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FULL PAPER

A dosimetric analysis of volumetric-modulated arc radiotherapy with jaw width restriction vs 7 field intensity-modulated radiotherapy for definitive treatment of cervical cancer

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Objective: Radiation therapy treatment planning was performed to compare the dosimetric difference between volumetric-modulated arc radiotherapy (RapidArc™ v. 10; Varian® Medical Systems, Palo Alto, CA) and 7-field intensity-modulated radiotherapy (7f-IMRT) in the definitive treatment of cervical cancer.

Methods: 13 patients with cervical cancer were enrolled in this study. Planning target volume (PTV) 50 and PTV60 were prescribed at a dose of 50 and 60 Gy in 28 fractions, respectively. The dose to the PTV60 was delivered as a simultaneous integrated boost to the pelvic lymph nodes. Owing to the mechanical limitation of the multileaf collimator in which the maximum displacement was limited to 15 cm, two types of RapidArc with different jaw width restrictions (15 and 20–23 cm) were investigated to evaluate their dosimetric differences. The RapidArc plan type with dosimetric superiority was then compared against the 7f-IMRT on the target coverage, sparing of

the organs at risk (OARs), monitor units, treatment time and delivery accuracy to determine whether RapidArc is beneficial for the treatment of cervical cancer.

Results: The 15-cm jaw width restriction had better performance compared with the restrictions that were longer than 15 cm in the sparing of the OARs. The 15-cm RapidArc spared the OARs, that is, the bladder, rectum, small intestine, femoral heads and bones, and improved treatment efficiency compared with 7f-IMRT. Both techniques delivered a high quality-assurance passing rate (>90%) according to the $\Gamma_{3mm,3\%}$ criterion.

Conclusion: RapidArc with a 15-cm jaw width restriction spares the OARs and improves treatment efficiency in cervical cancer compared with 7f-IMRT.

Advances in knowledge: This study describes the dosimetric superiority of RapidArc with a 15-cm jaw width restriction and explores the feasibility of using RapidArc for the definitive treatment of cervical cancer.

Volumetric-modulated arc therapy (RapidArc™ v. 10; Varian® Medical Systems, Palo Alto, CA) is a novel type of intensity-modulated radiation therapy (IMRT) in which the gantry speed, multileaf collimator (MLC) leaf position, and dose rate (DR) can vary simultaneously during delivery.¹ Compared with traditional IMRT, RapidArc is able to reduce treatment time and number of monitor units (MUs) while improving the dose to organs at risk (OARs) and healthy tissue sparing. It does this while producing similar or even better dose distributions.² Therefore, RapidArc has been widely applied in the treatment of various cancers, such as larynx carcinoma,³ peripheral lung tumour,⁴ nasopharyngeal

carcinoma,^{5,6} hepatocellular carcinoma,⁷ spinal metastases,⁸ total marrow irradiation,⁹ prostate cancer,¹⁰ cervical cancer^{11–13} and so on. The feasibility of RapidArc has been confirmed by many studies. However, no one has reported the influence of jaw width on the dose distribution, especially for the OARs. Only Vieillot et al¹⁴ had described that the RapidArc field size should be minimized to 15 cm in the x direction, although they did not perform additional experiments to confirm whether the 15-cm field size restriction was actually more beneficial than larger restriction sizes. Owing to the mechanical limitation, the maximum leaf span of the MLC is 15 cm. When the field size is set

to <15 cm, anywhere inside the field can be moderated by both sides of the MLC and this permits a higher degree of freedom for the MLC modulation to achieve better optimization results. Otherwise, when the field size is >15 cm, some areas in the field can only be reached by one side of the MLC, which may prohibit achieving better modulation for the treatment plans. Therefore, the dosimetric effect of different jaw widths needs to be further investigated.

Two previous studies reported that RapidArc produced significant improvements in the coverage of the target, sparing the OARs and reducing the treatment time for cervical cancer compared with 5-field (5f)-IMRT.^{11,12} However, it is still difficult to conclude that RapidArc is superior to IMRT in the treatment of cervical cancer. Because 5f-IMRT is not able to offer good conformity for the target, and taking 5f-IMRT as the benchmark is not sufficient to demonstrate the dosimetric superiority of RapidArc. The two studies were not consistent regarding the sparing of the bladder and rectum. Whether RapidArc achieves better sparing of the two organs than IMRT is still unknown. Moreover, only post-operative patients were enrolled in the two studies, and no simultaneous integrated boost (SIB) technique was used.

Because cervical tumours are usually surrounded by many organs, such as the bladder, rectum, bones, femoral heads and the small intestine, it is an ideal model to study the effect of jaw width on the dose distribution and the sparing of the OARs. Therefore, we aimed to investigate the dosimetric benefit of 15-cm RapidArc in the definitive treatment of cervical cancer with SIB to the pelvic lymph nodes that required an additional 10–15 Gy of radiation.¹⁵ We also aimed to compare the 15-cm RapidArc dose distribution and the sparing of the OARs with that of 7-field (7f)-IMRT. Although 9-field (9f)-IMRT was reported to produce improved dose distribution for cervical cancer compared with 7f-IMRT,¹⁶ it required longer treatment time and was not treatment efficient. Thus 7f-IMRT was used as a benchmark in this research. We hope that in addition to clarifying the effect of jaw width, our study will help to determine whether RapidArc is truly beneficial in the treatment of cervical cancer.

METHODS AND MATERIALS

Patients

In this study, we evaluated the treatment plans of RapidArc for cervical cancer using 6-MV photons and compared them with that of 7f-IMRT. Of the 13 patients with cervical cancer, 8 were at T3N1M0 and the remaining at T4N1M0 staging according to the American Joint Committee on Cancer, 7th edn. with cervical cancer were enrolled in the study. Each of them had evolved lymph nodes and was preparing to undergo definitive radiotherapy treatment. The mean age of the patients was 53.5 ± 8.9 years, and their median planning target volume (PTV) 50 and PTV60 were $1499.6 \pm 242.2 \text{ cm}^3$ (range, $1251.8\text{--}1661.6 \text{ cm}^3$) and $37.4 \pm 27.1 \text{ cm}^3$ (range, $16.9\text{--}116.7 \text{ cm}^3$), respectively. The volumes of the OARs were $201.2 \pm 114.1 \text{ cm}^3$ for the bladder, $41.7 \pm 14.7 \text{ cm}^3$ for the rectum and $1095.8 \pm 333.2 \text{ cm}^3$ for the small intestine.

Simulation, target and organs at risk delineation

CT simulation was performed in the supine position for all the patients. All patients were immobilized with a vacuum bag (MED-TEC, Orange City, IO). CT scans were obtained in the

treatment position using a PQ5000 CT scan (Picker, Highland Heights, OH). Images were acquired at a 5-mm slice thickness, and the scanning range was from the L2 vertebral body to 5 cm below the ischial tuberosities.

All structures, including the gross target volume (GTV), clinical target volume (CTV), PTV and all OARs, were contoured by the radiation oncologist. As no consensus guidelines for the definitive treatment of cervical cancer exists, we used the protocol proposed by Lim *et al*¹⁷ and Forrest *et al*.¹⁸ Briefly, GTV covered the cervix and any vaginal or uterine involvement. The CTV covered all macroscopic and potential microscopic disease, including the entire cervix and uterus, the parametria, uterosacral ligaments, presacral nodes and common iliacs. The upper border of the CTV started at fourth–fifth lumbar vertebra (L4–5), and the lower border extended to the obturator foramina. The involved lymph nodes were marked as GTVnd, and a uniform expansion of 5 mm in three dimensions for GTVnd and CTV were recorded as PTV60 and PTV50, respectively. The contouring of the small intestine started 2 cm above the PTV and included a volume surrounding the loops of the small bowel out to the edge of the peritoneum.¹⁹ The rectum included from the anus to the point where it joined the sigmoid colon. As we employed weekly cone beam CT to correct the patients' setup, a 0.5-cm margin expansion was large enough to create the PTV.

Planning objectives

An Eclipse® v. 10.0 (Varian Medical Systems) treatment planning system was used in this study. Our objective was to guarantee that 100% of the prescription covered 95% of the PTV60. Patients were all planned for a total dose of 60 Gy in 28 fractions. The OAR restrictions were according to the Radiation Therapy Oncology Group 0724 trial¹⁹ for post-operative patients: 30% of the small intestine to receive no more than 45 Gy; 60% of the rectum to receive no more than 45 Gy; and 35% of the bladder to receive no more than 50 Gy. Before optimization, two shell-like rings were generated to obtain better conformity for the targets.

Planning techniques

Intensity-modulated radiotherapy

To find whether RapidArc is more beneficial than fixed field IMRT in treating cervical cancer, we used seven evenly spaced beams at coplanar gantry angles of 210°, 260°, 310°, 0°, 50°, 100° and 150°. In Eclipse, the IMRT optimization engine computed the optimal fluence maps from the dose–volume constraints derived from the general planning objectives.¹¹ The optimal fluence was then converted into actual fluence maps by leaf motion calculator. Two types of leaf motion that can be used in Eclipse v. 10.0. One is called step and shoot and the other is sliding window. We performed preliminary studies on the effect of the two types of MLC motions and found that too many segments were required for the step and shoot to obtain a similar dose distribution. Consequently, only the sliding window was used in the present research, and all of the segments were set to 166 control points. The 7f-IMRT DR was set at 600 MU min^{-1} .

RapidArc

Dosimetric characteristics of the two types of RapidArc techniques with different jaw widths (15 and 20–23 cm) were compared

Figure 1. Effect of jaw width on dose distribution. PTV planning target volume.

in this study. Because dual arc can increase the modulation factor during optimization and offer better PTV coverage and sparing of the OARs than the single arc,⁵ it was used for planning and dosimetric comparison in this study. To achieve the desired level of modulation, an optimizer was enabled to continuously vary the DR, MLC leaf positions and the gantry rotational speed for RapidArc continuously.¹ A maximum DR of 600 MU min⁻¹ was set for comparing the 7f-IMRT treatment time. Two 360° coplanar arcs (one clockwise arc rotated from 181° to 179° and the other counter-clockwise arc rotated from 179° to 181°) sharing the same isocentre were used. Collimator rotations of the first and second arc were set at X° and (360-X)° to minimize the contribution of the tongue-and-groove effect to the dose.²⁰ The final dose was calculated using the anisotropic analytical algorithm (AAA_10028) accounting for inhomogeneous tissue, with a standard grid resolution of 2.5 mm, regardless of whether 7f-IMRT or RapidArc was utilized. The final dose calculation was normalized to D_{95%} of PTV60 (95% of PTV60 to receive 60 Gy).

Evaluation parameters

The D_{50%} was used as the evaluation parameter for the PTV. Other parameters used to evaluate the PTV coverage were the homogeneity index (HI) and the conformity index (CI). The HI was defined according to the International Commission on

Radiation Units and Measurements Report 83,²¹ and the CI was defined as the ratio of the volume of total tissue receiving a given isodose level to the volume of the target.²² In this research, we used CI_{100%} to assess the CI.

$$HI = \frac{(D_{2\%} - D_{98\%})}{D_{50\%}}$$

and

$$CI_{100\%} = \frac{\text{Volume within 100\% isodose line}}{\text{volume of PTV}}$$

Here, D_{x%} represents the dose received by x% volume of the organ. For example, D_{50%} means the dose received by 50% volume of the organ. The OARs were evaluated based on the D_{50%} and V_x, which is the volume of the organ receiving a dose of x. For example, V40 means the volume of the organ receiving a dose of 40 Gy.

Delivery efficiency and dose verification

The treatment time, including the field setup interval was recorded on the TrueBeam™ accelerator (Varian Medical Systems) by adding the “automation” function. Each plan was verified to assess the agreement between computed and delivered doses using three-dimensional detector array Delta4®

Table 1. Effect of different jaw widths on the median to the organs at risk

Organs	15 cm (cGy)	20–23 cm (cGy)	p-value
Bladder	4190.6 ± 127.5	4310.2 ± 151.4	0.039
Bones	3294.4 ± 170.5	3476.2 ± 142.1	0.007
Rectum	4252.6 ± 160.6	4380.1 ± 155.3	0.051
Small intestine	2375.7 ± 137.0	2435.7 ± 162.2	0.318
Left femoral head	2691.2 ± 305.1	2977.2 ± 270.8	0.018
Right femoral head	2618.0 ± 353.8	2865.5 ± 223.9	0.044

Table 2. Comparisons of the dosimetric parameters of the target

Parameters	7f-IMRT	RapidArc™	<i>p</i> -value
PTV50			
CI _{100%}	0.905 ± 0.040	0.900 ± 0.037	0.743
HI	0.093 ± 0.007	0.101 ± 0.006	0.007
<i>D</i> _{98%} (cGy)	5002.400 ± 19.700	4992.000 ± 23.800	0.128
<i>D</i> _{50%} (cGy)	5250.600 ± 34.700	5285.300 ± 21.200	0.005
PTV60			
CI _{100%}	0.877 ± 0.030	0.880 ± 0.036	0.819
HI	0.047 ± 0.014	0.043 ± 0.005	0.329
<i>D</i> _{98%} (cGy)	5965.200 ± 33.700	5969.500 ± 6.500	0.377
<i>D</i> _{50%} (cGy)	6136.200 ± 38.900	6122.600 ± 11.600	0.239

7f-IMRT, 7-field intensity-modulated radiotherapy; CI, conformity index; *D*_{x%}, dose received by x% volume of the organ; HI, homogeneity index; PTV, planning target volume.

RapidArc™ v. 10 is obtained from Varian® Medical Systems, Palo Alto, CA.

(ScandiDos, Uppsala, Sweden)²³ before treatment. The results were appraised in terms of Γ ($\Gamma_{3\text{mm},3\%}$) evaluation, which was calculated using spatial and dosimetric limits of 3-mm distance-to-agreement and a 3% dose difference, respectively.

Statistical analysis

To evaluate the differences between the 7f-IMRT and RapidArc, the statistical analysis entailed the paired two-tail Student's *t*-test

using SPSS® v. 13.0 (SPSS Inc., Chicago, IL). Differences were considered statistically significant when *p* < 0.05.

RESULTS

Effect of jaw width on organ at risk sparing and monitor units for RapidArc

We find that the jaw width has a substantial influence on the dose distribution and MUs. When jaw width is limited to 15 cm, the lower isodose lines are much closer to the inner surface of

Figure 2. Dose distributions in transversal, frontal and sagittal views from a representative case. RapidArc™ v. 10 is obtained from Varian® Medical Systems, Palo Alto, CA. 7f-IMRT, 7-field intensity-modulated radiotherapy; PTV; planning target volume.

Table 3. Summary of the dosimetric results for the organs at risk

Organs at risk	7-field intensity-modulated radiotherapy	RapidArc™	<i>p</i> -value
Bladder			
V30 (%)	82.2 ± 3.3	79.0 ± 2.9	0.015
V40 (%)	59.3 ± 2.2	55.6 ± 2.0	0.000
V45 (%)	48.0 ± 2.7	44.2 ± 2.5	0.001
V50 (%)	35.7 ± 2.2	32.6 ± 1.7	0.000
<i>D</i> _{50%} (cGy)	4273.2 ± 152.5	4190.6 ± 127.5	0.039
Bones			
V10 (%)	97.6 ± 1.2	96.9 ± 1.5	0.201
V20 (%)	90.2 ± 3.2	80.4 ± 5.7	0.000
V30 (%)	61.6 ± 3.9	57.6 ± 3.6	0.012
V40 (%)	31.7 ± 5.5	29.4 ± 5.1	0.280
V45 (%)	22.1 ± 6.0	20.5 ± 5.6	0.489
V50 (%)	13.7 ± 5.1	12.7 ± 4.7	0.608
<i>D</i> _{50%} (cGy)	3435.8 ± 178.6	3294.4 ± 170.5	0.050
Rectum			
V30 (%)	94.9 ± 2.8	91.8 ± 3.7	0.024
V40 (%)	74.0 ± 4.5	67.4 ± 4.4	0.001
V45 (%)	52.7 ± 4.8	47.8 ± 4.8	0.016
V50 (%)	26.3 ± 3.1	30.0 ± 3.7	0.006
<i>D</i> _{50%} (cGy)	4315.0 ± 126.0	4252.6 ± 160.6	0.281
Small intestine			
V30 (%)	38.8 ± 4.1	36.0 ± 4.0	0.09
V40 (%)	19.8 ± 3.4	16.9 ± 3.0	0.030
V45 (%)	13.1 ± 2.4	11.0 ± 2.0	0.023
V50 (%)	7.5 ± 1.1	6.8 ± 1.2	0.134
<i>D</i> _{50%} (cGy)	2495.5 ± 130.4	2375.7 ± 137.0	0.032
Left femoral head			
V30 (%)	54.8 ± 9.3	36.9 ± 10.5	0.000
V40 (%)	12.6 ± 4.4	7.6 ± 4.5	0.009
<i>D</i> _{50%} (cGy)	3160.5 ± 206.6	2691.2 ± 305.1	0.000
Right femoral head			
V30 (%)	53.6 ± 11.5	34.9 ± 14.4	0.001
V40 (%)	10.9 ± 3.2	5.7 ± 2.8	0.000
<i>D</i> _{50%} (cGy)	3072.5 ± 284.7	2618.0 ± 353.8	0.000

*D*_{x%}, dose received by x% volume of the organ; *V*_x, volume of the organ receiving a dose of x. RapidArc™ v. 10 is obtained from Varian® Medical Systems, Palo Alto, CA.

the bladder, rectum and bones (Figure 1), thus reducing the median dose to the OARs. However, more MUs are needed for the 15-cm RapidArc. Table 1 summarizes the effect of different jaw widths on the sparing of the OARs. Because the 15-cm RapidArc has a lower median dose for all the organs, it is used in the dosimetric comparison between RapidArc and IMRT.

Conformity index, homogeneity index and median dose of targets

The CI of RapidArc and 7f-IMRT are quite similar, and no significant difference was found (Table 2). They also have similar HI of PTV60 (0.047 ± 0.014 for 7f-IMRT and 0.043 ± 0.005 for RapidArc; *p* = 0.329). However, 7f-IMRT has a better HI of PTV50 (0.093 ± 0.007 for 7f-IMRT and 0.101 ± 0.006 for RapidArc;

Figure 3. Mean dose–volume histograms for planning target volume (PTV) 50, PTV60, bladder, rectum, small intestine, bones and femoral heads. RapidArc™ v. 10 is obtained from Varian® Medical Systems, Palo Alto, CA. 7f-IMRT, 7-field intensity-modulated radiotherapy; L, left; R, right.

$p = 0.007$). The $D_{50\%}$ of PTV50 is a little higher with RapidArc than with 7f-IMRT ($p = 0.005$). All target-evaluation parameters of the two techniques are listed in Table 2.

Dose to the organs at risk

A typical dose distribution is shown in transversal, frontal and sagittal views (Figure 2). For all of the OARs, RapidArc has a better performance than 7f-IMRT. The median bladder dose is 4273.2 ± 152.5 cGy with 7f-IMRT and 4190.6 ± 127.5 cGy with RapidArc ($p < 0.05$). Other OARs show a similar trend. The median bone dose decreases from 3435.8 ± 178.6 cGy with 7f-IMRT to 3294.4 ± 170.5 cGy with RapidArc. The median rectum dose with RapidArc (4252.6 ± 160.6 cGy) is slightly lower than that with 7f-IMRT (4315.0 ± 126.0 cGy); however, the difference is not statistically significant. The median small intestine dose with RapidArc is 120 cGy lower than that with 7f-IMRT

($p < 0.05$). Compared with that of 7f-IMRT, the RapidArc plans have significant reductions in the median dose (approximately 500 cGy) to the femoral heads ($p < 0.05$). RapidArc has a reduced dose at the V30, V40 and V45 levels ($p < 0.05$) of the rectum except for the V50. More detailed OAR doses are provided in Table 3. Figure 3 displays the mean dose–volume histograms of both techniques for the targets and the OARs, including the bladder, rectum, small intestine, femoral heads and bones. The black line labelled with the triangles represents the 7f-IMRT plan and the line with the circles represents the RapidArc plan.

Delivery efficiency and quality assurance

The total MUs for RapidArc plans are 732 ± 51 with an average treatment time of 126 ± 6 s at a maximum DR of 600 MU min^{-1} per fraction. In comparison, 7f-IMRT has average MUs of

Figure 4. Result of Delta4® (ScandiDos, Uppsala, Sweden) verification. The mean passing rate was $94.1 \pm 3.5\%$ for 7-field intensity-modulated radiotherapy (7f-IMRT), and 97.9 ± 2.1 for RapidArc™ (Varian® Medical Systems, Palo Alto, CA).

Figure 5. Comparison of multileaf collimator (MLC) motion at different jaw widths. Circle: the mechanical limitation of MLC whose maximum displacement is 15 cm.

1277 ± 114 with an average treatment time of 306 ± 12 s at the same DR. Reductions of 42.7% and 41.2% in MUs and treatment time, respectively, are achieved by RapidArc.

Both of the two techniques present a high accuracy in terms of the γ passing rate ($>90\%$) of the $\Gamma_{3\text{mm}, 3\%}$ criterion. The Γ indices for 7f-IMRT and RapidArc are $94.1 \pm 3.5\%$ and $97.9 \pm 2.1\%$, respectively. Figure 4 shows the verification results using Delta4.

DISCUSSION

The present study reported a dosimetric comparison between 15-cm RapidArc and 7f-IMRT on cervical cancer treatment with SIB to the pelvic lymph nodes. The comparison covered the median dose to the OARs, MUs and delivery time. The dosimetric benefit of the 15-cm jaw restriction of RapidArc was the major concern of the comparison. To the best of our knowledge, such a comparison has not been reported. We found that the 15-cm jaw width restriction could result in improvement in the sparing of the OARs. This was owing to the fact that not only part of the targets but also some parts of the OARs were excluded in the radiation field during the gantry rotation by using the jaw restriction. By setting the 15-cm jaw width restriction, all of the leaf positions are possible during the optimization process (Figure 5, left), in which the degree of modulation would increase evenly if part of the volume is excluded from the beam at each gantry position.¹⁴ While the jaw width was set to 20–23 cm, some areas in the field could only be reached by one side of the MLC owing to the mechanical limitation of the MLC (Figure 5, right, circle). Therefore, the 15-cm jaw width restriction helps to bring lower isodose lines (2000, 3000 and 4000 cGy) much closer to the PTV50. However, because part of the volume was excluded outside the field, the MUs were increased further to attain the equivalent dose for the targets.

It is interesting to compare our results with those of Renard-Oldrini et al.¹² They found that RapidArc had a worse result

regarding the median bladder and rectum doses compared with that of 5-field IMRT. Conversely, we found that the 15-cm restriction RapidArc spared the bladder and rectum better than 7f-IMRT. As the major difference between our RapidArc treatment and that employed by Renard-Oldrini et al.¹² is based on the 15-cm jaw width restriction, we thought that the inconsistency could be attributed to the different jaw width settings. By adopting the 15-cm jaw width restriction in our RapidArc treatment, the lower isodose lines could be brought closer to the target, thus improving the sparing of the OARs. This result demonstrates the benefits of the 15-cm jaw width restriction.

To date, various dosimetric studies have quantitatively evaluated the dose–volume relationships of the OARs for pelvic irradiation. Marks et al.²⁴ found that the majority of the bladder could be irradiated with approximately 30–50 Gy; when the bladder dose approached 50–60 Gy, the risk of bladder dysfunction begins to increase and severe urinary toxicity might be encountered. The small intestine is an organ that could develop acute gastrointestinal (GI) toxicity after radiation. Roeske et al.²⁵ and Simpson et al.²⁶ reported that the increasing bowel V45 was correlated with increased GI toxicity in patients with cervical cancer who are undergoing IMRT. Another investigation clearly showed that Grade 2 or more severe acute bowel toxicity was highly correlated with the intestinal cavity receiving 40–50 Gy.²⁷ A dose bath of approximately 40–50 Gy to large portions of the rectum has been reported to increase the incidence of bleeding, and it was suggested that the volume receiving 40–50 Gy should not exceed 60%.^{28–31} Fiorino et al.³² suggested that V40 of the rectum should be kept $<65\text{--}70\%$ to reduce the risk of persistent late incontinence. The pelvic bones provide the major contribution to blood component production; approximately 50% of the bone marrow of a woman is distributed in the pelvic region.³³ More attention has been devoted to the quantitative analysis of the dose–volume relationships between the pelvic bones and haematological toxicity in recent years. Mell et al.³³ found that

increased pelvic V10 was associated with increased Grade 2 or worse leukopenia and neutropenia. Similar findings (V10–V20 as the best predictors) were reported in a cohort of patients treated with IMRT and concomitant chemotherapy for anal cancer.³⁴ In summary, V50 of the bladder, V40 and V45 of the small intestine, V40 of the rectum and V20 of the bones were considered to be correlated with acute and late toxicities. Our research found that the dose–volume predictors were improved by using 15-cm RapidArc compared with using 7f-IMRT. It is encouraging for its potential to reduce toxicity, particularly in the organs that are most commonly associated with significantly acute and late toxicity (the bladder, small intestine, rectum and bones) and to reduce the possibility of radiation complications for patients with cervical cancer.

RapidArc was previously reported to save MUs and improve treatment efficiency.^{2,11,20,35} We also found in our study that RapidArc produced a remarkable reduction in MUs compared with 7f-IMRT (732 ± 51 with RapidArc and 1277 ± 114 with 7f-IMRT). It is known that the scattered radiation administered to

a patient's body outside of the treatment volume is at first order directly proportional to the applied MUs in the treatment using linear accelerators.¹¹ The risk of radiation-induced secondary malignancies also increases with more excessive MUs. Therefore, a reduction in MUs is beneficial to patients and to the radiation oncologists and therapists. Another advantage of RapidArc is its capability to deliver the dose over a shorter time. In this research, we found a reduction of approximately 3 min in treatment time with RapidArc (126 ± 6 s with RapidArc, whereas 306 ± 12 s with 7f-IMRT). The treatment time reduction can improve the treatment quality by avoiding uncomfortable treatment and reducing the risk of internal organ motion during the radiation. All of these factors impact the final treatment outcomes of patients.

CONCLUSIONS

In conclusion, the 15-cm jaw width restriction has the advantage in the sparing of the OARs. The RapidArc with such a restriction has superior dosimetry for the treatment of cervical cancer than high-quality 7f-IMRT.

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