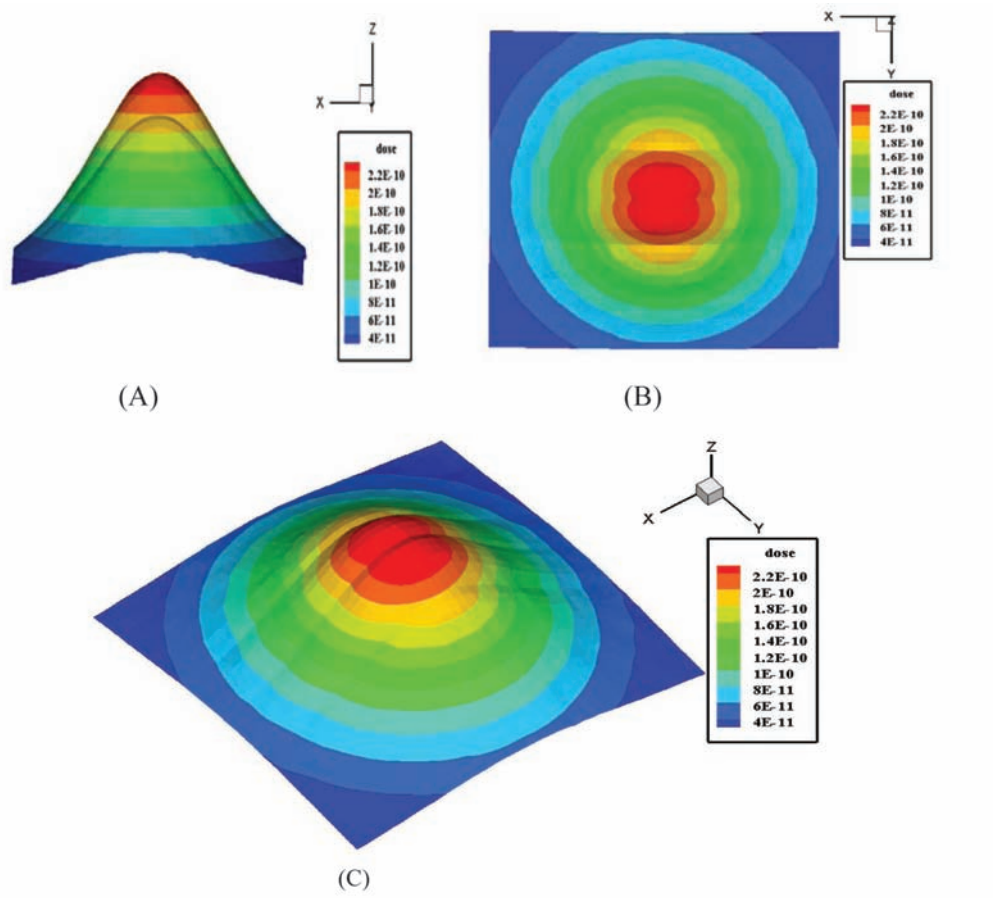

Figure 4. The Monte-Carlo simulated 3D dose distribution on the middle slice (Z=0) for the prostate implant in patient 2. Lateral view (A), top view (B), isometric view (C).

technique in to routine brachytherapy treatment planning.

Conclusion

This retrospective study indicates that changes in the skin radiation exposure due to bladder filling in patients who receive a permanent prostate implant with radioactive seeds are negligible.

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