Vaginal Cylinder HDR Brachytherapy: Effect of Inhomogeneity on Dose Calculation

M. Meftahi [1], W. Song [1]
1 VIRGINIA COMMONWEALTH UNIVERSITY

JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION

Vaginal cylinder (VC) inhomogeneity in treatment planning can affect the dose coverage, depending on the material, the density, the size, and the design of the applicator. The current standard of practice for brachytherapy absorbed dose calculations relies on the AAPM Task Group 43 (TG43) formalism.

The dosimetry parameters used in TG43 are obtained for a single Brachytherapy (BT) source located at the center of a fixed-volume, homogeneous, liquid-water phantom. As a result, this method cannot consider the effect of patients' body shape and the presence of materials other than water, such as VCs [1-4].

AIM

In this study, we assessed the effect of the VC inhomogeneity in the dose distribution using the GEANT4 Monte Carlo simulation code.

METHOD

A Varian ^{192}Ir Gamma Med Plus source was simulated using GEANT4 Monte Carlo simulation code (toolkit 10.05). 2D data acquisition was performed, such that the source and the extension of the cable were placed across the Y axis.

First, the source was placed in various positions in a 30x30x30 cc water phantom, gridded into voxels with a side length of 1 mm, based on a clinical template plan's dwell positions.

In order to consider the effect of inhomogeneity of the vaginal cylinder applicator, at the second step, the source was positioned in the same condition in a simulated single lumen Varian's vaginal cylinder made of PPSU plastic with a 30 mm diameter, a density of 1.29 g/cc, and a 3 mm dead space at the apex.

The MATLAB software was used for data analysis.

RESULTS

The results from positioning of the source in the VC applicator, and those from TG43 is given in the Figures 1 and 2, repectively. The prescription dose line is shown in red. As mentioned, the TG43 model does not account for the inhomogeneity of the VC, assuming all the environment as water as opposed to the MC calculations. Based on the results, the dose distribution inside the cylinder (-15 mm < x < 15 mm) is noticeably different from TG43 Model, so that unlike TG43 Model, the isodose lines 6000 cGy and 4500 cGy cover a larger area inside the VC applicator.

In addition, the isodose lines slightly shrink (1 mm) at the periphery beyond the VC surface, indicating a reduction in the dose coverage. In further investigation, a point by point dose analysis at the boundary of the applicator and water phantom was also performed across the horizontal line y= 50 mm with an interval of 1 mm.

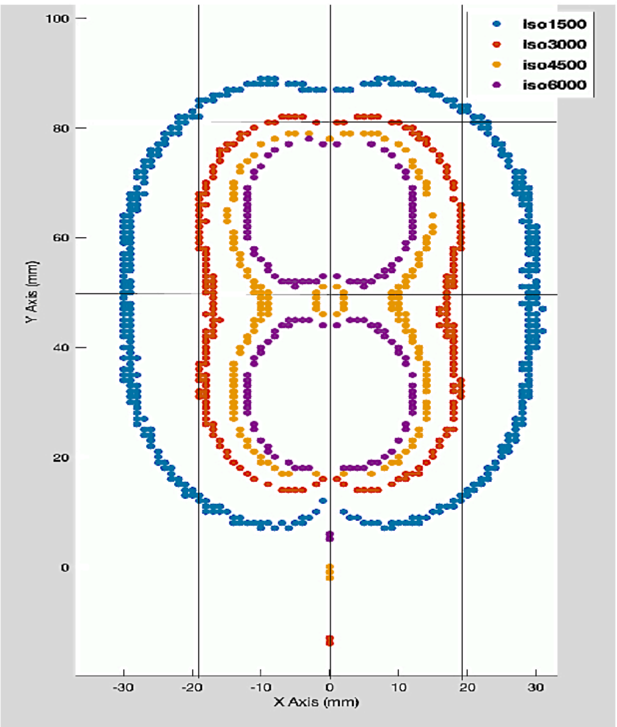

Figure 1, isodose lines (cGy) obtained from GEANT4 MC simulations for TG43 model, considering all the environment as water

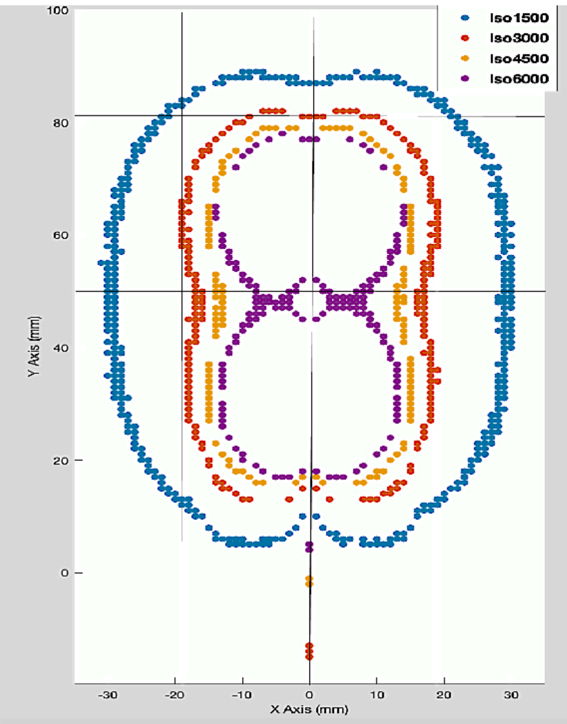

Figure 2, isodose lines (cGy) obtained from GEANT4 MC simulations for a 30 mm diameter cylinder

The dose values are given in the Table 1. Comparing the data at the surface of the cylinder (x = 15 mm) indicates that there is a significant dose increase of more than **19%** at the **boundary** (3364.25 vs 4022.78 cGy), resulting in an unintended **hot spot** at the surface.

The coverage at the apex looks pretty similar in both models at prescription dose (red lines). However, the same type of analysis is given across the horizontal line x=0. The dose values are shown in the Table 2.

Comparing the dose values at y = 76 mm (the surface of the VC) in the two models indicates a difference of about **28%** near the apex surface of the applicator (7281.08 vs 9379.19 cGy), causing unintended **hot spot** at the **boundary**. In addition, according to the Table 2 there is an average increase of 5% in dose values beyond the boundary (y = 76.5 mm) across the line in the water phantom.

	x (mm)	11	12	13	14	15	16	17
TG43	Dose (cGy)	4250.81	4041.24	3754.78	3601.63	**3364.25**	3192.67	3079.86
VC	Dose (cGy)	5107.47	4826.51	4627.29	4226.85	**4022.78**	3103.05	2925.12

Table 1, Dose per Point at y=50 mm obtained from GEANT4 MC simulations, for TG43 Model as well as a 30 mm diameter VC applicator

	y (mm)	74	75	76	77	78	79	80
TG43	Dose (cGy)	14581.54	9986.77	**7281.08**	5632.91	4610.98	3769.89	3154.48
VC	Dose (cGy)	18988.07	12435.45	**9379.19**	5955.89	4773.11	3973.22	3380.43

Table 2, Dose per Point at x=0 mm obtained from GEANT4 MC simulations, for TG43 Model as well as a 30 mm diameter VC applicator

CONCLUSIONS

It was shown the inhomogeneity of the cylinder can increase the dose at the surface of the cylinder both at the apex and periphery. The main reason for this phenomenon is **the higher density of the VC** than water (1.29 g/cm^3), which causes gamma and x rays with lower energies to have more interactions in the applicator as opposed to when TG43 model is assumed with water everywhere. As a result, the applicator has more absorbed dose in comparison to when the water is in place. In addition, radiation gets hardened slightly after passing through the higher density applicator and the beam intensity is also slightly reduced, which explain the decrease of the dose values beyond the surface at the periphery.
The magnitude of anisotropy at the apex is slightly different in the two dose calculation models, as well. This is because of the presence of the lumen at the center of the VC applicator. Since the channel is not filled with the applicator material (but rather with air), there is no major interaction and therefore attenuation inside it. Consequently, the dose increases at the apex of the applicator as opposed to the TG43 model predictions.
In conclusion, the VC heterogeneity analysis of this research based on MC simulation calculations indicates that prescribing to the VC surface suffers from significant uncertainty because of the dose increase at the surface (i.e. hot spots), which should be taken into account in treatment planning. In addition, the presence of hot spots at the surface could increase the risk of vaginal stenosis, in particular, when prescribing the dose to 5 mm beyond the VC surface, since the magnitude of the dose at the boundary is much higher.

REFERENCES

1 Abe, K., Kadoya, N., Sato, S., Hashimoto, S., Nakajima, Y., Miyasaka, Y., Ito, K., Umezawa, R., Yamamoto, T., Takahashi, N., Takeda, K., & Jingu, K. (2018). Impact of a commercially available model-based dose calculation algorithm on treatment planning of high-dose-rate brachytherapy in patients with cervical cancer. *Journal of Radiation Research*, *59*(2), 198–206.

2 Mikell, J. K., & Mourtada, F. (2010). Dosimetric impact of an 192 Ir brachytherapy source cable length modeled using a grid-based Boltzmann transport equation solver. *Medical Physics*, *37*(9), 4733–4743.

3 Rivard, M. J., Coursey, B. M., DeWerd, L. A., Hanson, W. F., Huq, M. S., Ibbott, G. S., Mitch, M. G., Nath, R., & Williamson, J. F. (2004). Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations. Medical Physics, 31(3), 633–674.

4 Rivard, M. J., Melhus, C. S., Granero, D., Perez-Calatayud, J., & Ballester, F. (2009). An approach to using conventional brachytherapy software for clinical treatment planning of complex, Monte Carlo-based brachytherapy dose distributionsa. Medical Physics, 36(6), 1968–1975.

CONTACT INFORMATION

Moeen Meftahi: meftahim@vcu.edu