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Determination of the TG-43 dosimetry parameters and isodose curves of ^{103}Pd source model OptiSeed^{TM} in soft tissue phantom

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ABSTRACT

Introduction: ^{103}Pd brachytherapy sources are used normally in prostate and breast cancer therapy. For calculating the effect of source shield or applicators and dose distribution usually Monte Carlo codes such as MCNP and GEANT are applied. The aim of this work is to determine the dosimetric parameters of a ^{103}Pd source in soft tissue phantom.
Method: In this present work, we have used MCNP4C code to calculate relative dose in soft tissue phantom. We have calculated the dose distribution in soft tissue phantom with 1.04 g/cm^3 density which is more accurate than water phantom for human tissue.
Results: We have determined the isodose curves and anisotropy function, F(r,θ), and radial dose function, g(r), which are important dosimetric parameters. Our result are in good agreement with others result.
Conclusion: Dose deposition in high gradient region, near the source, can only be calculated accurately by Monte Carlo method. The obtained value of g(r) and F(1 cm, θ) as the TG-43 parameters for the source, are agree quite well with the result of others.

Introduction

^{103}Pd brachytherapy sources are used normally in prostate and breast cancer therapy (1-3). The first breast cancer treatments in the world using small beads of ^{103}Pd has been done successfully by radiation oncologists at Toronto Sunnybrook regional cancer centre in Canada (3). Theoretical and experimental dosimetric studies have been supplied useful information on the dependence of the brachytherapy source geometry and material (4-7). Usually, Monte Carlo method has been used to define dose distribution function, the radial dose variation, and the dose calculation close the source in brachytherapy. Rivard presented a discretized approach to determining TG-43 brachytherapy dosimetry parameters using Monte Carlo calculations for the MED3633 ^{103}Pd source (7). Also, Meigooni at al. have determined dosimetric characteristics for brachyseed^{TM} ^{103}Pd, model Pd-1 source theoretically and experimentally (5). Corriveau et al. discussed morbidity effect of the time gap between supplemental beam radiation and Pd-103 prostate brachytherapy (8).

In this present work, we have used MCNP4C code [9] to calculate relative dose in soft tissue phantoms. Then the isodose curves and dosimetric characteristics for OptiSeed^{TM} ^{103}Pd source have been determined. Comparison our results with other published data show a good agreement.

Materials and Methods

The OptiSeed ^{103}Pd source

Figure 1 shows the design of the new polymer encapsulated OptiSeed^{TM} manufactured by IBT (10). Externally, the source is a right cylinder with a physical length of 5 mm and 0.8 mm diameter with an internal centrally located gold marker of 2 mm length. The encapsulation is made of a biocompatible polymer molded into the shape of two cups—right circular cylinders open on one end and closed on the other. Equal amounts of polymer palladium mixture are deposited into the cups so that it forms a pellet adjacent to the sealed bottom of the cups. The open ends of the partially filled cups are slid over the ends of the gold marker and bonded together to form a hermetically sealed source. The air gap between the ends of the gold marker and the palladium mixture surface is nominally 0.2 mm. The ends of the seed capsule contains a spherical socket, which can accept a 'snap-in' ball at the end of a spacer, facilitating making a strand of seeds for applications requiring this configuration. Cell features represented in Figure 1 is accurately represented in the Monte Carlo computational geometry, including the air gaps and the spherical sockets (10, 11). The photons spectrum emitted per decay of ^{103}Pd and their intensity are listed in Table 1 (7) which is used for input file of MCNP4C code.

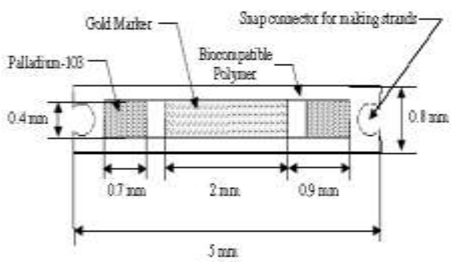

Fig. 1: Schematic of the OptiSeed ^{103}Pd source (10).

Method of Dose Calculation in Soft Tissue Phantom

MCNP, the Monte Carlo *N*-Particle code version 4C with photon cross-section library DLC-200 has been used for the dose rate simulations (9). The cutoff energy was set at 1keV. In the present work, the dose distribution has been calculated around the ^{103}Pd source located in the center of 30cm × 30cm × 30cm phantom by using tally *F8:p of MCNP code (9). The tally in the sphere of 0.1mm diameter cell was evaluated as dose in the point center of the sphere. First, along the X axis with 0.1mm step and along the Y axis with 0.1mm step, relative dose curves have been calculated. The dose distribution was normalized to

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100% at the point X=2mm, Y=0mm as a reference point. We found the isodose curves from relative dose curves by interpolate method. Soft tissue composition that used in this work, are listed in Table 2 with 1.04 g cm^{-3}density (12).

2-3 TG-43 formalism

Anisotropy function, F(r,θ), and radial dose function, g(r), are dosimetry important parameters that have been determined to compare our result with which were obtained by others. According to TG43 protocol (13, 14), the absorbed dose rate can be expressed as:

$$D(r,\theta) = S_k \Lambda t \frac{G(r,\theta)}{G(r_0,\theta_0)} g(r) F(r,\theta) \qquad (1)$$

where S_k is the air kerma strength, Λ is the dose rate constant, $G(r,\theta)$ is the geometry factor, $F(r,\theta)$ is the anisotropy function, g(r) is radial dose function, t is time of exposure, and (r_0,θ_0) is the reference point. For the use of our simulated data in treatment planning programs based on TG43 formalism, we have extracted from the dosimetry parameters that appear in the following expression:

$$F(r,\theta) = \frac{D(r,\theta)}{D(r,\theta_0)} \frac{G(r,\theta_0)}{G(r,\theta)} \qquad (2)$$

$$g(r) = \frac{D(r,\theta_0)}{D(r_0,\theta_0)} \frac{G(r_0,\theta_0)}{G(r,\theta_0)} \qquad (3)$$

Results

Relative dose calculation and measurement

Figure 2 shows the PDD variation along the Y=0mm, Y=2mm, Y=3mm, and Y=4mm which the effect of source shield is very clear. Also, the PDD variation along the X=0.5mm, X=1mm, X=1.5mm and X=2mm are shown in Figure 3. The isodose curves for PDD = 100%, 80%, 60%, 40% and 20% results in soft tissue phantom are shown at Figure 4. It can be seen that D=D(r,θ), dose distribution depends to r and θ, distance from the center of source and polar angle, respectively. We mention that the error in these calculations is less than 1%.

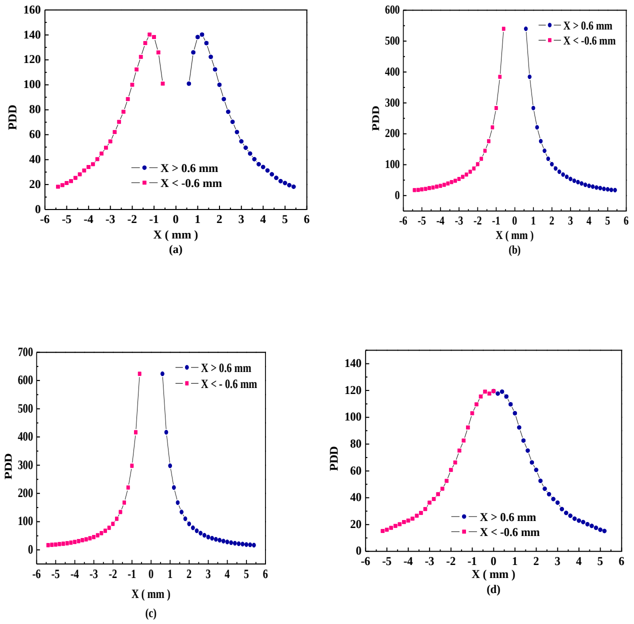
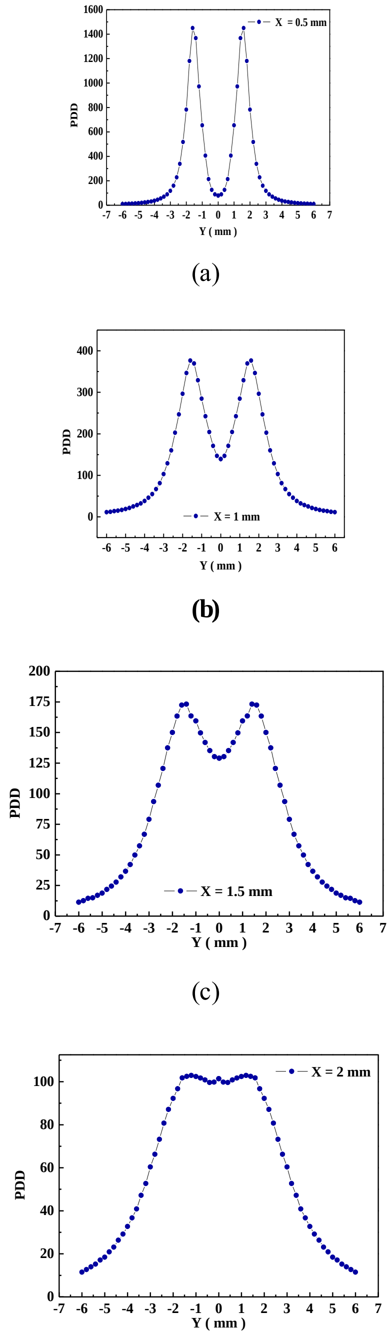


Figure 2: The Monte Carlo PDD along: (a) Y=0mm, (b) Y=1mm, (c) Y=2mm and (d) Y=4mm



(a)

(b)

(c)

(d)

Figure 3: The Monte Carlo PDD along: (a) X=0.5mm, (b) X=1mm, (c) X=1.5mm and (d) X=2mm

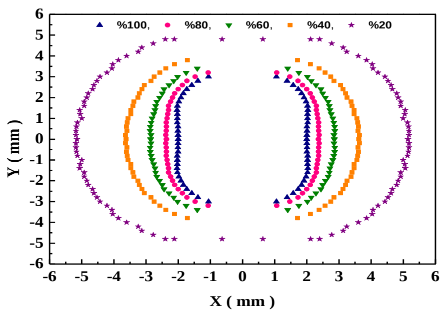


Figure 4: The isodose curves calculated in soft tissue phantom (the reference point: X=2mm, Y=0mm)

Determination of TG-43 dosimetry parameters

In this section, we have presented the Tg-43 dosimetry parameters result according to equations (2) and (3). Table 3 show F(r, θ) against θ for soft tissue phantoms obtained in this study. The result shows the anisotropy function close to unit value by increasing r and θ. Moreover, computational of g(r) value against r for the ^{103}Pd source model OptiSeed^{TM} in soft tissue phantom are listed in Table 4.

Discussions

Upon comparison of g(r) for the ^{103}Pd source measured or calculated by Wang (10) and this work in Figure 5, it is evident there was a good agreement over all radial distances and maximum percentage of difference is 5.2% at r=5cm. Moreover, Figure 6 shows a comparison of F(1 cm, θ) obtained in this study and the results of Bernard (11). The results of Bernard and Wang for F(r, θ) and g(r) are expressed for water phantom but aren't contained the soft tissue phantom. As it can bee seen in Figure 3, the dose is falling in about 5 mm from reference point. Thus, this seed shouldn't apply in small tumors with size smaller than 5mm.

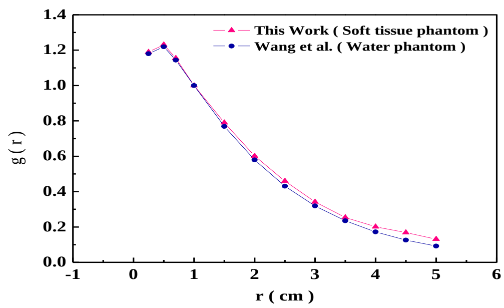


Figure 5: Comparison of the results g(r) in this study with the result of Wang in water phantom (10)

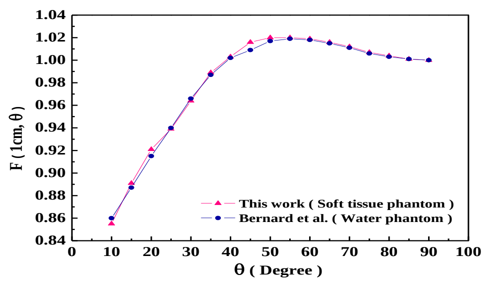


Figure 6: Comparison of the results F(1 cm, θ) in this study with the result of Bernard (11).

Conclusions

We have calculated the dose distribution in soft tissue phantom with 1.04 g/cm^3 density which is more accurate than water phantom for human tissue. Dose deposition in high gradient region, near the source, can only be calculated accurately by Monte Carlo method. The TG-43 parameters calculated result can be used in treatment planning systems. The evaluated value of g(r) and F(1 cm, θ) for the source agree quite well with the result of Bernard (11) and Wang (10). The present work demonstrates a useful approach using MCNP code in dose calculation and medical physics field.

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Table 1: Photons spectrum of ^{103}Pd per decay (7)

Photon Energy (keV)	Photons per disintegration (%)	Photon Energy (keV)	Photons per disintegration (%)	Photon Energy (keV)	Photons per disintegration (%)
20.074	22.4	23.312	1.94	294.95	0.0028
20.216	42.3	39.755	0.0683	357.46	0.0221
20.717	10.4	62.51	0.00104	497.054	0.00401

Table 2: The soft tissue composition that we used in MCNP input (12).

Element	Mass Percentage	Element	Mass Percentage
H	10.454	S	0.204
C	22.663	Cl	0.133
N	2.490	K	0.208
O	63.525	Ca	0.024
Na	0.112	Fe	0.005
Mg	0.013	Zn	0.003
Si	0.030	Rb	0.001
P	0.134	Zr	0.001

Table 3: Calculated anisotropy function, F(r,θ), for OptiSeed[TM] ^{103}Pd source in soft tissue phantom

θ (deg)	r(cm)								
	0.5	1	2	2.5	3	4	5	6	7
0	-	-	-	-	0.752	0.751	0.748	0.745	0.744
5	-	-	-	0.763	0.763	0.756	0.754	0.750	0.752
10	0.855	0.800	0.791	0.785	0.781	0.779	0.776	0.778	0.781
15	0.891	0.845	0.832	0.823	0.821	0.818	0.819	0.815	0.812
20	0.921	0.899	0.881	0.876	0.864	0.855	0.854	0.851	0.842
25	0.939	0.911	0.901	0.894	0.892	0.889	0.885	0.884	0.876
30	0.964	0.942	0.932	0.929	0.927	0.923	0.924	0.919	0.914
35	0.989	0.969	0.958	0.953	0.951	0.950	0.947	0.943	0.940
40	1.003	0.985	0.981	0.975	0.970	0.969	0.967	0.966	0.962
45	1.016	0.994	0.990	0.987	0.983	0.981	0.980	0.978	0.977
50	1.020	1.006	0.997	0.996	0.993	0.992	0.990	0.989	0.986
55	1.020	1.010	1.005	1.002	0.998	0.998	0.995	0.994	0.991
60	1.019	1.010	1.008	1.005	1.002	1.001	0.999	0.998	0.996
65	1.016	1.009	1.007	1.004	1.001	1	0.999	0.999	0.997
70	1.012	1.007	1.005	1.003	1.002	1.001	0.998	0.997	0.998
75	1.007	1.005	1.003	1.002	1.001	1.001	1.001	1	0.999
80	1.004	1.003	1.002	1.001	1.001	1	0.999	0.999	0.998
85	1.001	1.001	1	1.001	1	0.999	1	1	0.999
90	1	1	1	1	1	1	1	1	1

Table 5: Computational of g(r) value against r

Distance along transverse axis (cm)	0.25	0.50	0.70	1.0	1.5	2	2.5	3	3.5	4	4.5	5
Soft Tissue Phantom	1.189	1.231	1.155	1.000	0.790	0.601	0.460	0.342	0.254	0.201	0.168	0.131