Medical Dosimetry, Vol. 29, No. 3, pp. 204-209, 2004

0958-3947/04/$–see front matter

doi:10.1016/j.meddos.2004.03.018

THE EFFECT OF THE RADIAL FUNCTION ON I-125 SEEDS USED FOR PERMANENT PROSTATE IMPLANTATION

BARBY PICKETT, M.S. and JEAN POULIOT, PH.D.
Department of Radiation Oncology, University of California San Francisco (UCSF), San Francisco, CA

(*Received* 10 *September* 2003; *accepted* 10 *March* 2004)

Abstract—The purpose of this study was to evaluate the integrity of eight commercially-available low-activity Iodine-125 (^{125}I) seeds for their radial function g(r) and its effect on the dose delivered to the adjacent critical structures when used in permanent prostate implants (PPI). Ten previously treated patients were retrospectively used in this comparison. The Amersham Health Oncura seed was used to peripherally design an isodose distribution with urethral and anterior rectal wall sparing. Plan criteria included minimum coverage of 144 Gy to the planning target volume (PTV), ≤ 70% dose to 150% of the PTV volume (V150-PTV), and the quantity of needles ≤ 70% of the size of the PTV, in cc. Upon completion of the Oncura plan, the seed type was changed and the activity was adjusted until the V100-PTV for each of the other 7 seed types matched the V100-PTV defined by the Oncura seed. Computed tomography (CT)-based postimplant dosimetry was used to determine the dose to 40% (D40) of the bulb of the penis (in Gy). Dose-volume histograms (DVH) were used to evaluate the differences to V100 (in %) and D40 (in Gy) of the anterior rectal wall and bulb of the penis, and V100 (in %) of the urethra. The data was tabulated. Radioactive ^{125}I sources included in this study were ^{125}I Source 2301 (Best); I-Plant (MedTech), IoGold (Mentor), Oncura (Amersham Health), ProstaSeed (UroCor), SelectSeed (Nucletron), SourceTech (Bard), and Symmetra (UroMed). The sizes of the PTV for the 10 patients ranged from 18.82 cc to 48.99 cc. The Oncura seed was used as the reference seed and all other seed types were normalized to it for data comparison. It was determined that the dose rate constant (Λ) and anisotropy factor (ϕ) contribute to the activity needed to achieve comparable V100-PTV doses, but a strong dependence on the radial function g(r) was found to effect the doses to the critical structures studied. Values of g(r) at 4 cm were calculated and the IoGold and SourceTech seeds were determined to have the highest g(r) values, with ProstaSeed and SelectSeed having the lowest values. ^{125}I Source 2301 and IoGold required less activity per seed to achieve the same dose to the V100-PTV due to the higher dose rate and anisotrophy constants ($\Lambda.\phi$). The seed types with silver were less penetrating and resulted in the production of characteristic x-rays that modified the energy spectrum and influenced the radial function. The seeds requiring the lowest activity showed the highest dose to the anterior rectal wall, a posterior adjacent structure; the urethra, an interior structure; and the bulb, an inferior structure.This study was designed to investigate the integrity of eight different commercially-available seed types, and their dependence on the g(r) in seed choice. It was determined that the dose rate constant and anisotropy factor determine the activity needed for implantation but a strong dependence on the radial function was found to effect the doses to the adjacent structures. © 2004 American Association of Medical Dosimetrists.

Key Words: **Seed model comparison, Permanent prostate implant, Radial function, Dose rate constant, Anisotropy, Seed activity.**

INTRODUCTION

Radioactive seed implantation has become a popular alternative treatment option for men with localized prostate cancer.[1] The success of this procedure depends on the accurate placement of radioactive isotopes within a known volume of prostate cancer. Planning a 3-dimensional (3D) peripherally-loaded seed array before implantation involves choosing a radioactive seed type and an appropriate activity that will adequately encompass the prostate gland while minimizing the dose to the surrounding adjacent structures. A postimplant assessment is necessary to quantify the implant following the surgical procedure. This study was not designed to determine which Iodine-125 (^{125}I) seed is best, but rather to investigate the integrity of the eight commercially-available low-activity ^{125}I seeds for their dosimetry and dose to the adjacent critical structures. The initial plan involved acquisition of transrectal ultrasound (TRUS) volumes one week prior to implantation on axial slices taken throughout the length of the prostate gland. The urethra and PTV were drawn onto TRUS by the urologist and transferred onto the treatment planning software by the physicist. The PTV was conformally planned in a peripheral array, using STRATA software, (a commercially-available PPI planning software system supported by Rosses Medical Systems, Baltimore, MD), with special attention given to minimizing the dose throughout the urethra. These patients were selected for monotherapy based on their Gleason score (3 + 3), and PSA (≤ 10). Ten milligrams of Decadron was administered perioperatively, to decrease the rate of post implant swelling to the prostate gland.[2]

Reprint requests to: Barby Pickett, University of California, 1600 Divisadero St H1031 San Francisco, CA 94143-0226. E-mail: pickett@radonc17.ucsf.edu

Table 1. Vendors ordered by radial function g(r)

Seed (Vendor) Name	Physical Description	Dose Rate Constant × Anisotropy Constant	% (Activity) Range Normalized to Oncura	Patient Activity Range	Radial function g(r) at 4 cm
ProstaSeed (UroCor)	Ceramic surrounding silver spheres	0.893	+9.56 to +5.85	0.357–0.424	0.405
SelectSeed (Nucletron)	Silver rod	0.8929	+1.80 to +3.60	0.344–0.403	0.451
Oncura (Nycomed-Amersham)	Silver rod	0.911		0.334–0.393	0.463
I-125 Source (Best-2301)	Tungsten marker in organic matrix	1.031	−14.44 to −12.17	0.298–0.347	0.514
Symmetra (UroMed)	Gold marker surrounded by I-125 ceramic	0.960	−10.94 to −8.23	0.306–0.357	0.533
I-Plant (MedTech)	Pointed silver marker surrounded by ceramic core	0.9595	−9.67 to −7.74	0.310–0.360	0.534
SourceTech (Bard)	Gold marker in Al & Cu skin	0.935	−4.61 to −2.14	0.327–0.379	0.544
Io-Gold (Mentor)	Gold/copper markers with resin beads on end	1.007	−11.62 to −8.90	0.302–0.355	0.588

Three-dimensional isodose distributions were designed to encompass the PTV within the $>$ 98% ($>$ 141.12 Gy) isodose line without inserting needles into any part of the urethra. Special attention was given to minimize the number of needles used ($<$ 70% of the PTV size, in cc). Individual ^{125}I seeds were preloaded with sterile Lucite spacers into 18-gauge needles and inserted through a fixed template into the prostate gland under transrectal ultrasound guidance (TRUS). During the procedure, the urethra was visualized using K-Y jelly aerosolized with contrast (Hypaque).

The urologist and radiation oncologist placed stabilization needles into predetermined locations that would not interfere with the planned implant. These needles were affixed to a Siemens template to minimize internal organ movement during the PPI procedure. Gold seeds measuring 1.2 × 2.2 mm were then inserted into the base and apex of the prostate gland to aid in fluoroscopic visualization of the prostate gland during the needle placement, for post implant CT prostate localization and MRI correlation.

CT scans were obtained at 5-mm increments taken 4 weeks post implantation. Correlated magnetic resonance images (MRI) were used to identify the prostate and bulb of the penis and to quantify the postimplant dosimetry. Dose-volume histograms (DVHs) were used to evaluate the coverage of the PTV, urethra, anterior rectal wall, and bulb of the penis.

METHODS AND MATERIALS

Ten patients with pretreatment prostate sizes ranging from 18.82cc to 48.99 cc were selected for this study. Patients were implanted with individually-loaded loose Amersham Health Oncura seeds activities ranging from 0.334 to 0.393 mCi, conforming to task group (TG)-43 National Institute of Standards and Technology (NIST) 99 standards.[3] These patients were then retrospectively studied by changing the seed type and activity needed to achieve the same V100-PTV for all seeds studied. The patient and seed data was accumulated in 3 tables. Table 1 represents a tabulated account, including columns of seed vendors studied, and physical description of the seeds ordered by increasing g(r), for r = 4 cm. The third column refers to the $\Lambda\phi$, for the 8 seed types studied. The fourth column distinguishes the range of activity (%) needed for all patients studied normalized to the Oncura seed. The fifth column tabulates the patient activity range needed for the 10 patients, and the last column denotes the g(r) at 4 cm for each seed type.

For this study, each seed was substituted into the original treatment plan for comparison with the initially planned Oncura seed. The seed activity was altered until all V100-PTV values for all 8 seed types were found to be equal. The adjusted seed activity and normalized change (relative to the Oncura seed) in activity for each seed were documented. Once the seed activity was determined, so that all V100-PTV values were equal, the DVH data for the PTV, urethra, and anterior rectal wall was tabulated. This process was continued until all 8 seeds and 10 patients were compared. Data for the prostate were tabulated in Table 2 and data for the rectal wall, urethra, and bulb were tabulated in Table 3.

RESULTS

All seed types studied required a difference in seed activity (A) as compared to the Oncura seed. Similarities in the dosimetry of the seeds included the half-life of 59.4 days and Air Kerma Strength Conversion Factor 1.27 U/mCi. Differences included dose rate constant (Λ), anisotropy factor (ϕ), and radial function g(r). Table 2 represents the doses to V150-PTV, D90 (Gy), and the change in activity needed to cover the V100-PTV as

Table 2. Doses delivered to patients, sorted by increasing size

Patient/Size	PTV Coverage	ProstaSeed (UroCor)	SelectSeed (Nucletron)	Oncura (Amersham)	2301 (Best)	Symmetra (UroMed)	I-Plant MedTech	SourceTech Bard	IoGold (Mentor)
2	V150 in %	67.550	62.73	61.02	61.65	59.94	58.85	59.94	61.65
	D90 in Gy	178.310	178.31	176.68	176.13	176.13	176.13	176.13	176.13
18.82 cc	Activity (mCi)	0.357	0.344	0.334	0.298	0.306	0.31	0.327	0.302
	Δ in Activity (%)	6.89	2.99	-	−12	−9.15	−7.74	−2.14	−10.06
5	V150 in %	69.70	63.22	61.43	63.36	58.54	57.85	56.89	64.26
	D90 in Gy	193.53	189.18	187.01	189.18	187.01	184.83	184.83	189.18
20.66 cc	Activity (mCi)	0.367	0.351	0.342	0.307	0.312	0.316	0.331	0.309
	Δ in Activity (%)	7.31	2.6	-	−11.4	−9.62	−8.23	−3.32	−10.68
1	V150 in %	66.59	61.64	60.19	60.31	57.06	57.18	57.06	61.04
	D90 in Gy	179.79	169.61	169.61	169.61	169.61	167.4	167.44	169.61
23.0 cc	Activity (mCi)	0.42	0.397	0.387	0.343	0.351	0.356	0.373	0.35
	Δ in Activity (%)	8.53	2.58	-	−12.83	−10.26	−8.7	−3.75	−10.57
4	V150 in %	71.02	68.91	66.1	66.7	65.7	64.99	64.69	66.7
	D90 in Gy	180.48	178.31	176.13	178.31	176.13	176.13	173.96	176.13
28.75 cc	Activity (mCi)	0.417	0.403	0.389	0.347	0.357	0.36	0.378	0.351
	Δ in Activity (%)	7.200	3.6	-	−12.1	−8.23	−8.06	−2.91	−10.83
10	V150 in %	59.88	55.07	54.36	54.06	52.01	52.11	51.4	55.07
	D90 in Gy	167.44	165.26	165.26	165.26	165.43	165.09	165.09	165.26
29.33 cc	Activity (mCi)	0.415	0.393	0.386	0.34	0.3504	0.3556	0.3726	0.347
	Δ in Activity (%)	7.51	1.8	-	−11.9	−9.2	−7.9	−3.6	−8.9
9	V150 in %	66.12	61.09	59.71	59.67	57.89	57.45	56.5	61.01
	D90 in Gy	176.13	176.13	176.13	174.1	173.96	173.96	173.96	176.13
34.26 cc	Activity (mCi)	0.39	0.369	0.36	0.3173	0.326	0.33	0.345	0.325
	Δ in Activity (%)	7.69	2.5	-	−13.46	−10.43	−9.09	−4.17	−10.77
7	V150 in %	64.35	62.43	61.06	59.07	58.24	58.1	58.24	60.1
	D90 in Gy	178.31	176.13	176.13	176.13	173.96	173.96	176.13	176.13
43.86	Activity (mCi)	0.42	0.398	0.387	0.41	0.347	0.351	0.371	0.347
	Δ in Activity (%)	7.86	2.84	-	−12.4	−10.34	−9.3	−4.3	−10.34
6	V150 in %	59.25	58.1	57.39	55.33	58.33	55.33	58.33	58.1
	D90 in Gy	167.44	169.61	169.61	169.61	171.79	169.61	171.79	169.61
47 cc	Activity (mCi)	0.416	0.403	0.393	0.416	0.356	0.36	0.379	0.355
	Δ in Activity (%)	5.85	2.5	-	−13.58	−10.39	−9.17	3.69	−10.79
3	V150 in %	63.67	58.74	58.13	57.23	56.1	55.48	54.37	58.16
	D90 in Gy	169.61	169.61	169.61	171.79	169.61	169.61	169.61	169.71
48.63 cc	Activity (mCi)	0.393	0.371	0.363	0.3172	0.3272	0.331	0.347	0.3252
	Δ in Activity (%)	8.26	2.2	-	−14.44	−10.94	−9.67	−4.61	−11.62
8	V150 in %	62.2	55.27	55.09	57.17	54.68	54.56	55.39	57.23
	D90 in Gy	176.13	173.96	173.96	176.13	176.13	176.13	178.31	176.13
48.99 cc	Activity (mCi)	0.424	0.396	0.387	0.345	0.353	0.358	0.379	0.352
	Δ in Activity (%)	9.56	2.3	-	−10.85	−8.79	−8.1	−2.07	−9.04

Each seed was evaluated for the dose at 150% of the volume of the PTV delivered in % (V150). The dose to 90% of the PTV delivered in Gy (D90-PTV), the seed activity needed to equal the V100-PTV of all the other seed types and the amount of change in activity needed normal to the Oncura are tabulated. The seed types are sorted by increasing g(r).

normalized to the Oncura seed. The I-125 Source 2301, IoGold, Symmetra, and I-Plant seeds required the lowest activity, ranging from 0.298 to 0.31 mCi, as compared to 0.334 mCi needed by the Oncura seed. The ProstaSeed seed required the highest activity of 0.357 mCi, with SourceTech and SelectSeed requiring similar activities to the Oncura seed. Adjustments in the seed activity between the vendors were primarily due to attenuation and physical differences associated with the seed design. (It should be noted that for this comparison only, the activity per seed was adjusted, not the seed arrangement.)

Isodose distributions were evaluated with respect to the new activity and seed vendor in an attempt to ascertain differences in prostate coverage and adjacent critical structures. The differences in isodose distributions between all seed vendors were small.

DVH data shown in Tables 2 and 3 are ordered by g(r) showing the ProstaSeed, and SelectSeed having the lowest g(r) at 4 cm and the highest. V150-PTV and D-90-PTV. SourceTech and BrachySeed revealed the highest g(r) at 4 cm but the lowest V150-PTV and D-90-PTV. The data in Table 1 evaluate the change in

Table 3. Doses to patients, sorted by increasing size

Patient	Rectum/Bulb/ Urethra	ProstaSeed UroCal	SelectSeed Nucletron	Oncura Amersham	IoGold Mentor	Symmetra UroMed	2301 Best	SourceTech Bard	I-Plant MedTech
2	R-D90 (Gy)	41.32	43.49	43.49	43.49	45.66	45.66	45.66	45.66
	U-D90 (Gy)	128.3	128.3	126.12	126.12	126.12	128.3	126.12	126.12
	B-V(40%)	43.2	43.7	43.7	45.6	46.6	45.4	47.3	47.8
	R-V(40%)	50.81	55.08	55.86	57.03	62.5	62.5	66.41	64.84
5	R-D90 (Gy)	45.66	47.84	47.84	47.84	50.01	50.01	50.01	50.01
	U-D90 (Gy)	82.63	84.81	84.81	84.81	84.81	86.98	84.81	84.81
	B-V(40%)	43.1	43.5	43.7	45.2	46.4	45.2	47.3	47.8
	R-V(40%)	76.81	80.29	80.58	81.74	82.32	83.19	82.32	82.9
1	R-D90 (Gy)	41.32	43.49	43.49	45.66	45.66	45.66	45.66	45.66
	U-D90 (Gy)	141.34	141.34	141.34	141.34	141.34	141.34	141.34	141.34
	B-V(40%)	38.3	38.3	38.3	38.8	38.8	39.9	38.9	39.2
	R-V(40%)	51.2	56.8	59.6	62	63.6	63.2	66	66.8
4	R-D90 (Gy)	41.32	43.49	43.49	43.49	45.66	45.66	45.66	45.66
	U-D90 (Gy)	69.58	71.34	71.76	71.76	73.93	73.93	73.96	76.13
	B-V(40%)	36.2	36.6	36.6	39.1	39.5	40.2	40.1	39.8
	R-V(40%)	53.19	56.8	71.28	72.32	75.46	75.98	75.46	75.98
8	R-D90 (Gy)	52.19	52.19	52.19	54.36	54.36	58.71	56.54	58.71
	U-D90 (Gy)	108.72	108.72	108.72	110.9	113.04	110.9	113.07	113.13
	B-V(40%)	32.4	32.8	32.9	36.1	36.1	38.2	38.4	38.8
	R-V(40%)	81.61	82.3	84.14	86.67	85.67	90.34	89.43	90.11
10	R-D90 (Gy)	41.32	43.49	43.49	45.66	45.71	47.84	45.61	47.84
	U-D90 (Gy)	82.63	84.81	86.98	84.81	87.07	86.98	89.06	89.15
	B-V(40%)	22.1	22.1	22.1	24.5	24.6	26.2	26.6	26.4
	R-V(40%)	62.05	65.06	68.67	68.67	71.15	73.19	73.73	74.02
7	R-D90 (Gy)	45.66	47.84	47.84	50.01	50.01	52.19	52.19	52.19
	U-D90 (Gy)	86.98	86.98	86.98	80.46	89.15	89.15	89.15	89.15
	B-V(40%)	23.2	24.9	24.9	26.6	26.9	26.7	28.1	29.2
	R-V(40%)	74.88	76.37	76.37	77.61	78.61	81.84	79.85	80.85
6	R-D90 (Gy)	47.84	50.01	52.19	52.19	54.36	54.36	54.36	54.36
	U-D90 (Gy)	106.55	108.72	108.72	110.9	110.9	110.9	110.9	110.9
	B-V(40%)	22.4	23.9	23.9	25.6	26.1	25.4	27.1	27.2
	R-V(40%)	78.07	83.42	83.42	84.49	84.76	85.56	85.03	85.83
3	R-D90 (Gy)	43.49	45.66	45.66	47.89	47.84	50.06	47.84	50.01
	U-D90 (Gy)	39.14	39.14	41.32	41.32	43.49	45.71	43.49	43.49
	B-V(40%)	19.1	19.1	19.1	20.2	23.1	23.5	24.9	24.8
	R-V(40%)	71.89	74.25	76.61	77.47	79.4	80.96	80.04	81.33
9	R-D90 (Gy)	39.14	41.32	41.32	41.32	43.49	45.7	43.49	45.66
	U-D90 (Gy)	110.9	113.07	113.07	113.07	115.25	113.16	115.25	115.25
	B-V(40%)	19.4	19.5	19.5	24.8	25.6	23.8	26.8	27.2
	R-V(40%)	60.46	64.05	65.03	65.03	69.61	70.32	70.26	70.59

Each seed was evaluated for the Dose at 90% of the anterior rectal wall delivered in Gy (D90), D90-urethra, the dose to 40% of the bulb of the penis in % (V40), and V40-anterior rectal wall. The seed types are sorted by increasing g(r).

activity from the different seed types studied. The total range in seed activities from the eight seed types studied varied by $>$ 20%.

Table 3 also ordered the seed vendors by g(r), for r $>$ 1 cm, and found doses to the bulb, urethra, and rectal wall were lowest for seeds containing silver, including ProstaSeed, SelectSeed, and Oncura and were higher for non-silver seeds Symmetra, ^{125}I Source 2301, and SourceTech. The I-Plant seed containing a pointed "silver" marker surrounded by a ceramic core had the highest doses to all adjacent structures. Although this seed contains two silver spheres for localization purpose, the small amount of silver combined the specific geometry, (silver sphere at each end of the seed, but Iodine not absorbed in silver), does not result on a significant amount of characteristics x-ray. For this seed, the g(r) function shows a behavior closer to seeds that do not contain silver than to seeds using ^{125}I absorbed on a silver core.

Doses to V90 rectal wall ranged from 39.14 Gy to 58.71 Gy. Doses to the V40 rectal volume ranged from 51% to 71% of the total delivered dose. These data do not seem to show a pattern of dose delivered to the anterior rectal wall relative to prostate size.

Doses to D90-urethra ranged from 39.14 Gy to 141.34 Gy. This wide range in dose differences is probably due to the position of the urethra relative to the size of the prostate. The data suggest that patients with smaller prostates reveal higher urethral doses than larger prostate glands, possibly due to the close proximity of the seeds needed for smaller gland sizes.

The V40 bulb ranged from 19.4% to 47.8%. It was noted that patients with smaller prostates received higher doses to the bulb than larger prostates, possibly due to the narrower distribution of the seeds at the apex of the gland compared to a wider distribution for a larger prostate.

DISCUSSION

All of the seed models studied were unique in their physical design. This resulted in varying doses to the adjacent critical structures outside the intended treatment field. It is customary to calculate the relative activities of different commercially-available sources that will yield the same dose by use of the dose rate constant and anisotrophy factor, ignoring the radial dose function. Based on the analysis of this study, it appears that these relative activities do not produce equivalent prostate dosimetry. This is due to the neglect of the radial function when volumes significantly larger than 1 cc are irradiated. This study implies that the relative activities need to be generated from clinical data or some other model to achieve equivalent prostate dosimetry.

In addition to the Amersham Health (Oncura) seed,[4–10] seven other radioactive ^{125}I seed types were selected for this study, including STM1251 (Bard),[10] I-125 Source 2301 (Best), ProstaSeed (UroCor),[11] I-Plant (MedTech), IoGold (Mentor),[12] SelectSeed (Nucletron), and Symmetra (UroMed).[13] From TG43 formalism and NIST99 standards, the dose D at a given distance from a seed should be characterized by the dose rate constant Λ, anisotropy factor ϕ, activity of the seed A, and radial dose function, g(r).

$$D = A_1 \cdot \Lambda_1 \cdot \phi_1 \cdot g(r)_1 = A_2 \cdot \Lambda_2 \cdot \phi_2 \cdot g(r)_2 \qquad (1)$$

The indices 1 and 2 refer to different seed models. Λ is defined as the dose rate relative to water at a distance of 1 cm on the transverse axis of a unit air-kerma strength source in a water phantom. ϕ refers to the anisotropy factor that accounts for the nonuniformity of the dose distribution around the ends of the source, including the effects of absorption and scatter in the medium. From the equation above and assuming for the moment that g(r) is independent of the seed model at a given distance (in fact, $g(r) = 1$ at 1 cm, by definition), it is clear that the activity A, for seeds with different sets of constants (Λ, ϕ) must be adjusted to obtain the same dose D.

In addition, each seed model comes with a complete description of g(r) parameterized with a 5th order polynomial and a set of six constants. This function is evaluated for clinically relevant radii ranging from 0.5 to 10.0 cm. The presence of a silver core, ceramic, tungsten, platinum, and gold in the seed alters g(r) and ultimately impacts the dose to the adjacent structures. The seed models are grouped into two different classes with very similar g(r) within each class. One class is for seed models (ProstaSeed, SelectSeed, and Oncura) with a silver core inside the cylinder. The presence of a silver core results in the production of characteristic x-rays that modify the energy spectrum and influence the radial function.[14] The other classes of seed models (Source 2301, IoGold, SourceTech, and Symmetra) use tungsten and gold, which do not produce characteristic, x-rays.

The relative prostate coverage obtained for each type of seed is governed by the dose rate constant and the anisotropy constant, as described in Eq. (1). The slope of the g(r) function influences the protection of the organs at risk (for instance, $g[r = 4\text{ cm}]$ in Table 1). This is due to the fact that, on average, the sources are at a larger distance from the organs at risk than from the prostate cells. At a distance of 4 cm, the values of g(r) range from 0.4 to 0.6. This range is 0.4 to 0.5 for seeds with a silver core. This is due to the characteristic x-ray produced by fluorescence from the silver markers in the seed. The fluorescence slightly reduces the average value of the energy spectrum, resulting in less penetrating radiation. This concept was recently exploited to enhance the relative biological effectiveness of the ^{125}I seed by reducing the average value of energy spectrum emitted by the source. The authors show that by coating the inner wall of the ^{125}I seed with Molybdenum, a deeper, steeper g(r) was obtained.[15]

Although the group of silver seeds is grouped together, the physical characteristics are somewhat different. The Amersham Health Oncura seed consists of a welded titanium capsule containing ^{125}I absorbed onto a 3.0-mm silver rod. The physical characteristics of the group of seeds that do not contain silver are interesting. The STM1251 seed uses iodine deposited on copper then nickel. The Bard SourceTech seed has a titanium capsule hermetically sealed by laser welding to encapsulate a gold core marker (for visualization under fluoroscopy CT scanning and x-ray filming). This seed is then surrounded by a 17-nm-thick layer of radioactive iodine deposited on top of a thin copper layer which, in turn, is deposited upon a nickel coated 3.81-mm-long aluminum cylinder. Mentor IoGold sources consist of a welded titanium capsule containing ^{125}I absorbed onto four resin beads. The capsule body also contains two centrally-located inactive gold beads that serve as seed markers, to identify source location and orientation. The Symmetra UroMed seed has a full-length pure gold marker surrounded by uniform ^{125}I within porous ceramic then encapsulated in a titanium tube.

It is these physical characteristics that cause differences in the anisotropy and radial function g(r), resulting in the varying doses to the adjacent critical structures.

The filtration through the titanium capsule and the respective energy range determines the doses delivered to the anterior rectal wall and bulb of the penis. The energy ranges for the seed types using silver range from 27.4 to 31.4-KeV x-rays and 35.5 KeV gamma emission with 22.1 and 25.2 KeV fluorescent x-rays from the silver. The gold seed types have energy ranging from 27.2- to 31.4-KeV x-rays and 35.5 KeV gamma emission for the Mentor seed and 22- to 23-KeV Au K-edge x-rays and ^{125}I primary x-rays for the Symmetra seed.

The Symmetra seed, utilizing a gold marker, is surrounded by ^{125}I absorbed on ceramic, and having a high ($\Delta\ \phi$) but a mid-range for g(r). The I-125 Source 2301 seed with a tungsten marker in an organic matrix has the highest ($\Delta\ \phi$) and has a mid range g(r). These data suggest that nonsilver markers and nonsilver beads result in the highest ($\Delta\ \phi$) and mid-range g(r). Prosta Seed with ceramic surrounding silver spheres, Select-Seed with silver rods, and Oncura with a silver rod all have the lowest ($\Delta\ \phi$) and the lowest g(r) values at 4 cm.

When reporting data, it is important to report activity per seed used, total activity used, and vendor when referring to the dosimetry of the implant. This study compared eight commercially-designed ^{125}I seeds to the Oncura seed. It is possible that plans generated from seeds with higher g(r) values might have a different seed array, and the resulting DVH would be entirely different. This study was done to evaluate posterior, inferior, and interior structures used to determine the effect of the g(r) on the seed type when compared to the Oncura seed.

CONCLUSIONS

Postimplant dosimetry, utilizing isodose distributions and DVH to quantify delivery of dose for prostate cancer, can reliably determine the dose received to the diseased tissue and the normal adjacent structures. If morbidity associated with high doses is to be studied, the radial function (g(r)) associated with the implanted ^{125}I seed needs to be included. This study was designed to investigate the integrity of eight unique commercially-available seed types, and their dependence on the g(r) in seed choice. It was determined that the dose rate constant and anisotropy factor determine the activity needed for implantation, however, a strong dependence on the radial function was found to affect the doses to adjacent structures.

REFERENCES

1. Blasko, J.C.; Grim, P.D.; Ragde, H.; Schumacher, D. Implant therapy for localized prostate cancer. In: Ernstoff, M.S., Heaney, J.A.; Peschel, R.E.; editors. Prostate Cancer. Cambridge; MA: Blackwell Science; 1998;137–55.
2. Speight, J.; Pickett, B.; Roach, M. Prostate volume change after radioactive seed implantation possible benefit of improved dose volume histogram with perioperative steroid. *Int. J. Radiat. Oncol. Biol.* **48**:1461–7; 2000.
3. Nath, R.; Anderson, L.; Luxton, G.; Weaver, K. Dosimetry of interstitial brachytherapy sources: Recommendations of the AAPM Radiation Therapy Committee Task Group No. 43. *Med. Phys.* **22**:209–34; 1995.
4. Kubo, D.; Coursey, B.; Hanson, W.; Kline, R.W. Report of the Ad Hoc Committee of the AAPM Radiation Therapy Committee on I-125 Sealed Source Dosimetry. *Int. J. Radiat. Oncol. Biol. Phys.* **40**:697–702; 1998.
5. Anderson, L.L.; Shipley, W.U. Dose inhomogeneity in interstitial implants using I-125 seeds. *Int. J. Radiat. Oncol. Biol. Phys.* **5**:419–25; 1979.
6. Ling, C.C.; Schell, M.C.; Yorke, E.D. Two-dimensional dose distribution of I-125 seeds. *Med. Phys.* **12**:652–5; 1985.
7. Schell, M.C.; Ling, C.C.; Cromadzki, Z.C.; Werking, K.R. Dose distributions of model 6702 I-125 seeds in water. *Int. J. Radiat. Oncol. Biol. Phys.* **13**:795–9; 1987.
8. Williams, J.; *et al*. Guidance to users of Nycomed-Amersham and North American Scientific, Inc., I-125 Interstitial Sources: Dosimetry and calibration changes: Recommendations of the American Association of Physicists in Medicine Radiation Therapy Committee Ad Hoc Subcommittee on Low-Energy Seed Dosimetry. *Med. Phys.* **26**:570–3; 1999.
9. Hedtjarn, H.; Carlsson, G.; Williamson, J. Monte Carlo-aided dosimetry of the symmetra model 125.So6 I-125, interstitial brachytherapy seed. *Med. Phys.* **27**:1076–85; 2000.
10. Kirov, A.; Williamson, J. Monte Carlo-Aided dosimetry of the Source Tech Medical I-125 interstitial brachytherapy seed. *Med. Phys.* **27**:132; 2000.
11. Wallace, R. Empirical dosimetric characterization of model I125-SL I-125 brachytherapy source in phantom. *Med. Phys.* **27**: 2796–802; 2000.
12. Bice, W.S.; Prestidge, B.R.; Prete, J.J.; Dubois, D.F. Clinical impact of implementing AAPM Task Group 43 on permanent prostate brachytherapy using I-125. *Int. J. Radiat. Oncol. Biol. Phys.* **40**:1237–41; 1998.
13. Alzitzoglou, T. The half life of I-125. *Applied Radiat. Isotopes* **42**:493; 1991.
14. Heintz, B.; Wallace, R.; Hevezi, J. Comparison of I-125 sources for permanent interstitial implants. *Med. Phys.* **28**:671–82; 2000.
15. Taschereau, R.; Roy, R.; Pouliot, J. RBE enhancement of an I-125 brachytherapy seed. *Med. Phys.* **29**:1397–1402; 2002.