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Assessment of radiation safety instructions to patients based on measured dose rates following prostate brachytherapy

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ABSTRACT

PURPOSE: To validate radiation safety instructions to patients and to evaluate the potential radiation doses to members of the public after ¹²⁵I or ¹⁰³Pd prostate implantation.

METHODS AND MATERIALS: Radiation dose rate measurements were made in the immediate postoperative period on 636 consecutive patients with stage T1-T2 prostate cancer who underwent transperineal ¹²⁵I or ¹⁰³Pd implantation at Memorial Sloan-Kettering Cancer Center during the period from August 1995 through January 2003.

RESULTS: The mean radiation dose rate at the anterior skin surface following a prostate implant was 37 μ Sv/hr for ¹²⁵I and 8 μ Sv/hr for ¹⁰³Pd. At 30 cm from the anterior skin surface, these dose rates were reduced to 6 μ Sv/hr for ¹²⁵I and 3 μ Sv/hr for ¹⁰³Pd. At 1 m from the anterior skin surface the dose rates from both types of implants were reduced to less than 1 µSv/hr. The effect of body weight on dose rates from ¹²⁵I sources was examined for a select sub-group of patients and the measured dose rate was found to decrease with increasing body weight. In another group of patients, dose rate measurements were made on both lateral skin surfaces and were less than 16.8 µSv/hr in all cases. Assuming a 33% occupancy factor and utilizing the mean measured dose rate for ¹²⁵I, the time required to reach an effective dose equivalent limit of 5 mSv for caregivers was estimated to be 19 days on contact with the skin surface. Using a similar calculation, the lifetime doses for ¹²⁵I at a distance of 30 cm from the anterior skin surface, as well as the lifetime doses for ¹⁰³Pd on contact with the skin surface and at 30 cm from the anterior skin surface can be shown to be less than 5 mSv.

CONCLUSIONS: The large number of cases available for this study permits a validation of radiation safety recommendations and provides concrete information from which the permitted exposure times following implantation can be estimated. The data support the conclusion that patients treated with these implants do not represent a radiation risk to members of the public. © 2004 American Brachytherapy Society. All rights reserved.

Keywords: Prostate cancer; Brachytherapy; Radiation safety; Dose rate

Introduction

The use of ¹²⁵I for interstitial implantation was developed in the 1960s and various sites including the prostate were implanted with ¹²⁵I seeds in the 1970s (1). During this period, the release of patients from medical confinement relied on

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the so-called "30 mCi or 5 mR/hr" rule, a rule that resulted almost exclusively from the use of ¹³¹I sodium iodide for radiopharmaceutical therapy (2). It seemed that this rule could not apply to ¹²⁵I implants and some alternative approach was needed. In 1970, the National Council on Radiation Protection and Measurements (NCRP) published report number 37 (3) which recommended that patients be released based on a measured exposure rate and an expected total dose to persons in the vicinity of the patient of less than 5 mSv to total decay.

In the 1980s, revised implantation techniques based on the use of ultrasound resulted in a renaissance for the use of 125 I seeds in prostate implantation (4, 5). Around the same

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time, the use of ¹⁰³Pd seeds was also introduced as an alternate treatment modality. The popularity of seed implantation has continued to increase and this technique has specific appeal to many patients. Currently, more than 40,000 implantations for prostate cancer are performed annually in the US, and the number of permanent implants now exceeds the number of radical prostatectomies (6).

In the United States of America, the Nuclear Regulatory Commission (NRC) regulates the medical uses of radioactive byproduct material and specifies requirements for the release from facility control of patients with radioactive seed implants. Section 274 of the Atomic Energy Act of 1954, as amended, allows the NRC and a State to enter a regulatory agreement (7), whereby the State assumes regulatory authority for these materials. Therefore, requirements discussed in this article may be regulated directly by an "Agreement State" that must have a program for the control of radiation hazards that is compatible with the NRC's program. As such, we will therefore consider the NRC regulations as guiding regulations. According to NRC regulation a licensee may authorize the release from its control of any individual who has been administered implants containing byproduct material if the total effective dose equivalent (TEDE) to any other individual from exposure to the released individual is not likely to exceed 5 mSv and the TEDE to a member of the general public is not likely to exceed 1 mSv(3, 8). In addition, prostate brachytherapy patients are to be given instructions on actions recommended to maintain doses to other individuals as low as is reasonably achievable (ALARA), because the total activity of ¹²⁵I or ¹⁰³Pd is typically greater than 2 mCi or 8 mCi activity limits specified in a reference table (8). This requirement is consistent with the NRCP recommendations that all exposures be maintained ALARA (9).

The NRC does not require a specific set of patient instructions. Instead, instructions are left to the discretion of the institution. Release instructions to patients, therefore, have relied on a community consensus developed from literature and practice. They were generally based on limiting time in the vicinity of the patient and special concern with regard to children and pregnant women (10). Typical instructions have included: not holding children in the patient's lap and not sleeping in the "spoon" position (i.e., in close contact with anterior surface of the implanted patient) with a partner (11).

There is little peer-reviewed or corroborating data available regarding measured dose rates or the variability of dose rates among patients following prostate brachytherapy (12, 13). The purpose of this study was to utilize the large data set available at Memorial Sloan-Kettering Cancer Center to broaden our knowledge of exposure and risk, to validate the typical radiation safety instructions given to patients, and evaluate the variability of radiation dose rates to members of the public after ¹²⁵I or ¹⁰³Pd prostate implantation.

Methods and materials

Six hundred thirty-six consecutive patients with stage T1-T2 prostate cancer who underwent transperineal ¹²⁵I (557 cases) or ¹⁰³Pd (79 cases) implantation at Memorial Sloan-Kettering Cancer Center from August 1995 through January 2003 were studied. Implants were performed as previously described (4, 5).

Radiation dose rate measurements were obtained in the immediate postoperative period (i.e., within 1-2 h) at the surface of the anterior skin at the point of the symphysis pubis and at 100 cm perpendicular from the surface of the anterior skin. A subset of patients were measured at 30 cm perpendicular from the surface of the anterior skin (representing the "lap" area dose rate) and at the skin surface of the right and left lateral torso at the locations of the femoral heads. Dose rate measurements were obtained using a Keithley model 36100 x/ γ radiation ionization chamber survey meter calibrated with ¹³⁷Cs. This unit has generally linear response through the ¹²⁵I and ¹⁰³Pd energy range. Calibration-corrected readings for ¹²⁵I and ¹⁰³Pd energies were utilized in this study. The radionuclide utilized, either ¹²⁵I or ¹⁰³Pd, the total activity (MBq) implanted, dose rate measurements (µSv/hr), and in 38¹²⁵I cases the preoperative weight (kg), were recorded and later evaluated retrospectively.

The lifetime exposure at various distances from the patient was calculated using the following equation (8):

$$D(\infty) = 34.6T_P \dot{D}(0)E$$

where:

 $D(\infty) =$ lifetime exposure in μ Sv;

 T_P = physical half-life in days;

 $\dot{D}(0) =$ dose rate at a given distance immediately following implantation,

at time t_0 (µSv/hr);

E = Occupancy factor based on the fraction of time a person could be in the vicinity of the implanted patient.

The total dose over a given time period (from time t_0 to time t) is calculated using the following equation (8, 13):

$$D(t) = 34.6T_P \dot{D}(0)E[1 - e^{-0.693t/T_P}]$$

where D(t) = total dose over a given time period (t_o to t), where $t_0 = 0$.

The length of time to reach a given total dose was calculated by rearranging the prior equation and solving for t:

$$t = \left[\frac{-T_P \ln\left(1 - \frac{D(t)}{34.6T_P \dot{D}(0)E}\right)}{0.693}\right]$$

Calculations were performed using a half life (T_P) of 60.14 days for ¹²⁵I and 16.96 days for ¹⁰³Pd. In addition, two sets of calculations were made using the mean dose measurements. In the first set of calculations the occupancy factor was assumed to be 1 (100%) representing the dose to a caregiver who is present for 100% of their time at the distance at which the dose rate was measured (i.e., on contact or at 30 cm from the anterior surface of the patient). In the second set

of calculations the occupancy factor was assumed to be 0.33 representing the dose to a caregiver that is present 1/3 of any day at the given distances. This second set of calculations was intended to represent the typical sleeping arrangement of a caregiver near the patient for 8 out of 24 h or as a conservative estimate for other members of the public in close proximity to the implanted patient.

Results

The ¹²⁵I and ¹⁰³Pd results are summarized in Tables 1 and 2. The mean radiation dose rate at the anterior skin surface following an ¹²⁵I implant was 37.3 μ Sv/hr (range, 0.9–221 μ Sv/hr). The mean radiation dose rate at 30 cm from the anterior skin surface, i.e., the lap area, following an ¹²⁵I implant was 6.0 μ Sv/hr (range, 0.9–33 μ Sv/hr). Figures 1 and 2 show the left-skewed variability in dose rate with 90% of the measured values \leq 70 μ Sv/hr for anterior skin surface and a similar percentage of the measured values \leq 15 μ Sv/ hr for 30 cm.

In both cases, the dose rate was found to correlate directly with ¹²⁵I implanted activity. Figures 3 and 4 show these correlations.

The mean radiation dose rate at the anterior skin surface following a ¹⁰³Pd implant was 8.2 μ Sv/hr (range, 0.9–64 μ Sv/hr). The mean radiation dose rate at 30 cm from the anterior skin surface, i.e., the lap area, following a ¹⁰³Pd implant was 2.9 μ Sv/hr (range, 0.9–15 μ Sv/hr). Figure 5 shows a similarly left-skewed variability in dose rate similar to that seen with ¹²⁵I, with 90% of the values $\leq 18.6 \mu$ Sv/ hr for dose rates at the anterior skin surface. As in the ¹²⁵I cases, the dose rate was found to correlate with ¹⁰³Pd implanted activity (Fig. 6).

All dose rates at 1 m from the anterior skin surface following either an ^{125}I or a ^{103}Pd implant were $<1\,\mu Sv/hr$ and dose rates at the lateral skin surfaces were $<16.8\,\mu Sv/hr$. Additionally, for ^{125}I implants, Fig. 7 shows that activity normalized surface anterior dose rates ($\mu Sv/hr/GBq$) generally decrease with increasing patient weight.

Tables 3 and 4 list the calculated lifetime doses and the time in days to reach the 5 mSv limit specified in the NRC

regulations (2). Table 3 shows the results assuming 100% occupancy while Table 4 shows the results assuming 33% occupancy. For 100% occupancy, the lifetime doses from ¹²⁵I or ¹⁰³Pd on contact with the anterior skin surface were 77.6 mSv and 4.8 mSv, respectively. The 100% occupancy lifetime doses from ¹²⁵I or ¹⁰³Pd at 30 cm from the anterior skin surface were 12.5 mSv and 1.7 mSv, respectively. For 100% occupancy, the times required to reach the 5 mSv limit were 5.8 days and 44.4 days for ¹²⁵I at contact and 30 cm respectively, while the times required to reach the 1 mSv limit were 1.1 days and 7.3 days, respectively. Because the ¹⁰³Pd lifetime doses assuming 100% occupancy both at contact and at 30 cm were less than 5 mSv, calculated times to reach 5 mSv are not applicable.

Assuming 33% occupancy, the lifetime doses from ¹²⁵I or ¹⁰³Pd on contact with the anterior skin surface were 25.6 mSv and 1.6 mSv, respectively. Using a similar occupancy factor, lifetime doses from ¹²⁵I or ¹⁰³Pd at 30 cm from the anterior skin surface were 4.1 mSv and 0.6 mSv, respectively. Again using the same occupancy factor, the time required to reach the 5 mSv regulatory limit was 18.8 days on contact for ¹²⁵I, while the times required to reach the 1 mSv general public regulatory limit were 3.5 days for contact and 24.1 days for 30 cm. Using ¹⁰³Pd seeds and assuming 33% occupancy, the time required to reach the 1 mSv general public limit was 24.3 days at the anterior skin surface. Because the calculated lifetime doses using the 33% occupancy with ¹²⁵I at 30 cm and with ¹⁰³Pd both on contact and at 30 cm were all less than 5 mSv, calculated times required to reach 5 mSv were not applicable.

The cases discussed above will generally overestimate member of the public doses, as they are based on contact and 30 cm direct dose readings. Using a conservative dose rate of 1 μ Sv/hr at 1 m as well as a conservative occupancy of 33%, the lifetime doses to members of the public are estimated to be below 0.7 mSv and 0.2 mSv for ¹²⁵I and ¹⁰³Pd, respectively. Both of these values are below the 1 mSv general public limit.

Discussion

The study reported here is based a large set of direct dose measurements taken immediately following implantation.

Tabl	e 1	
¹²⁵ I 1	results	summary

	Sample		Standard			
Description	size	Mean	deviation $(+/-)$	Minimum	Maximum	
Total activity (GBq)	557	1.50	0.38	0.48	2.67	
Surface anterior dose rate (µSv/hr)	545	37.3	31.2	0.88	221	
Activity normalized surface anterior dose rate (µSv/hr/GBq)	545	25.3	20.6	0.55	203	
30 cm anterior lap dose rate (μ Sv/hr)	398	6.00	4.90	0.88	32.7	
Surface lateral dose rate (µSv/hr)	87	1.92	2.22	0.88	16.8	
Pre-operative weight (kg)	38	86.4	11.0	65.9	115	

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Table	2	
$^{103}\mathrm{Pd}$	results	summary

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Sample size	Mean	Standard deviation (+/-)	Minimum	Maximum	
79	4.30	2.34	1.44	11.9	
72	8.19	11.1	0.88	63.6	
72	1.87	1.93	0.12	8.15	
17	2.91	3.57	0.88	15.0	
45	1.38	1.04	0.88	6.19	
	Sample size 79 72 72 72 17 45	Sample size Mean 79 4.30 72 8.19 72 1.87 17 2.91 45 1.38	Sample size Standard deviation (+/-) 79 4.30 2.34 72 8.19 11.1 72 1.87 1.93 17 2.91 3.57 45 1.38 1.04	Sample size Standard deviation (+/-) Minimum 79 4.30 2.34 1.44 72 8.19 11.1 0.88 72 1.87 1.93 0.12 17 2.91 3.57 0.88 45 1.38 1.04 0.88	

Such a data set facilitates the useful evaluation of the variability of patient dose rates (Figs. 1, 2, and 5), as well as providing a foundation for generic assumptions using mean values, representing typical patients. The mean dose rates following ¹²⁵I or ¹⁰³Pd permanent brachytherapy implantation are generally quite low. In all cases, dose rates were found to be less than the regulatory exposure dose rates at 1 m of 0.01 mSv/hr for ¹²⁵I or 0.03 mSv/hr for ¹⁰³Pd (3, 8) that permit patient discharge from the hospital.

There is a marked variability in dose rates measured from patient to patient (Figs. 1, 2, and 5). The wide range of reported dose measurements are due in large part to the variability in total activity implanted and the variability in depth of the prostate. Figure 7 shows that activity normalized surface anterior dose rates (μ Sv/hr/GBq) generally decrease as patient weight increases. These results are corroborated by the results of Smathers *et al.* (12), who reported that increasing patient weight generally increased the depth at which the prostate was located. Thus, with more overlying tissue as shielding, lower dose rates are expected, and are here generally observed, for heavier patients.

Although differing in methodology and numbers of data points, a few previous studies support the findings of our research. Smathers *et al.* measured dose rates from 38 ¹²⁵I

or ¹⁰³Pd prostate brachytherapy patients and suggested that patients need not be concerned about being a radiation risk to the general public following their procedure (12). Michalski *et al* (13). measured patient exposures and members of patient family exposures from 44 patients receiving a permanent prostate brachytherapy implant (either with ¹²⁵I or ¹⁰³Pd) using optically stimulated dosimeters to measure dose. They concluded that the exposure to family members from those patients was well below the NRC limits (3, 8).

As performed in this present study, direct dose measurements from a large number of prostate brachytherapy implantation patients provides specific information for assessing the typical instructions to patients to keep members of the family and patient caregiver doses as low as reasonably achievable. Although exposure estimates based on measurements made in contact with patients and at 30 cm away will in general overestimate calculations of lifetime exposures to members of the public (13), the present study provides mean directly measured dose rates, calculated lifetime doses as well as the time in days required to reach the 1 mSv member of the public limit and the 5 mSv limit specified in the NRC regulations. These provide useful conservative estimates upon which evaluations of instructions to patients can be based.



Fig. 1. Histogram of surface anterior dose rate for ^{125}I activity. N = 545, with 90% $\leqslant 70~\mu Sv/hr.$



Fig. 2. Histogram of 30 cm anterior dose rate for ^{125}I activity. N = 398, with 90% $\leqslant 15~\mu Sv/hr.$

250

200

150

100

50

0

35

30

25

20

15

10

5

0

0.00

Dose Rate at 30 cm

(microSv/hr)

Anterior Surface Dose Rate

(microSv/hr)



Based on the present research, it will take ~19 days to

reach the 5 mSv limit for caregivers (e.g., spouses, partners,

etc.) in contact with patients that have received ¹²⁵I implanta-

tion, assuming a 33% occupancy or 8 h/d in close proximity

to the patient (e.g., sleeping next to the patient). The lifetime

dose, estimated at the 30 cm distance, is less than 5 mSv.

This suggests that ¹²⁵I patients should be provided with

instructions to increase distance when sleeping next to a

caregiver, but that the distance need not be more than 30 cm

(i.e., 1 ft). For ¹⁰³Pd, allowable exposure times are generally

Therefore, special instructions to increase distance or reduce time for close contact with caregivers is not a regulatory requirement for ¹⁰³Pd patients, but may be considered prudent to maintain doses ALARA. The results of this study also suggest that instructions to increase distance and reduce time for close contact (i.e., ~30 cm or nearer) with members of the public (e.g., children, pregnant women, family members, etc.) are appropriate.

There are inherent limitations in any retrospective study. This retrospective study was limited by the lack of specific measured prostate depth (and therefore a more rigorous evaluation of the thickness of overlying tissue) using computed tomography images. Such an approach may be undertaken for future prospective studies.

much longer (i.e., up to ~7 times longer) than for ¹²⁵I due to the lower energies and typically lower initial dose rates from ¹⁰³Pd. While the lifetime doses for ¹⁰³Pd at 30 cm are \sim 3 times less than those at contact, both are less than 5 mSv.

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with 90% $\leq 18.6 \,\mu$ Sv/hr.



I-125 Activity (MBq)

2.00

3.00

1.00







Fig. 5. Histogram of surface anterior dose rate for 103 Pd activity. N = 72,

Fig. 6. Surface anterior dose rate correlates with 103 Pd activity. N = 72, Pearson's R = +0.48, p < 0.005.



Fig. 7. Normalized surface anterior dose rate correlates with patient weight for ¹²⁵I. N = 38, Pearson's R = -0.38, p < 0.02.

Conclusion

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The use of direct dose rate measurements, calculated times to meet regulatory limits, occupancy factor adjustments, and estimates of lifetime doses are appropriate for evaluating radiation exposure risks to patient caregivers and members of the public associated with prostate brachytherapy patients. When applied to a large patient data set, such as in this study, these methods provide information on dose variability as well as providing a foundation for generic assumptions and considerations of standard ALARA instructions using mean values.

This data set provides a basis for the validation of current radiation safety recommendations and provides clinicians with more concrete information regarding allowable exposure times for caregivers and members of the public after prostate implantation. Based on the results of this study, radiation safety ALARA instructions to patients following permanent prostate brachytherapy should include: avoiding close contact, i.e., within 30 cm, with others (including children and pregnant women) for extended periods of time; and avoiding sleeping in the "spoon" position (i.e., in contact) with the primary caregiver.

Table 3

Calculated lifetime doses and times required to reach 5 mSv	
assuming 100% occupancy (N/A = calculated times are not	
applicable because lifetime doses are less than 5 mSv)	

	¹²⁵ I	¹⁰³ Pd
Contact with anterior skin surface		
Mean dose rate (µSv)	37.3	8.2
Lifetime dose (mSv)	77.6	4.8
Time to reach 5 mSv (days)	5.8	N/A
Time to reach 1 mSv (days)	1.1	5.7
30 cm from anterior skin surface		
Mean dose rate (µSv)	6	2.9
Lifetime dose (mSv)	12.5	1.7
Time to reach 5 mSv (days)	44.4	N/A
Time to reach 1 mSv (days)	7.3	21.7

Table 4

Calculated lifetime doses and times required to reach 5 mSv assuming 33% occupancy (N/A = calculated times are not applicable because lifetime doses are less than 5 mSv)

	¹²⁵ I	¹⁰³ Pd
Contact with anterior skin surface		
Mean dose rate (µSv)	37.3	8.2
Lifetime dose (mSv)	25.6	1.6
Time to reach 5 mSv (days)	18.8	N/A
Time to reach 1 mSv (days)	3.5	24.3
30 cm from anterior skin surface		
Mean dose rate (µSv)	6	2.9
Lifetime dose (mSv)	4.1	0.6
Time to reach 5 mSv (days)	N/A	N/A
Time to reach 1 mSv (days)	24.1	N/A

Patients treated with either isotope (¹²⁵I or ¹⁰³Pd) do not represent a radiation risk to members of the public (including children and pregnant women) if these radiation safety ALARA instructions are observed and moderately allowable exposure times are maintained.

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