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Technical Note

Impact of different Ir-192 source models on dose calculations in high-dose-rate brachytherapy

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ABSTRACT

In high-dose-rate brachytherapy, the geometry of the radioactive source is sometimes updated. Some institutions use a different source model for the dose calculation in treatment planning and treatment. The effects of this discrepancy were examined for four types of treatment plans, and ten patients were selected for each treatment plan. The impact of different source models depended on the types of treatment plan, patients, and dose index. To reduce the uncertainty and improve the reliability of the data, it would be better to use more robust metrics (D_{90} and D_{2cc}) for treatment planning evaluation in facilities with this problem.

1. Introduction

High-dose-rate (HDR) brachytherapy is a good treatment option for prostate and cervical cancers [1,2]. The radioactive isotope Ir-192 is widely used as a radiation source [3]. The radiation dose for HDR brachytherapy is generally calculated based on the formalism in the updated *American Association of Physicists in Medicine Task Group No. 43*, in which the parameters to calculate dose distribution are defined [4]. Because these parameters are specific to the source geometry, users must use the appropriate parameters for the given source model in their treatment planning systems (TPSs).

The geometry of the radioactive source is sometimes changed, and the source model used in the TPS must also be updated when this occurs. However, some institutions have been unable to update the source model parameters because their TPS version was outdated; they hence needed to use a different source model for the dose calculation in treatment planning and treatment. This discrepancy between the source model and used model data are particularly problematic in multi-institutional clinical trials because it calls into question the integrity of the treatment plan data. To improve the reliability of the treatment plan data, uncertainties and variations should be kept as small as possible and mistakes should be eliminated. The discrepancy between the source model and the model data falls under the category of mistakes, so that strictly speaking, a facility with this problem should not be allowed to participate in a clinical trial.

In contrast, Granero et al. reported that the impact of different Ir-192 source models on dose calculations was negligible, that is, within 0.5% of the calculated radial distance of ≥ 0.25 cm from the radioactive source [5]. However, this value was not evaluated using the dosimetry parameters adopted in a commercial TPS; it was estimated by comparing the results of several Monte Carlo code calculations from different researchers. Furthermore, the impact of different source models on clinical treatment planning has not been evaluated. Therefore, in this study, the differences in planned dose distributions were evaluated, and the impact of differences in dose index parameters and different source models using commercial TPS was examined.

2. Material and methods

2.1. Ir-192 source models

In this study, the impact of different Ir-192 source models were evaluated using V2 and V2r (Supplementary Fig. 1) [5,6]. In 2012, the source model of the microSelectron® HDR Afterloader System (Nucletron, Elekta AB, Stockholm, Sweden) was changed from V2 to V2r. The timing of the introduction of the V2r model varied across countries. The V2r source improved upon the V2 source by strongly welding the source capsule and wire connection, which changed the dosimetry parameters (dose rate constant, anisotropy, and radial-dose functions).

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2.2. Patients and treatment planning

The following four treatment plans were analyzed: a two-dimensional (2D) tandem-ovoid plan for cervical cancer, three-dimensional (3D) cylinder plan for cervical cancer, 3D tandem-ovoid plan for cervical cancer, and 3D interstitial brachytherapy plan for prostate cancer. Ten patients were randomly selected for each treatment plan and underwent HDR brachytherapy between 2010 and 2012 at Osaka General Medical Center, Osaka, Japan (2D tandem-ovoid plan) or Osaka University Hospital, Osaka, Japan (3D treatment plans). All treatment planning was performed with the aid of the Oncentra® Brachy TPS version 4.1 (Nucletron, Elekta AB, Stockholm, Sweden). The organ at risk, high-risk clinical target volume, and planning-target volume were contoured by a radiation oncologist. The prescribed doses were 6 and 6.5 Gy per fraction for cervical and prostate cancers, respectively. The dose was prescribed to a depth of 5 mm into the vaginal wall in the 3D cylinder plan. In the 2D and 3D tandem-ovoid plans, the dose was prescribed to Point A [7]. In the 3D prostate plan, the dose distribution was created by geometric optimization and manual modification.

2.3. Evaluation of differences in dose distributions and dose indices

To evaluate the differences in planned dose distributions, all 3D treatment plans were transferred to MapCHECK version 6.6 (Sun Nuclear Corporation, Melbourne, FL, USA) from the TPS. Three types of treatment plans were prepared. For the V2 plan, the treatment plan was calculated according to the V2 source model. For the V2r plan, the treatment plan was calculated according to the V2r source model. For the Assignment plan, the treatment plan was calculated according to the V2r source model using the dwell-time of the V2 plan. The Assignment plan represented the use of the V2 model for treatment planning despite the use of the V2r model for treatment. The dose difference criteria (0.1%, 0.5%, and 1%; threshold 0%, with global dose error normalization) were used for dose point pass rates to observe trends in the analyzed data. Three types of plane were assessed: the mid-sagittal plane of the 3D cylinder plan, the viewing coronal plane of Point A of the 3D tandem-ovoid plan, and the mid-axial plane of the 3D prostate plan.

In addition, the dose indices for the treatment plans were calculated for the V2 and Assignment plans and compared. The evaluation dose indices were selected according to recommendations [8,9]. For all these calculations, a Ir-192 source strength of 10,000 cGycm^2/h was used, and each calculation setting was uniform (high dose limit, 4; sample point, 100,000; bins, 200). The voxel and calculation sizes were 1 mm^3 and 150 mm^3, respectively.

3. Results

3.1. Evaluation of differences in dose distributions

Fig. 1 shows the differences in planned dose distributions in each single treatment plan for a patient. In the 3D cylinder and 3D tandem-ovoid plans, there were dose differences in the longitudinal direction and in the area far from the applicator, respectively. The median pass rates of the treatment plans of all patients were calculated as an indicator of the degree of coincidence (Table 1). The pass rate depended on the type of treatment plan and patient. With a dose difference criterion of 0.5%, in 8 out of 30 treatments, the pass rate was below 60%. However, there was still an over 99% pass rate at a criterion of 1%. In all patients receiving the 3D cylinder and 3D tandem-ovoid plans, the median pass rates were 100% with a dose difference criterion of 1%. Furthermore, the difference between the V2r and Assignment plans was small, and pass rates were > 99% for all treatment types with a criterion of 0.5%.

3.2. Evaluation of differences in dose indices

The impact of different source models on dose calculations depended on the type of dose index and patient. Supplementary Table 1 shows the dose indices of the 2D tandem-ovoid plan. The maximum relative change value was observed in the in-vivo rectum probe detector fifth position (5.3%). For the 3D cylinder plan and the 3D tandem-ovoid plan, the median relative change values were < 1.0% (Supplementary Tables 2, 3). A larger range of relative change was observed in the high sensitivity dose indices (D_{98} and $D_{0.1cc}$) compared with other dose indices. For the 3D tandem-ovoid plan, the largest dose difference was observed in the rectum (0.11 Gy), and a negative value was observed in one case for the sigmoid $D_{0.1cc}$. The relative change in value of the dose index in the rectum was less in the 3D prostate plan than in the 3D tandem-ovoid plan (Supplementary Table 4). As shown in Supplementary Tables 1–4, all dose index values of the Assignment plan were larger than those of the V2 plan, except for the $D_{0.1cc}$ of the sigmoid.

4. Discussion

In this study, the impact of different source models on dose indices was evaluated. To the best of our knowledge, this study is the first to estimate the effect of differences between the V2 and V2r source models on patient data. The treatment plan comparisons failed to identify dose differences sufficient to significantly affect clinical results (Supplementary Tables 1–4). The difference in dose distribution due to the source model was decreased by the arrangement of multiple dwell positions. From these facts, even though the problem of a discrepancy between the V2 and V2r source models falls under the category of mistakes, its occurrence is not sufficiently serious to stop treatment. However, it is not a favorable condition from the perspective of clinical data management, because the discrepancy between the source model and model data definitely reduces the reliability of the treatment data. There are several types of uncertainties in the treatment process, and some authors have made efforts to analyze the uncertainty and improve the reliability of treatment data [10–17]. DeWerd et al. claimed that, by propagating the uncertainties from all components to obtain the dose at 10 mm on the source transverse plane, the uncertainty for high-energy sources was 6.8% (k = 2) [10]. Kiristis et al. performed an evaluation using a simulated rectum in the case of intracavitary cervix treatments with seven different treatments planning systems. The D_{2cc} showed a mean standard deviation of 1%, and that of $D_{0.1cc}$ was 3% [11]. The uncertainty was subsequently estimated in the case of intracavitary brachytherapy for cervical cancer, and the total uncertainty was assumed to be 12% (k = 1) [12]. In the present results, almost all median dose index differences between the V2r and Assignment plans were less than 1%, which is very small compared with the value of the uncertainty.

Granero et al. evaluated the dose difference between the V2 and V2r source models using a Monte Carlo simulation and found that it was within 0.5% of the calculated radial distance of ≥0.25 cm from the radioactive source [5]. In contrast, the present results show that the dose index difference was > 1% in some cases, which was caused by the difference in the evaluation method. Granero et al. evaluated the dose difference in units of voxels, and the present study evaluated them with respect to the dose index parameters in each region of interest. The slight dose differences in voxel units resulted in large differences in highly sensitive dose indices such as D_{98} and $D_{0.1cc}$, in contrast to the differences in D_{90} and D_{2cc}. Therefore, to maintain the uncertainty at the lowest possible level, it would be better to use more robust metrics (D_{90} and D_{2cc}) for treatment planning evaluation in facilities with this problem.

In 2012, the dosimetry parameters of V2r were reconsidered and changed by the High Energy Brachytherapy Source Dosimetry Working Group [18]. The V2c model data were released from Oncentra® Brachy

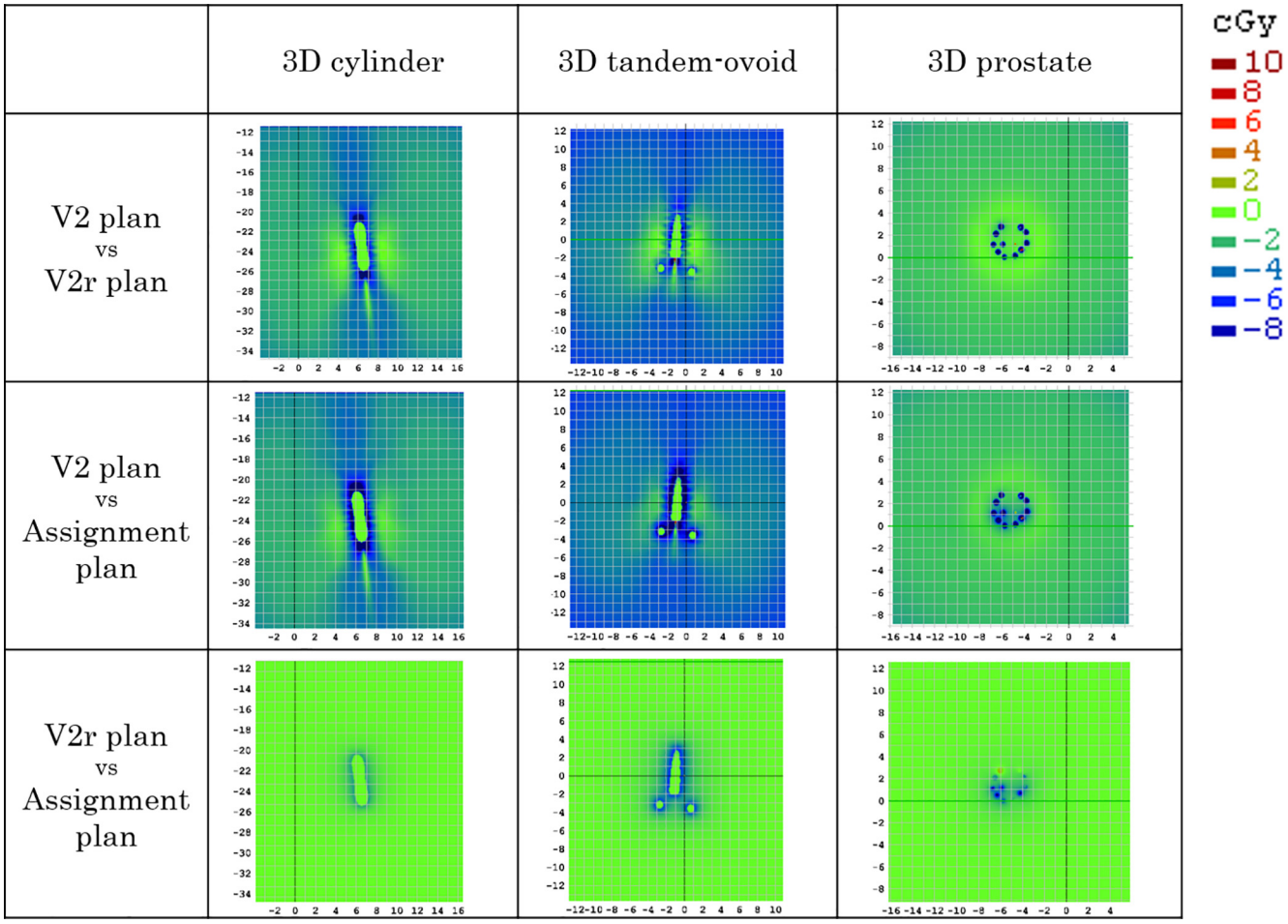

Fig. 1. Treatment plans evaluated: (1) mid-sagittal plane of the three-dimensional (3D) cylinder plan; (2) Point A viewing the coronal plane of the 3D tandem-ovoid plan; and (3) mid-axial plane of the 3D prostate plan. A positive value indicates that the dose of the former plan is higher than that of the latter. Dimensions are presented in cm.

TPS version 4.5. The source shape is the same for V2r and V2c, but some dosimetry parameters used for dose calculation (half-life period, dose rate constant, anisotropy, and radial-dose functions) have been changed. In a multi-institutional clinical trial, the same source model should be used for dose calculation, and efforts should be made to improve the reliability of the data. Nonetheless, quality assurance personnel should check the impact on the treatment plan of the use of V2c source model data. As for PLATO (Nucletron, Elekta AB, Stockholm, Sweden) TPS users, coefficient values can be manually entered; however, the number of parameters is approximately 1200, which means that the possibility of incorrect input must be considered.

In conclusion, the impact of difference source models (V2 and V2r) on dose index parameters reported in the current study are less than other sources of uncertainties in HDR brachytherapy. However, to reduce the uncertainty and improve the reliability of the treatment plan data, it would be better not to use high sensitivity dose indices (D_{98} and

Table 1
Comparison of the pass rates of the mid-sagittal plane of the three-dimensional (3D) cylinder plan, Point A viewing the coronal plane of the three-dimensional tandem-ovoid plan, and the mid-axial plane of the three-dimensional prostate plan. The dose difference criteria (0.1%, 0.5%, and 1%; threshold 0%, with global dose-error normalization) were used for the dose-point pass rates.

Treatment plan	Dose difference criterion (%)	Pass rate (%)		
		V2 plan vs. V2r plan	V2 plan vs. Assignment plan	V2r plan vs. Assignment plan
		Median (range)	Median (range)	Median (range)
3D cylinder	0.1	22.8 (1.8–46.5)	6.0 (0.1–40.3)	99 (79.9–100)
	0.5	99.3 (42.3–100)	100 (37.5–100)	99.9 (99.9–100)
	1	100 (100–100)	100 (100–100)	100 (100–100)
3D tandem-ovoid	0.1	9.9 (0–48.1)	5.5 (0–24.5)	94.1 (89.6–98.5)
	0.5	100 (6.6–100)	99.9 (1.7–100)	100 (100–100)
	1	100 (99.3–100)	100 (99–100)	100 (100–100)
3D prostate	0.1	99.4 (99.3–99.5)	96.7 (88–98.5)	97.9 (96.2–99.5)
	0.5	99.7 (99.6–99.7)	99.6 (99.3–99.7)	100 (100–100)
	1	99.9 (99.9–100)	99.8 (99.6–99.8)	100 (100–100)

$D_{0.1cc}$) but more robust metrics (D_{90} and D_{2cc}) for treatment planning evaluation in facilities with this problem. This problem should be given special consideration in multi-institutional clinical trials.

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Conflict of interest statement

The authors declare no conflicts of interest associated with this manuscript.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.phro.2018.08.004.

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