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Postoperative intravaginal brachytherapy for endometrial cancer: dosimetric analysis of vaginal colpostats and cylinder applicators•

Robert Y. Kim*, Prem Pareek, Jun Duan, Hasan Murshed, Ivan Brezovich

Department of Radiation Oncology, Comprehensive Cancer Center, University of Alabama at Birmingham, 619 S. 19th St. (WTI 107), Birmingham, AL 35249

Abstract

Purpose: To investigate the dosimetric differences between colpostats and cylinder applicators for intravaginal brachytherapy.

Methods and Materials: Dose distributions near vaginal colpostats and dome cylinders were computed with a commercial high–dose-rate treatment-planning system and verified by spot measurements by using LiF thermoluminescent dosimeters. Taking source anisotropy into account, dwell times were optimized by the computer by using the polynomial optimization on dose points method to give uniform doses along the lateral surfaces of the applicators. In addition, the effects of vaginal packing and the separation distance between colpostats were studied by computing the dose to the vaginal mucosa, assuming 0.5 and 1.0 cm of vaginal packing and colpostat separation, respectively.

Results: The computed and measured doses agreed within ±7%. Surface doses were similar for both types of applicators when the effect of shielding in the colpostats was neglected. However, percent depth doses in the anterior/posterior and lateral directions were higher for the cylinder, whereas the dose fall-off along the longitudinal patient axis was less pronounced for the colpostats. When vaginal packing at the anterior and posterior surface of the colpostats was increased from 0 to 5, 10, and 15 mm, the corresponding vaginal dose decreased from 97% of the prescription dose to 60%, 39%, and 26%, respectively. Separating the colpostats from 0 to 5 and 10 mm reduced the surface dose near the bladder/rectum to 80% and 67%, respectively, whereas the respective apex dose decreased from 105% of prescription to 91% and 77%.

Conclusions: Colpostats and cylinder applicators for intracavitary brachytherapy have their advantages and disadvantages in depth dose distribution and clinical use. If treatment is confined to the vaginal apex, either applicator can be used. However, the colpostat separation should be kept to a minimum, and vaginal packing should be applied with great care to avoid generating cold spots along the upper vaginal surface and vaginal cuff.

Keywords: High dose rate; Brachytherapy; Endometrial cancer; Dosimetry; Intracavitary applicator

Introduction

Endometrial cancers are the most common female genital tract malignancy in the United States (1). Most such malignancies are confined to the uterus. Standard treatment of organ-confined uterine cancer is total abdominal hysterectomy and bilateral salpingo-oophorectomy. To reduce recurrences in the pelvis, especially the vagina, surgery may be followed by external pelvic radiotherapy, intracavitary brachytherapy, or both to the vaginal vault, depending on tumor grade and depth of myometrial invasion. However, improvements in surgical staging, including pelvic node sampling, have led to questions regarding the role of pelvic radiotherapy in patients with disease confined to the uterus. A recent Gynecologic Oncologic Group study in patients with surgical Stage Ib and Ic disease and negative lymph node metastases found that adjuvant pelvic radiation reduced pelvic recurrences, especially in the vagina, but it found no significant difference in survival (2). Because the main benefit of pelvic radiotherapy is the reduction of vaginal recurrences, it is reasonable to consider vaginal brachytherapy alone in patients with no pelvic node metastasis because it has fewer adverse effects, such as bowel complications (3).

Vaginal brachytherapy is often performed with colpostats (4, 5) and cylinders (6, 7). When colpostats are used, vaginal packing is used to stabilize the applicator in position and

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* Corresponding author. Tel.: +1-205-934-2762; fax: +1-205-975-0784.

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to reduce bladder and rectal doses. Recently, the inconvenience and the potential acute morbidity associated with the long hospitalization required by low–dose-rate brachytherapy, as well as radiation exposure to personnel, have led to increased use of remote afterloading high–dose-rate (HDR) brachytherapy. The most widely used radioactive isotopes are ^{137}Cs for low–dose-rate and ^{60}Co or ^{192}Ir for HDR brachytherapy.

Although vaginal colpostats and cylinders have been used for many years, detailed dosimetric comparisons of these two modalities are not available in the literature. The purpose of this study was to provide dosimetric comparisons for these HDR applicators and to investigate the potential of underdosing the vaginal surface because of colpostat separation and vaginal packing.

Methods and materials

Dose computations were performed with a commercial system (HDR Treatment Planning System, UPS Version 11.43; Nucletron Cooperation, Veenendaal, The Netherlands), taking the anisotropic character of the source into account. The computed doses were verified at a number of selected points by using 1-mm-diameter, 6-mm-long rods or 3.2 × 3.2 × 0.9 mm LiF thermoluminescence dosimeter (TLD) chips (Model TLD 100; Bicron Industrial Ceramics Corp., Solon, OH), in conjunction with a reader (Model 3500 Manual TLD Reader) made by the same company. Details about the calculation and measurement methods have been described previously (8).

Dose distributions were calculated for a single-channel vaginal cylinder and for colpostats with five source stopping positions. The 5-mm-spaced stopping positions were determined from a set of orthogonal films by using the manufacturer supplied dummy strings. Dwell times were optimized to give a uniform dose along the lateral surface, using the polynomial optimization method on dose points. This optimization method aims at achieving equal doses at all dose points by properly selecting the dwell times at the individual stopping positions. The dose points were located along the surface of each applicator opposite the respective dwell positions. On the basis of these optimized dwell times, radiation doses were calculated at four sets of points (Figs. 1 and 2). For both types of applicator, points L are located along the transverse axis of the patient, with point L_0 lying on the surface of the applicator. Points $L_{0.5}$ and $L_{1.0}$ are located, respectively, 0.5 and 1.0 cm from the surface. Points M lie along the anterior-posterior axis of the patient. For the colpostat applicator, the first point, M_0, is located midway between the two anterior or posterior flat surfaces of colpostats. For the cylinder, point M_0 is located at its surface. The remaining points, $M_{0.5}$ and $M_{1.0}$, are again spaced at 0.5-cm intervals. (For the cylindrical applicator, the dose to points M and L is the same because of symmetry.) For both applicators, points N are located along the patient's longitudinal axis. For the vaginal cylinder, point N_0 lies on its apex, whereas for the colpostats, the corresponding point lies midway along a transverse line tangent to the surfaces of the colpostats. Points H are defined only for the colpostat applicator and are located along an extended line connecting the dwell positions in each colpostat. Point H_0 is at the surface of the colpostat, whereas the remaining points are located at 5-mm intervals.

The first stopping position for the vaginal cylinder was adjusted such that point N_0 receives the same dose as point L_0. For the colpostats, the stopping positions were determined by the positions of the dummy string provided by the manufacturer for treatment planning.

On the basis of the computed doses to the various points, the two applicators (2.0-cm colpostats and 4.0-cm cylinder) were compared for their ability to produce uniform doses along the vaginal surface and for the doses delivered at 0.05, 1.0, and 1.5 cm depths. The effects of vaginal packing and colpostat separation were also examined by analyzing doses at points H, L, M, and N. In addition, the dose distribution of the 3.0-cm cylinder (the most frequently used size) was calculated.

Results

Experimental verification of dose computations

Table 1 compares computed with experimentally determined doses at three sets of points near the HDR applicators (points L, M, and N) by using 2.0-cm colpostats and a 4.0-cm cylinder. Agreement was generally within ±7%, the uncertainty in dose response specified by the manufacturer of the TLD. However, at points M in the colpostat applicator, the measured doses were lower than the computations. The difference was attributed to the 4.5-mm-thick shields, which are not taken into account by the computer. When experiments were repeated with colpostats that provided no shielding, the new measurements (indicated in Table 1 with daggers) agreed well with the computations.

Dose distributions

Table 2 shows computed radiation doses at points L, M, N, and H near the 2.0-cm colpostats and 4.0-cm cylinder, as well as the 3.0-cm cylinder; the effect of the shields in the colpostats at points M has been (as is customary) neglected. Again, dwell times were optimized and normalized so that the average dose along the lateral surfaces of the applicator was 100 cGy for the colpostat applicator. For the cylinder, in addition to the dose optimization along the lateral surface, the position of the first stopping point was adjusted so that the apex also got 100% of the prescribed dose.

Surface doses

The vaginal cylinder exhibited good dose homogeneity at its surface, with the variation among points L_0, M_0, and N_0 being only 4%. The colpostats exhibited similar dose uniformity if shielding effects were neglected, although the dose near points H was 8% higher than the prescription. However, if shielding was considered, the colpostats exhib-

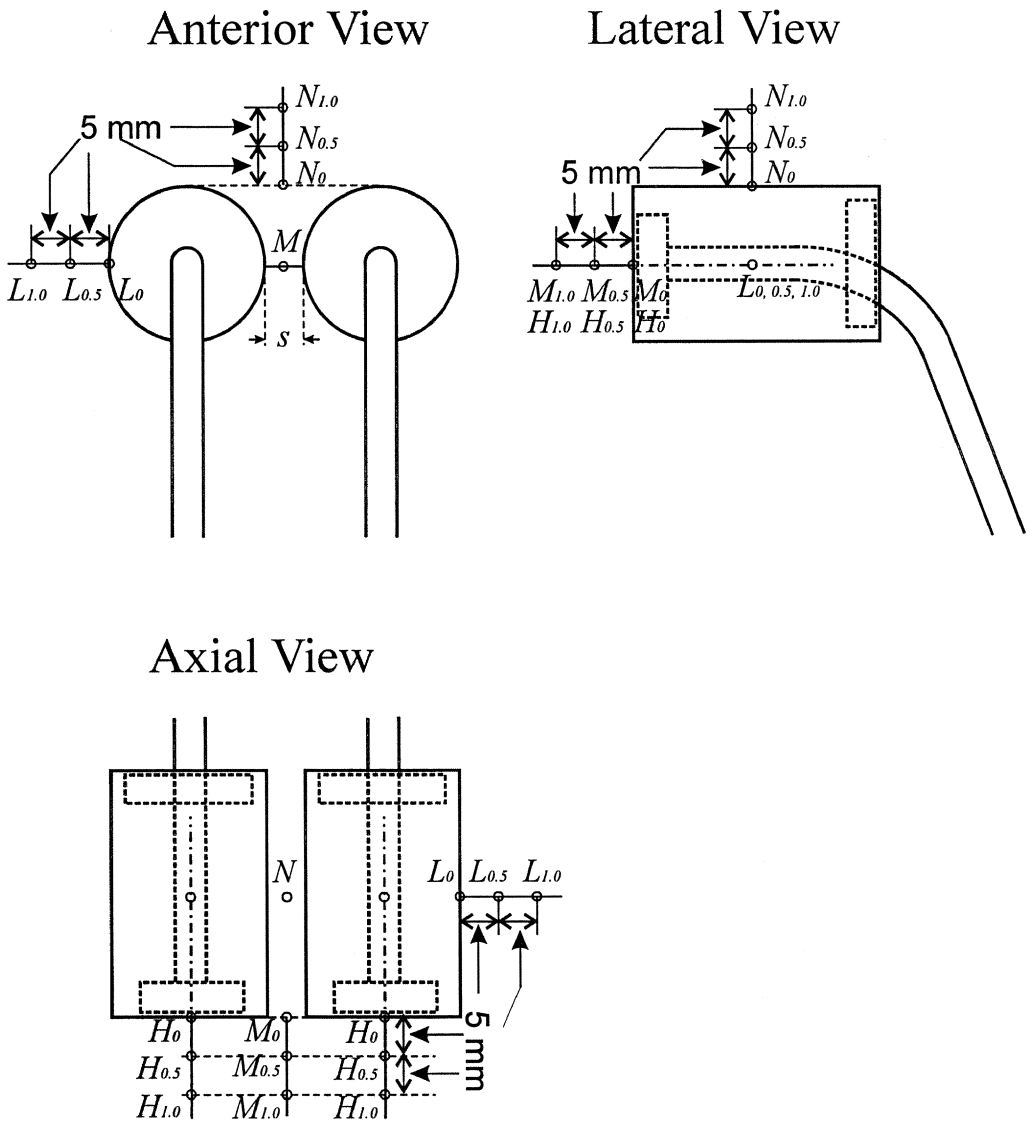

Fig. 1. Diagrams illustrating four sets of dose points (L, M, N, and H) near vaginal colpostats.

ited 10% lower doses near points adjacent to the bladder and rectum (point M_0).

Comparison of percent depth doses

For points M and L, the cylinder yielded higher percent depth doses (PDDs) than the corresponding points for the colpostats. At points N, the PDDs were higher for the colpostats than for the cylinder. This is due to the comparatively larger distances between points N and the dwell positions for colpostats than for the cylinders. To compensate for the anisotropic effects of the orientation of the line sources perpendicular to the vaginal cuff, the distance between point N_0 and the first dwell position has to be closer to the vaginal cuff for the cylinder. Comparing 3.0- and 4.0-cm cylinders, the larger-diameter cylinder (4.0 cm) has higher PDDs.

Effect of vaginal packing

Packing markedly affects the surface dose near colpostat applicators. If we assume that packing moves the mucosa adjacent to the rectum and bladder by only 5 mm away from the applicator, the surface point previously at the position M_0 moves to point $M_{0.5}$, and its dose is reduced from 97% to 60% of the prescription dose. However, if packing is increased to 10 and 15 mm, the corresponding doses decrease, respectively, to 39% and 26% of the prescription dose. Because the vaginal cylinder is used without packing, these considerations do not apply to that type of applicator. If colpostat shielding is taken into consideration, the doses at point M are further reduced by approximately 10%.

Effect of colpostat separation

Doses as a function of colpostat separation are also shown in Table 2. Moving the colpostats apart affects primarily the surface dose at points M and N, with the fall-off being more pronounced at points M. At points M and point N, the dose decreases from 97% to 80% and 67%, and from 106% to 91% and 77%, respectively, as the separation is in-

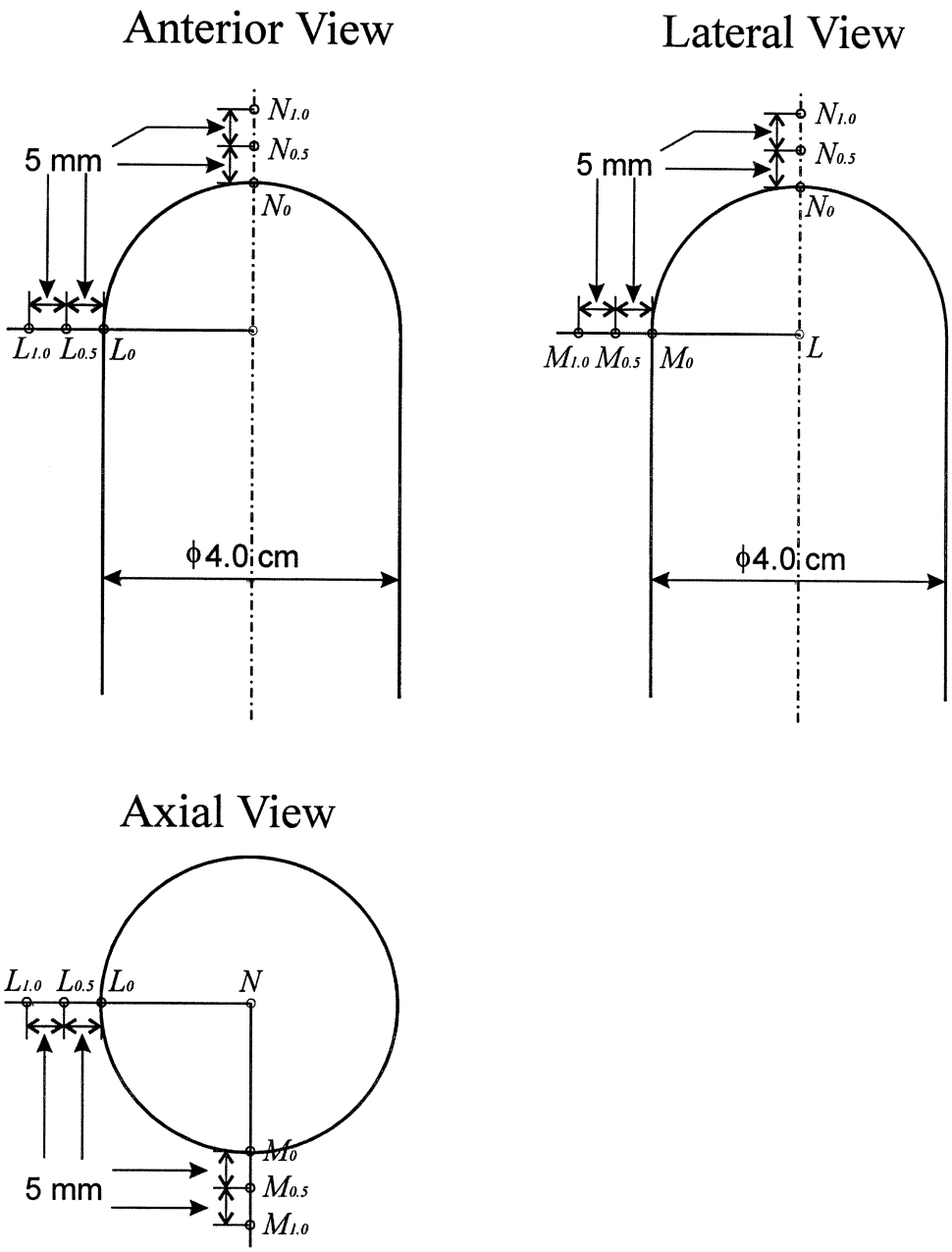

Fig. 2. Diagrams illustrating three sets of dose points (L, M, and N) near the vaginal cylinder.

creased from 0 to 5 mm and then to 10 mm. Doses at depth are little affected by the colpostat separation. The hot spot at H_0 remains nearly unchanged.

Discussion

Two of the most common HDR brachytherapy applicators were used to study dosimetric differences between colpostats and vaginal cylinders. It was found that colpostats with shielding exhibited lower doses at the vaginal surface near the bladder and rectum. However, colpostats without shielding and vaginal cylinders yielded similar dose uniformity along the applicator surface. There were differences in depth dose fractions. Whereas for the cylinder, PDDs were slightly higher in the lateral direction and toward the bladder and rectum, they were lower at the apex of the cylinder. More importantly, vaginal packing and separation of the colpostats markedly reduced the vaginal surface dose at the apex and near the bladder and rectum and led to cold spots. Furthermore, the amount and location of packing can be very inconsistent during each application in clinical practice.

Inhomogeneity of the dose distribution for the vaginal colpostat is expected when it is used with packing and separation, because this technique has been adapted from brachy-

Table 1
Comparison of computed and measured doses near applicator

	Colpostats (2.0 cm)			Cylinder (4.0 cm)	
Point	Computed*	Measured		Computed*	Measured
L_0	100	100		100	101
$L_{0.5}$	60	62		67	66
$L_{1.0}$	39	41		48	50
M_0	97	90	100†	100	NA‡
$M_{0.5}$	60	51	61†	67	NA‡
$M_{1.0}$	39	33	39†	48	NA‡
N_0	105	99		96	107
$N_{0.5}$	71	65		57	55
$N_{1.0}$	49	44		38	38

NA = not applicable.

*Normalized to 100 cGy average dose on the lateral surface of applicators.

†Measured without shielding in the colpostats. The treatment planning system does not take shielding into account.

‡Because of the cylindrical geometry, only points L were measured.

therapy for cervical cancer. When colpostats and tandem are used for cervical cancer, the dose prescription point is 2.0 cm superior to the external cervical os and 2.0 cm lateral to the cervical canal (point A). Therefore, the dose to the vaginal mucosa is still adequate despite vaginal packing, colpostat separation, and shielding in the colpostats. However, when colpostats are used for the adjuvant treatment of endometrial cancer, the prescription dose point is at the vaginal surface or 0.5 cm from the vaginal surface, and thus it is much closer to the radiation source than the prescription dose point (point A) for cervical cancer. In addition, no central tandem is inserted because of the previous hysterectomy. Because of these differences, the dose reduction from vaginal packing, colpostat separation, and shielding is of greater significance in the postoperative treatment of endometrial cancer than in cervical cancer. Because our goal is to treat the vaginal mucosa, the largest possible diameter colpostats should be used rather than vaginal packing around the colpostats or colpostat separation. Although the clinical implication of these dose reductions is unclear, the potential for local recurrence remains a concern. The most common argument for using vaginal packing with colpostats is the reduction of bladder and rectal doses. Although this argument is relevant, previous studies (6, 7, 9–15) have not shown higher complications with cylinder techniques, which suggests that bladder and rectal doses are not limiting factors (Table 3).

Unlike colpostats, vaginal cylinders have been specially designed for good vaginal mucosal contact, especially the dome of the cylinder. To achieve homogenous dose distribution on the dome surface, several designs of the applicator have been developed: high-activity radiation sources at both ends of the cylinder [Burnett applicator (16), Delclos dome applicator (17)], an ellipsoid shape of the cylinder (improvement of the dome-shaped design from the hemispherical shape for better dose homogeneity on the surface of the dome) (18), individualized vaginal molds (19), and two vertical sources at the dome of the cylinder in addition to the central tandem [preloaded Bloedorn applicator (17), afterloaded Mallinckodt Institute of Radiology Afterloading Vaginal Applicator (MIRALVA) applicator (20)].

By taking advantage of the small radiation sources and the high-speed computers that are now available for HDR therapy, even better dose uniformity can be achieved (21–23). Most vaginal cylinders have a single central channel. The multichannel vaginal applicator is a variation of the vaginal cylinder to improve anisotropy at the apex (24, 25). In this study, a single-channel and 4.0-cm-diameter cylinder was used for comparison with the 2.0-cm colpostats. However, a 3.0-cm-diameter cylinder was used most frequently

Table 2
Computed doses* at various points near applicators

	Colpostats (2.0 cm)				
Point	S = 0	S = 0.5 cm	S = 1.0 cm	Cylinder (4.0 cm)	Cylinder (3.0 cm)
L_0	100	100	100	100	100
$L_{0.5}$	60	59	59	67	62
$L_{1.0}$	39	39	38	48	42
$L_{1.5}$	28	27	27	36	30
M_0	97	80	67	100	100
$M_{0.5}$	60	55	49	67	62
$M_{1.0}$	39	38	35	48	42
$M_{1.5}$	26	27	26	36	30
N_0	105	91	77	96	97
$N_{0.5}$	71	66	59	57	50
$N_{1.0}$	49	48	44	38	31
$N_{1.5}$	35	35	33	28	21
H_0	108	108	106	NA	NA
$H_{0.5}$	53	51	50	NA	NA
$H_{1.0}$	33	32	31	NA	NA
$H_{1.5}$	24	23	22	NA	NA

S = the separation between the colpostats; NA = not applicable.

*Normalized to 100 cGy average dose on the lateral surface of applicators.

Table 3
Late toxicity of postoperative cylinder brachytherapy alone for endometrial cancer

Author	No. Cases	Dose specification	Dose	Vaginal recurrence	Grade 3/4 toxicity
Sorbe and Smeds (7)	404	HDR	7 Gy × 4		
		1.0 cm	6 Gy × 5		
			5 Gy × 6	2.4%	6.9%*
Kucera *et al.* (9)	106	HDR			
		0.5 cm	17 Gy × 2	1.0%	0.3%
Piver and Hempling (10)	81	LDR			
		surface	60 Gy		
		0.5 cm	30 Gy	0%	0%
Fanning *et al.* (11)	55	HDR			
		0.5 m	7 Gy × 3	0%	0%
Eltabbakh *et al.* (6)	303	LDR			
		0.5 cm	30 Gy	0%	0%
Hong *et al.* (12)	44	HDR			
		0.5 cm	7 Gy × 3	4.5%	2.1%
Weiss *et al.* (13)	122	HDR			
		surface	7 Gy × 3	1.6%	0%
Chadha *et al.* (14)	38	HDR			
		0.5 cm	7 Gy × 3	0%	0%
Anderson *et al.* (15)	102	HDR			
		0.5 cm	5 Gy × 3	1.0%	0%

LDH = low dose rate; HDR = high dose rate.
*Grade 2 included and dose specification at 1.0 cm depth away from the vaginal surface.

in daily practice. Therefore, the dose calculations of the 3.0-cm cylinder are also included in Table 2. In general, the larger-diameter cylinder has the advantage of higher depth dose percentage distribution (7, 26, 27) and, therefore, fewer mucosal adverse effects. In our institution, the first stopping position for the vaginal cylinder was adjusted to make the dose distribution uniform over the domed and flat portion of the cylinder. If the dose optimization points are placed only along the lateral flat portion of the cylinder, the dose distribution at the apex of the dome will be slightly higher than at the flat portion of the cylinder (28).

There are no standardized HDR brachytherapy practices regarding the length of vagina to be irradiated. Previous studies (4, 29–32) have indicated that most vaginal recurrences are located in the upper vagina. However, it is reasonable to treat the whole vagina with a cylinder in patients with poorly differentiated cancer. The disadvantage of treating the entire vaginal mucosa is the higher incidence of vaginal shortening and rectal complication (7). The American Brachytherapy Society recommends that the dose distribution be optimized to deliver the prescribed dose either at the vaginal surface or at the 0.5-cm depth, depending on the institutional policy, and that the upper vagina (proximal 3–5 cm) be treated (28). An important issue with intravaginal brachytherapy is the contact between the applicator surface and the vaginal mucosa, especially in the region of the vaginal vault, with both the colpostat and cylinder applicators.

Our study shows that the cylinder and colpostat applicators have their advantages and disadvantages with regard to depth dose characteristics. The vaginal colpostats have a better depth dose at the apex. The vaginal cylinder has a better depth dose on the lateral and anterior/posterior vaginal surfaces. If treatment is confined to the vaginal apex, either applicator can be used. However, the colpostats are more difficult to use. The colpostat separation should be kept to a minimum, and vaginal packing should be avoided at the vaginal cuff and upper vagina to prevent generating cold spots along the upper vaginal surface. Because of simpler use and improved patient comfort, as well as excellent local control without significant side effects, the vaginal cylinder is used at our institution rather than colpostats.

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