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ARTICLE

Benchmark of EGS5 for ^{125}I brachytherapy

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The Monte Carlo code 'EGS5' was benchmarked for the usage in brachytherapy treatment planning. For this purpose, the EGS5 calculation was compared with the formalism by the American Association of Physicists in Medicine Task Group No 43 Updated Protocol 1 (AAPM-TG43U1) currently utilized for dosimetry in brachytherapy. The source utilized was ^{125}I model STM1251. Consequently, EGS5 successfully reproduced the dose distribution by the TG43-U1 formalism.

Keywords: EGS5; benchmark; brachytherapy; ^{125}***I***

1. Introduction

At present, the dosimetry for brachytherpy is performed using the formalism by the American Association of Physicists in Medicine Task Group No 43 Updated Protocol 1 (AAPM-TG43U1) [1,2]. The TG43-U1 formalism was composed as a consensus of the available dosimetry data by calculations and experiments. This study benchmarked the Monte Carlo code 'EGS5' [3] for its usage in brachytherapy, by comparison with the TG43-U1 formalism.

2. Materials and method

2.1. Dose calculation

In order to check the validity of the EGS5 calculation, the radial dose function, $g(r)$, and the 2D anisotropy function, $F(r,\theta)$, as described in TG-43U1 were calculated [2]. Calculations were carried out using EGS5. At least $1\text{x}10^8$ histories were simulated to obtain statistical uncertainties below 2%, as described in TG-43U1.

The calculation geometry included a water sphere with a radius of 15 cm, with the ^{125}I source model 'STM-1251' (Bard, Inc., Murray Hill, NJ) at its center. The geometry input for the STM1251 was the same as that used by Kirov and Williamson [4,5]. The dose calculated in the publications [4,5] was adopted as a consensus dose distribution for the TG43-U1 formalism [2].

All dosimetric tally points had a sufficient backscatter margin of 5 cm or more [2,6]. The tally cells were set as water spheres around the source at various distances from the source, r, and angles with respect to the source central axis, θ. The radius of each tally cell was set at 4% of r. $g(r)$ and $F(r,\theta)$ were estimated using the output of EGS5 calculation.

2.2. Uncertainty estimation

The uncertainty due to the geometric uncertainties was estimated using the formalism of Dolan and Williamson [7]. The included geometric uncertainties were (1) the position of the copper rod in the Ti shell (±0.24 mm in longitudinal direction and ±0.065 mm in transversal direction with respect to the source centerline); (2) the angle (0–1.96°) between the rod and Ti shell axes. The rectangular probability distribution was assumed for the geometric uncertainties. Finally, the dose uncertainty by each geometric uncertainty component was combined in quadrature to obtain the Combined Standard Uncertainty (CSU) for the coverage factor, k, set at 1.

3. Results and discussion

The EGS5 results are shown in **Table 1** for $g(r)$ and in **Table 2** for $F(r,\theta)$. The estimated uncertainty is shown in **Table 3**. All Type A and Type B uncertainty estimates refer to 1-sigma standard deviations of the mean (67% confidence interval half width for Type A uncertainties). CSU(k=1) ranged from 0.5% for g(2 cm) to 6.5% g(0.1 cm), and from 0.4% for F(3 cm, 80°) to 14.1% F(1 cm, 0°).

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Table 1. *g(r)* calculated in this study and its combined standard uncertainty (*k*=1).

r (cm)	*g(r)*
0.1	0.961±0.062
0.15	0.993±0.044
0.25	1.013±0.015
0.5	1.031±0.019
0.75	1.020±0.013
1	1.000±0.004
1.5	0.932±0.006
2	0.855±0.004
3	0.695±0.004
4	0.550±0.010
5	0.426±0.005
6	0.324±0.006
7	0.246±0.003
8	0.184±0.002
9	0.139±0.001
10	0.103±0.001

Table 2. *F(r,θ)* calculated in this study and its combined standard uncertainty (*k*=1).

	r(cm)		
θ (°)	0.5	1	2
0	0.512±0.069	0.453±0.064	0.614±0.032
5	0.629±0.060	0.575±0.035	0.608±0.021
10	0.552±0.059	0.562±0.027	0.604±0.020
20	0.677±0.049	0.684±0.029	0.723±0.018
30	0.815±0.051	0.800±0.025	0.821±0.014
40	0.895±0.035	0.874±0.019	0.890±0.009
50	0.968±0.032	0.936±0.017	0.939±0.005
60	0.988±0.018	0.986±0.024	0.980±0.034
70	0.972±0.025	0.994±0.009	1.001±0.012
80	1.002±0.018	0.991±0.006	1.011±0.016

Table 2. (*cont.*)

	r(cm)		
θ(°)	3	4	5
0	0.661±0.021	0.658±0.024	0.700±0.020
5	0.636±0.023	0.643±0.016	0.649±0.019
10	0.647±0.016	0.659±0.016	0.679±0.014
20	0.746±0.012	0.753±0.019	0.765±0.012
30	0.830±0.008	0.836±0.017	0.841±0.006
40	0.895±0.006	0.897±0.016	0.901±0.005
50	0.945±0.005	0.946±0.008	0.945±0.010
60	0.985±0.005	0.975±0.017	0.979±0.006
70	0.999±0.006	1.004±0.013	0.998±0.007
80	1.011±0.004	1.011±0.007	1.006±0.005

Table 3. Uncertainty for EGS5 calculated data.

	Uncer- tainty			
Geometry parameter	*g*(0.1cm)	*g*(2cm)	*F*(1cm, 0°)	*F*(3cm, 80°)
Type A				
Statistic	1.3%	0.3%	4.8%	0.3%
Type B				
Rod shift (transversal)	1.4%	0.2%	2.8%	0.1%
Rod shift (longitudinal)	0.7%	0.2%	3.4%	0.1%
Rod tilt angle	6.1%	0.2%	12.5%	0.2%
Quadrature sum	6.3%	0.4%	13.2%	0.2%
CSU (*k* = 1)	6.5%	0.5%	14.1%	0.4%

The ratio of EGS5 data to the TG43U1 is shown in **Figure 1**. The exhibited error bar is the quadrature sum of the CSU(*k*=1) for EGS5 and the uncertainty for the TG43U1 parameters. The latter was set at a constant value of 5% as an example, while the uncertainty of the dose was not reported at all the positions and reported range of the uncertainty was about 3-10% [2]. Calculated *g(r)* using the EGS5 agreed with the TG43U1 consensus data set to within 3% at distances within 6 cm and 4-7% over 6cm. Also, the agreement was within the uncertainty. Similar agreement was observed with *F(r,θ)* to within 4%, with the exception of small values of *r* and *θ*. In those points, the discrepancy was about 6% at (0.5 cm, 5°), 7% at (1 cm, 0°), 35% at (2 cm, 0°), 32% at (3 cm, 0°), and 24% at (5 cm, 0°).

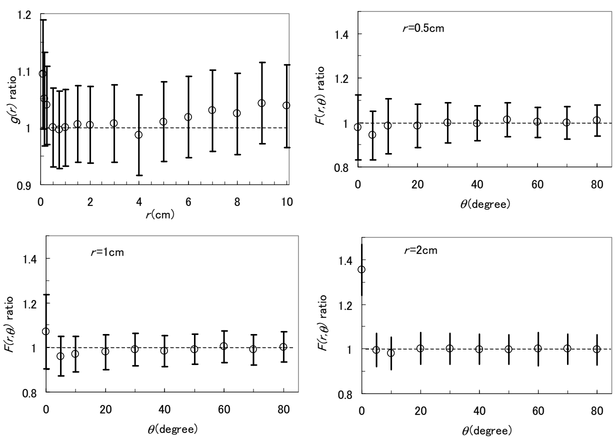

Figure 1. Comparison of *g(r)* and *F(r,θ)* between EGS5 and TG43U1. The exhibited values are the ratios of the EGS5 results to the TG43U1 parameters.

Among the previous studies about the TG43U1 parameters, *g(r)* and *F(r,θ)*, there are few detailed reports about the estimation method and discrepancy between their estimation and the TG43U1 formalism. Kirov and Williamson [4,5] reported the estimation by a Monte Carlo code 'MCPT' and the results were adopted as the TG43U1 parameters. Chiu-Tsao *et al.* [8] measured with thermoluminescent dosimeters and the results agreed with the TG43U1 parameters to within about 2-5% except for the positions on the source central axis (θ=0). At those positions, the discrepancy was 19-46%. Taylor *et al.* calculated the parameters with a Monte Carlo code 'BrachyDose' based on EGSnrc (EGS4) code. The discrepancy was about 1 % for $g(r)$ and 1-6 % for $F(r,\theta)$ [9]. The lack of agreement in the present study is consistent with previous publications.

4. Conclusion

The EGS5 was found to reproduce the TG43U1 parameters to within 3% at the distances within 6cm (7% over 6cm) for $g(r)$ and 4% $F(r,\theta)$ except for the points with small r or θ (6-32%). The agreement supports the validity of EGS5 and TG43U1 parameters.

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