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VERIFICATION OF DOSE CALCULATION ACCURACY OF RTP SYSTEMS BY MONTE CARLO SIMULATION

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Abstract

High dose rate brachytherapy has attained the good local control for cervix cancer because radioactive source can be put close to tumors, resulting in increasing the dose delivery per one fraction. However, quality assurance must be accompanied to reduce severe complication. We verified the dose distribution around the source by comparing measured dose with calculated dose by Radiation Therapy Planning systems (RTPS) as well as Monte Carlo simulation. We found as much as 10-30 % differences around Ir-192 source between measured dose with TLD (BeO)/grass dosimeters and calculated dose. The differences of the calculation algorithm of dose distribution affect about 10% between PLATO and Buchler facts. The source structure considerably affects the dose distribution especially in the forward direction. These data suggest that the appropriate parameters such as anisotropy function, radial dose function etc must be verified by their calculation algorism and source structures in the clinical practice of quality assurance.

1. Introduction

High dose rate brachytherapy has attained the good local control for cervix cancer because it can directly irradiate the tumors with a minimal damage to normal surrounding tissues. Radioactive source can be put close to tumors, resulting in increasing the dose delivery per one fraction. Although administration of high dose per fraction can kill tumors more effectively, it can also cause damage to normal tissues, if appropriate quality assurance were not made. Therefore it is important to measure the absolute dose as well as verify the dose distribution.

We have found as much as 10-30% differences around the Ir-192 source between measured dose with TLD (BeO)/grass dosimeter and calculated dose with Buchler facts radiation treatment planning system (RTPS). Therefore we investigated the accuracy of this RTPS in the view point of the dose calculation formalism.

The traditional dose calculation formalism is based on point-source approximation [1]. This formalism has been widely used in even recent RTPS. However, actual brachytherapy source exhibits considerably anisotropy and for such sources it is almost impossible to determine accurate dose distribution [1].

The AAPM (American Association of Physicists in Medicine) Radiation Therapy Committee Task Group No43 published the recommended formalism developed by the International Brachytherapy Collaborate Working Group (ICWG) in1995 [1]. The recommended protocol allows for two-dimensional dose calculations accounting for anisotropy of dose distribution produced by a source in a scattering medium. However, this formalism need to calculate several parameters associated with dose calculation. AAPM TG43 provided them only for wire type of Ir-192 source. In addition, such parameters were based on measured values. The determination of such data at short distances may involve large uncertainties due mainly to the large dose gradients in the vicinity of the source [2]. Monte Carlo simulation can provide these data with uncertainties significantly reduced compared with the experimental ones [3].

We verified the accuracy of 2 RTP systems (Buchler facts and PLATO) from the view point of dose calculation formalisms especially near the source.

2. Materials and Methods

1. Brachytherapy dosimetry

Brachtherapy dosimetry was performed with the cylindrical applicator which has 6 holes that can insert Ir-192 sources (fig.1). The purpose of this brachytherapy was to irradiate the target (uterus cervix) which located forward direction from the surface of applicator. Therefore we defined the point, 5 mm far from the surface, as the reference point. Irradiation time was decided so that reference dose is 5 Gy.

2. Comparison on dose calculation algorithm between two RTP systems

We used Buchler facts (Buchler line source) and PLATO (Micro Selectron) as planning systems. The dose calculation formalism of Buchler facts is given by

$$\dot{D}(r) = \frac{A^* \times \Gamma_\delta \times \sum_{k=1}^{m}\sum_{i=1}^{n} \varpi_i \times \Omega_k \times P(\Delta r_{i,k}) \times W(\alpha, \Delta r_{i,k}, Q_{a,z})}{(\Delta r_{i,k})^2}$$

where A is the apparent activity, Γδ is dose rate constant; ω_I is weighting factor for fictitious source position i; Ω_k is weighting factor for applicator k; P is empirical correction function for absorption and scattering in water; $r_{i,k}$ is fictitious point source location; W is experimental angular distribution in water depending on angle(a), type of applicator(a), relative position of the source within the applicator (z) and thedistance between impact and factious source. On the other hand, that of PLATO is given by

$$\dot{D}(r,\theta) = S_k \Lambda \left[\frac{G(r,\theta)}{G(r_0,\theta_0)}\right] g(r) F(r,\theta)$$

where S_k is air kerma strength; Λ is dose rate constant for specific source design, which include the effects of source geometry; $G(r,\theta)$ is geometry distribution; $g(r)$ is the radial dose function that accounts for radial dependence of photon absorption and scatter in the medium along the transverse axis and $F(r,\theta)$ is the anisotropy function that accounts for the angular dependence of photon absorption and scatter in the encapsulation and the medium.

Given the same in the same condition, Ir-192 activity and exposure time, calculated dose between PLATO and Buchler facts were compared.

3. Monte Carlo Simulation

EGS4/ PRESTA MonteCarlo algorism is used to examine the effects of 3 types of source structures (Table.1) (Buchler point source, Buchler line source, and Micro Selectron source) on their dose distribution and radial dose function g(r) which is defined as following formula.

$$g(r) = \frac{D(r, 2/\pi) G(r_0, 2/\pi)}{D(r_0, 2/\pi) G(r, 2/\pi)}$$

The geometry distribution $G(r,\theta)$ accounts for the variation of relative dose due to the spatial distribution of radioactivity in the source. When the distribution of radioactivity can be approximated by a point source or by a line source of length L, then $G(r,\theta)$ reduces to

$$G(r,\theta) = \begin{cases} r^{-2} & \text{for point source approximation} \\ \dfrac{\beta}{Lr\sin\theta} & \text{for line source approximation} \end{cases}$$

where L is the active length of the source, and β is the angle substended by the active source with respect point (r,θ). We used the line source approximation in order to be consistent with the ICWG formalism.

The geometry was based on simple cylinder-plan structure (Fig.2.). For the energy spectrum of Ir-192, E. Browne's data was used. The source routine was defined as cylindrical shape.

3. Results

1. Comparison of calculated dose by Plato with Buchler facts

Table.2 shows the dose calculated by Plato and Buchler facts in forward and radial directions. For both forward and radial directions, about 10 % differences were observed near the source between 2 RTP systems near the source.

2. Monte Carlo Simulation

Fig. 3 shows the effects of source structures on their dose distributions. Both forward and radial directions, the dose with Buchler line source showed good agreement with that of Micro Selectron. However, more than 20% differences were observed between Buchler point source and the other 2 sources at every distance from the center of the applicator. There were more than 20 % differences near the source between Buchler point source and another 2 sources.

Table.3 shows the *g(r)* data calculated with our Monte Carlo simulation, provided by AAPM TG43, and classical data. Near the source, there were about 10 % difference between *g(r)* provided by AAPM, and Clas. Also about 10% differences were observed at 9 cm far from the source.

4. Discussion

Because of the disagreement between the measured dose by TLDs/grass dosimeters and calculated dose by RTPSs, we preliminary investigated the accuracy of dose calculation of RTP systems by calculating some parameters associated with the calculation dose formalisms. And we first calculated radial dose function *g(r)*.

About 10 % differences of calculated dose near the source between PLATO and Buchler facts were observed. Because their source structures are different, we next examined the effects of source structures on their dose distributions using Monte Carlo Simulation (EGS4). However our data showed that there are no differences between Micro Selectron source and Buchler line source, suggesting that discrepancy of calculated dose between PLATO and Buchler facts was caused by their different formalisms.

The formalism TG43 of Kriger et al.(preTG43) is based upon photon fluence around the source in free space, whereas clinical application requires dose distribution in a scattering medium such as a patient [1]. This formalism could be adopted for only point source approximation. Therefore AAPM published the recommended formalism. Williamson et al. recommended that we should correct the calculated dose about 10% by the following formalisms using I-125 source [4].

$$D_{Px,TG43} = D_{Px,preTG43} \cdot \frac{\langle D_{TG43} \rangle}{\langle D_{preTG43} \rangle}$$

Our data also suggest that we should correct about 10% for Ir-192 source not only for I-125 source.

In the AAPM TG43, the parameter associated with the recommended formalism has provided only for seed type of Ir-192 source. We next calculated radial dose function *g(r)* for three wire type sources by EGS4. Our data showed that g (r) was affected by source structures especially near the source. Although we used simple cylinder-plane geometry, our calculated g(r) is acceptable agreement with the data of Mainegra et al. [5]. Therefore we should individually calculate the parameters such as $F(r,\theta)$, *g(r)* for each source for better accuracy.

Using our calculated *g(r)* by Monte Carlo, the RTPS calculated values become close to the measured data by about 6% near the source. However, it has still involved much error between the calculated dose by RTPS and measured dose. The further investigation is required to reach the definite conclusion to resolve the discrepancy between measured dose and the calculated dose by RTPS.

By calculating other parameter including $F(r,\theta)$ and Λ for each source, more accurate dose calculation should be performed.

References

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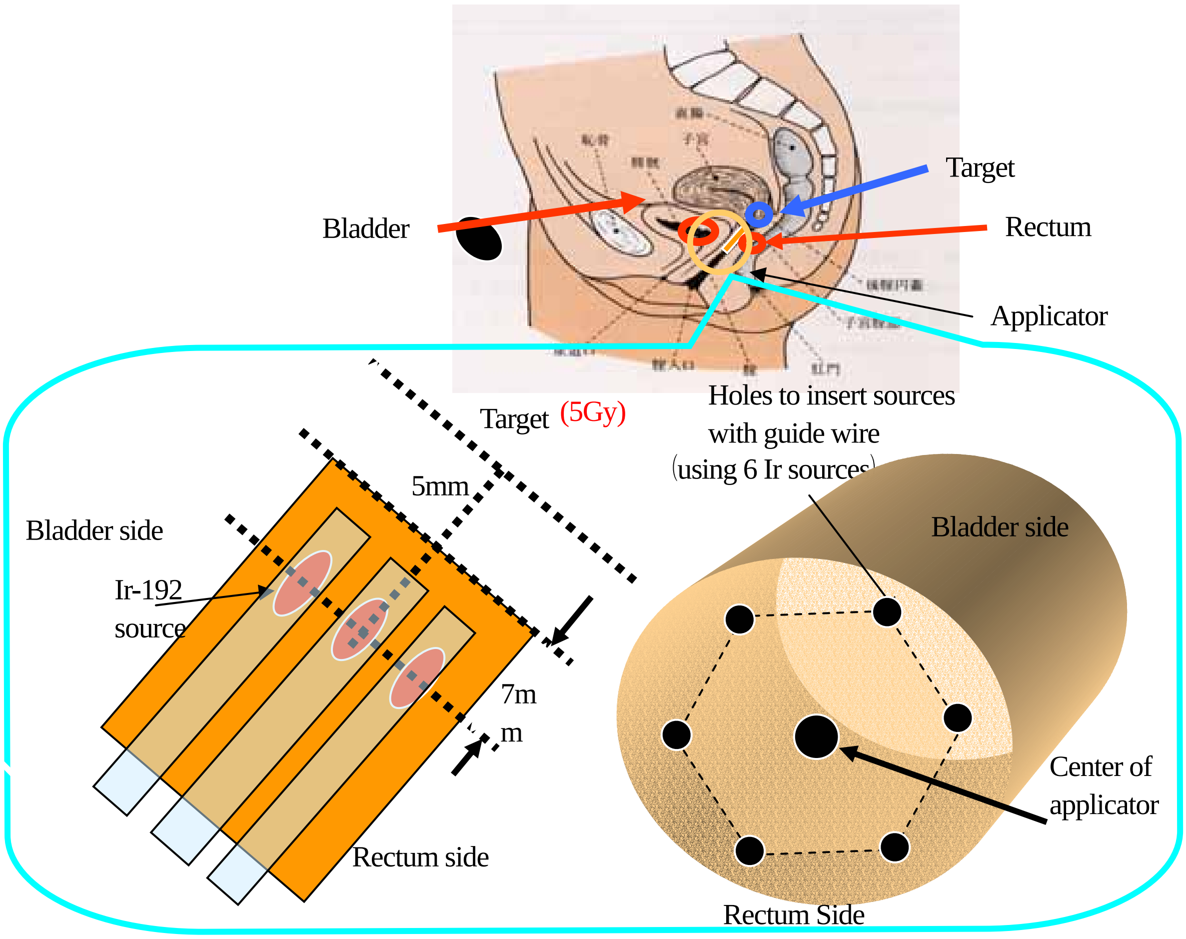


Figure 1. The geometry for the brachytherapy dosimetry.

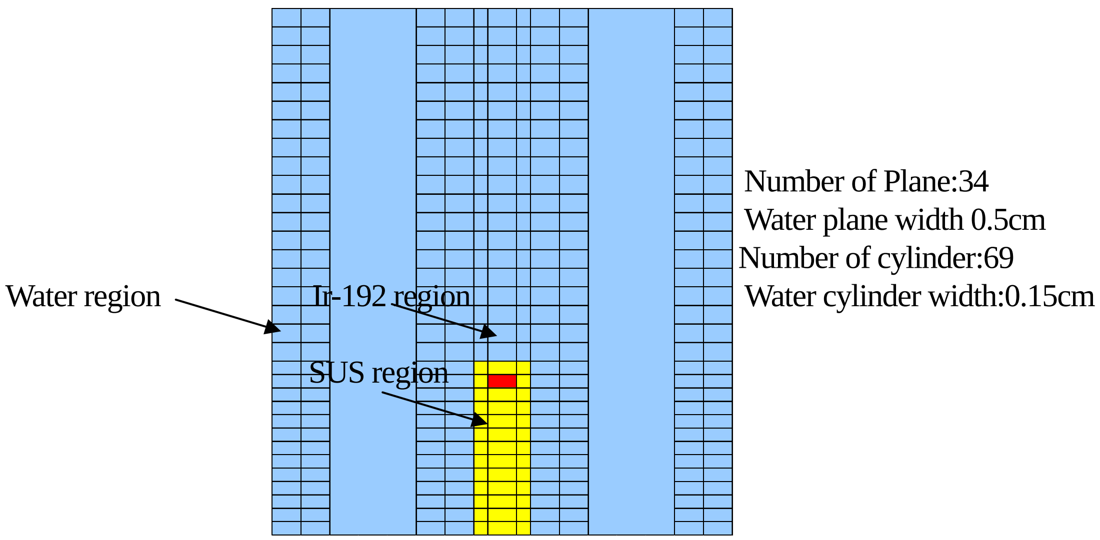
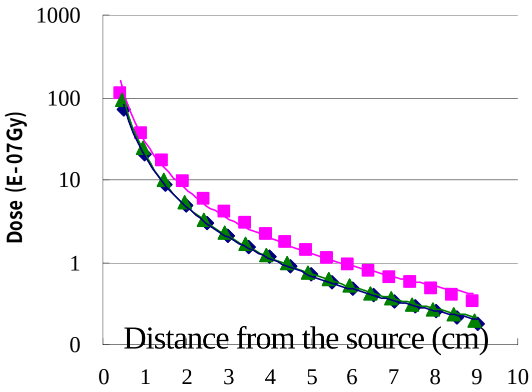


Fig 2. Geometry for Monte Carlo simulation. In various active length of Ir-192 sources and SUS thickness, absorbed doses were calculated in forward and radial water regions.

(A)



(B)

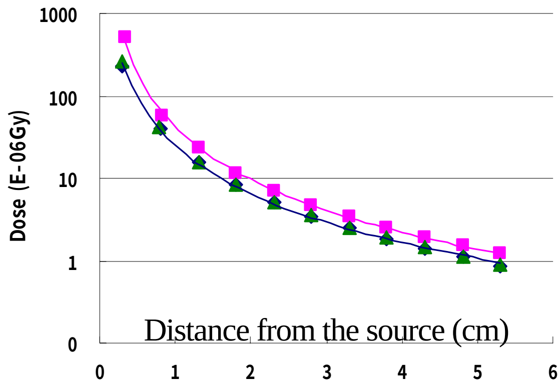


Fig.3 The effects of source structures on their dose distributions. A, Forward direction. B, Radialdirection. ■:Buchler Point source, ▲:Buchler line source, ◆:Micro Selectron

Table 1 Dimension of HDR Ir-192 Sources.

Source Model	Buchler Point	Buchler Line	Micro Selectron
Ir-192 length (mm)	1.2	3.6	3.6
Ir-192 diameter (mm)	1.2	0.6	0.6
Clad top thick (mm)	1.1	0.9	0.2
Clad diameter (mm)	1.6	1.1	0.9

Table 2 The dose calculated by Plato and Buchler facts in the geometry of fig.1.

Forward direction			Radial direction		
Distance from the source	PLATO	Buchler (Line source)	Distance from the source	PLATO	Buchler (Line source)
0.5 cm	4.50 Gy	5.00 Gy	1.35 cm	12.79 Gy	13.60 Gy
0.92 cm	2.84 Gy	3.05 Gy	1.75 cm	5.04 Gy	5.00 Gy

Table 3 The radial dose function g(r) calculated with our Monte Carlo simulation, provided by AAPM TG43, and by traditional formalism. The underlined values have more than 6% differences compared with AAPM data.

Distance from Source (r cm)	AAPM	Clas*	Monte Carlo (EGS4)		
	Ir seed	Ir seed	Buchler Point source	Buchler Line source	Micro Selectron
0.5	0.998	0.994	1.010	0.935	0.946
1.0	1.000	1.000	1.000	1.000	1.000
1.5	1.000	1.001	0.998	1.013	1.001
2.0	1.000	1.001	1.001	1.014	1.002
3.0	1.010	1.020	0.999	1.019	0.999
5.0	0.990	0.996	0.978	0.990	0.977
7.0	0.968	0.942	0.920	0.946	0.928
9.0	0.933	0.891	0.840	0.850	0.834

Clas*: Calculated value based on traditional formalism