Technical Note

Original paper

A nomogram to determine required seed air kerma strength in planar ^{131}Cesium permanent seed implant brachytherapy

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Abstract

Purpose: Intraoperatively implanted Cesium-131 (^{131}Cs) permanent seed brachytherapy is used to deliver highly localized re-irradiation in recurrent head and neck cancers. A single planar implant of uniform air kerma strength (AKS) seeds and 10 mm seed-to-seed spacing is used to deliver the prescribed dose to a point 5 mm or 10 mm perpendicular to the center of the implant plane. Nomogram tables to quickly determine the required AKS for rectangular and irregularly shaped implants were created and dosimetrically verified. By eliminating the need for a full treatment planning system plan, nomogram tables allow for fast dose calculation for intraoperative re-planning and for a second check method.

Material and methods: TG-43U1 recommended parameters were used to create a point-source model in MATLAB. The dose delivered to the prescription point from a single 1 U seed at each possible location in the implant plane was calculated. Implant tables were verified using an independent seed model in MIM Symphony LDR™. Implant tables were used to retrospectively determine seed AKS for previous cases: three rectangular and three irregular.

Results: For rectangular implants, the percent difference between required seed AKS calculated using MATLAB and MIM was at most 0.6%. For irregular implants, the percent difference between MATLAB and MIM calculations for individual seed locations was within 1.5% with outliers of less than 3.1% at two distal locations (10.6 cm and 8.8 cm), which have minimal dose contribution to the prescription point. The retrospectively determined AKS for patient implants using nomogram tables agreed with previous calculations within 5% for all six cases.

Conclusions: Nomogram tables were created to determine required AKS per seed for planar uniform AKS ^{131}Cs implants. Comparison with the treatment planning system confirms dosimetric accuracy that is acceptable for use as a second check or for dose calculation in cases of intraoperative re-planning.

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Key words: brachytherapy, Cesium-131, intraoperative brachytherapy, permanent seed implant, head and neck cancer, nomogram.

Purpose

The standard of care for patients with recurrent head and neck cancers is surgical salvage when feasible. The role and use of radiation are less well-defined; many patients in this group have previously received radiation and/or chemotherapy, which often limits the use of additional radiation due to the high-risk of toxicities.

Unlike external beam radiation therapy, Cesium-131 (^{131}Cs) permanent brachytherapy seed implants can be used to deliver highly localized re-irradiation in this setting. Cesium-131 is an electron-capture radionuclide that is gaining popularity in permanent seed implant (PSI) brachytherapy. The average photon energy of IsoRay™'s Proxcelan ^{131}Cs is 30.4 keV [1], which is slightly higher than that of Iodine-125 (^{125}I) or Palladium-103 (^{103}Pd) and can lead to improved dose homogeneity in prostate PSI [2]. Furthermore, the half-life of ^{131}Cs is 9.7 days [1], shorter than that of ^{125}I or ^{103}Pd, which can reduce the overall exposure to family members, and can be advantageous from a radiobiological standpoint [3].

Since Food and Drug Administration (FDA) 510(k) approval in 2003, the use of ^{131}Cs for PSI has been investigated for the treatment of prostate cancer [2,4,5,6], brain metastasis [7], recurrent gynecological cancers [8,9], lung cancer [10], and recurrent head and neck cancers [11,12,13]. Dosimetric parameters such as energy spectrum and dose-rate constant have been deter-

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mined using Monte Carlo simulations, radiochromic film, and thermoluminescent dosimetry measurements [1,14,15,16,17,18,19].

At our institution, ^{131}Cs implants following historical planar implant techniques are performed for resectable recurrent head and neck cancers at the time of surgical intervention. Treatment planning is typically done prior to surgery with a sophisticated brachytherapy treatment planning system (TPS), however, sometimes the treatment plan is changed during surgery due to intraoperative findings. In these cases, a nomogram can be used by the physicist to provide an estimate of the adjusted implant dose. Additionally, a nomogram can be used as a secondary check of the treatment plan created with the brachytherapy dose calculation system for all cases. Unlike other radionuclides, ^{131}Cs was first used in PSI well after sophisticated TPS were standard in clinics, so standard implant tables have not been published [20,21,22].

In this work, nomograms for efficient and simple point dose calculation of rectangular and irregular planar implants prescribed to a point 5 mm or 10 mm away from an implant plane are presented. The prescription dose is not defined, and nomogram tables may be used for any prescribed dose.

Material and methods

Clinical treatment planning and prescription

Cesium-131, Proxcelan Model CS-1 Rev2 (Isoray Medical, Richmond, WA) (Figure 1) implants are used to provide highly localized re-irradiation in recurrent head and neck patients at the time of salvage surgery. Source placement follows historical planar implant techniques. Uniform strength seeds for PSI are ordered pre-loaded in individual strands or in a mesh. Seeds are stranded 10 mm apart, with the intent to implant individual strands 10 mm apart. If a mesh is ordered, seeds are sewn into the mesh in a 10 mm by 10 mm grid pattern. The number of seeds required for an implant is determined by the estimated size of the future post-resection cavity. Dose is prescribed to a point 5 mm from the center of a single-plane implant. If the prescription point falls directly above a seed, as is the case for an implant with an odd number of rows and/or columns, the prescription point is moved 5 mm parallel to the implant plane in one or two directions such that it lies in between four seeds. For rectangular or symmetric irregular implants, the direction of the shift is irrelevant; for asymmetric implants, the prescription point is shifted towards the side(s) with more seeds (Figure 2). Air kerma strength per seed in U is selected such that the prescribed dose is delivered to this point and is rounded to 1 decimal place for seed ordering. This rounding error will be ≤ 3% for all seed activities ≥ 1.5 U.

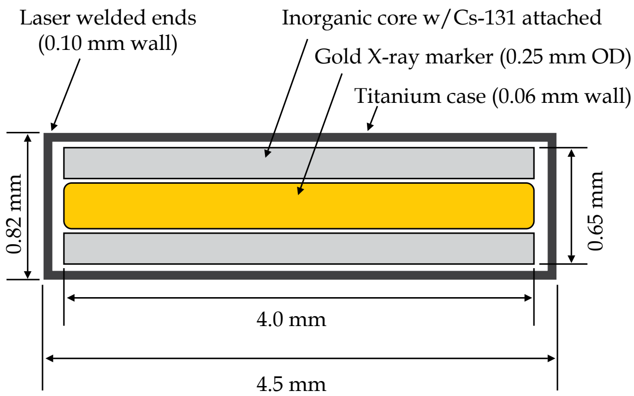

Fig. 1. The source geometry for Proxcelan ^{131}Cs seeds. Image provided by IsoRay Medical

While there is a number of commercially available brachytherapy treatment planning systems, most of them do not cater to the specifics of this type of free hand strand or mesh placement within the surgical cavity. Currently, treatment planning is performed in MIM Symphony LDR™ (version 6.5, Cleveland, Ohio). The estimated resection cavity dimensions and optimal implant plane are determined in collaboration with the radiation oncologist and surgeon. Seeds are manually placed in a grid pattern, and the prescription point is identified and delineated. The seed AKS is iteratively adjusted such that the prescription dose is delivered to the prescribed depth. This planning process requires coordination between the medical physicist, radiation oncologist, and surgeon, and can take a few hours from scan import, physician(s) contouring, and physicist planning to final physician(s) approval. Treatment planning using a nomogram can be done in minutes based on physician described implant dimensions rather than import and contouring of 3D volume imaging.

Rectangular implant tables

Calculations for rectangular implant tables were performed using MATLAB (Mathworks®, Natick, MA). The ^{131}Cs (Rev 2) point source and line source seed model data, as per the American Association of Physicists in Medicine's TG-43 equation [23] (dose-rate constant, radial dose function, and 1D/2D anisotropy functions [17]) were input into MATLAB. Linear interpolation between each data point was used. The dose-rate at a prescription point 5 mm or 10 mm away from the implant plane was calculated for rectangular arrays of 1 U seeds placed 10 mm apart in a grid pattern ranging from 1 × 1 up to 16 × 16 seeds. The total dose delivered by a single seed n was calculated by integrating the dose-rate of that seed $\dot{D}_{0,n}$ over the duration of the permanent implant.

$$D_n = \int_0^\infty \dot{D}_{0,n} \frac{1}{2}^{(t/T_{1/2})} dt$$

The total dose delivered to the prescription point over the lifetime of the implant was calculated by summing the contribution from each seed n in an implant of N seeds:

$$D_{total} = \sum_{n=1}^{N} \int_0^\infty \dot{D}_{0,n} \frac{1}{2}^{(t/T_{1/2})} dt = \frac{T_{1/2}}{ln2} \sum_{n=1}^{N} \dot{D}_{0,n}$$

Irregular implants

To determine the dose delivered by a non-rectangular planar implant, the dose rate at the 5 mm and 10 mm prescription points from a single 1 U seed at each possible location in the 16 × 16 cm^2 grid was calculated in MATLAB using the methods described above for regular implants. This was done using the 1D and 2D formalisms.

Verification of implant tables using MIM Symphony LDR

Verification of the implant tables was performed in MIM Symphony LDR™ for the 1D and 2D formalisms. The point source seed model data were input into MIM during previous commissioning [24]. Seeds were placed at a distance of 10 mm center-to-center in a single planar arrangement. The total dose delivered by a 1 U seed was recorded for each possible seed position in the 16 × 16 cm^2 grid to verify the irregular implant tables, and the total dose from an array of seeds was recorded to verify the rectangular implant tables. These values were compared to those calculated in MATLAB.

Application to patient implants

Nomogram tables were used retrospectively to determine the required seed AKS for the three most recent rectangular and three most recent irregular clinical implant cases. All six implants were prescribed 60 Gy to a point 5 mm from the implant plane. The implant geometry and prescription point for each patient are shown in Figure 2.

For the rectangular plans, the dose rate in the implant table represents a rectangular arrangement of 1 U seeds. The desired AKS is calculated using the following equation:

$$\textit{Required AKS} = \frac{\textit{Prescription dose}}{\textit{Dose delivered to prescription point by } 1 \textit{ U seeds}}$$

For irregular seed arrangements, the desired AKS per seed is obtained by dividing the prescription dose by the sum of the total dose delivered to the prescription point by each seed in the implant:

$$\textit{Required AKS} = \frac{\textit{Prescription dose}}{\sum_{n \textit{ seeds}} \textit{Dose delivered to prescription point by seed } n}$$

The required AKS calculated by the implant tables and by MIM were recorded.

Results

Rectangular implant tables

The total dose delivered to 5 mm and 10 mm prescription points by a planar array of 1 U seeds calculated in MATLAB are presented in Table 1 (1D formalism) and Table 2 (2D formalism). Using the 1D formalism, all differences in required AKS between MATLAB and MIM were less than 0.6%. Using the 2D formalism, all differences were less than 1.4%.

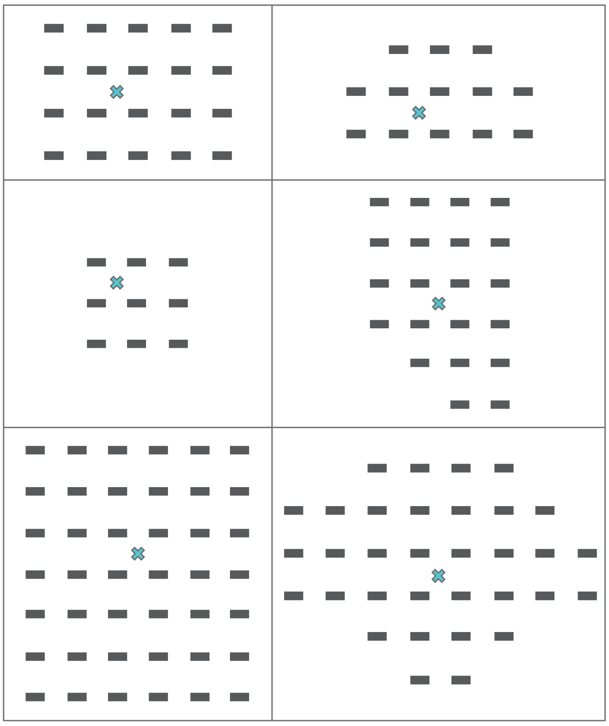

Fig. 2. The implant geometry for the three most recent rectangular and irregular patients. The projection of the prescription point onto the implant plane is indicated by the blue 'x'. The prescription point is 5 mm perpendicular to the implant plane for all six implants

Irregular tables

The dose delivered over the lifetime of an implant by a 1 U seed at each location in an implant to prescription points located 5 mm and 10 mm perpendicular to the center of the implant plane are presented in Table 3 using the 1D and 2D formalisms. The numbering along the table edges are used to represent the seed indexing number, and not a distance from the prescription point. To highlight differences between the two dose calculation formalisms, bolded values indicate a difference between line and point source models that are greater than 5% for a single seed's contribution to the prescription point; bolded and underlined values indicate greater than 10%, with a maximum of 16.9%.

Application to patient plans

The required AKS per seed was determined clinically using MIM and then retrospectively using the implant tables for the three most recent rectangular and three most recent irregular implants. The seed AKS calculated using MIM and implant tables are presented in Table 4. For all six patient plans, the percent difference was less than 3%.

Discussion

The nomogram tables created with MATLAB show good agreement with those calculated using MIM (maximum difference of 3.0%). For seeds very close to the pre-

Table 1. The total dose delivered (in Gy) to the prescription points (**A**) 5 mm and (**B**) 10 mm perpendicular to the implant plane by a rectangular array of x by y 1 U seeds, calculated using the 1D formalism in MATLAB. All implant arrangements prescribed to 5 and 10 mm have differences between the MIM and MATAB calculations of less than 0.4%, and 0.6%, respectively

A

y \ x	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	4.60	9.19	10.37	11.55	11.97	12.40	12.59	12.78	12.87	12.97	13.02	13.07	13.10	13.13	13.15	13.17
2		18.38	20.74	23.10	23.95	24.80	25.18	25.56	25.75	25.94	26.04	26.15	26.20	26.26	26.30	26.33
3			23.74	26.75	27.90	29.06	29.59	30.13	30.40	30.68	30.83	30.98	31.06	31.15	31.20	31.25
4				30.39	31.86	33.32	34.01	34.70	35.06	35.42	35.61	35.81	35.92	36.04	36.10	36.17
5					33.51	35.16	35.97	36.77	37.19	37.61	37.85	38.08	38.22	38.35	38.44	38.52
6						37.01	37.92	38.83	39.32	39.81	40.08	40.35	40.51	40.67	40.77	40.86
7							38.91	39.89	40.42	40.96	41.26	41.56	41.74	41.92	42.03	42.13
8								40.95	41.53	42.11	42.44	42.77	42.97	43.17	43.29	43.41
9									42.14	42.75	43.11	43.46	43.67	43.88	44.01	44.14
10										43.40	43.77	44.15	44.37	44.60	44.74	44.87
11											44.16	44.55	44.79	45.02	45.17	45.31
12												44.96	45.21	45.45	45.60	45.76
13													45.46	45.71	45.87	46.03
14														45.97	46.14	46.30
15															46.30	46.47
16																46.64

B

y \ x	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	2.25	4.50	5.40	6.31	6.68	7.06	7.23	7.41	7.50	7.59	7.64	7.69	7.72	7.74	7.76	7.78
2		8.99	10.81	12.62	13.37	14.11	14.46	14.81	15.00	15.18	15.28	15.38	15.43	15.49	15.52	15.56
3			13.16	15.51	16.54	17.56	18.06	18.55	18.81	19.07	19.22	19.36	19.45	19.53	19.58	19.63
4				18.40	19.71	21.01	21.65	22.29	22.63	22.97	23.16	23.35	23.46	23.57	23.64	23.70
5					21.19	22.66	23.41	24.16	24.56	24.96	25.19	25.41	25.54	25.68	25.76	25.83
6						24.32	25.17	26.02	26.48	26.95	27.21	27.47	27.63	27.78	27.88	27.97
7							26.09	27.01	27.52	28.03	28.32	28.61	28.78	28.96	29.06	29.16
8								28.00	28.55	29.11	29.43	29.75	29.94	30.13	30.25	30.36
9									29.14	29.72	30.06	30.40	30.61	30.81	30.94	31.06
10										30.34	30.70	31.06	31.28	31.50	31.63	31.77
11											31.08	31.45	31.68	31.91	32.05	32.19
12												31.84	32.08	32.32	32.47	32.62
13													32.33	32.58	32.73	32.88
14														32.83	32.99	33.15
15															33.15	33.32
16																33.48

Table 2. The total dose delivered (in Gy) to the prescription points (**A**) 5 mm and (**B**) 10 mm perpendicular to the implant plane by a rectangular array of z by r 1 U seeds, calculated using the 2D formalism in MATLAB, where z and r and the number of seeds along the seeds' long axis and radial directions respectively. All implant arrangements prescribed to 5 and 10 mm have differences between the MIM and MATAB calculations of less than 0.8% and 1.4%, respectively

A

r \ z	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	4.67	9.35	10.43	11.51	11.87	12.24	12.40	12.56	12.64	12.72	12.76	12.81	12.83	12.86	12.87	12.89
2	9.35	18.70	20.86	23.02	23.75	24.48	24.79	25.11	25.28	25.44	25.53	25.62	25.67	25.72	25.75	25.78
3	10.58	21.17	23.98	26.78	27.81	28.83	29.30	29.76	29.99	30.23	30.36	30.49	30.57	30.64	30.69	30.73
4	11.82	23.64	27.09	30.55	31.87	33.19	33.80	34.40	34.71	35.03	35.20	35.37	35.47	35.57	35.63	35.68
5	12.26	24.53	28.30	32.08	33.59	35.10	35.81	36.53	36.90	37.28	37.48	37.69	37.81	37.93	38.00	38.07
6	12.71	25.42	29.51	33.60	35.31	37.01	37.83	38.66	39.09	39.53	39.77	40.01	40.15	40.30	40.38	40.46
7	12.91	25.82	30.07	34.33	36.14	37.96	38.86	39.75	40.24	40.72	40.99	41.26	41.42	41.58	41.67	41.77
8	13.11	26.22	30.63	35.05	36.98	38.91	39.88	40.85	41.38	41.91	42.21	42.51	42.68	42.86	42.97	43.07
9	13.21	26.42	30.92	35.43	37.42	39.42	40.44	41.45	42.01	42.57	42.90	43.22	43.41	43.60	43.71	43.83
10	13.31	26.62	31.21	35.80	37.86	39.93	40.99	42.06	42.65	43.24	43.58	43.93	44.13	44.34	44.46	44.58
11	13.36	26.73	31.37	36.01	38.11	40.21	41.31	42.40	43.02	43.63	43.99	44.35	44.56	44.78	44.91	45.04
12	13.42	26.83	31.52	36.21	38.36	40.50	41.63	42.75	43.39	44.02	44.39	44.77	44.99	45.22	45.36	45.50
13	13.45	26.90	31.61	36.33	38.50	40.67	41.81	42.96	43.61	44.26	44.64	45.02	45.26	45.49	45.63	45.78
14	13.48	26.96	31.70	36.45	38.64	40.83	42.00	43.16	43.83	44.49	44.88	45.28	45.52	45.76	45.91	46.06
15	13.50	26.99	31.76	36.52	38.73	40.93	42.11	43.29	43.96	44.63	45.04	45.44	45.68	45.93	46.08	46.24
16	13.52	27.03	31.81	36.59	38.81	41.03	42.22	43.41	44.09	44.78	45.19	45.60	45.85	46.10	46.26	46.41

B

r \ z	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	2.33	4.65	5.54	6.42	6.77	7.11	7.26	7.42	7.50	7.58	7.62	7.66	7.69	7.71	7.73	7.74
2	4.65	9.31	11.08	12.85	13.53	14.22	14.53	14.84	15.00	15.15	15.24	15.32	15.37	15.42	15.45	15.48
3	5.60	11.21	13.53	15.85	16.80	17.76	18.21	18.65	18.88	19.11	19.24	19.36	19.44	19.51	19.55	19.59
4	6.55	13.10	15.98	18.85	20.07	21.30	21.88	22.47	22.77	23.07	23.24	23.40	23.50	23.60	23.65	23.71
5	6.94	13.89	17.05	20.21	21.61	23.02	23.70	24.39	24.75	25.11	25.31	25.51	25.63	25.75	25.82	25.89
6	7.34	14.67	18.12	21.57	23.15	24.73	25.52	26.31	26.73	27.15	27.39	27.62	27.76	27.90	27.98	28.06
7	7.52	15.04	18.64	22.24	23.93	25.62	26.48	27.34	27.80	28.27	28.53	28.80	28.95	29.10	29.20	29.29
8	7.70	15.41	19.16	22.91	24.71	26.50	27.44	28.37	28.88	29.39	29.68	29.97	30.14	30.31	30.41	30.52
9	7.80	15.60	19.43	23.27	25.13	26.99	27.97	28.94	29.48	30.02	30.33	30.65	30.83	31.02	31.13	31.24
10	7.90	15.79	19.71	23.62	25.55	27.47	28.50	29.52	30.09	30.66	30.99	31.33	31.52	31.72	31.84	31.97
11	7.95	15.90	19.86	23.82	25.78	27.75	28.80	29.85	30.44	31.04	31.39	31.73	31.94	32.15	32.28	32.41
12	8.00	16.00	20.01	24.02	26.02	28.02	29.10	30.19	30.80	31.41	31.78	32.14	32.36	32.58	32.71	32.85
13	8.03	16.06	20.10	24.13	26.16	28.19	29.28	30.38	31.01	31.64	32.01	32.39	32.61	32.84	32.98	33.12
14	8.06	16.12	20.18	24.25	26.30	28.35	29.47	30.58	31.23	31.87	32.25	32.64	32.87	33.10	33.25	33.39
15	8.08	16.16	20.24	24.32	26.38	28.44	29.57	30.71	31.36	32.01	32.40	32.79	33.03	33.27	33.42	33.57
16	8.10	16.19	20.29	24.39	26.46	28.54	29.68	30.83	31.49	32.15	32.55	32.94	33.19	33.43	33.59	33.74

Table 3. Total dose delivered (in Gy) to the 5 mm and 10 mm prescription points by each 1 U seed in an irregular implant, using the point and line source models. Each quadrant can be mirrored about the prescription point to create a full table. Bolded values indicate a difference between line and point source models that are greater than 5% for a single seed's contribution to the prescription point; bolded and underlined values indicate greater than 10%, with a maximum of 16.9%

r	z	Point source model								Line source model							
		8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8
5 mm	8	0.005	0.005	0.007	0.009	0.012	0.014	0.016	0.017	0.018	0.017	0.015	0.012	0.010	0.007	0.005	0.005
	7	0.005	0.008	0.011	0.014	0.019	0.023	0.027	0.029	0.031	0.028	0.024	0.019	0.015	0.011	0.008	0.005
	6	0.007	0.011	0.015	0.021	0.029	0.038	0.047	0.052	0.054	0.049	0.040	0.030	0.022	0.015	0.010	0.007
	5	0.009	0.014	0.021	0.032	0.047	0.065	0.083	0.096	0.101	0.087	0.067	0.048	0.032	0.021	0.014	0.009
	4	0.012	0.019	0.029	0.047	0.073	0.111	0.156	0.190	0.199	0.162	0.114	0.073	0.046	0.029	0.018	**0.011**
	3	0.014	0.023	0.038	0.065	0.111	0.190	0.309	0.424	0.445	0.319	0.191	0.109	0.062	**0.036**	**0.021**	**0.013**
	2	0.016	0.027	0.047	0.083	0.156	0.309	0.641	1.181	1.235	0.647	0.297	**0.144**	**0.075**	**0.041**	**0.024**	**0.014**
	1	0.017	0.029	0.052	0.096	0.190	0.424	1.181	4.595	4.675	**1.081**	**0.364**	**0.159**	**0.081**	**0.045**	**0.026**	**0.015**
10 mm	1	0.017	0.029	0.050	0.091	0.176	0.373	0.906	2.249	2.327	0.885	**0.342**	**0.155**	**0.079**	**0.043**	**0.024**	**0.015**
	2	0.016	0.026	0.045	0.079	0.145	0.278	0.540	0.906	0.949	0.550	0.272	**0.137**	**0.072**	**0.040**	**0.023**	**0.014**
	3	0.014	0.022	0.037	0.062	0.105	0.176	0.278	0.373	0.392	0.288	0.177	0.103	0.060	**0.035**	**0.021**	**0.013**
	4	0.012	0.018	0.029	0.045	0.070	0.105	0.145	0.176	0.185	0.151	0.108	0.070	0.044	0.028	0.017	**0.011**
	5	0.009	0.014	0.021	0.031	0.045	0.062	0.079	0.091	0.095	0.083	0.064	0.046	0.031	0.021	0.013	0.009
	6	0.007	0.010	0.015	0.021	0.029	0.037	0.045	0.050	0.052	0.047	0.038	0.029	0.021	0.015	0.010	0.007
	7	0.005	0.007	0.010	0.014	0.018	0.022	0.026	0.029	0.030	0.028	0.023	0.019	0.014	0.010	0.007	0.005
	8	0.005	0.005	0.007	0.009	0.012	0.014	0.016	0.017	0.018	0.017	0.014	0.012	0.009	0.007	0.005	0.005

Table 4. The rectangular and irregular implant tables are used to determine AKS (in U) for the three most recent rectangular and irregular patient plans. The percent difference in seed strengths determined using the two methods is presented for each case

Patient	Seed arrangement	Number of seeds	Tables		MIM Symphony		% difference	
			1D	2D	1D	2D	1D	2D
1	Rectangle: 5 × 4	20	1.88	1.88	1.9	1.9	–1.1%	–1.1%
2	Rectangle: 3 × 3	9	2.53	2.50	2.5	2.5	1.2%	0.0%
3	Rectangle: 6 × 7	42	1.58	1.59	1.6	1.6	–1.3%	–0.6%
4	Irregular: 5, 5, 3	13	2.23	2.23	2.3	2.2	–3.0%	1.4%
5	Irregular: 6, 6, 5, 4	21	1.88	1.86	1.9	1.9	–1.1%	–2.1%
6	Irregular: 4, 7, 8, 8, 4, 2	33	1.67	1.67	1.7	1.7	–1.8%	–1.8%

scription point, differences between MIM and MATLAB are attributed to the large effect of the inverse square law for small uncertainties in manual seed and prescription point placement in MIM as well as a large volume averaging effect. For seeds located further from the prescription point, differences are attributed to limited significant figures in the dose value displayed in MIM, which has a larger relative effect when the dose at the prescription point is very small. The AKS determined with the tables agreed with MIM-determined AKS for six previous implants within 3%. Differences are due to errors in manual seed and prescription point placement in MIM and rounding of AKS to a single decimal place for ordering. While measurement tools are available in MIM, precise placement of a prescription point and measurement perpendicular to implant plane are challenging especially when the implant plane is not aligned with an axial, coronal, or sagittal slice of the image set. MIM Symphony LDR™ allows the user to overlay the digital projection of an external prostate seed implant template but the templates are limited in size and often not large enough. Due to these limitations, the nomogram tables provide more consistent dose calculations than manually creating implants in MIM Symphony LDR™.

Although treatment planning and seed ordering are performed during a preoperative CT planning session using sophisticated treatment planning software, the final dose is modified intraoperatively to fit the surgical defect in 10-20% of cases. Intraoperative considerations that can lead to these alterations include: location and exposure of the carotid artery within the operative field, bony anatomy that causes contour alterations, free flap reconstruction, and unexpected changes in the area of greatest concern for recurrence. Nomogram tables are used in the operating room to provide the surgeon and radiation oncologist an accurate dose estimate based on a number or arrangement of seeds that differs from the preoperative planning session. A second check of the pre-planning dose is performed for all cases.

Unlike other permanent seed implant radionuclides, ^{131}Cs was not used clinically until brachytherapy TPS were common in radiation therapy departments. Because of this, historical implant systems and data tables do not exist. The uniform seed strength and uniform seed spacing reported here is reminiscent of the Quimby system [25]. However, the choice of a prescription point that is not directly above a seed means that the prescription dose is the minimum dose in the central region of the 5 mm or 10 mm prescription point plane. The Manchester [26] and Quimby systems are prescribed such that the prescription dose is the modal or maximum dose in the treatment plane, respectively. The system of implant dosimetry reported here would therefore deliver more dose than an implant prescribed using the Manchester or Quimby conventions.

Conclusions

Nomogram tables to determine AKS per seed for rectangular and irregular planar ^{131}Cs implants prescribed to 5 mm and 10 mm from the implant plane are presented. The nomogram tables may be adapted to any prescription dose. Tables were verified against MIM Symphony LDR™ planning system, including previous patient plans and yield seed activities well within clinically acceptable accuracy. These nomogram tables reduce time required for treatment planning or independent verification of a treatment plan. They also facilitate treatment planning in the operating room when patient anatomy requires an implant to deviate from the treatment plan.

Disclosure

Authors report no conflict of interest.

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