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ORIGINAL ARTICLE

Vaginal Applicators in High-Dose Rate Brachytherapy for Endometrial Carcinoma: A Dosimetric Study

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OBJECTIVE

Intracavitary brachytherapy is one of the most important methods of gynecological cancer treatment. The effect of attenuation by the applicators is not considered in the dose calculation method released by the AAPM TG-43. In this study, the attenuation due to various segmented vaginal cylinders made up of polyetheretherketone was measured.

METHODS

A plan created by the treatment planning system (TPS) for the patient was executed using Gafchromic films that were taped on the surface of the applicator, and the dose recorded on the films was measured. The same plan was also executed using a well-type ionization chamber. First, a water equivalent material, Elasto-Gel was used in a well-type ionization chamber for charge collection, and then a segmented vaginal cylinder was used for charge collection measurement; thus, the attenuation due to the various segmented vaginal cylinders was obtained.

RESULTS

The doses recorded on the Gafchromic films were measured and showed that the TPS overestimated the dose for the segmented vaginal applicators and that the maximum overestimation of the dose was 4.75% for 35 mm diameter vaginal cylinders. This was further confirmed by calculating the percentage attenuation due to vaginal cylinders using a well-type ionization chamber.

CONCLUSION

Due to the attenuation by the various applicators used in vaginal vault brachytherapy, it can be concluded that due to overestimation of dose by the TPS, the dose actually received by the target and the organs at risk in vaginal vault brachytherapy are less and needs to be considered for actual dose estimation.

Keywords: Brachytherapy, Elasto-Gel, overestimation of dose, treatment planning system, vaginal applicators.

INTRODUCTION

In the west, endometrial carcinoma is the most common malignancy among women; however, in India, the incidence rates are low.[1] Most endometrial cancers are confined to the uterus.[2] If the malignancy is confined to the uterus, then the standard treatment is abdominal hysterectomy and bilateral salpingo-oophorectomy. In most cases, the surgery is followed by external beam radiotherapy to the pelvis to reduce the

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chances of recurrence. In some cases, depending on the tumor grade and depth of myometrial invasion, external beam radiotherapy is then followed by intracavitary brachytherapy. A study was conducted by the Gynecologic Oncologic Group in patients with surgical Stage Ib and Ic (FIGO 2018) disease and negative lymph node metastases, wherein it was found that although the adjuvant pelvic radiation reduced recurrences; however, there was no significant difference in survival.[3] The main advantage of pelvic radiotherapy is the reduction in vaginal recurrences, so vaginal brachytherapy alone can be justified in patients with no pelvic node metastasis because it has fewer complications.[4] The ASTEC study and PORTEC 2 study reports resulted in the use of brachytherapy alone in the majority of intermediate-risk patients.[5–11] Patients who receive brachytherapy alone may have a better quality of life, as it results in fewer gastrointestinal complications.[12–14]

Intracavitary high dose rate (HDR) brachytherapy of the vagina can be given by various types of applicators, and the segmented vaginal cylinder is one of them. These vaginal applicators are made up of comparatively high Z material and have a high density compared to water. In HDR brachytherapy of the vagina, the applicator is first inserted into the patient, and then the patient is taken for CT imaging. Finally, the same CT scan is transferred to the treatment planning system (TPS). A suitable patient plan is then created with the help of the TPS. The Task Group No. 43 (TG-43) formalism given by the American Association of Physicists in Medicine is primarily used in most commercially available TPSs for dose estimations in brachytherapy. The TG-43 formalism considers a bare source in the center of water for calculations and does not account for heterogeneity correction within the human body.[15–17] Thus, in brachytherapy TPS, scatter conditions and photoelectric effect cross-sections in relation to water are taken into account when calculating the dose, surrounding the radioactive source. However, in practice, the segmented vaginal applicators used in vaginal brachytherapy have a high CT number compared to water, and as a result, their scattering and absorption within the human body differ greatly from water, and thus the attenuation offered by these applicators differs considerably when compared to water.

The vaginal applicator set studied in this article consists of vaginal cylinders with varying diameters, as shown in Figure 1. The universal segmented cylinder vaginal applicator set can be used for cancer treatment of the vagina, vaginal stump, and rectum. These are CT compatible applicators manufactured by Varian and are compatible with afterloaders such as the VariSource iX, VariSource 200, GammaMedplus iX, and GammaMedplusTM having catalog number GM11011100. Although various types of vaginal applicators are used for the treatment of endometrial carcinoma, the dose attenuation due to this type of applicator material has not been yet studied. This research aims to investigate the effects of vaginal applicator wall attenuation and compare it with soft-tissue attenuation. In this study, the attenuation coefficient of segmented vaginal cylinders of different diameters was practically measured using EBT3 Gafchromic film. In addition, a novel technique, the use of a well-type ionization chamber, was employed to measure the attenuation caused by different diameters of segmented vaginal applicators, and the results were compared with those obtained using Gafchromic films. The majority of other investigators ei-

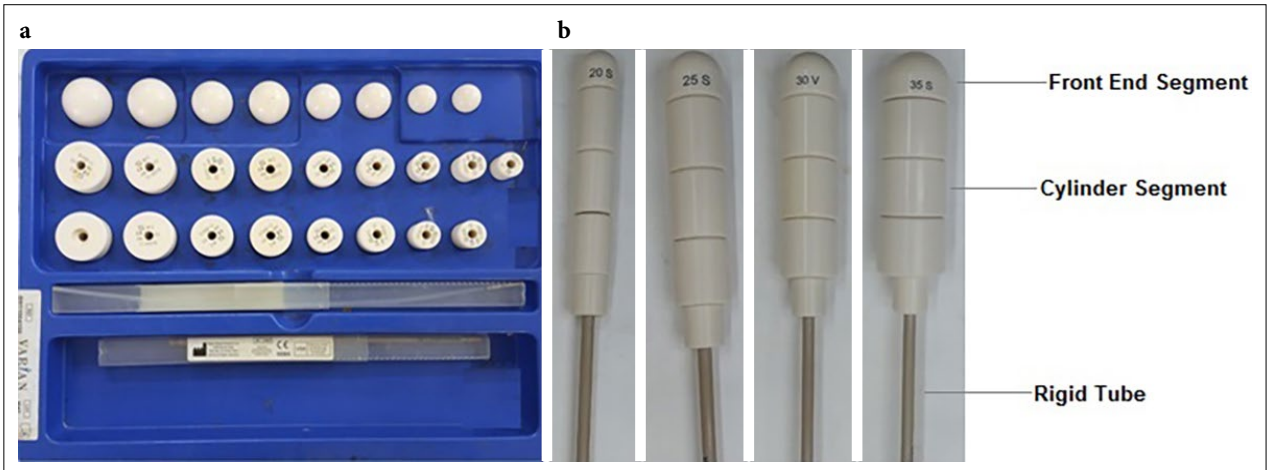

Fig. 1. The Vaginal applicator set. (a) Without being assembled. (b) After being assembled.

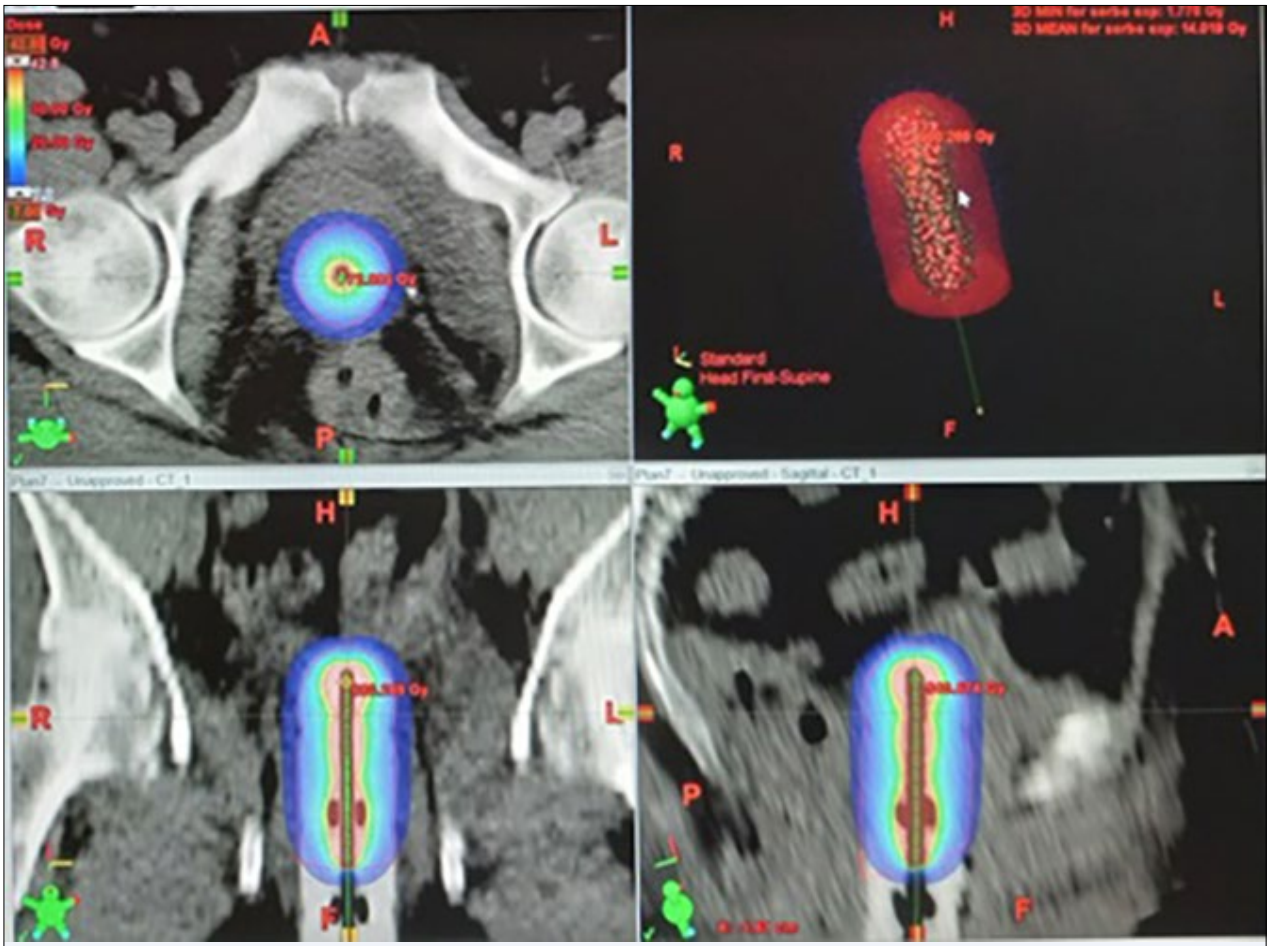

Fig. 2. Representative dose in color wash for 7 Gy prescription at 0.5 cm from applicator surface in multiplanar view and three-dimensional view.

ther used 0.125 cc ion chambers or performed film and TLD dosimetry for such type of measurements. However, using a well-type ionization chamber for such measurements is reasonably easy and quite accurate.

MATERIALS AND METHODS

This study was carried out in a tertiary care hospital. The hospital is equipped with the latest radiotherapy equipment capable of delivering a precise dose to the target. The HDR brachytherapy unit used for this study is a fifth generation, 24 channels afterloader, Varian made, GammaMedplus IX. The GammaMedplus IX afterloader is fully integrated with the BrachyVision™ TPS. The dose calculation algorithm in BrachyVision is based on the TG-43 formalism given by the American Association of Physicists in Medicine. The GammaMed plus IX afterloader HDR unit is housed with an Ir-192 radioactive source. The Ir-192 source housed in the unit has a 3.5 mm active length and 0.7 mm diameter.[18–20] The unit is also provided with various types of applicators for brachytherapy treatment. The Universal Segmented Cylinder Applicator studied in this article, as shown in Figure 1, consists of a rigid guide tube of 250 mm length, front end segment of 20 mm diameter and 50 mm length, front end segment of 25 mm diameter and 52.5 mm length, front end segment of 35 mm diameter and 57.5 mm length. In addition, the applicator set also consists of four types of cylinder segments, each having a length of 30 mm and diameters of 20 mm, 25 mm, 30 mm and 35 mm. The front end segment and the rigid guide tube allow for a distal first dwell position to enable a high dose delivery to the vaginal stump. The front end segment and the cylinder segments are made up of polyetheretherketone (PEEK) of density 1.32 g/cc, whereas the rigid tube is made up of polytetrafluoroethylene.

For the intracavitary brachytherapy treatment of endometrial cancers, the segmented vaginal applicator of

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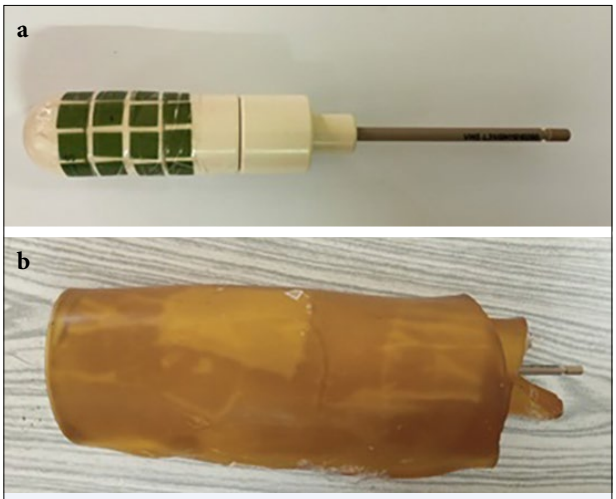

Fig. 3. (a) Applicator surface taped with EBT3 Gafchromic films. (b) Applicator surface wrapped in Elasto-Gel bolus.

appropriate diameter was first inserted into the vaginal vault of the patient, and then the patient had to undergo computed tomography (CT) scan. The CT data set was then transferred to the Brachyvision TPS. The target and other organs at risk were contoured by the radiation oncologist, and then the medical physicist performed the dose optimization process on the TPS so that the prescribed dose of 7 Gy was received at 5 mm from the surface of the segmented applicator, as shown in Figure 2. If the plan was deemed satisfactory, the radiation oncologist would then approve the plan and was transferred to the control console for the treatment execution.

Use of EBT3 Gafchromic Films for Dose Measurement

This specific patient treatment plan was delivered on a phantom, mimicking the patient setup, with EBT3 Gafchromic film sheets, 1×1 cm^2 in size, wrapped in thin, transparent polythene, and attached to the vaginal cylinder's surface, as shown in Figure 3a. The films were adhered with tape on the surface of the vaginal applicator in such a way that there was no air gap between the curved applicator surface and the films. The films were positioned on the vaginal cylinder's surface at predefined intervals from the distal end of the cylinder so that the same can be easily reproduced on the TPS. To imitate backscatter within the patient, the applicator was then covered with an Elasto-Gel bolus (water-based gels containing acrylic polymer) with a density of 1.02 g/cm^3 and a thickness of 6 cm as shown in Figure 3b.

For accurate film dosimetry, a standard protocol was followed.[21] The EBT3 films were first exposed to known doses and then scanned with an Epson scanner, and the input data thus obtained was fed to Omnipro software. The same Epson scanner and Omnipro software were then used to measure the dose recorded on the exposed EBT3 film placed on the surface of the vaginal cylinder.

Fig. 4. Water equivalent elasto gel of various diameters.

Use of a Well-type Ionization Chamber for Dose Measurement

The well-type ionization chamber is widely used in brachytherapy for dosimetric purposes. Well-type ionization chambers are equipped with a source holder that is unique to each brachytherapy source and is commonly referred to as a source jig. The charge collected by the chamber for a particular brachytherapy source depends on the source jig used for the measurement. For Ir-192, the source jig is made up of an air equivalent material with CT number ranging from −930 to −980. To obtain the attenuation due to the various cervix applicators, the source jig was replaced with water equivalent Elasto-Gel. To mimic the various vaginal cylinder sizes, the Elasto-Gel of respective diameters were designed, that is, 35 mm, 30 mm, 25 mm, and 20 mm as shown in Figure 4. The measurements were made first with vaginal cylinder within the well of the chamber and then vaginal cylinder was replaced with the Elasto-Gel of respective diameter.

Case 1

The plan created for the treatment of the patients was executed on HDR 1000 plus well-type ionization chamber, and the same diameter of the vaginal cylinder was used in the well of the chamber as shown in Figure 5a. The total charge collection by the electrometer was noted down.

Case 2

In the second case again the same plan was again executed on HDR 1000 plus well-type ionization chamber but in this case, the Elasto-Gel of the same diameter was used instead of the vaginal cylinder, as shown in Figure 5b. Again the charge collection by the electrometer was noted down.

The ratio of charges obtained using the segmented vaginal cylinder and Elasto-Gel source jig in the well-type ionization chamber gave the effective attenuation by the segmented vaginal cylinder, and the same principle was used in this study to obtain the attenuation due to various segmented vaginal cylinder applicators.

Pertinently, in both of the aforementioned cases, it was ensured that the distal end of the vaginal applicator and Elasto-Gel was placed at the same location in the base of the well-type ionization chamber. Thus, the dwell positions of the Ir-192 source within the chamber were precisely the same in both cases and there was no difference between the two scenarios in terms of the Ir-192 source's relative dwell positions inside the chamber.

A similar procedure was repeated for different patients wherein the patient was first inserted with the appropriate applicator and then the plan was created on the TPS, and the same plan was executed with Gafchromic film taped on the surface of the applicator. Subsequently, the charge collection using a well-type ionization chamber was also measured. In this way, the results were obtained for different diameters of applicators.

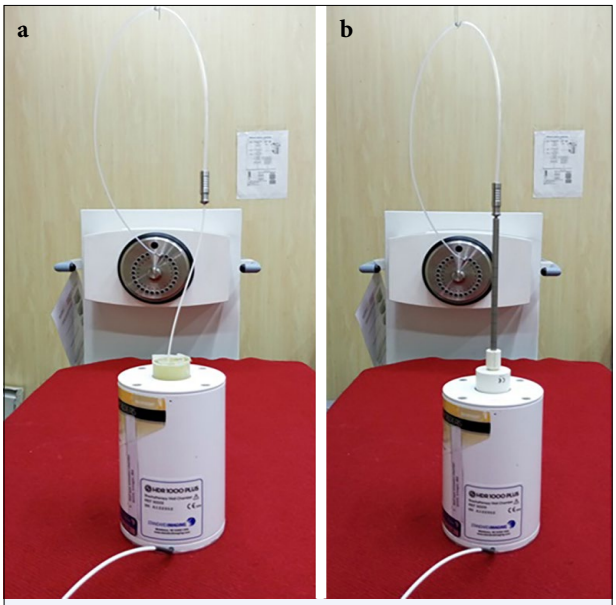

Fig. 5. Setup for the measurement of charge collection using (a) 35mm Elasto-Gel within the well of chamber. (b) 35mm vaginal applicator within well of chamber.

The TPS calculated dose and the measured dose recorded by the Gafchromic films were compared using a paired t-test and examined in the data editor of SPSS Version 20. Using the same test, the charge collected using vaginal cylinder and Elasto-Gel in well-type ionization chamber was also compared. p=0.10 or less was considered significant.

Ethical statement

The study was approved by the Ethics Review Committee of Sher I Kashmir institute of Medical Sciences (reference: SIMS 131/IEC-SKIMS/2022-196). Consent from patients was not required as datasets were not for clinical use of patients.

RESULTS

A total of 20 intracavitary brachytherapy insertions were studied, five insertions for each 35 mm, 30 mm, 25 mm, and 20 mm diameter vaginal applicator. The dosimetric results were obtained using both Gafchromic films and a well-type ionization chamber. The mean overestimation of dose by the TPS was calculated for each applicator

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Table 1 Comparison of mean *in vitro* doses and calculated (treatment planning system – TPS) doses in intracavitary brachytherapy (ICBT) with the cylinder applicator

S/N	Cylinder, diameter (mm)	Treatment, length (cm)	Prescribed dose (Gy)	Mean calculated (TPS) dose at surface of applicator (Gy)	Mean measured (*in vitro*) doses (Gy) at surface of applicator by using Gafchromic films	Deviations (calculated-measured dose)	Percentage overestimation of dose By TPS
1	35	5	6.0	10.4	9.94	0.46 Gy	4.42%
2	35	4	6.0	10.2	9.86	0.34 Gy	3.33%
3	35	4	6.0	10.5	9.96	0.54 Gy	5.14%
4	35	4	6.0	10.6	9.88	0.72 Gy	6.79%
5	35	5	6.0	10.2	9.79	0.41 Gy	4.02%
					Mean deviation	0.494 Gy	Mean overestimation 4.74%
6	30	5	6.0	9.8	9.37	0.43 Gy	4.39%
7	30	4	6.0	9.7	9.42	0.28 Gy	2.89%
8	30	5	6.0	9.9	9.68	0.22 Gy	2.22%
9	30	4	6.0	9.9	9.39	0.51 Gy	5.15%
10	30	4	6.0	9.8	9.42	0.38 Gy	3.88%
					Mean deviation	0.364 Gy	Mean overestimation 3.71%
11	25	4	6.0	9.1	8.93	0.17 Gy	1.87%
12	25	4	6.0	9.0	8.84	0.16 Gy	1.78%
13	25	4	6.0	9.3	8.87	0.43 Gy	4.62%
14	25	4	6.0	9.1	8.91	0.19 Gy	2.09%
15	25	4	6.0	9.0	8.80	0.20 Gy	2.22%
					Mean deviation	0.23 Gy	Mean overestimation 2.52%
16	20	4	6.0	8.7	8.56	0.14 Gy	1.61%
17	20	5	6.0	8.5	8.41	0.09 Gy	1.06%
18	20	5	6.0	8.7	8.58	0.12 Gy	1.38%
19	20	5	6.0	8.6	8.51	0.09 Gy	1.05%
20	20	5	6.0	8.5	8.36	0.14 Gy	1.65%
					Mean deviation	0.12 Gy	Mean overestimation 1.35%

using Gafchromic films. The maximum overestimation of TPS dose for the 35 mm vaginal applicator was 4.74% and the least was for the 20 mm vaginal applicator; the results are shown in Table 1. The graphical representation of the TPS overestimated dose versus the diameter of the applicator is shown in Figure 6.

The mean attenuation by the various applicators was also calculated by using a well-type ionization chamber, and the results obtained for attenuation by vaginal cylinders were in accordance with the results obtained using Gafchromic films and are given in Table 2. From Table 2, it can be observed that the vaginal cylinder of 35 mm resulted in maximum attenuation of 4.456%. The graphical representation of mean attenuation by the various applicators versus the diameter of the applicator is shown in Figure 7.

The results of the statistical analysis in both Gafchromic measurements and well-type measure-

Table 2 Comparison of mean charge collected for Elasto Gel and mean charge collected with vaginal applicators in a well-type ionization chamber

S/N	Cylinder, diameter (mm)	Treatment, length (cm)	Prescribed dose (Gy)	Mean charge collected for source jig (nC)	Mean charge collected for applicator (nC)	Percentage Attenuation by applicator
1	35	5	6.0	9671.3	9240.0	4.46%
2	35	4	6.0	9672.0	9239.6	4.47%
3	35	4	6.0	9671.9	9241.4	4.45%
4	35	4	6.0	9670.9	9240.6	4.45%
5	35	5	6.0	9671.2	9241.0	4.45%
						Mean attenuation 4.456%
6	30	5	6.0	9411.8	9117.5	3.13%
7	30	4	6.0	9412.6	9118.1	3.13%
8	30	5	6.0	9411.2	9117.3	3.22%
9	30	4	6.0	9410.9	9118.3	3.11%
10	30	4	6.0	9412.2	9119.1	3.21%
						Mean attenuation 3.16%
11	25	4	6.0	9156.3	8905.7	2.74%
12	25	4	6.0	9155.2	8904.1	2.74%
13	25	4	6.0	9158.1	8908.2	2.73%
14	25	4	6.0	9157.9	8905.2	2.76%
15	25	4	6.0	9155.9	8901.9	2.77%
						Mean attenuation 2.748%
16	20	4	6.0	8766.4	8661.6	1.20%
17	20	5	6.0	8763.9	8659.2	1.19%
18	20	5	6.0	8769.4	8660.1	1.25%
19	20	5	6.0	8765.3	8664.1	1.15%
20	20	5	6.0	8764.8	8663.1	1.16%
						Mean attenuation 1.19%

ments showed that there was no significant difference in the measured doses for different diameters of vaginal applicators ($p>0.10$).

DISCUSSION

The attenuation provided by PEEK segmented vaginal cylinders has been explored in this study, which was yet to be investigated. Using EBT3 Gafchromic films and a well-type ionization chamber, the dosimetric influence of various segmented vaginal cylinders in brachytherapy dose was determined.

The dose calculation method in BrachyVision TPS (version 11) is based on the TG-43 algorithm, which effectively neglects the material of the applicator inserted within the patient and calculates the dose by considering a radioactive source inside the homogeneous water medium. There is a difference between the results obtained from the TPS and practical dose measurements, and the difference is due to the TPS calculation method, in which a uniform water equivalent phantom is assumed. The segmented vaginal cylinders are made up of comparatively high Z material and have CT number ranging from 250–300 HU; however, the CT number of water is zero HU.[22] The CT number of material directly reflects the linear attenuation coefficient of the material of interest. A higher linear attenuation coefficient means more interactions per cm and hence more attenuation. Thus, these segmented cylinders have quite different dosimetric properties compared to water. This is further confirmed by the study conducted

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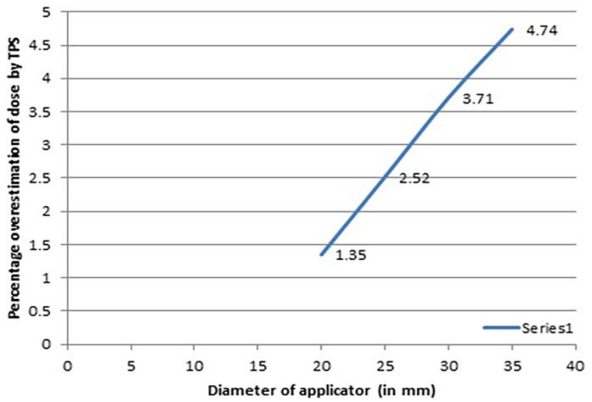

Fig. 6. Graphical representation of percentage overestimation of dose with applicator size (measured by using Gafchromic films).

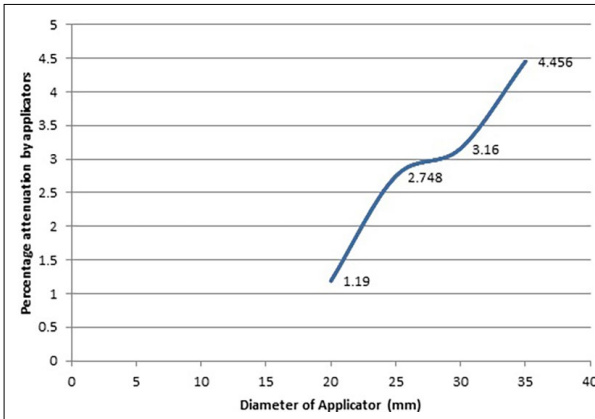

Fig. 7. Graphical representation of percentage attenuation by applicators with applicator size (measured in well type ionization chamber).

by Meigooni et al.,[23] wherein the authors concluded that solid water is equivalent to water for dosimetry in brachytherapy; however, polystyrene and PMMA are not equivalent to water and are further supported by the findings of Lewis et al.[24]

In this study, the doses at the surface of the various segmented cylinders were obtained by placing the Gafchromic films on the surface of the applicator. The effect of segmented cylinders on net charge collection versus the charge collection with a water equivalent Elasto-Gel was also studied using a well-type ionization chamber. As the charge collection in the well-type ionization chamber is directly proportional to the dose delivered, thus in both cases, we effectively measured the effect of segmented cylinders on the dose delivered to the patient. Both methods used in this study showed that the brachytherapy TPS based on TG-43 formalism overestimates the dose.

The dose recorded on the films was measured using an Epson scanner with IMRT Omnipro software. The recorded dose on the films is given in Table 1, which reveals that there is the maximum overestimation of the TPS dose for the 35 mm vaginal cylinder, and it is lowest for the 20 mm cylinder.

The percentage attenuation values obtained by using a well-type ionization chamber are shown in Table 2, and here, it can also be observed that a vaginal cylinder of diameter 35 mm resulted in maximum attenuation and the least attenuation of the dose was due to a vaginal cylinder diameter of 20 mm. In both the aforementioned methods, it was found that the attenuation in the dose increases with an increase in the diameter of the vaginal cylinder and can be attributed to the increase in the applicator wall thickness with an increase in diameter of the vaginal cylinder. The study conducted by Oyekunle et al.[25] and Gholami et al.[26] concluded that there is an overestimation of dose by the TPS due non-water equivalent material of the applicator and the same should be considered for the better estimation of doses to the target and organs at risk. Ye et al.[27] in their study using ion chamber and Monte Carlo simulation found that if the applicator attenuation is neglected the dose overestimates along the transverse plane by up to 3.5% and even worsens the error in oblique angles.

In our study, although there is no statistically significant difference between the TPS and detector measured dose, both the methods are in agreement with each other in measuring the TPS overestimation. Accounting for the dose attenuation by these vaginal cylinders is therefore expected to improve the HDR dose delivery accuracy.

CONCLUSION

This work assesses the dose variance brought on by the brachytherapy TPS and advances toward the good practice of HDR vaginal vault brachytherapy treatment. Although not statistically significant, the overestimation of the dosage by the brachytherapy TPS based on the AAPM TG-43 calculation algorithm can be taken into account for the precise dose estimation to the target and organs at risk. Therefore, determining the attenuation coefficients of vaginal cylindrical applicators and incorporating them into the brachytherapy TPS can improve treatment accuracy. Thus, we draw the conclusion that by taking into account the segmented vaginal cylinder applicator heterogeneity in the TPSs, the dose calculations in brachytherapy can be improved.

Peer-review: Externally peer-reviewed.

Conflict of Interest: All authors declared no conflict of interest.

Ethics Committee Approval: The study was approved by the Sher I Kashmir institute of Medical Sciences Institutional Ethics Committee (no: SIMS 131/IEC-SKIMS/2022-196, date: 10/05/2022).

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