Radial dose functions of GZP6 intracavitary brachytherapy ^{60}Co sources: treatment planning system versus Monte Carlo calculations

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Background: The Monte Carlo (MC) method is not only used for dose calculations around brachytherapy sources but also for benchmarking treatment planning systems (TPS) calculations. ***Materials and Methods:*** Three ^{60}Co sources of GZP6 brachytherapy unit were simulated using MCNP4C MC Code. The radial dose functions were calculated by MC method and GZP6 TPS and were compared. ***Results:*** There was a good agreement between MC and TPS calculations for all sources. Discrepancies up to 10% were observed for points close to the sources, but for those farther than 7mm from source center, differences were less than 2% for all sources. ***Conclusion:*** Our results showed that GZP6 TPS calculations can accurately be used for dose calculations in brachytherapy treatments for points farther than 7mm from the source center. **Iran. J. Radiat. Res., 2008; 5 (4): 181-186**

Keywords: *Brachytherapy, high dose rate (HDR), ^{60}Co, Monte Carlo.*

INTRODUCTION

The aim of brachytherapy is the placement of radioactive sources near the tumor volume in order to maximize the dose delivered to the tumor and minimize the dose delivered to the surrounding normal tissues. Several factors affect the purpose including the rapid dose fall-off near the sources, difficulties in localizing the tumor and normal organs, and inconsistencies in the methods employed for dose calculation.

Nowadays, high dose rate ^{60}Co and ^{192}Ir sources of various designs are currently used in brachytherapy (1, 2). Dose calculation accuracy plays a vital role in the outcome of brachytherpay treatment due to steep dose gradient around the source which makes it susceptible for dosimetric errors, and over or under-dosage of target volume consequently. The Sievert integral is applied as a dose calculation algorithm in many commercially available treatment planning systems (3, 4).

Although, algorithms implementation and simplifications may vary among different manufacturers, quality assurance of treatment planning system prior to clinical use is one of the tasks of medical physicists. The establishment of a quality assurance protocol to guarantee the desired treatment accuracy is mandatory at present, and it is an important task to verify the accuracy in the dose calculation of the treatment planning programs. The methods implemented to test these programs often make use of standard data sets and phantoms and compare the programs results with the values expected for those standards.

Several calculation methods, especially Monte Carlo (MC) method have been employed to assess the absorbed dose near brachytherapy sources (5-7). In contrast to measurements, the Monte Carlo dose estimates are not affected by errors in detector positioning, detector energy, angular dependence, and steep dose gradients near the sources. In current study, the ^{60}Co sources of a new high dose rate after loading system were simulated using MCNP4C MC Code. One of the important dosimetric properties of sources, radial dose function was calculated using MC method to compare the results of dedicated TPS of the brachytherapy system.

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MATERIALS AND METHODS

HDR ^{60}Co sources

This study was performed on three HDR ^{60}Co sources of GZP6 afterloading unit (Nuclear Power Institute of China). This unit uses six linear braid type sources including one stepping and five non-stepping sources for intracavitary treatment such as cervix, rectum, esophagus and nasopharynx malignancies. The sources were consisted of ^{60}Co active cylinders (length=3.5 cm, diameter=1.5 mm) sealed by titanium capsules and inactive steel balls (diameter=1.5 mm) which were covered by a steel spring. The position of active elements was constant in the source braid and was not changed for different treatments. Each braid source was situated in given channel and was loaded independently by mechanical transport system from shielded container to applicators for treatment. However, channels 3 and 4 were loaded simultaneously and used for ovoid applicators. Schematic representation of the three sources used in this study is shown in figure 1.

Monte Carlo simulations

The MCNP4C radiation transport code was used for MC calculations. This code allows for the development of the detailed three dimensional model of brachytherapy sources and dose calculations in complex geometries and materials (8). The detailed simulation of photon transport included photoelectric absorption with the creation of K- and L-shell fluorescent photons and auger electrons, coherent and incoherent scattering, and pair production. The simulations were done in photon mode and energy cutoff of 1 keV was used for low energy photons.

The sources were simulated using physical measurements and information provided by manufacturer. The active cores were considered as cylinders composed of ^{60}Co with uniform distribution of radioactive material. Two photons with emission probabilities of 0.5 and energies of 1.17 and 1.33 MeV were defined in source definition card. For dose calculations in water, a phantom with dimensions of 30×30×30 cm^3 was simulated.

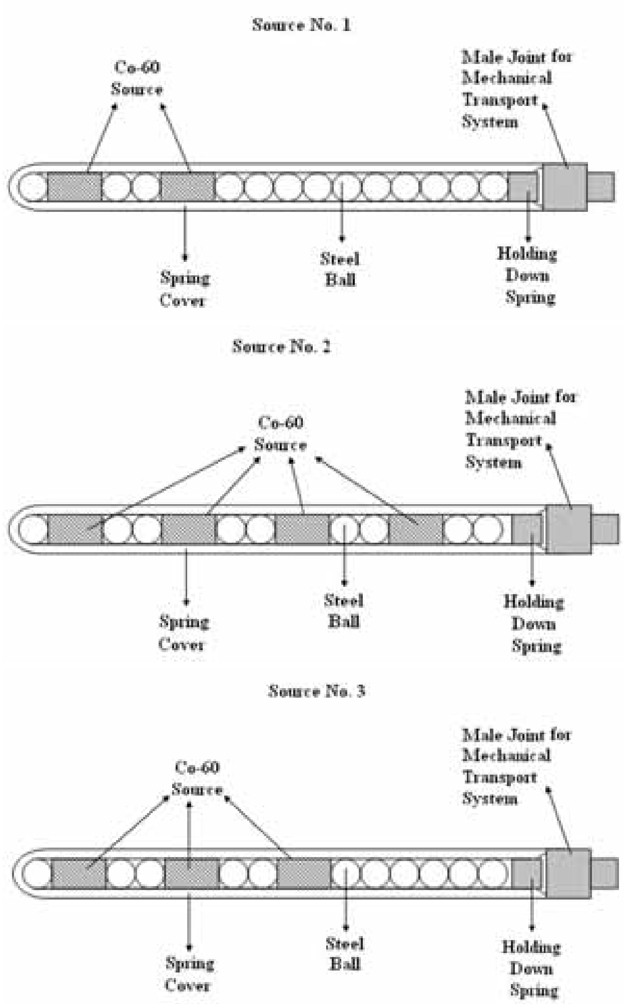

Figure 1. Schematic diagrams of GZP6 ^{60}Co braid type sources used for intracavitary treatments.

The simulated sources were located at the centre of simulated water phantom. The water phantom absorbed doses were calculated from 0.3 to 4.2 cm from the source center in radial direction, in 0.1 cm increments. Scoring cells were consisted of concentric cylindrically symmetric cells with increasing radius from 0.3 to 4.2 cm. The length of scoring cylinders was 0.2 cm (figure 2). The longitudinal location of radial line was selected for each source in a way that the active source distribution in both sides of line was symmetric as shown in the insets of figures 3, 4 and 5.

An "F6" tally was employed for the absorbed dose calculation in each cell. The energy deposited in each cell was scored per simulation in terms of $MeVg^{-1}$. For radial dose

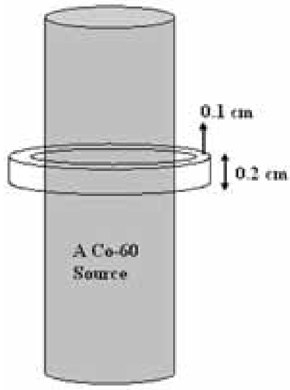

Figure 2. Diagram of a cylindrically symmetric scoring cell used for simulations.

function calculation, the absorbed doses were normalized to the value of the cell located 1cm from the source center. 100 million photons were run to acquire less than 1% statistical uncertainty in a scoring cell 4 cm from source center.

GZP6 treatment planning system

This system uses Sievert integral for 3D dose rate calculations around brachytherapy sources. The following represents the classical Sievert integral, generalized to 3D radioactivity distributions and incorporating

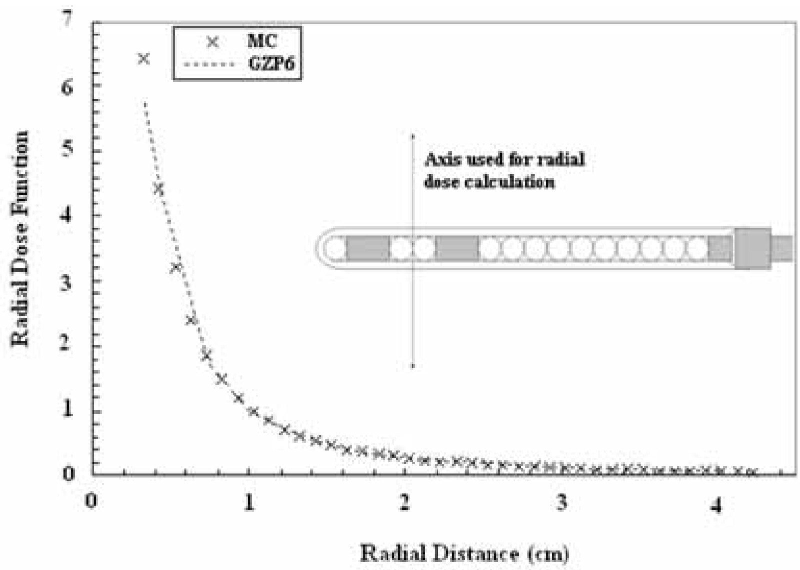

Figure 3. Comparison of radial dose functions calculated by GZP6 TPS and MC method for source1.

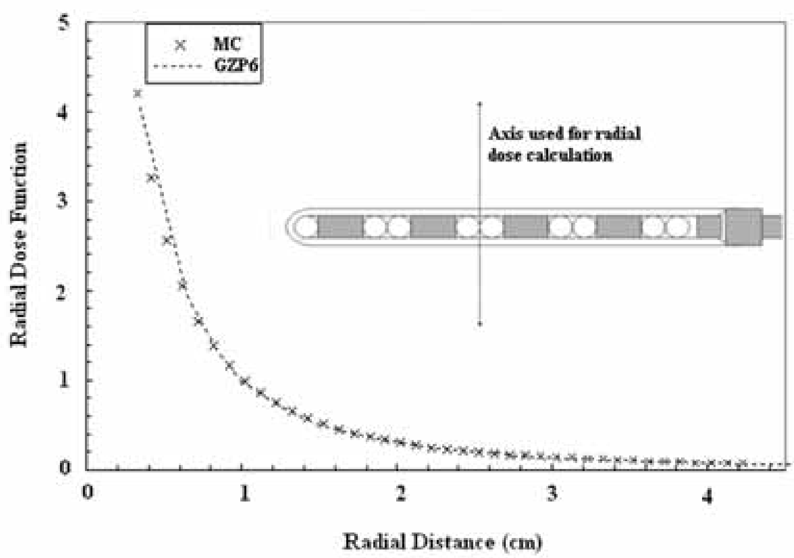

Figure 4. Comparison of radial dose functions calculated by GZP6 TPS and MC method for source2.

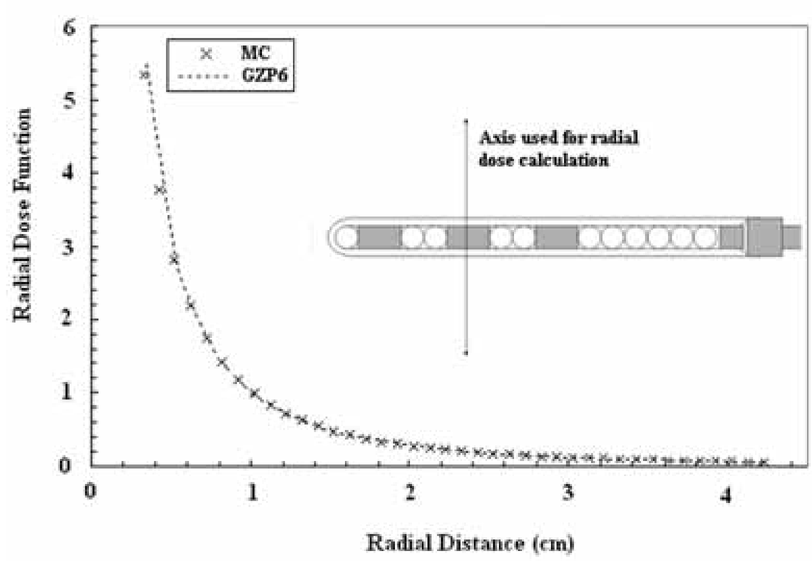

Figure 4. Comparison of radial dose functions calculated by GZP6 TPS and MC method for source3.

photon attenuation and scattering by the surrounding medium [4]:

$$\dot{D}(\vec{r}) = \frac{S_k \cdot \overline{(\mu_{en}/\rho)}_{air}^{wat}}{F(\vec{r}_c)} \cdot \int_V (\vec{r} - \vec{r}')^{-2} \cdot \exp\left[-\sum_{j=1}^{3} \mu_i(\lambda'_j) \cdot \lambda'_j\right] \cdot [1 + SPR(\lambda'_3)] dV$$

This formula calculates the dose rate $\dot{D}(\vec{r})$ in cGy/h at location $\vec{r}$ near the brachytherapy source and V denotes space enclosed the active source core. The indices j=1,..., etc denote the media composing the active core, the source encapsulation, and surrounding medium while λ'_j denotes the corresponding distances traversed by primary photons passing from source to r. The other symbols are defined as follows: (1) S_k= is the air-kerma strength of the source in units of $\mu Gy.m^2.h^{-1}$. (2) $F(\vec{r}_c)$= is the self absorption/filtration correction for the reference air-kerma rate specification geometry. (3) $\overline{(\mu_{en}/\rho)}_{air}^{wat}$= the ratio of mass-energy absorption coefficient, averaged over the photon spectrum in free space for water to that of air.(4) $\mu_i(\lambda_i)$ = for the case of surrounding medium, it is assumed to be average linear attenuation coefficient which describes the fall-off of the primary dose component over the thickness of water.

RESULTS AND DISCUSSION

The newly developed TPS of GZP6 HDR brachytherapy unit uses Sievert integral for dose distribution calculations. In the present study, radial dose functions of three ^{60}Co sources were calculated using TPS and MC method. The results are shown in figures 3, 4 and 5. The dose values were normalized to the 1cm value for both methods. To provide more dosimetric quantitative data on these sources the MC calculated values is shown in table 1. Comparing radial dose functions of all three sources (table 1), it was observed that increasing the active source length led to a decrease in the dose gradient near the source; however, there was no considerable change for the dose falloff for points beyond the normalization point.

Figures 3, 4 and 5 show that there has been a good agreement between MC and TPS calculations, especially for the points locating farther than 1 cm from the source center. For the points very close to the source center (<7mm), there was a considerable discrepancy up to 10% between two calculation methods for all sources. For points farther than normalization point, the

Table 1. The Monte Carlo calculated radial dose functions g(r) for ^{60}Co HDR sources.

r (cm)	g(r) for source No.1	g(r) for source No.2	g(r) for source No.3
0.3	642.42	421.53	533.11
0.4	443.03	326.15	375.68
0.5	321.21	256.15	281.08
0.6	241.21	205.38	218.92
0.7	187.27	166.92	175.00
0.8	148.48	140.00	142.57
0.9	120.61	117.69	118.92
1.0	100.00	100.00	100.00
1.1	84.24	86.92	85.14
1.2	71.52	75.76	72.97
1.3	61.21	66.23	63.78
1.4	53.15	58.23	55.81
1.5	46.55	51.92	49.26
1.6	41.03	46.53	43.72
1.7	36.55	41.84	39.05
1.8	32.73	37.76	35.07
1.9	29.58	34.38	31.62
2.0	26.61	31.15	28.78
2.1	24.12	28.30	26.22
2.2	21.94	26.07	23.92
2.3	20.12	24.07	21.96
2.4	18.36	22.38	20.2
2.5	16.91	20.61	18.65
2.6	15.58	19.15	17.23
2.7	14.48	17.84	16.01
2.8	13.45	16.61	14.86
2.9	12.55	15.53	13.85
3	11.78	14.53	12.97
3.1	11.03	13.69	12.16
3.2	10.24	12.92	11.42
3.3	9.64	12.07	10.74
3.4	9.03	11.38	10.14
3.5	8.55	10.69	9.53
3.6	8.06	10.15	9.05
3.7	7.64	9.61	8.51
3.8	7.21	9.07	8.04
3.9	6.85	8.69	7.57
4.0	6.48	8.23	7.16
4.1	6.12	7.76	6.82
4.2	5.82	7.40	6.48

difference was less than 2% for all cases. The TPS assumed the point source geometry for dose calculation in water, hence in MC calculations the actual physical source was simulated which led to large differences in the points close to the source. In a study by Demarco *et al.* on ^{125}I seeds large discrepancy between calculated and measured value was observed due to point source geometry assumption in calculations (5). The present study's results proved the method to be reliable for dose calculation in the TPS for radial dose function calculations. However, other dosimetric factors such as anisotropy and geometry factors should be evaluated for more accurate dose calculations around brachytherapy sources (6, 9). The Sievert integral method has shown acceptable accuracy in dose calculation for different type brachytherapy sources (3, 4, 10).

In a study by Williamson the Sievert integral method was revisited for different brachytherapy sources (4). Their results showed that the classical Sievert model fails to accurately calculate dose distributions around highly filtered sources emitting photons with average energies of 28 to 400 keV. However, their modified Sievert method accurately modeled dose distributions for a wide range of sources. In a similar study on the dosimetric accuracy of the Sievert integral method, the dosimetric quantities of ^{192}Ir sources were calculated by Sievert integral method (10).

Sievert calculations were found in excellent agreement with MC published results. The implementation of this method in any new TPS will be influenced by the required simplifications and modifications. It is the responsibility of the medical physicist to assure the accuracy of any newly installed TPS before clinical use. Finally, as a preliminary step in quality assurance of a TPS, The accuracy of TPS calculation in the present study has been was evaluated and found to be acceptable for clinical use.

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