Rep Pract Oncol Radiother, 2008; 13(1): 35-48

Original Paper

Received: 2007.07.09
Accepted: 2007.12.13
Published: 2008.02.29

Optimization in high dose rate vaginal cylinder for vaginal cuff irradiation

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Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

Summary

Aim The aim of this study is to evaluate the influence of high dose rate (HDR) brachytherapy source step size, source dwell position, dose prescription depth, dose specification points and optimization technique on dose distribution around Microselectron HDR brachytherapy vaginal cylinders and to evaluate the influence of distal dwell position and optimization technique on rectal and bladder dose of patients treated for vaginal cuff irradiation.

Materials/Methods Orthogonal radiographs of vaginal cylinders of diameter 2.0, 2.5, 3.0 and 3.5cm form the basis of the study. Dose distribution using the PLATO brachytherapy treatment planning system (version 14.1) was generated. Two different HDR cylinder models, namely the non-curved dome model (NCDM) and curved dome model (CDM), were studied. To evaluate bladder and rectum dose in the patients NCDM was used.

Results CDM gives more uniform dose distribution around the cylinder than NCDM. Dose prescription at 5mm depth from the surface results in very high dose to apex and dome as compared with the surface dose prescription. Dose prescription depth and dwell positions influence the length of prescription isodose. Optimization method and dwell positions affect the bladder and rectal dose of the studied patients.

Conclusions Uniform dose distribution can be obtained for HDR vaginal cylinders by appropriately selecting dose specification points and optimization method. Dose distribution can be configured to provide a uniform dose on the surface, if the apex and curved surface of the cylinder are considered for dose specification and optimization. Appropriate HDR parameters are identified to minimize the dose to the apex of the vaginal cylinder, essential to reduce the dose to overlying small bowel and reduce the dose to rectum and bladder.

Key words **optimization • Dwell position • Curved Dome Model • Non-Curved Dome Model**

Full-text PDF: http:/www.rpor.eu/pdf.php?MAN=11556

Word count: 2281
Tables: 9
Figures: 6
References: 9

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Background

Endometrial carcinoma is the most common malignancy arising in the female genital tract. External beam radiotherapy with or without brachytherapy is an integral component in the postoperative adjuvant therapy and in the management of inoperable or recurrent endometrial cancer. The purpose of intravaginal brachytherapy is to prevent recurrences at the vaginal vault and in the inner part of the vagina. Vaginal cylinders are often used to deliver brachytherapy dose to the vaginal apex and to the upper vagina or to the entire vaginal surface.

The organs at risk (OAR) in the vaginal cuff irradiation are the rectum, bladder and small bowel. Anatomically the bladder lies anteriorly and the rectum posteriorly to the vaginal cylinder placed in the vaginal cavity. The small bowel lies in proximity to the apex and curved dome of the vaginal cylinder.

The most important risk factor in vaginal cuff irradiation is the mucosal surface dose, the dose gradient in the mucosa, or the dose at the level of the connective tissue. Study shows [1] that choosing the dose prescription depth according to mucosal thickness can minimize the late radiation reaction. It is reported in the literature that irradiation of the entire vagina results in increased rectal [2] toxicity. Study indicates an association between reference isodose length and vaginal shortening [3]. Symptoms of acute radiation for small bowel depend on dose per fraction and amount of small bowel in the treatment volume [4]. Hence reducing the dose to the small bowel assumes importance in the treatment of vaginal cuff irradiation. Comparison of dose distribution between low dose rate and high dose rate vaginal cylinders has been studied [5]. Modern stepping source high dose rate brachytherapy system and optimization techniques offer scope to customize dose distribution according to clinical requirement. Though the American Brachytherapy Society [6] has given recommendations for HDR brachytherapy for Ca. of the endometrium in the year 2000, a recent survey in the year 2005 [7] indicated that the majority of HDR vaginal brachytherapy users are using different dose fractionation [8] and dose prescription methods and are not including dose points at the curved end in their plan optimization.

Aim

The aim of the work is to evaluate the influence of Microselectron HDR source step size, dwell position, optimization technique, dose prescription depth and dose specification points on dose to apex and dome points of the vaginal cylinders. The influence of distal dwell position and optimization technique on rectal and bladder dose is also evaluated for 20 patients who had undergone vaginal cuff irradiation.

Materials and Methods

The Microselectron HDR vaginal cylinder set is constructed with a series of disk-shaped pieces assembled over a central tandem. Each disk is 25mm in length. The apical piece is dome shaped. Vaginal cylinders of diameter 2.0, 2.5, 3.0 and 3.5cm were taken for the study. Vaginal cylinders were placed on the simulator couch and orthogonal radiographs were acquired using the isocentric technique. These radiographs were used for applicator reconstruction.

Two different HDR cylinder models, namely the non-curved dome model (NCDM) and curved dome model (CDM), were studied. NCDM assumes that the applicator is cylindrical in shape and without a curved dome. In this model the dose specification points are placed lateral to each source dwell position on the surface of the cylinder or at 5mm from the surface of the cylinder. It is the most commonly used model in routine brachytherapy planning due to its simplicity. CDM accounts for the dome shape of the cylindrical HDR applicator. In this model the dose specification points are placed on the lateral and curved dome surface of the applicator. Schematic diagrams of CDM and NCDM are shown in Figures 1 and 2.

Source dwell positions are activated from the distal to proximal end (where the applicator is connected with the transfer tube) of the applicator for an intended treatment length of 4cm. The nearest dwell position is approximately 6mm from the apex. Optimized dose distribution (for 100cGy dose prescription) for CDM and NCDM of a vaginal cylinder with source step size of 2.5mm and 5mm, for dose point optimization (DPO) and geometric optimization (GO), with and without considering apex for dose specification, were generated. Optimized dose distribution for CDM was generated for surface prescription only.

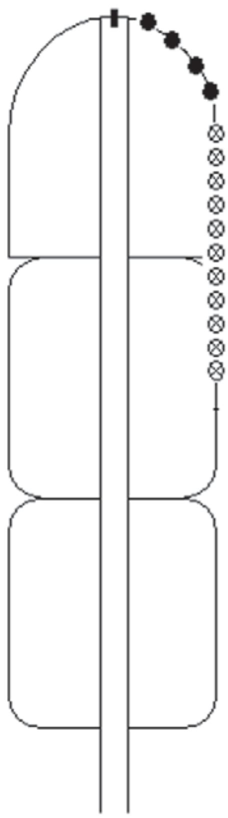

Figure 1. Curved Dome Model (CDM). ● Dome Points. ⊗ Dose points. ▌Apex.

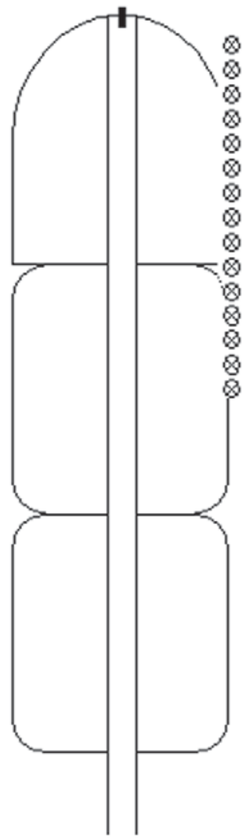

Figure 2. Non-Curved Dome Model (NCDM). ⊗ Dose points. ▌Apex.

For patients who had undergone HDR vaginal cuff irradiation, a cylinder that fit comfortably in the vagina of the patient was selected and used. Numbers of cylinders and dwell positions are chosen according to the intended length of the vagina to be treated. To evaluate the bladder and rectal dose, the organs are identified on the orthogonal radiograph as described. The bladder is visualized by placing 7cc of contrast medium into the Foley catheter balloon. The bladder point is marked on the radiograph as per the guidelines of ICRU 38 [9]. On the anterior view of the radiograph the bladder reference point is taken at the centre of the balloon. In the lateral view, the reference point is chosen on an anterior-posterior line drawn through the Foley catheter balloon centre at the posterior surface. A standard rectal marker is inserted through the anal canal to identify the rectal position. Four rectal reference points spread uniformly over the treatment length are marked on the anterior and lateral radiographs. NCDM, the widely used vaginal cylinder model in brachytherapy planning, alone is considered for dose computation. Source dwell positions are 5mm apart. Dose points are placed at 5mm from the surface of the cylinder for prescription and optimization. Influence of distal dwell position on rectal and bladder dose is evaluated for DPO and GO.

PLATO brachytherapy treatment planning system (version 14.1) with anisotropy calculations is used for dose computation.

Results

Dose to apex, dome points, dose points, prescription isodose covering volume and total treatment time are evaluated for CDM and NCDM.

Curved Dome Model

Dose to apex is generally higher with geometric optimization than with dose point optimization.

Source Step Size: Changing source step size from 2.5mm to 5mm increases the dose to apex. The increase in dose to apex is higher when the mode of optimization is GO as compared to DPO (refer Tables 1–4).

Table 1. Evaluated parameters for vaginal cylinder of 2.0cm diameter.

Step size (mm)	Dose at apex (cGy)	Dose at dome points (cGy)	Dose on dose points* (cGy)	Treatment time for 100cGy	Prescription isodose volume (cc)	For optimization
Curved Dome Model						
Dose point optimization – dose prescription on the surface of the cylinder						
2.5	84.7	107.8,101.1,98.5	103.1,101.5,93.3	163.4	15.3	Apex not considered
5.0	90.8	108.0,104.4, 97.0	103.9,103.5,91.5	164.3	15.3	
2.5	90.0	111.8, 97.3, 97.6	102.0, 99.5, 93.2	164.0	15.3	Apex considered
5.0	93.5	111.1, 96.8, 95.2	103.3,102.9,91.8	163.4	15.2	
Geometric optimization – dose prescription on the surface of the cylinder						
2.5	94.0	109.7,101.9,94.1	103.8,101.8, 96.1	158.3	14.9	Apex not considered
5.0	114.0	130.9, 109.7,95.9	101.6,101.4,99.9	161.1	15.1	
2.5	92.3	106.9, 92.6, 94.6	104.4,101.4,96.6	159.1	14.9	Apex considered
5.0	112.8	124.7, 99.1, 94.8	100.4,100.3,98.7	159.4	14.9	
Non-Curved Dome Model						
Dose point optimization – dose prescription on the surface of the cylinder						
2.5	122.0	146.3,123.5,102.8	103.7,102.3,101.5	169.0	16.0	Apex not considered
5.0	127.9	146.5,120.4,102.2	103.8,103.4,100.1	168.5	15.9	
2.5	103.5	127.5,117.3,102.2	103.8,103.7,98.9	166.9	15.6	Apex considered
5.0	105.2	125.2,112.3,100.8	105.2,102.7,86.3	167.1	15.5	
Dose point optimization – dose prescription at 5mm						
2.5	208.8	294.0, 223.6,190.2	104.1,102.8,98.8	292.8	37.6	Apex not considered
5.0	225.1	294.4, 213.7, 182.4	103.1,100.9,96.6	291.0	37.5	
2.5	106.2	180.4, 178.3, 178.0	104.0, 98.9, 91.3	283.6	35.4	Apex considered
5.0	112.1	168.8, 162.1, 159.1	99.3, 93.1, 85.2	278.2	35.2	
Geometric optimization – dose prescription on the surface of the cylinder						
2.5	104.8	111.5, 103.6, 95.6	102.4, 97.6, 90.4	160.2	15.1	Apex not considered
5.0	116.9	134.3, 112.5, 98.3	103.5,103.1,95.1	165.3	15.7	
2.5	104.4	111.0, 103.2, 95.2	102.0, 97.2, 89.9	160.2	15.1	Apex considered
5.0	116.2	133.3, 111.7, 97.6	103.3,102.8,99.2	164.2	15.3	
Geometric optimization – dose prescription at 5mm						
2.5	159.2	221.5, 177.4,164.3	100.4, 95.2,88.6	276.8	34.9	Apex not considered
5.0	205.1	264.9,192.7,168.9	100.9, 97.1, 91.7	283.8	36.3	
2.5	154.0	214.5, 171.7, 159.1	97.2, 92.2, 85.8	267.9	33.2	Apex considered
5.0	193.7	250.3, 182.1, 159.6	95.4, 91.7, 86.6	268.2	33.0	

Dose Point* – Dose specification points placed on the lateral sides of the vaginal cylinder.

Dose Specification/Optimization Points: Considering the apex point for dose specification reduces dose to apex in the case of GO and increases with DPO.

Non-Curved Dome Model

Source Step Size: Dose to apex increases when source step size is changed from 2.5mm to 5mm.

Table 2. Evaluated parameters for vaginal cylinder of 2.5cm diameter.

Step size (mm)	Dose at apex (cGy)	Dose at dome points (cGy)	Dose on dose points* (cGy)	Treatment time for 100cGy	Prescription isodose volume (cc)	For optimization
Curved Dome Model						
Dose point optimization – dose prescription on the surface of the cylinder						
2.5	85.8	104.3,101.1,96.7	102.1,101.4, 95.6	200.9	22.9	Apex not considered
5.0	92.0	107.6,100.2,94.6	104.0,102.8, 99.2	200.4	23.0	
2.5	91.0	112.3,104.3,96.8	103.9,103.7,100.8	201.0	23.1	Apex considered
5.0	95.5	113.9,102.9,94.9	104.0, 102.8, 99.2	200.3	23.0	
Geometric optimization – dose prescription on the surface of the cylinder						
2.5	106.9	130.9,111.7,97.8	102.5,100.1, 95.1	192.8	21.6	Apex not considered
5.0	133.7	156.1,123.5,102.5	97.9, 96.8, 94.8	192.4	21.6	
2.5	106.4	130.5,111.4,97.5	100.9, 98.6, 95.1	191.6	21.6	Apex considered
5.0	131.4	153.5,121.4,100.8	94.7, 96.8, 94.8	190.1	21.0	
Non-Curved Dome Model						
dose point optimization – dose prescription on the surface of the cylinder						
2.5	148.8	181.3,147.5,121.2	103.9,103.4, 99.8	212.2	24.8	Apex not considered
5.0	156.8	183.8,144.9,118.7	104.1,102.7, 98.5	211.5	24.7	
2.5	104.5	136.6,123.9,110.7	105.7,101.6, 93.7	206.1	24.0	Apex considered
5.0	109.6	134.9,117.8,105.1	106.1,105.9, 96.7	205.3	23.9	
Dose point optimization – dose prescription at 5 mm						
2.5	239.6	296.3, 246.0,204.5	103.3,101.7,98.0	343.3	51.3	Apex not considered
5.0	243.9	287.2,228.7,188.8	101.7, 98.8, 94.3	337.0	50.5	
2.5	106.6	164.8,159.2,158.9	101.3, 95.9, 88.8	328.9	48.4	Apex considered
5.0	118.2	146.9, 146.1,143.7	96.1, 89.8, 82.3	319.1	46.7	
Geometric optimization – dose prescription on the surface of the cylinder						
2.5	111.8	136.6,116.6,102.1	100.9, 95.7, 88.7	200.9	20.1	Apex not considered
5.0	143.1	166.9,132.0,109.6	101.4, 97.9, 92.6	206.6	24.0	
2.5	111.0	134.0,114.3,100.0	98.8, 93.8, 86.9	196.9	22.9	Apex considered
5.0	139.5	163.0,128.9,107.1	98.5, 96.7, 91.5	201.8	23.1	
Geometric Optimization – Dose Prescription at 5mm						
2.5	179.6	219.8,187.6,164.2	99.8, 94.8, 88.7	323.1	47.5	Apex not considered
5.0	229.0	267.1,211.2,175.4	100.3, 96.3, 91.0	330.8	49.2	
2.5	172.1	210.6,179.6,157.2	95.6, 90.8, 84.9	309.2	44.9	Apex considered
5.0	213.7	249.3,197.2,163.7	93.6, 89.9, 84.9	308.8	44.3	

Dose Point * – Dose specification points placed on the lateral sides of the vaginal cylinder.

The increase in dose to apex is higher when mode of optimization is GO as compared to DPO (see Tabless 1–4).

Prescription Depth: Dose prescription at 5mm from the surface of the cylinder results in very high dose to apex and curved portion of the

Table 3. Evaluated parameters for vaginal cylinder of 3.0 cm diameter.

Step size (mm)	Dose at apex (cGy)	Dose at dome points (cGy)	Dose on dose points* (cGy)	Treatment time for 100cGy	Prescription isodose volume (cc)	For optimization
Curved Dome Model						
Dose point optimization – dose prescription on the surface of the cylinder						
2.5	87.0	106.9,105.1,103.9	101.0,94.6,86.0	272.7	32.9	Apex not considered
5.0	94.7	110.9,102.0,100.8	108.1,102.6,90.2	269.5	32.4	
2.5	92.0	111.8,107.3,107.1	100.4, 94.0, 85.7	273.0	33.1	Apex considered
5.0	98.2	114.1,103.1,101.1	107.8, 102.2,89.9	269.5	32.4	
Geometric pptimization – dose prescription on the surface of the cylinder						
2.5	133.3	148.7,116.3,104.9	98.7, 94.9, 90.0	257.4	30.5	Apex not considered
5.0	166.9	177.8,128.2,109.5	94.1, 91.5, 85.6	257.2	30.6	
2.5	132.3	152.7,120.2,107.9	96.9, 93.8, 88.4	252.7	29.7	Apex considered
5.0	159.6	169.9,122.5,114.7	90.8, 87.5, 81.8	247.8	28.7	
Non-Nurved Dome Model						
Dose point optimization – dose prescription on the surface of the cylinder						
2.5	194.0	216.4,163.5,139.3	100.0, 94.8, 88.2	293.8	36.6	Apex not considered
5.0	203.0	218.0,157.8,133.8	104.5,103.5,101.1	292.9	36.5	
2.5	105.5	131.9,123.0,118.9	103.9, 99.1, 91.7	285.6	35.4	Apex considered
5.0	111.7	127.9,111.3,106.5	107.3,103.1,92.2	280.5	34.5	
Dose point optimization – dose prescription at 5mm						
2.5	280.3	333.8, 253.3, 215.7	102.2,100.2,96.6	447.3	68.9	Apex not considered
5.0	297.9	302.1,222.7,191.9	100.6, 96.9, 92.2	433.7	66.3	
2.5	117.0	159.7,157.8,155.1	98.6, 93.1, 86.4	421.1	63.4	Apex considered
5.0	122.7	140.7,136.8,132.8	93.8, 87.2, 79.9	410.0	61.0	
Geometric pptimization – dose prescription on the surface of the cylinder						
2.5	147.2	163.7,128.9,115.7	100.0, 95.0, 88.4	277.8	34.1	Apex Not considered
5.0	190.4	202.7,146.1,124.8	107.3, 104.3, 97.6	286.0	35.7	
2.5	143.6	159.7,125.7,112.8	101.4, 97.6, 92.5	271.9	33.0	Apex considered
5.0	175.1	186.4,134.4,114.8	98.7, 94.9, 89.9	273.0	33.1	
Geometric pptimization – dose prescription at 5mm						
2.5	223.1	247.9,195.3,175.3	99.6, 94.8, 89.1	422.0	64.3	Apex Not considered
5.0	278.6	302.9,218.4,186.5	99.9, 95.9, 91.0	431.5	66.3	
2.5	208.8	232.1,182.8,164.1	93.2, 88.7, 83.4	395.2	57.9	Apex considered
5.0	258.0	274.8,198.1,169.2	90.6, 87.1, 82.6	391.5	57.1	

Dose Point* – Dose specification points placed on the lateral sides of the vaginal cylinder.

cylinder as compared with the surface dose prescription. Table 5 shows the percentage increase in dose to apex when dose prescription changed from surface to 5mm depth.

Prescription Isodose Line Length: Dose prescription depth and diameter of the cylinder are the two major parameters influencing the length of the prescription isodose and treatment time.

Table 4. Evaluated parameters for vaginal cylinder of 3.5cm diameter.

Step size (mm)	Dose at apex (cGy)	Dose at dome points (cGy)	Dose on dose points* (cGy)	Treatment time for 100cGy	Prescription isodose volume (cc)	For optimization
Curved Dome Model						
Dose point optimization – dose prescription on the surface of the cylinder						
2.5	90.0	103.1, 99.3, 97.7	102.0,100.6, 98.1	300.1	43.5	Apex not considered
5.0	98.8	107.8, 95.8, 92.9	102.9, 99.8, 95.8	295.3	43.2	
2.5	95.1	109.7, 99.4, 96.1	101.7,100.0,96.9	300.1	43.6	Apex considered
5.0	100.2	108.3, 95.9, 92.8	102.6, 99.5, 95.5	295.6	42.9	
Geometric pptimization – dose prescription on the surface of the cylinder						
2.5	154.9	165.2,118.9,101.5	100.6, 99.5, 97.7	288.8	41.2	Apex not considered
5.0	172.6	175.7, 123.8, 100.8	97.0, 96.4, 95.1	295.1	41.5	
2.5	149.1	158.9, 114.4, 97.7	97.6, 96.6, 94.8	279.9	39.2	Apex considered
5.0	162.2	169.4, 116.4, 94.8	92.1, 91.5, 90.8	273.9	38.0	
Non-Curved Dome Model						
Dose point optimization – dose prescription on the surface of the cylinder						
2.5	213.9	220.6,156.2,117.1	103.4,101.2,98.1	335.2	50.8	Apex not considered
5.0	216.5	226.7,146.2,114.3	101.8, 98.9, 94.4	329.1	49.9	
2.5	107.6	141.9,124.2,106.1	101.3,96.1,89.1	322.1	48.0	Apex considered
5.0	113.1	123.9,113.8,106.2	96.4, 90.2, 82.9	312.7	46.3	
Dose point optimization – dose prescription at 5mm						
2.5	294.0	312.7, 300.5, 223.6	98.6, 94.9, 90.0	483.6	89.6	Apex not considered
5.0	305.0	316.4, 306.5, 227.0	95.9, 91.0, 85.4	467.5	84.2	
2.5	117.4	170.3, 162.7, 157.9	90.6, 84.2, 77.4	449.4	79.0	Apex considered
5.0	124.6	145.3, 144.9, 141.2	85.8, 79.0, 72.1	444.3	77.4	
Geometric optimization – dose prescription on the surface of the cylinder						
2.5	172.8	175.0,127.2,113.7	96.3, 95.5, 91.5	315.3	47.1	Apex not considered
5.0	191.4	196.4,137.3,111.8	100.3, 96.3, 85.8	323.1	48.8	
2.5	161.3	169.3,124.9,110.9	99.9, 94.9, 88.7	304.0	44.3	Apex considered
5.0	175.9	178.3,127.9,104.2	94.5, 90.7, 85.8	304.4	43.8	
Geometric optimization – dose prescription at 5mm						
2.5	264.1	274.5, 235.8, 189.9	95.0, 89.7, 83.8	461.2	82.2	Apex not considered
5.0	284.5	295.5, 199.9, 162.8	95.9,91.2,85.8	470.6	85.3	
2.5	215.9	226.7, 173.9,148.5	86.9, 82.2, 76.8	422.4	72.6	Apex considered
5.0	246.2	261.1, 176.6, 143.8	84.7, 80.6, 75.8	415.7	70.8	

Dose Point* – Dose specification points placed on the lateral sides of the vaginal cylinder.

Source loading length of 4cm gives a prescription isodose length of more than 5cm depending on the chosen HDR parameters. Table 6 shows the length of prescription isodose line for both modes of optimization for the studied vaginal cylinders.

Table 5. Effect of prescription depth on dose to apex – NCDM.

Step size (mm)	Mode of optimization	Diameter of the cylinder – 2.0cm: Dose at apex, Prescription at surface	Diameter of the cylinder – 2.0cm: Dose at apex, Prescription at 5mm	Diameter of the cylinder – 2.0cm: % increase in apex dose	Diameter of the cylinder – 2.5cm: Dose at apex, Prescription at surface	Diameter of the cylinder – 2.5cm: Dose at apex, Prescription at 5mm	Diameter of the cylinder – 2.5cm: % increase in apex dose	For optimiatization
2.5	DPO	122.0	208.8	71.1	148.8	239.6	61.0	Apex not considered
	GO	104.8	159.2	51.9	111.8	179.6	60.7	
2.5	DPO	103.5	106.2	2.7	104.5	106.6	2.0	Apex considered
	GO	104.4	154.0	47.5	111.0	172.1	55.0	
5.0	DPO	127.9	225.1	76.0	156.8	243.9	55.5	Apex not considered
	GO	116.9	205.1	75.5	143.1	229.0	60.0	
5.0	DPO	105.2	112.1	6.6	109.6	118.2	7.8	Apex considered
	GO	116.2	193.7	66.7	139.5	213.7	53.2	

Step size (mm)	Mode of optimization	Diameter of the cylinder – 3.0 cm: Dose at apex, Prescription at surface	Diameter of the cylinder – 3.0 cm: Dose at apex, Prescription at 5mm	Diameter of the cylinder – 3.0 cm: % increase in apex dose	Diameter of the cylinder – 3.5 cm: Dose at apex, Prescription at surface	Diameter of the cylinder – 3.5 cm: Dose at apex, Prescription at 5mm	Diameter of the cylinder – 3.5 cm: % increase in apex dose	For optimiatization
2.5	DPO	194.0	280.3	44.5	213.9	294	37.4	Apex not considered
	GO	147.2	223.1	51.6	172.8	264.1	52.8	
2.5	DPO	105.5	117	10.9	107.6	117.4	9.1	Apex considered
	GO	143.6	208.8	45.4	161.3	215.9	33.8	
5.0	DPO	203.0	297.9	46.7	216.5	305	40.9	Apex not considered
	GO	190.4	278.6	46.3	191.4	284.5	48.6	
5.0	DPO	111.7	122.7	9.8	113.1	124.6	10.2	Apex considered
	GO	175.1	258.0	47.3	175.9	246.2	40.0	

Dose Specification/Optimization Points: Considering the apex point for dose specification reduces dose to apex as well as at the curved portion of the cylinder, and it is more pronounced with DPO than GO (see Tables 1–4).

Effect of Distal Dwell Position: Skipping the distal dwell position reduces the dose to apex, and shrinks the prescription isodose. Table 7 shows dose to apex with and without distal dwell position for dose prescription at surface and at 5mm and without considering apex for optimization.

Dose to Organ at Risk: Distal dwell position, dose prescription depth and mode of optimization influence the dose to bladder and rectum.

Skipping the distal dwell position and dose prescription on the surface of the cylinder reduces dose to rectum and bladder in the studied patients, as shown in Table 8 and Table 9. Dose to rectum and bladder is less for GO than DPO. For DPO mean bladder dose with and without distal dwell position is 84.2% and 74.3% and for GPO 75.7% and 66.6% respectively. For DPO mean rectal dose with and without distal dwell position is 68.4% and 66.9% and for GPO 67.3% and 65.9% respectively.

Discussion

PLATO brachytherapy software offers the choice to place dose points for dose prescription at a desired depth from the centre of the vaginal applicator. The simplest and fastest way to perform optimization for a single straight catheter is to use DPO or GO on dose points placed at a desired depth along the catheter. The influence of various HDR parameters and optimization technique on the dose distribution of HDR vaginal

Table 6. Length of prescription isodose (in cms) – NCDM.

Step size (mm)	Mode of optimization	Diameter of Vaginal cylinder (2.0cm)		Diameter of Vaginal cylinder (2.5cm)		For optimiatization
		Dose prescription at surface	Dose prescription at 5mm	Dose prescription at surface	Dose prescription at 5mm	
2.5	DPO	5.4	5.85	5.65	6.1	Apex not considered
	GO	5.2	5.55	5.6	5.8	
2.5	DPO	5.4	5.6	5.5	5.75	Apex considered
	GO	5.2	5.5	5.4	5.7	
5.0	DPO	5.5	5.85	5.65	6.1	Apex not considered
	GO	5.45	5.8	5.6	6.0	
5.0	DPO	5.4	5.7	5.5	5.8	Apex considered
	GO	5.35	5.6	5.4	5.75	
Step size (mm)	**Mode of optimization**	**Diameter of Vaginal cylinder (3.0cm)**		**Diameter of Vaginal cylinder (3.5cm)**		**For optimiatization**
		Dose prescription at surface	**Dose prescription at 5mm**	**Dose prescription at surface**	**Dose prescription at 5mm**	
2.5	DPO	5.8	6.4	6.1	6.6	Apex not considered
	GO	5.7	6.05	5.8	6.3	
2.5	DPO	5.6	5.9	5.75	6.15	Apex considered
	GO	5.5	5.8	5.7	6.0	
5.0	DPO	5.85	6.4	6.2	6.5	Apex not considered
	GO	5.8	6.2	6.1	6.4	
5.0	DPO	5.7	6.1	5.95	6.3	Apex considered
	GO	5.6	5.8	5.7	6.0	

Table 7. Effect of Distal Dwell Position (DDP*) on Dose to Apex** (NCDM – 5mm stepsize).

Diameter of the cylinder (cm)	Mode of optimization	Dose prescription at surface		% decrease in dose to apex	Dose prescription at 5mm		% decrease in dose to apex
		With DDP	Without DDP		With DDP	Without DDP	
2.0	DPO	127.9	75.4	69.6	225.1	128.7	74.9
	GO	116.9	65.0	79.8	205.1	112.7	82.0
2.5	DPO	156.8	93.4	67.9	243.9	139.8	74.5
	GO	143.1	80.5	77.8	229.0	130.0	76.1
3.0	DPO	203.0	114.7	77.0	297.9	158.6	87.8
	GO	190.4	104.0	83.1	278.6	160.7	73.4
3.5	DPO	216.5	129.3	67.4	305.0	162.7	87.5
	GO	191.4	120.8	58.4	284.5	176.0	61.6

* Distal Dwell Position; Dose to Apex** – Apex Not considered for dose prescription and optimization.

Table 8. Influence of Distal Dwell Position and Optimization on Bladder Dose.

Patient number	Cylinder diameter (cms)	Intended treatment length (cms)	Bladder dose (%)						Percentage increase in Bladder Dose with Distal Dwell Point	
			With distal Dwell source position			Without distal Dwell source position			Dose point optimization	Geometric optimization
			Dose point optimization	Geometric optimization	% decrease in the dose	Dose point optimization	Geometric optimization	% decrease in the dose	% increase in the dose	% increase in the dose
1	3	8	125.0	109.0	12.8	105.0	92.0	12.4	19.0	18.5
2	3.5	7.5	94.0	85.0	9.6	87.0	78.0	10.3	8.0	9.0
3	3.5	7	98.8	88.1	10.8	82.4	73.8	10.4	19.9	19.4
4	3.5	8	90.1	81.7	9.3	80.0	73.0	8.8	12.6	12.0
5	3.5	5.75	48.8	45.0	7.8	40.0	36.5	8.8	22.0	23.3
6	3.5	7.5	140.6	123.4	12.2	121.6	106.8	12.2	15.6	15.5
7	3.5	6.5	80.3	76.5	4.7	74.6	70.4	5.6	7.6	8.7
8	3	6.5	114.0	104.0	8.8	105.0	93.2	11.2	8.6	11.6
9	3	7	112.8	98.8	12.4	84.5	74.9	11.4	33.5	31.9
10	3	6.75	84.3	73.5	12.8	81.0	70.5	13.0	4.1	4.3
11	3	9.5	79.9	71.5	10.5	71.0	63.0	11.3	12.5	13.5
12	3	7	67.7	62.0	8.4	62.0	57.0	8.1	9.2	8.8
13	3	7	79.8	71.7	10.2	66.7	59.6	10.6	19.6	20.3
14	3	9	55.8	51.0	8.6	52.0	47.3	9.0	7.3	7.8
15	3	10	119.0	102.0	14.3	103.0	87.8	14.8	15.5	16.2
16	2	9.5	37.5	34.0	9.3	34.0	31.0	8.8	10.3	9.7
17	3.5	10	73.0	66.2	9.3	65.0	58.6	9.8	12.3	13.0
18	3	8	76.6	70.9	7.4	72.0	65.4	9.2	6.4	8.4
19	3	10	41.2	38.0	7.8	39.7	37.0	6.8	3.8	2.7
20	3	7	65.0	61.2	5.8	60.4	57.2	5.3	7.6	7.0
Mean dose in %			84.2	75.7		74.3	66.6			
Standard deviation			28.2	24.0		23.3	19.8			

cylinder models (CDM and NCDM) was elaborately studied.

Parameters such as number of source dwell position, dwell position, choice of dose prescription depth and optimization choice influence the dose distribution and offer scope to reduce the dose to organs in close proximity to the vaginal cylinder in vaginal cuff irradiation.

Though the CDM with DPO gives more uniform dose over the dome region, the shape of the prescription isodose in the dome region is constricted laterally as compared with the NCDM (Figure 3A CDM and Figure 3B NCDM). Although the apex of the vagina has high radiation tolerance, the overlying bowel receives a significant radiation dose, as it is proximal to the apex of the vaginal cylinder. Our study shows that in NCDM the dose to the apex increases when the apex is not considered for dose specification, leading to delivery of a significant dose to the overlying small bowel. However, in the NCDM, dose to apex and dome points are less when the apex is not considered for dose specification in GO compared to DPO. Thus optimization technique also influences the

Table 9. Influence of distal Dwell position and optimization on rectal dose.

Patient number	Cylinder diameter (cms)	Intended treatment length (cms)	Rectal dose (%)						Percentage increase in rectum dose with distal Dwell point	
			With distal Dwell source position			Without distal Dwell source position			Dose point pptimization	Geometric optimization
			Dose point optimization	Geometric optimization	% decrease in the dose	Dose point optimization	Geometric optimization	% decrease in the dose	% increase in the dose	% increase in the dose
1	3	8	80.0	79.2	1.0	79.4	78.6	1.0	0.8	0.8
2	3.5	7.5	58.0	57.3	1.2	56.1	55.2	1.6	3.4	3.8
3	3.5	7	52.5	51.8	1.3	51.8	51.2	1.2	1.4	1.2
4	3.5	8	58.2	57.0	2.1	57.2	55.3	3.3	1.7	3.1
5	3.5	5.75	68.9	68.1	1.2	68.2	67.4	1.2	1.0	1.0
6	3.5	7.5	68.3	67.4	1.3	67.9	67.1	1.2	0.6	0.4
7	3.5	6.5	87.6	86.0	1.8	83.6	81.8	2.2	4.8	5.1
8	3	6.5	70.0	67.3	3.9	67.3	66.8	0.7	4.0	0.7
9	3	7	57.8	57.4	0.7	55.4	54.6	1.4	4.3	5.1
10	3	6.75	76.3	74.2	2.8	75.2	73.9	1.7	1.5	0.4
11	3	9.5	68.3	67.9	0.6	67.6	67.2	0.6	1.0	1.0
12	3	7	77.4	76.2	1.6	76.8	75.2	2.1	0.8	1.3
13	3	7	70.3	69.4	1.3	68.6	68.2	0.6	2.5	1.8
14	3	9	77.4	75.6	2.3	72.8	72.4	0.5	6.3	4.4
15	3	10	63.0	62.2	1.3	62.0	61.0	1.6	1.6	2.0
16	2	9.5	52.5	51.8	1.3	51.4	50.7	1.4	2.1	2.2
17	3.5	10	90.5	90.0	0.6	89.7	89.1	0.7	0.9	1.0
18	3	8	72.0	70.3	2.4	71.6	69.0	3.6	0.6	1.9
19	3	10	54.7	54.0	1.3	53.2	52.0	2.3	2.8	3.8
20	3	7	64	63.1	1.4	62.8	61.5	2.1	1.9	2.6
Mean dose in%			68.4	67.3		66.9	65.9			
Standard deviation			11.0	10.8		10.8	10.8			

dose to the apex and dome region of the vaginal cylinder. Influence of optimization technique on the shape of the prescription isodose is illustrated in Figure 4A (dose point optimization) and Figure 4B (geometric optimization)

Dose on the first dome point is always higher than on the apex and dose points. Higher dose value at the first dome point may be attributed to the fact that the dome point lies closer to the first dwell position of the source than the dose points that lie at a distance equal to the radius of the applicator.

Change in dose prescription depth from the surface of the applicator to 5mm depth results in a high dose to apex and dome points in the studied vaginal cylinders. The American Brachytherapy Society (ABS) suggests treating only the upper half of the vagina [6]. Irradiated length by HDR brachytherapy source is higher than the physical source loading length. Our study shows that source loading length of 4 cm gives a prescription isodose enclosing a length between 5.5cm and 6.6cm for dose prescription depth of 5mm depending on the diameter of the cylinder, optimization tech-

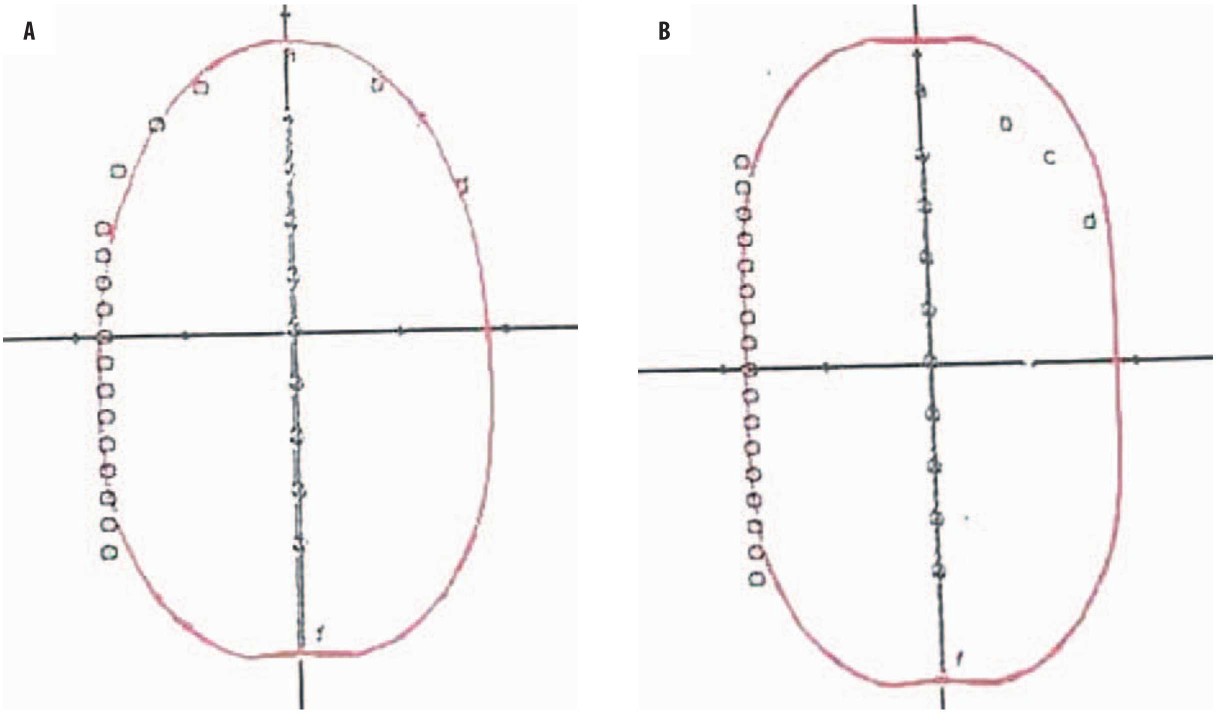

Figure 3. Illustration of shape of prescription isodose line for CDM and NCDM vaginal cylinder. (**A**) Curved Dome Model (CDM). (Vaginal cylinder diameter – 3.0cm, dose prescription on the surface, step size – 5mm. Apex point excluded for dose prescription, dose point optimization). Dose points for dose prescription. (**B**) Non-Curved Dome Model (NCDM). (Vaginal cylinder diameter – 3.0cm, dose prescription on the surface, step size – 5mm, apex point excluded for dose prescription, dose point optimization]. Dose points for dose prescription.

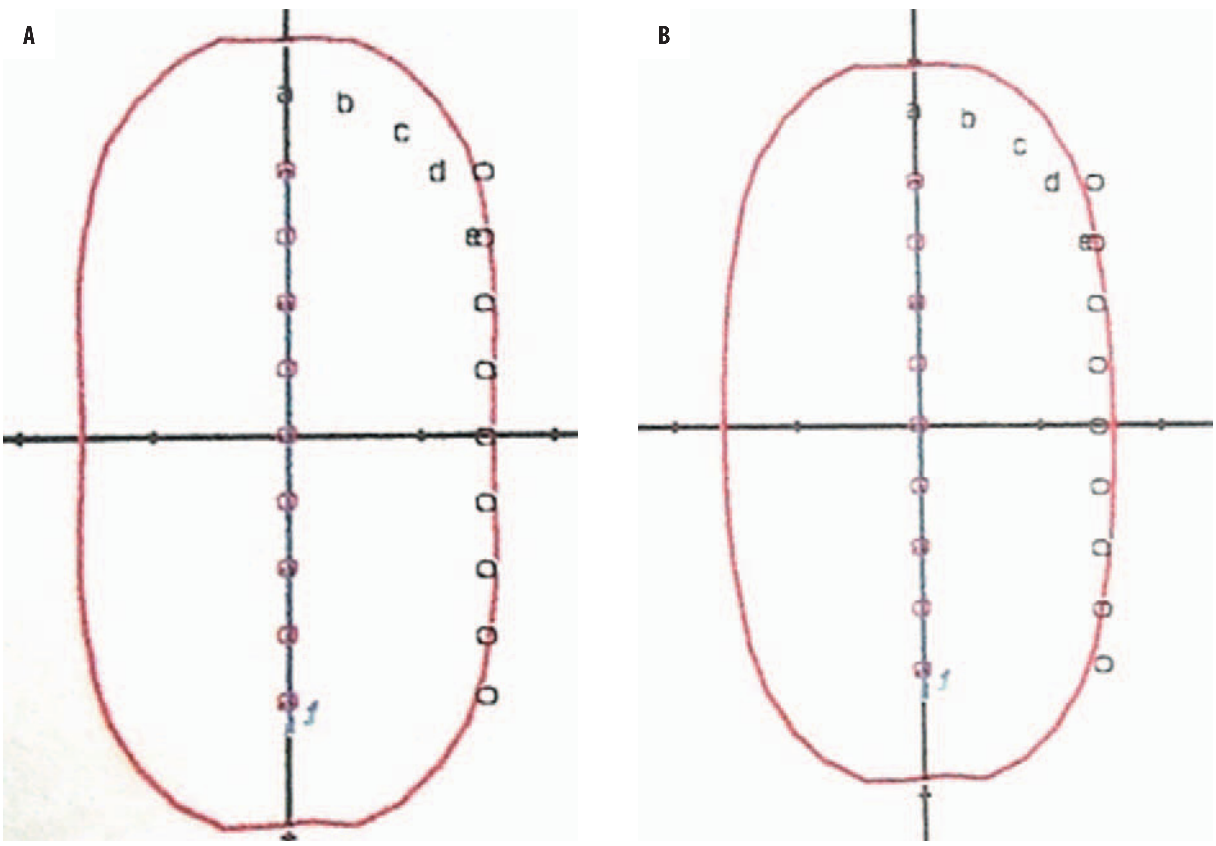

Figure 4. Illustration of influence of optimization technique on the shape of the prescription isodose line. (**A**) Non-Curved Dome Model (NCDM), Dose point optimization. Vaginal cylinder diameter – 3.0cm, dose prescription on the surface, step size – 5mm. (**B**) Non-Curved Dome Model (NCDM). Geometric optimization. Vaginal cylinder diameter – 3.0cm, dose prescription on the surface, step size – 5mm.

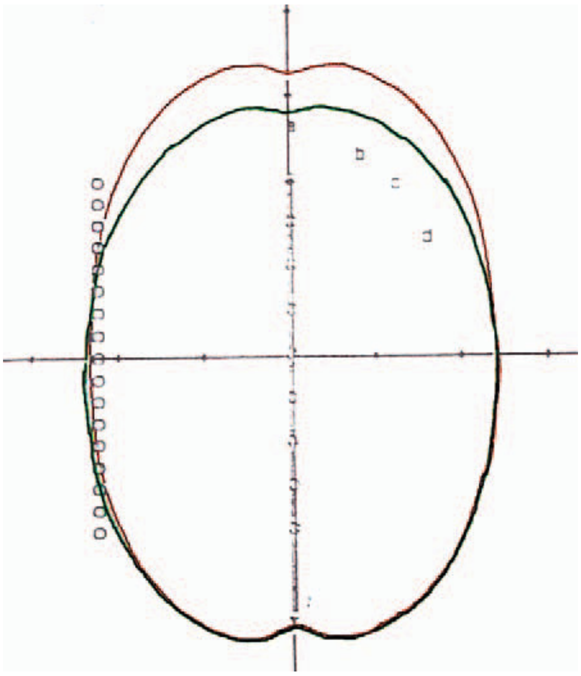

Figure 5. Illustration of shape of the prescription isodose line (superimposed) with and without considering apex for dose prescription (geometric optimization). Non-Curved Dome Model. Vaginal cylinder diameter – 3.5cm, step size – 5mm, dose prescription at 5mm from the surface. — Red prescription isodose line – without apex point for dose prescription. — Green prescription isodose line – with apex point for dose prescription.

nique and dose specification points. Considering the apex for dose specification reduces the length of the enclosing prescription isodose to 5mm in 3cm and 3.5cm diameter vaginal cylinder for dose point optimization. Figure 5 illustrates the influence of apex point for dose prescription on the length of the prescription isodose for NCDM. Thus it is clear from our study that if the source loading length is kept the same as that of the intended treatment length, a higher dose to both apex and lower part of the vagina will be delivered. Skipping the distal dwell position brings the isodose line closer to the apex of the cylinder and reduces the dose to the apex, rectum and bladder. Influence of skipping distal dwell position on the

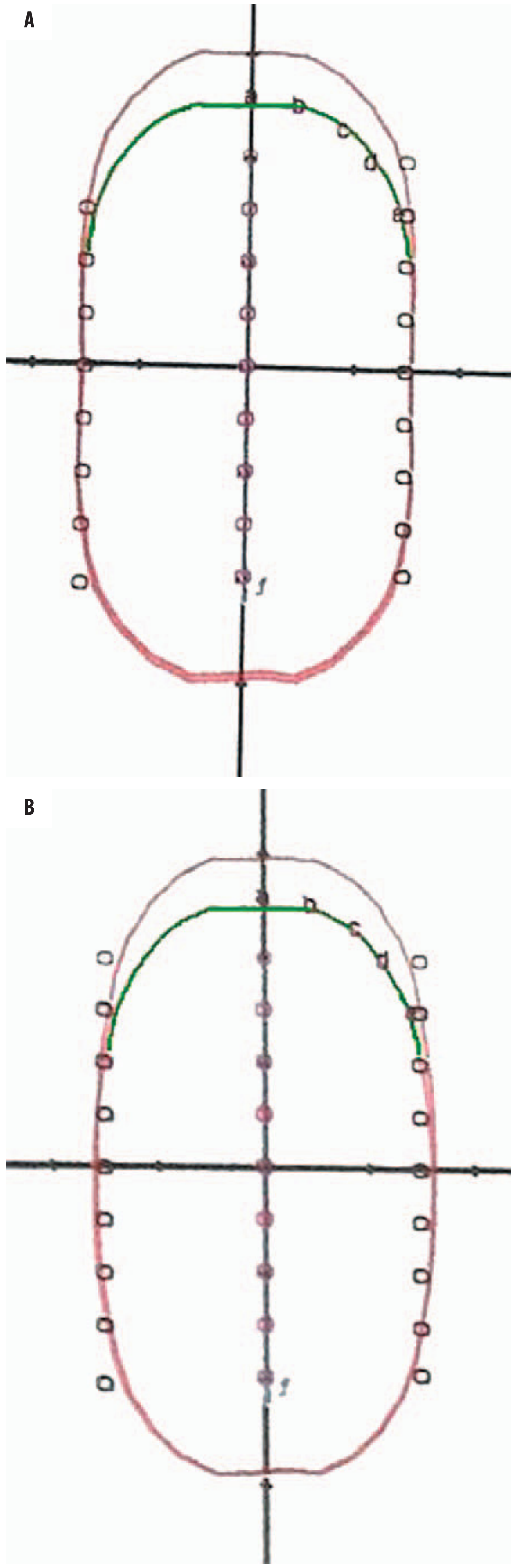

Figure 6. Illustration of influence of distal dwell position on the length of prescription isodose line (superimposed). (**A**) Non-Curved Dome Model. Dose point optimization. Vaginal cylinder diameter – 3.0cm, step size – 5mm, dose prescription on the surface. Red prescription isodose line – with distal dwell position. Green prescription isodose line – without distal dwell position. (**B**) Non-Curved Dome Model. Geometric optimization. Vaginal cylinder diameter – 3.0cm, step size – 5mm, dose prescription on the surface. — Red prescription isodose line – with distal dwell position. — Green prescription isodose line – without distal dwell position.

length of the prescription isodose is illustrated in Figure 6A (dose point optimization) and Figure 6B (geometric optimization). However, dose prescription depth on the surface of the cylinder without distal dwell position for 2cm and 2.5cm vaginal cylinder reduces the length of the prescription isodose and brings it well below the apex, resulting in a dose to the apex lower than the prescribed dose. Depending on the diameter of the vaginal cylinder and dose specification depth, the most distal and two dwell positions on the proximal side can be removed to reduce dose at apex and to lower vaginal mucosa. In estimating the bladder dose, a reference point on the posterior part of the bladder alone is considered. The variation in the reduction of dose may be attributed to the difference in the distance between bladder point and the applicator. From the studied HDR patients, though skipping distal dwell position reduces the dose to the rectum and bladder, the decision should be taken by the clinician. American Brachytherapy Society guidelines on HDR treatment for endometrial carcinoma suggest that a pre-calculated treatment plan can be used for patient treatment delivery. However, the disadvantage with using a standard plan is that the dose to OAR cannot be computed.

Conclusions

HDR parameters influencing the dose distribution around the vaginal cylinders are identified. By appropriately selecting the parameters, the dose to the apex of the vaginal cylinder can be reduced in vaginal cuff irradiation, which helps to minimize the dose to the small bowel. Choice of optimization and dose specification points affects rectal and bladder dose. CDM with dose point optimization results in more uniform dose distribution around the vaginal cylinder than NCDM. Apex point needs to be considered for dose prescription and optimization to obtain a uniform dose. Dose distribution for all the vaginal cylinders can be stored as a library plan and the best matched dose distribution according to the target geometry can be used for treatment.

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