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Comparison of dosimetry parameters of two commercially available Iodine brachytherapy seeds using Monte Carlo calculations

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Background: Iodine brachytherapy sources with low photon energies have been widely used in treating cancerous tumors. Dosimetric parameters of brachytherapy sources should be determined according to AAPM TG-43U1 recommendations before clinical use. Monte Carlo codes are reliable tools in calculation of these parameters for brachytherapy sources. ***Materials and Methods:*** Dosimetric parameters (dose rate constant, radial dose function, and anisotropy function) of two I-125 brachytherapy sources (models LS-1 and Intersource) were calculated with MCNP4C Monte Carlo code following task group #43 (TG-43U1) recommendations of American Assossiation of Physicists in Medicine. The simulations were done inside a spherical water phantom because of its tissue equivalent properties. The Monte Carlo simulations for radial dose function were performed at distances ranging from 0.25 to 10 cm from the source center. The anisotropy functions F(r, θ), for both sources, were calculated at distances of 1, 2, 3, 5 and 7 cm from the source center for angles ranging from 15 to 90 degree. ***Results:*** The results of the Monte Carlo simulation indicated a dose rate constant of 0.952 $cGyh^{-1}U^{-1}$ and 0.986 $cGyh^{-1}U^{-1}$ for models LS-1 and Intersource, respectively. The tabulated data and fifth order polynomial coefficients for radial dose functions along the source are described in this paper .The results indicated that the anisotropy in dose distribution increased along the source axis. ***Conclusion:*** The obtained results were in good agreement with measurements and calculations of other investigators, using other Monte Carlo codes. **Iran. J. Radiat. Res., 2010; 7 (4): 217-222**

Keywords: *Brachytherapy, radial dose function, Monte Carlo, TG-43.*

INTRODUCTION

Encapsulated radioactive materials are used in several medical applications for treatment of common tumor sites such as prostate, breast, eye, and cervix. ^{125}I and ^{192}Ir are among the most commonly used sources recently. Dosimetric characteristics of commercially available iodine sources have been reported previously (1-4).

Monte Carlo codes are reliable tools in dosimetry of brachytherapy sources. The codes used to model photon transport for brachytherapy dose calculation should be able to support detailed 3D modeling of source geometry and appropriate dose estimation techniques (5). Among Monte Carlo codes, MCNP4C has been used in this research to determine the dose distribution around two commercially available iodine sources (Models LS-1 and Intersource). The dosimetry parameters of these two sources have been previously determined by other investigators by experimental measurements and other Monte Carlo codes. The use of MC for preparing the tabulated dosimetry data of brachytherapy sources is a common practice. In 2002 Meigooni *et al.*, determined the dosimetric parameters of Intersource iodine source using TL dosimetry and calculations using PTRAN Monte Carlo code according to the recommendations of task group number 43 of American association of physicist in medicine (AAPM) (4). Several investigators have also made detailed experimental and theoretical studies on TG-43 dosimetry parameters of LS-1, source (6-9). The goal of this project was to determine the dosimetric parameters, such as dose rate constant, radial dose function and anisotropy functions for LS-1 and Intersource I-125 sources using MCNP4C code

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according to the TG-43U1, the update of TG-43 protocol and comparing the data with the predetermined data of other investigators using the original TG-43 protocol.

MATERIALS AND METHODS

Models of sources

The Model LS-1, I-125 source with a length of 4.4 mm and an outer diameter of 0.8 mm, had titanium container and was composed of two 0.55 mm diameter ceramic pellets containing ^{125}I, separated by a 2.972 mm long X-ray marker. A 1.189 mm long titanium annulus surrounded the X-ray marker, and two titanium spacers each 1.189 mm long, 0.691 mm OD and 0.589 mm ID flanked the annulus to keep it centered during manufacture. Two ceramic beads with a diameter of 0.5 mm were located at the ends of the source. ^{125}I was uniformly distributed within the beds (6).

The model Intersource I-125 source had a physical length of 4.5mm with an outer dimension of 0.81 mm with a 0.045mm thick Pt/Ir X-ray marker and three bands of an insoluble organic matrix containing iodine (4).

Dose calculation formalism

Characteristics of the iodine sources were determined theoretically following task Group number 43 (TG43-U1) of the American associations of physicists in medicine (AAPM) (5, 10).

According to the recommendations of TG-43 protocol, the absorbed dose rate distribution around a sealed brachytherapy source, for line source approximation can be determined using the following formalism:

$$\dot{D}(r,\theta) = S_k.\Lambda.\frac{G_L(r,\theta)}{G_L(r_0,\theta_0)}.g_L(r).F(r,\theta), \qquad (1)$$

Where Λ is the dose rate constant, $G_L(r, \theta)$ is the geometry function, $g_L(r)$ is the radial dose function, F(r, θ) is the anisotropy function. The above quantities are defined and discussed in detail in TG-43 (4, 6). The subscript "*L*" has been added in TG-43U1 to denote the line source approximation used for the geometry function. The dose rate constant was obtained from equation 2 as:

$$\Lambda = \frac{\dot{D}(r,\theta)}{S_K}. \qquad (2)$$

The radial dose function, $g_X(r)$ describes the attenuation in tissue of the photons emitted from the brachytherapy source. The radial dose function is defined as:

$$g_X = \frac{\dot{D}(r,\theta_0)}{\dot{D}(r_0,\theta_0)} \frac{G_X(r_0,\theta_0)}{G_X(r,\theta_0)}. \qquad (3)$$

The revised dose-calculation formalism has added the subscript "*X*" to the radial dose function and geometry function to indicate whether a point-source, "*P*," or line-source, "*L*," geometry function was used in transforming the data. where and $D(r,\theta_0)$ and $D(r_0,\theta_0)$ are the dose rates measured at distances of r and 1 cm, respectively, along the transverse axis of the source. $G_X(r, \theta)$ is known as the geometry function which takes into account the effect of the interior geometry of source on the dose distribution at a given point. The geometry function is defined by the AAPM TG-43 as:

$$Gp\ (r, \theta) = r^{-2} \qquad \text{Point source approximation}$$

$$G_L(r,\theta) = \begin{cases} \dfrac{\beta}{Lr \quad \sin\theta} & if \quad \theta \neq 0^\circ \\ \left(r^2 - L^2/4\right)^{-1} & if \quad \theta = 0^\circ \end{cases} \qquad \text{Line source approximation} \qquad (4)$$

Where β is the angle, in radians, subtended by the tips of the hypothetical line source with respect to the calculation point, P(r,θ) (5).

2D anisotropy function, F(r, θ) is defined as:

$$F(r,\theta) = \frac{\dot{D}(r,\theta)}{\dot{D}(r,\theta_0)} \frac{G_L(r,\theta_0)}{G_L(r,\theta)} \qquad (5)$$

Monte Carlo calculations

A Monte Carlo N-particle Transport Code (MCNP4C) (11) was used to calculate the dose rate distribution in water, and dry air around the two iodine sources. This code is able to consider photoelectric, coherent, Compton and pair production interaction processes. There are many different tally types available in MCNP for scoring diverse physical characteristics. In this work, the *F4 tally was used to score the dose distribution and Kerma rate around the sources. The photon spectrum of ^{125}I was taken from TG-43 report (10). The active length of Intersource was determined from the distance between the outer edges of the two outer active bands, and for LS-1 source, the distance between distal surfaces of one pellet to the other pellet was used during the calculation of the geometric functions.

In MCNP4C simulations, the source was simulated at the center of a spherical water phantom 60 cm in diameter, and the ring torus tally cells of 0.5 mm minor radius, with the major radius corresponding the distance between the calculation point and the longitudinal axis of the source, were employed to score dose rate in different distances around the sources. To score air-kerma strength, SK, a spherical dry air phantom, with radius of 3m was simulated with the 0.5mm radius tally cells inside the phantom. A 5 keV energy cutoff was considered to exclude the low energy or contaminant photons (5).

RESULTS

The dose-rate constant, $\Lambda=\dot{D}\,(r=1\mathrm{cm})/SK$, for the LS-1 source has been found to be 0.952±0.09, and 0.986±0.09 for model Intersource. In table 1 the measured or calculated dose rate constants are presented for these two clinically available ^{125}I sources. The revisions proposed in TG-43U1 protocol were also considered in this study.

The radial dose function, $g_L\,(r)$, accounts for dose fall-off on the transverse-plane due to photon scattering and attenuation, excluding fall-off included by the geometry function. The radial dose function data obtained for the sources have been fitted to a fifth-degree polynomial between 0.5 and 10 cm. The obtained coefficients are a_0=0.6445, a_1=0.63326, a_2=-0.38351, a_3=0.080697, a_4=-0.0075139, and a_5=0.00025938 for LS-1 source and a_0= 0.99869, a_1=0.12696, a_2=-0.13946, a_3=0.028808, a_4=-0.0025236, and a_5=8.21E-05 for iodine source model Intersource. Tabulated obtained data, using TG-43 protocol or coefficients of these fifth order polynomials, can be entered as the input of treatment planning systems for dose estimation at each distance from the source.

A comparison between the radial dose functions of ^{125}I source model LS-1 determined in different investigations is presented in figure 1. As it can be derived from the figures, the values of obtained g(r) using MCNP4C code are in good agreement with those obtained in other investigations, and these values decrease with increasing the distance from the source center as expected. The small difference observed between the values of g(r) obtained using different methods, may be due to the fact that the TG-43U1 protocol has been used in this study instead of the original TG-43 protocol. Another reason for these differences may be the difference in cross section libraries used in MCNP4C relative to other codes.

Radial dose function of two models of iodine sources are compared in figure 2. The difference between the radial dose functions of the two sources are mostly due to the difference between the source geometries especially the thickness of the source tube. Most treatment planning systems use the TG-43 parameters in their dose calculation algorithms.

Table 1. Dose rate constant for two iodine sources.

Model	$\Lambda(\mathrm{cGyh^{-1}U^{-1}})$	Method	Reference
LS-1	0.953	Monte Carlo (MCNP4C)	This work
LS-1	0.967	Monte Carlo (EGS4)	6
LS-1	0.920	Monte Carlo	7
LS-1	1.02	Measurement	9
Intersource	0.986	Monte Carlo (MCNP4C)	This work
Intersource	0.981	Monte Carlo (PTRAN)	4

The anisotropy functions, F(r, θ), of the sources in Water phantom were calculated at 15° angle increments relative to the source longitudinal axis at distances of 2, 3, 5, and 7 cm from the center of the seed using MCNP4C Monte Carlo code. The anisotropy functions of LS-1 source at different distances and degrees are shown in table 2 and figure 3, shows anisotropy function of LS-1 source at 5cm and 7 cm from the source center. Close agreement was observed between the anisotropy function of the LS-1 source calculated in this study and those obtained by Wang *et al.* (6). As expected, the values of F(r, θ) was unified, at the transverse axis of the source (θ=90°) and decreased as θ approached 0° or 180°. This decrease in F(r, θ) was due to the increase in the thickness of source encapsulations towards the longitudinal axis of the source. A comparison of F(r, θ) of the two sources at 7 cm from the source center in Water phantom based on MCNP4C calculations is shown in figure 4. The observed differences between the anisotropy function of these parameters in these two sources were mostly, because of the different geometries and encapsulations of them, i.e., the lack of radioactive material in the central portion of the LS-1 source. These calculated dosimetry parameters of brachytherapy sources can be used in treatment planning systems to determine the dose distributions around the brachytherapy sources according to TG-43 formalism (equation 1). In this work all dosimetry parameters were obtained according to the TG-43U1 protocol. The results suggest that internal and external geometry of the source has significant effect on producing anisotropy in dose distribution around the source. A total dose reduction of about 20% was observed beyond the tip of the source relative to the dose on the transverse axis of the source, and the shielding effects of the source encapsulation and the geometry of the source was responsible for this reduction.

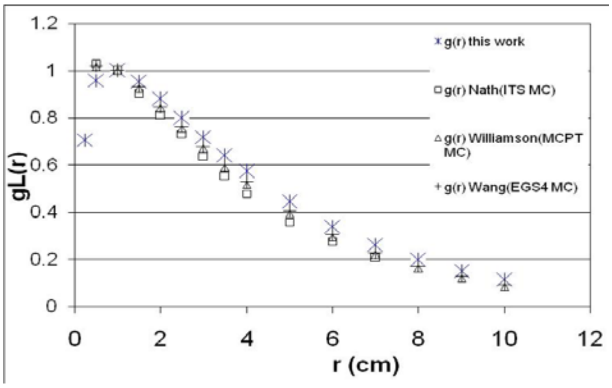

Figure 1. Linear radial dose function for model LS-1 brachytherapy source (6-9).

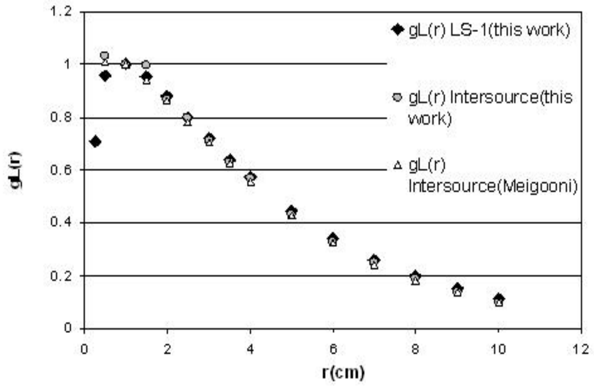

Figure 2. A comparison of linear radial dose functions of models LS-1 and Intersource Iodine brachytherapy source (4).

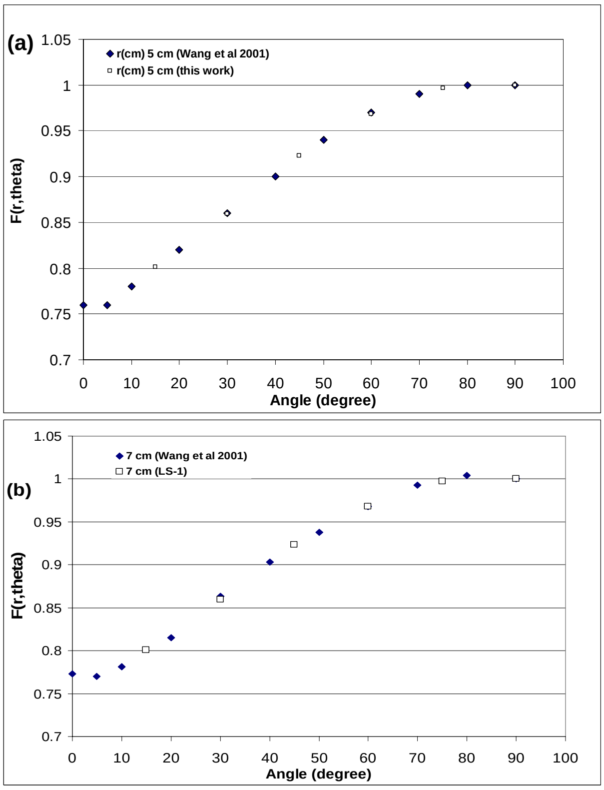

Figure 3. A comparison of anisotropy functions of model LS-1 source at a) 5cm and b) 7 cm distances from the source center (6).

Table 2. Anisotropy functions of the LS-1 source at different distances for different angles.

r(cm) theta	1cm (Wang)	1cm (this work)	2cm (Wang)	2cm (this work)	3cm (Wang)	3cm (This work)	5 cm (Wang)	5cm (this work)	7 cm (Wang)	7cm (this work)
0	0.814		0.763		0.761		0.760		0.773	
5	0.811		0.753		0.756		0.760		0.770	
10	0.816		0.777		0.773		0.780		0.781	
15				0.807		0.799		0.801		0.801
20	0.844		0.811		0.809		0.820		0.815	
30	0.872	0.919	0.849	0.864	0.85	0.859	0.860	0.859	0.863	0.859
40	0.9		0.895		0.896		0.900		0.903	
45		0.949		0.921		0.919		0.923		0.923
50	0.93		0.93		0.937		0.940		0.938	
60	0.96	0.976	0.958	0.966	0.965	0.968	0.970	0.968	0.968	0.968
70	0.983		0.989		0.987		0.990		0.993	
75		0.996		0.992		0.994		0.997		0.997
80	0.996		0.995		1		1		1.004	
90	1	1	1	1	1	1	1	1	1	1

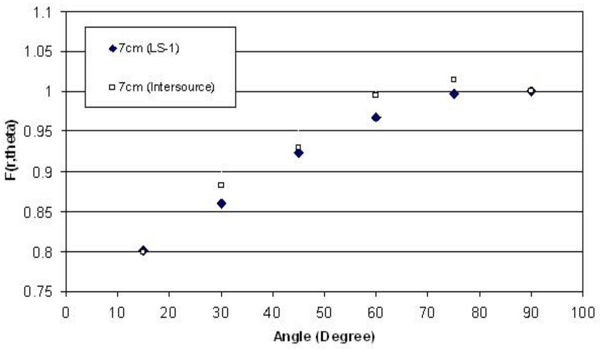

Figure 4. A comparison of anisotropy functions of model LS-1 source and Intersource I-125 at distance 7 cm from the source center.

DISCUSSION

Dose rate constants, radial dose functions and anisotropy functions of two commonly used brachytherapy sources were determined following the recommendations by TG-43U1 AAPM protocol. These parameters have already been determined by different investigators using theoretical and experimental methods according to the TG-43 original protocol. In this study, the simulations were performed in water phantom using MCNP4C Monte Carlo code. The tabulated data of the dosimetry parameters of this source have been presented in this article and the results were compared with the previous investigations. Excellent agreement was observed between the results of this study and the results obtained by other investigators. The calculated values of the anisotropy functions of the LS-1 source model were compared with those of Intersource. However, due to the geometric structure of the Model LS-1 source, some differences were observed between this source and model LS-1. The differences are mainly due to the lack of radioactive material in the central portion of the LS-1 source, as compared to the Intersource. According to the results of this investigation, the MCNP Monte Carlo code was a reliable tool in dosimetry of brachytherapy sources. The values of the dose rate constants, radial dose functions and anisotropy functions of the sources can be used to determine the dose distribution in any point around the sources according to the formalism of TG-43U1.

The good agreement between the results of this study and the achieved results by other investigations suggest that MCNP4C can be used as a approximately reliable tool in dose approximations around the I-125 brachytherapy sources along with the experimental methods of dosimetry.

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