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OPTIMUM TREATMENT MODE APPLIED TO POST-OPERATIVE CERVICAL CANCER FOR 5F-IMRT PLAN BASED ON FOUR VARIABLES IN VARIAN ECLIPSE TPS

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Purpose: This study aimed to determine the dosimetric effect on the target volume, organs at risk (OARs) and normal tissues based on the different choice for four types of mechanical variables, i.e., treatment position, dose calculation algorithm, mulitleaf collimator (MLC) motion mode and X-ray energy; and to investigate the optimum treatment mode applied to post-operative cervical cancer for 5-field intensity-modulated radiation therapy (5F-IMRT) technique. **Methods:** The dosimetric difference on the target volume and OARs under the influence of four types of variables were initially compared by changing one variable at a time. Then, based on the above compared results, we compared the dosimetric difference on planning target volume (PTV) and OARs between group A composed of the superior four variables and group B composed of the relatively inferior four variables. The dosimetric parameters included dose distribution of the target volume, OARs and normal tissues, conformal index (CI), homogeneity index (HI), monitor units (MU) and beam-on time (T). The independent and paired t-tests were used for statistical analysis, and the threshold for statistical significance was $P \leq 0.05$. **Results:** Compared with the supine position, the maximum dose of PTV ($D_{\text{max-PTV}}$), the maximum dose of small intestine ($D_{\text{max-small intestine}}$) and V_{50} of bladder

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($V_{50\text{-bladder}}$) were all lower in prone position. In contrast with the pencil beam convolution (PBC), CI of PTV (CL_{PTV}) was larger while HI of PTV (HL_{PTV}) was lower, both $V_{50\text{-bladder}}$ and the maximum dose of rectum ($D_{\text{max-rectum}}$) were lower using anisotropic analytical algorithm (AAA). Moreover, the same results were obtained using sliding window (SW) compared with multiple static segments (MSS). The mean dose of PTV ($D_{\text{mean-PTV}}$) and CL_{PTV} was larger while the maximum dose of the spinal cord ($D_{\text{max-spinal cord}}$), $V_{50\text{-bladder}}$ and the maximum dose of femoral heads were lower with 15 MV X-rays compared with 6 MV X-rays. In comparison with group B comprising the supine position, PBC, MSS and 6 MV X-rays, $D_{\text{mean-PTV}}$ and HL_{PTV} decreased 1.4% and 53.4% respectively, CL_{PTV} increased 5.8% medially, while $D_{\text{max-small intestine}}$, $D_{\text{max-rectum}}$, $V_{50\text{-bladder}}$ and $D_{\text{max-femoral heads}}$ all decreased in group A comprising of prone position, AAA, SW and 15 MV X-rays. **Conclusion:** The treatment mode composed of prone position, AAA algorithm, SW and 15 MV X-rays is chosen for the post-operative cervical cancer of 5F-IMRT technique, which is more capable of meeting the target volume constraints and maximal protection of OARs.

Keywords: Post-operative cervical cancer; 5F-IMRT; treatment position; dose calculation algorithm; X-ray energy.

1. Introduction

Cervical cancer is one of the most common gynecologic malignant tumors, early cases of which are often treated surgically. However, radiotherapy is necessary for post-operative residual carcinoma, intra-operative pelvic lymph node metastasis, incomplete surgery and post-operative recurrence after surgery. The target volume is relatively large for post-operative cervical cancer radiotherapy. As the dose requirements of the target cannot be met with less fields and low dose region will be larger with more fields, 5-field intensity-modulated radiation therapy (5F-IMRT) is chosen in this paper.

As to designing treatment plans in Varian Eclipse TPS, both prone and supine positions can meet the clinical requirements, but the influence of radiotherapy plans caused by these two positions is different. The anisotropic analytical algorithm (AAA) and pencil beam convolution (PBC) are generally used for accurate dose calculation. Nonetheless, the effects on the precision of different algorithms with AAA differ from that with PBC. In terms of the MLC motion mode, the Varian accelerator provides sliding window (SW) and multiple static segments (MSS), which can result in different effects on TPS optimization and dose calculation. Moreover, both 15 MV and 6 MV have been widely applied in post-operative radiotherapy of cervical cancer, but the impact on the calculation results is different.

A series of studies have reported the dosimetric parameters of the target and OARs can remarkably affect the treatment plans. Nevertheless, these studies only focus on one type of variables and have not investigated the effects of multiple types of parameters on the target and OARs. The purpose of this paper is particularly to present the more superior radiotherapy mode and provide a clinical reference for post-operative cervical cancer patients with 5F-IMRT technique.

2. Materials and Methods

2.1. *Case selection*

In this study, 20 patients with post-operative cervical cancer treated in a hospital in 2014 (8 males and 12 females; age range, 36–62 years old; median age, 55 years old) were randomly selected for 5-F IMRT. International Federation of Gynecology and Obstetrics (FIGO) covered stage IB∼IIA, and the IB, IC, ID, IIA with five cases, respectively. The post-operative pathology showed middle-and-low differentiated squamous cell carcinoma. The patients should be subject to post-operative pelvic cavity radiotherapy if high risk factors occurred in the post-operative pathology.

2.2. *Instruments and equipment*

The equipment consisted of the following: Toshiba KXO-50N simulation positioning machine; thermoplastic mask, prone position fixed frame, supine position fixed frame (Klarity Medical & Equipment Co., LTD); large-aperture 16 rows spiral CT of GE Medical Systems; Eclipse treatment planning system (TPS, Version 8.6, Varian Medical Systems); Clinac IX medical linear accelerator. Moreover, MLC consisted of 60 pairs of leaves collimator, 40 pairs of leaves were in collimator center, and projected width 0.5 cm at the isocenter, 20 pairs of leaves were in both ends, and projected width 1.0 cm at the isocenter. The maximum speed of leaf was 2.5 cm/s, and the gantry had a rotation angular velocity of 4.8°/s.

2.3. *CT scans*

Among the 20 patients, 10 were immobilized in the supine position with both arms raised above their heads, while another 10 were immobilized in the prone position with both arms laced behind their heads. The 20 patients were fixed using a carbon fiber position fixing device and the thermoplastic masks. Then the signs were marked on both the body surface of patient and the thermoplastic mask. CT scans with a slice thickness of 5 mm were obtained using large-aperture 16 rows spiral CT of GE medical systems. Moreover, the scanning range included the whole pelvic cavity plus 5 cm margins isotropically. The CT images were transmitted into the Varian Eclipse TPS workstation then.

2.4. *Target volume, OARs delineation and dose constraints*

The target volume and OARs delineation were contoured by one experienced radiation oncologist. The target volume included clinical target volume (CTV) and planning target volume (PTV), PTV included CTV plus 0.7 cm margins around and 1 cm margins up and down (Fig. 1).

The OARs outlined included the spinal cord, bladder, small intestine, rectum and femoral heads. The prescription dose given was 5000 cGy, which was irradiated for 25 times, herein, for fractionated dose of 200 cGy, 99% of PTV is supposed to

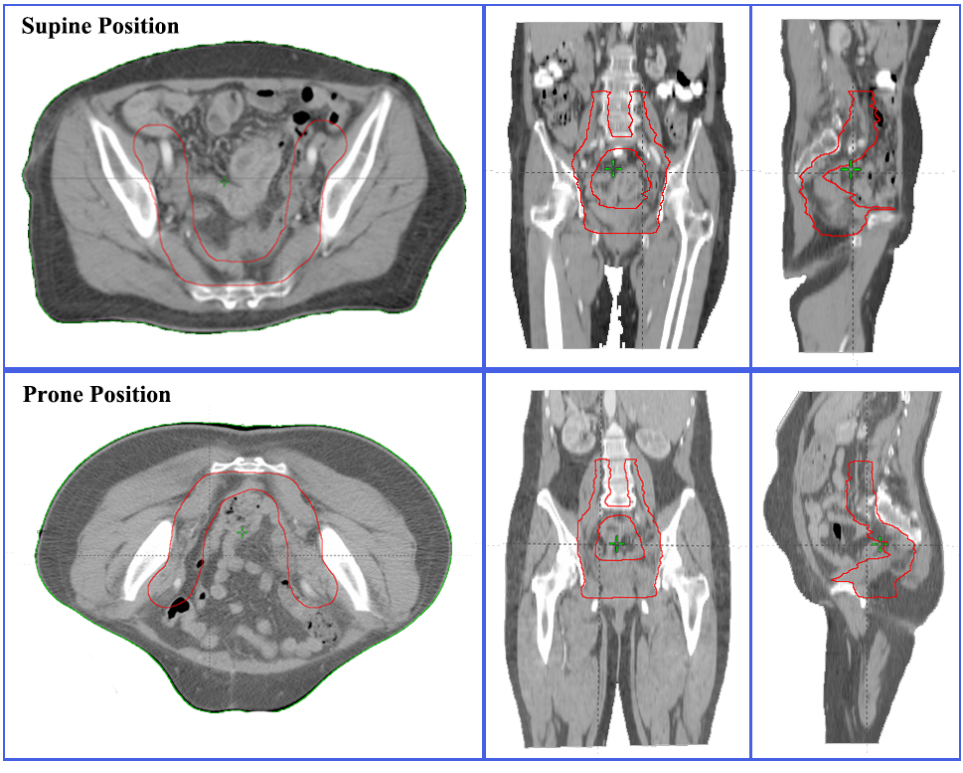

Fig. 1. Transversal, sagittal and coronal views for PTV.

receive at least 95% of prescription dose (4750 cGy),[1] the maximum dose of PTV does not exceed 5400 cGy. The OARs dose should be as low as reasonably possible, but it should at least comply with the following constraints: bladder $\geq$ 5000 cGy in $\leq$ 50% volume; the maximum dose of spinal cord ($D_{\text{max-spinal cord}}$) $\leq$ 4500 cGy; the maximum dose of small intestine ($D_{\text{max-small intestine}}$) $\leq$ 5000 cGy; the maximum dose of rectum ($D_{\text{max-rectum}}$) $\leq$ 5000 cGy; and the maximum dose of femoral heads ($D_{\text{max-femoral heads}}$) $\leq$ 5000 cGy.

2.5. *Treatment plan evaluation*

The treatment plan was evaluated based on dose distribution and dose volume histogram (DVH) generated with resolution ratio of 1 cGy and 1 cm^3. PTV of each patient is normalized where 99% of PTV receives 95% of prescription dose during comparison. The dosimetric parameters include the mean dose of PTV ($D_{\text{mean-PTV}}$), the maximum dose of PTV ($D_{\text{max-PTV}}$), the minimum dose of PTV ($D_{\text{min-PTV}}$), conformal index of PTV (CI_{PTV}) and $D_{\text{max-small intestine}}$, $D_{\text{max-spinal cord}}$, $D_{\text{max-rectum}}$, $D_{\text{max-femoral heads}}$, V_{50} of bladder ($V_{50\text{-bladder}}$), monitor units (MU) and beam-on time (T). Furthermore, $D_{\text{mean-PTV}}$ should be as low as reasonably possible, but it should

not be lower than the prescription dose (5000 cGy). CI[2,3] is expressed by

$$\mathrm{CI} = \frac{V_{t,\mathrm{ref}}}{V_t} \times \frac{V_{t,\mathrm{ref}}}{V_{\mathrm{ref}}}, \tag{1}$$

where V_t stands for the target volume, $V_{t,\mathrm{ref}}$ stands for the target volume surrounded by reference isodose surface, V_{ref} is the volume of all areas surrounded by reference isodose surface. Here, CI ranges from 0 to 1, and higher CI values indicate better conformity. HI[4] is given by

$$\mathrm{HI} = \frac{D_2 - D_{98}}{D_{\mathrm{prescription}}} \times 100\%, \tag{2}$$

where D_2 and D_{98} (dose received by the 2% and 98% of the volume, respectively) are metrics for minimum and maximum doses. $D_{\mathrm{prescription}}$ is the prescription dose, and lower HI values indicate superior dose homogeneity of the target volume.

2.6. *Statistical Approach*

A statistical analysis was implemented using the IBM SPSS Statistic 19.0 software package. Independent-samples t-test and paired-samples t-test were performed to design comparison between and within groups, respectively. The threshold for statistical significance was $\alpha = 0.05$, $P \leq 0.05$.

3. Results

The prone and supine positions are suitable for the patients with post-operative cervical cancer in 5F-IMRT. Additionally, when designing 5F-IMRT plan under the Varian Eclipse treatment planning system (TPS, Version 8.6), under the premise of same optimal condition, AAA or PBC algorithm was optional to dose calculation, MSS or SW to MLC motion mode, 6 MV or 15 MV X-rays. Different set of variables probably had a relatively different influence on radiotherapy. For 5F-IMRT, a concrete study of more superior treatment plan for the post-operative cervical cancer patients is carried out by comparing these variables.

3.1. *Dosimetry difference statistics changing one variable at a time*

3.1.1. *Effect of treatment position*

The 10 patients were in the way of isocenter beam set-up of coplanar five fields, and gantry angles were set to 40°, 95°, 180°, 265° and 320°, separately, which were in accordance with the cervical structure. Another 10 patients were also in the way of isocenter beam field of coplanar five fields, and gantry angles were set to 0°, 85°, 140°, 220° and 275° (Fig. 2). For each patient, the position of secondary collimator was required to be adjusted as it is necessary to fasten the collimator jaws during optimization in the TPS.

In order to eliminate the influence of other factors, a concrete analysis of the effects of different treatment positions on 5-F IMRT was implemented for the 20

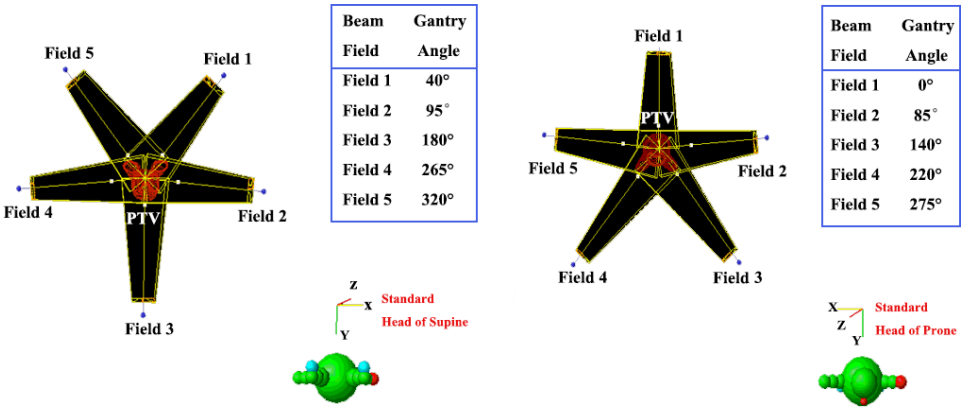

Fig. 2. Beam field set for supine and prone positions of a patient being scanned.

patients. For 5-F IMRT, plans were designed selecting the angles of collimator and treatment couch set to 0°, the dose rate (DR) of 300 MU/min, 6 MV X-rays, SW motion mode was, PBC algorithm, and the dose calculation grid was set to 2.5 mm. The treatment plans were repeatedly designed and optimized until each plan met the dosimetric parameters. Independent-sample t-test was conducted using the IBM SPSS Statistic 19.0. Furthermore, PTV was normalized where 99% of PTV volume received 95% of prescription dose (4750 cGy).

Table 1 demonstrates that $D_{\text{mean-PTV}}$, $D_{\text{max-small intestine}}$ and $V_{50\text{-bladder}}$ are all lower in the prone position compared with the supine position. Results are considered statistically significant ($P \leq 0.05$).

3.1.2. *Effect of different dose calculation algorithm*

The treatment plans were designed with the prone position, and the PBC algorithm was used for optimization calculation based on other conditions kept constant.

Table 1. Dosimetric parameters comparison of in the prone and supine positions.

Parameter		Prone position	Supine position	t	P
PTV	$D_{\text{mean-PTV}}$ (cGy)	5088.91 ± 25.25	5119.40 ± 39.11	-4.56	0.001
	$D_{\text{max-PTV}}$ (D_2, cGy)	5253.80 ± 29.86	5306.60 ± 67.94	-2.42	0.039
	$D_{\text{min-PTV}}$ (D_{98}, cGy)	4797.73 ± 24.75	4816.25 ± 7.22	0.79	0.45
	CL_{PTV}	0.73 ± 0.025	0.73 ± 0.024	1.50	0.017
	HL_{PTV}	0.091 ± 0.003	0.098 ± 0.012	-8.06	0.00
OARs	$D_{\text{max-small intestine}}$ (cGy)	4708.24 ± 141.48	4893.04 ± 87.46	-1.52	0.16
	$D_{\text{max-spinal cord}}$ (cGy)	3531.56 ± 245.44	3717.52 ± 228.65	0.16	0.88
	$V_{50\text{-bladder}}$ (%)	29.39 ± 13.43	50.10 ± 5.60	-2.97	0.016
	$D_{\text{max-rectum}}$ (cGy)	4908.33 ± 66.33	4910.22 ± 26.43	-5.43	0.00
	$D_{\text{max-femoral heads}}$ (cGy)	4852.95 ± 70.02	4877.85 ± 56.23	3.32	0.22
Monitor units	MU	1467.20 ± 85.59	1465.40 ± 42.32	-0.54	0.61
Beam-on time	T (min)	4.8907 ± 0.28	4.89 ± 0.14	-0.54	0.61

Table 2. Dosimetric parameters comparison between AAA and PBC algorithm.

	Parameter	AAA	PBC	$X \pm S$	t	P
PTV	$D_{\text{mean-PTV}}$ (cGy)	5049.54 ± 23.20	5088.91 ± 25.24	-39.37 ± 27.30	-4.56	0.001
	$D_{\text{max-PTV}}$ (D_2, cGy)	5230.99 ± 28.73	5253.80 ± 29.86	-22.81 ± 29.84	-2.42	0.039
	$D_{\text{min-PTV}}$ (D_{98}, cGy)	4803.78 ± 7.82	4797.73 ± 24.75	6.04 ± 24.29	0.79	0.45
	CI_{PTV}	0.74 ± 0.016	0.73 ± 0.023	0.0087 ± 0.020	1.50	0.017
	HI_{PTV}	0.085 ± 0.0050	0.091 ± 0.003	-0.0058 ± 0.020	-8.06	0.00
OARs	$D_{\text{max-small intestine}}$ (cGy)	4509.34 ± 415.31	4708.24 ± 141.48	-198.90 ± 414.40	-1.52	0.16
	$D_{\text{max-spinal cord}}$ (cGy)	3537.61 ± 238.4	3531.56 ± 245.44	6.05 ± 119.53	0.16	0.88
	$V_{\text{50-bladder}}$ (%)	24.97 ± 12.86	29.39 ± 13.43	-4.42 ± 4.71	-2.97	0.016
	$D_{\text{max-rectum}}$ (cGy)	4838.93 ± 54.85	4908.44 ± 66.33	-69.40 ± 40.44	-5.43	0.00
	$D_{\text{max-femoral heads}}$ (cGy)	4895.06 ± 74.62	4852.95 ± 70.02	42.11 ± 40.17	3.32	0.22
Monitor units	MU	1451.70 ± 81.62	1467.20 ± 85.60	-15.50 ± 90.92	-0.54	0.61
Beam-on time	T (min)	4.84 ± 0.27	4.89 ± 0.29	-0.052 ± 0.31	-0.54	0.61

Similarly, PTV was normalized where 99% of PTV received 95% of prescription dose (4750 cGy). Comparison of dosimetric parameters with respect to AAA and PBC algorithms (Table 2), which demonstrates that CI_{PTV} of the target is higher, $V_{\text{50-bladder}}$, $D_{\text{max-rectum}}$ and HI_{PTV} are lower with the AAA than PBC algorithm. Results are considered statistically significant ($P \leq 0.05$).

3.1.3. *Effect of MLC motion mode*

Both SW and MSS are suitable for the MLC motion mode, for whichever mode is chosen, and the dose accuracy is dependent on the right set for the dosimetric parameters of dynamic multileaf collimator (DMLC).

Based on the treatment plans in the prone position and with the AAA, SW motion mode was selected for dose calculation then. Similarly, PTV is normalized through 99% of PTV receiving 95% of the prescription dose. Table 3 shows the dosimetric parameters comparison between SW and MSS, and reveals that compared with MSS, the use of SW results in a significant increase in CI_{PTV} of the target, but decrease in HI_{PTV}.

3.1.4. *Effect of X-ray energy*

Based on the radiotherapy plan above for these 10 patients in the prone position using AAA algorithm and SW motion mode, 15 MV is chosen for TPS optimizing and calculation again. PTV is normalized where 99% of PTV volume received 95% of prescription dose (4750 cGy). Table 4 depicts a detailed comparison for the dosimetric parameters with 6 MV X-rays.

Both $D_{\text{mean-PTV}}$ and CI_{PTV} were increased, and a decrease of HI_{PTV} was observed with 6 MV X-rays when compared with 15 MV X-rays (Table 4). In terms of OARs, $D_{\text{max-spinal cord}}$, $V_{\text{50-bladder}}$ and $D_{\text{max-femoral heads}}$ were lower. Furthermore, both MU and T were lower than the threshold for statistical significance ($P \leq 0.05$), but no statistical differences were found in both $V_{\text{50-bladder}}$ and $D_{\text{max-rectum}}$.

Table 3. Dosimetric parameters comparison between SW and MSS.

	Parameter	SW	MSS	$X \pm S$	t	P
PTV	$D_{\text{mean-PTV}}$ (cGy)	5049.54 ± 28.73	5066.82 ± 45.55	-42.11 ± 29.75	-3.55	0.006
	$D_{\text{max-PTV}}$ (D_2, cGy)	5230.99 ± 7.82	5273.11 ± 9.53	-3.40 ± 6.64	-4.48	0.002
	$D_{\text{min-PTV}}$ (D_{98}, cGy)	4803.78 ± 7.82	4807.18 ± 9.53	-3.40 ± 6.65	-1.62	0.14
	$\text{CL}_{\text{-PTV}}$	0.74 ± 0.016	0.73 ± 0.017	0.0066 ± 0.0043	4.83	0.001
	$\text{HL}_{\text{-PTV}}$	0.085 ± 0.0047	0.093 ± 0.0071	-0.0077 ± 0.0055	-4.42	0.002
OARs	$D_{\text{max-small intestine}}$ (cGy)	4509.34 ± 415.31	4744.07 ± 129.21	-234.73 ± 415.46	-1.79	0.11
	$D_{\text{max-spinal cord}}$ (cGy)	3537.61 ± 238.40	3497.45 ± 238.06	40.16 ± 136.24	0.93	0.38
	$V_{50\text{-bladder}}$ (%)	24.97 ± 12.85	27.182 ± 12.69	-2.21 ± 6.89	-1.013	0.033
	$D_{\text{max-rectum}}$ (cGy)	4838.93 ± 54.85	4895.54 ± 66.62	-56.61 ± 33.43	-5.35	0.00
	$D_{\text{max-femoral heads}}$ (cGy)	4895.06 ± 74.62	4893.73 ± 98.01	1.33 ± 51.54	0.082	0.94
Monitor units	MU	1451.70 ± 81.62	1339.1 ± 83.21	112.60 ± 70.82	5.028	0.00
Beam-on time	T (min)	4.839 ± 0.27	4.226 ± 0.28	0.375 ± 0.24	5.028	0.001

Table 4. Dosimetric parameters comparison between 6 MV and 15 MV.

	Parameter	6 MV X-rays	15 MV X-rays	$X \pm S$	t	P
PTV	$D_{\text{mean-PTV}}$ (cGy)	5049.54 ± 23.20	5031.17 ± 17.03	18.37 ± 8.77	6.62	0.00
	$D_{\text{max-PTV}}$ (D_2, cGy)	5231.00 ± 28.73	5189.90 ± 21.76	41.09 ± 9.79	13.27	0.00
	$D_{\text{min-PTV}}$ (D_{98}, cGy)	4803.78 ± 7.82	4796.95 ± 4.52	6.82 ± 5.82	3.71	0.005
	$\text{CL}_{\text{-PTV}}$	0.74 ± 0.016	0.76 ± 0.012	-0.018 ± 0.0047	-11.92	0.00
	$\text{HL}_{\text{-PTV}}$	0.085 ± 0.0047	0.079 ± 0.0038	0.0068 ± 0.0020	13.02	0.00
OARs	$D_{\text{max-small intestine}}$ (cGy)	4509.34 ± 415.31	4567.18 ± 95.59	-157.80 ± 404.75	-1.23	0.25
	$D_{\text{max-spinal cord}}$ (cGy)	3537.61 ± 238.40	3481.25 ± 244.08	56.36 ± 31.73	5.62	0.00
	$V_{50\text{-bladder}}$ (%)	24.97 ± 12.85	21.32 ± 11.90	3.65 ± 2.40	4.82	0.001
	$D_{\text{max-rectum}}$ (cGy)	4838.93 ± 54.85	4827.60 ± 26.04	11.33 ± 39.33	0.91	0.39
	$D_{\text{max-femoral heads}}$ (cGy)	4895.06 ± 74.63	4825.43 ± 78.22	69.63 ± 41.97	5.25	0.001
Monitor units	MU	1451.70 ± 81.63	1358.40 ± 57.69	93.30 ± 56.66	5.21	0.001
Beam-on time	T (min)	4.839 ± 0.272	4.528 ± 0.192	0.311 ± 0.189	5.21	0.001

3.2. *Dosimetric difference statistics of multiple series-wound mechanical variables*

In order to compare the dosimetric differences of treatment mode using different combined mechanical variables, 20 patients were equally divided into group A and group B on the basis of other conditions unchanged, and the radiotherapy plan was designed for each patient in group A and group B. Here, group A comprised prone position, AAA, SW of MLC motion mode and 15 MV while group B comprised supine position, PBC algorithm, MSS of MLC motion mode and 6 MV. Table 3 (i.e., transversal, sagittal and coronal views) lists the dose distribution of 95% of prescription dose (4750 cGy).

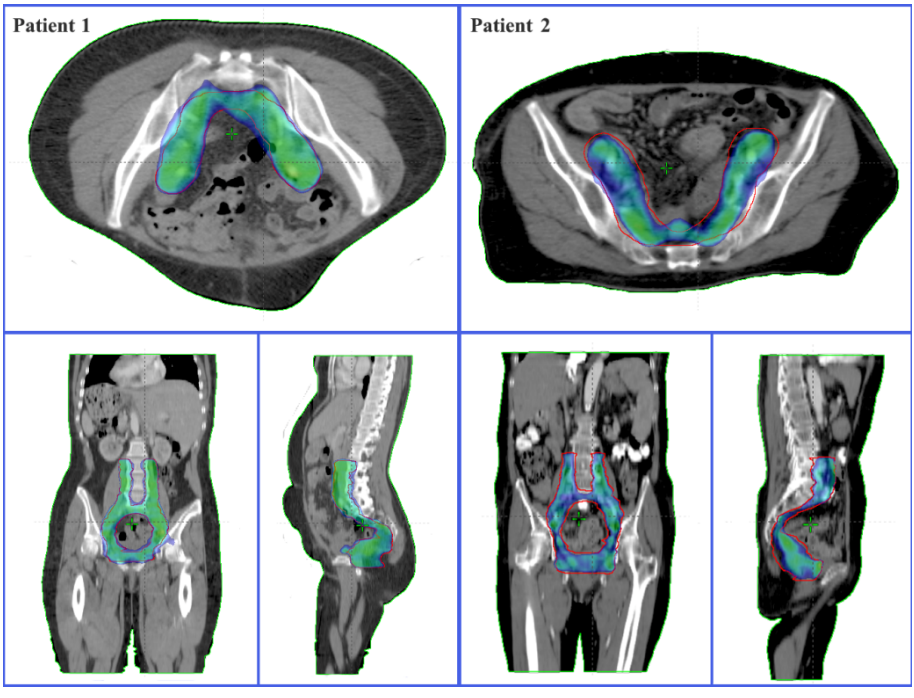

Fig. 3. Dose distribution comparison of patients 1 and 2.

The dose distribution of patient 1 is obviously superior to that of patient 2 (Fig. 3). In order to meet the dose constraints of PTV, the dose distribution of each patient needed to be normalized with 99% of PTV volume receiving 95% of prescription dose (4750 cGy). Furthermore, each mechanical parameter is computed using independent-samples t-test (Table 5).

Table 5. Dosimetric parameters comparison of two groups.

Parameter		Group A*	Group B*	t	P
PTV	$D_{\text{mean-PTV}}$ (cGy)	5031.17 ± 17.03	5101.90 ± 42.82	-4.85	0.00
	$D_{\text{max-PTV}}$ (D_2, cGy)	5189.90 ± 21.76	5295.41 ± 63.24	-4.99	0.00
	$D_{\text{min-PTV}}$ (D_{98}, cGy)	4796.95 ± 4.52	4692.33 ± 38.45	1.07	0.31
	$\text{CI}_{\text{-PTV}}$	0.76 ± 0.012	0.7145 ± 0.034	3.84	0.003
	HL_{PTV}	0.079 ± 0.0038	0.12 ± 0.067	-1.99	0.042
OARs	$D_{\text{max-small intestine}}$ (cGy)	4667.18 ± 95.59	4873.55 ± 415.31	-5.15	0.00
	$D_{\text{max-spinal cord}}$ (cGy)	3481.25 ± 244.08	3611.11 ± 238.40	-1.11	0.28
	$V_{50\text{-bladder}}$ (%)	21.32 ± 11.90	44.59 ± 12.85	-5.34	0.001
	$D_{\text{max-rectum}}$ (cGy)	4827.60 ± 26.04	4935.68 ± 57.81	-5.39	0.00
	$D_{\text{max-femoral heads}}$ (cGy)	4825.43 ± 78.22	4897.28 ± 60.17	-2.30	0.00
Monitor units	MU	1358.40 ± 57.69	1245.13 ± 71.05	3.92	0.001
Beam-on time	T (min)	4.53 ± 0.19	4.150 ± 0.236	3.92	0.001

*Group A = prone position + AAA algorithm + SW + 15 MV X-rays
Group B = supine position + PBC algorithm + MSS + 6 MV X-rays

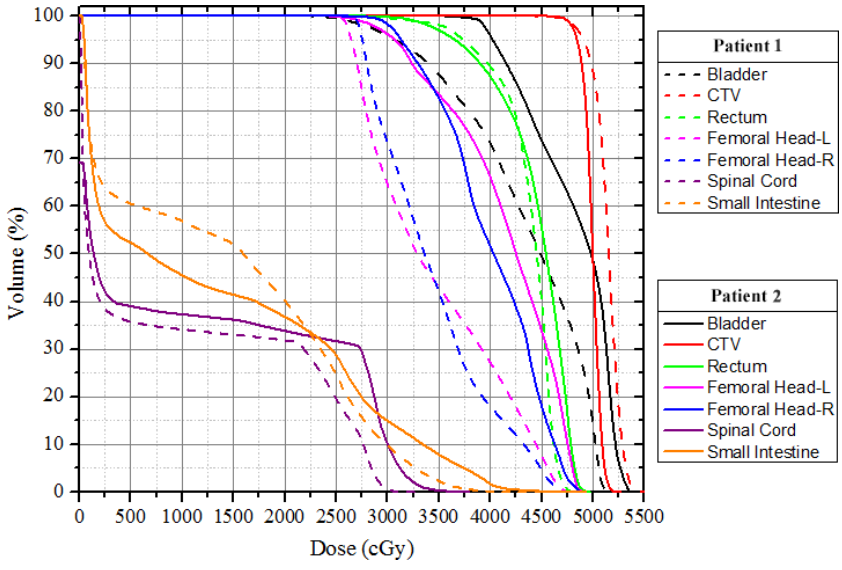

Fig. 4. DVH comparison between patients 1 and 2.

Our results demonstrate that compared with group B, group A results in a increase in $\mathrm{CI}_{\text{-PTV}}$, MU and T, a decrease in $D_{\text{max-small intestine}}$, $D_{\text{max-rectum}}$, $V_{\text{50-bladder}}$ and $D_{\text{max-femoral heads}}$, which are considered statistically significant ($P \leq 0.05$). $D_{\text{min-PTV}}$ and $D_{\text{max-spinal cord}}$ has no statistical difference.

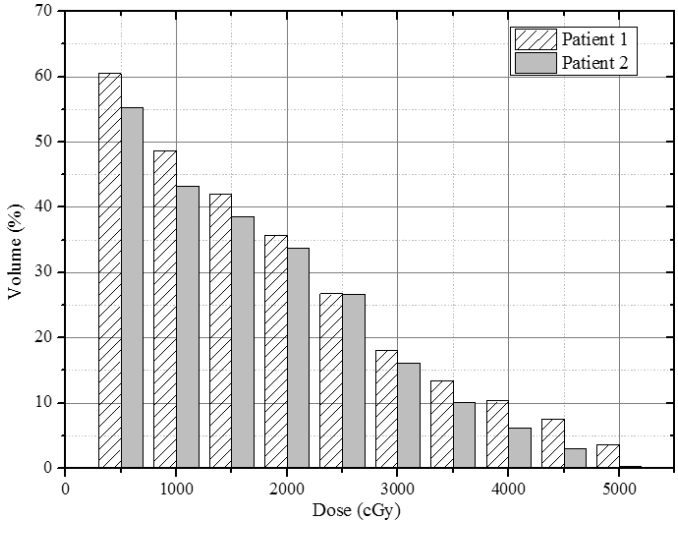

Fig. 5. Dose histogram comparison of the normal tissues for patients 1 and 2.

Figures 4 and 5 depict DVH and dose histogram comparisons between patients 1 and 2, respectively. Herein, the normal tissues are defined as the volume surrounded by the skin subtracting PTV and organs.

The irradiation dose of both PTV and OARs for patients 1 and 2 meets the clinical dosimetric requirements (Fig. 4). Nevertheless, the DVH curve and dose distribution of patients 1 are remarkably superior than those of patient 2; the maximum dose of small intestine, rectum, femoral heads and the spinal cord are all relatively lower. However, the irradiation dose of normal tissues for patient 2 is lower than that for patient 1 (Fig. 5).

4. Discussion

4.1. *Treatment position selection*

Table 1 illustrates the small intestine and bladder which can be preferably protected in the prone position instead of supine position. Whereas, the source skin distance (SSD) changes constantly with the breathing exercises and the bladder filling differences of a patient in the supine position during radiotherapy. According to the principle of high energy X-ray intensity inversely proportional to squared distance, the percentage depth dose (PDD) is in inverse proportion to SSD, which brings bigger dose errors and affects the radiotherapy. Nevertheless, for patients in the prone position, the vertical marker is on his/her back, and the abdominal pelvic naturally sags to the square hole of abdominal fixed mount; thus reducing the positioning errors and adverse reactions, enhancing the control rate of local tumors and survival rate, and ensuring the treatment effect.[5] Ymala *et al.*[6] compared the effects of pelvic cavity radiotherapy on the irradiation dose delivered to the normal tissues of rectal cancer patients in the supine and prone positions; and found the irradiated volume in the prone position is larger than that in the supine position when the irradiation dose delivered to the small intestine is 5–10 Gy. It is Noteworthy that the dose for statistical significance is 5–15 Gy, but no significant differences are found ranging from 20 Gy to 45 Gy.

Bhatnagar *et al.*[7] demonstrated that the pelvic cavity radiotherapy in the prone position is in favor of protecting the buttocks especially the skin of gluteal fold, and enhancing the tolerance dose of the target and OARs. Kim *et al.*[8] found the irradiated volume of the small intestine has statistical significance after CT scans for 20 cases applying four types of positions ($P < 0.05$), as well, it is the optimum method in which patients are treated in the prone position with a full bladder. Moreover, Rozilawati *et al.*[9] reported that bladder filling can enhance the accuracy of radiotherapy, decrease the uterus displacement and positioning errors for cervical cancer patients. In this study, the results present that the irradiation dose to the spinal cord, bladder, small intestine, rectum, and femoral heads in the prone position is relatively less than those in the supine position. Hence, prone position has certain

advantages from the point of position selection for post-operative cervical cancer radiotherapy.

4.2. *Dose calculation algorithm selection*

TPS is a rather critical step in tumor radiotherapy, therefore the question whether the dose calculation algorithm implemented in the TPS is accurate or not must be primarily considered.[10] Various difficulties may be occurred when different kinds of algorithms perform electron transfer on the interface of different density of media, also, different limitations can be brought using different algorithms.[11,12] A series of articles[13–15] showed that PBC algorithm could better satisfy the accuracy of dose calculation in most cases,[16] but not accurately reflect the secondary build-up effect when ray passes through two different densities of tissues. Since AAA algorithm considers the effects of original ray, electron beam contamination, collimator scattering and the dose calculation in inhomogeneous medium can be more accurately corrected, AAA algorithm is theoretically more precise.[17] Numerous studies have shown that PBC algorithm tends to overestimate the absorbed dose of low density of tissues in the target volume. There have been many reports on dosimetric comparison between AAA and PBC algorithms for lung cancer patients,[18] which emphasize the irradiation dose distinction of lungs. Bragg *et al.*[18] and Aarup *et al.*[19] indicated that the results can be closer to the actually measured values using the AAA compared with PBC algorithm, which still underestimate the irradiation dose delivered to the lungs. Rønde *et al.*[20] verified that the AAA algorithm is superior to PBC algorithm in uneven tissues. Not only can preferable conformity and homogeneity of the target volume be obtained using the AAA algorithm in contract with the PBC algorithm, but the irradiation dose to the bladder and rectum can be better controlled (Table 2). Therefore, AAA algorithm is superior for post-operative cervical cancer patients in IMRT technique.

4.3. *MLC motion mode selection*

The SW of MLC motion mode (Varian accelerator) refers to each pair of leaf moving along the same direction at a specific speed, which is characterized by simultaneous beam in the process of MLC movement and obtaining different ray intensity curves then. Whereas the main factors influencing MSS motion mode are the optimizing algorithm of subfield[21] and spatial resolution of two-dimensional intensity distribution. Potter *et al.*[22] found that these two factors directly lead the number of subfields optimization to change and then affect the efficiency of the whole treatment. Theoretical studies show that more subfields and smaller MLC gap can bring more exquisite intensity adjustment, obtain more three-dimensional (3D) homogeneous dose and irradiate OARs with less dose.[23,24] In terms of the target and OARs protection, preferable conformity and homogeneity can be obtained in SW motion mode compared with MSS at the cost of MU and T (Table 3). Moreover, the target dose distribution is more in accordance with the clinical requirements, as well as the bladder and rectum can be preferably protected with SW.

4.4. *X-ray energy selection*

As with 15 MV, preferable conformity and homogeneity of PTV can be obtained, also, the spinal cord, bladder and femoral heads can be better protected compared with 6 MV. As the pelvic cavity has the features of thick relative tissues and little cavity tissues, and 15 MV is characterized by strong penetrability and high utilization, the number of MU, the irradiation dose to the normal tissues and OARs are relatively less. However, Madani *et al.*[25] reported 6 MV is more suitable for lung cancer patients, when compared with 18 MV. Moreover, a similar research on 13 cases was performed by Elisabeth *et al.*,[26] but pros and cons were not found between 6 MV and 15 MV. Essentially, because of the PDD difference of 6 MV and 15 MV, 15 MV is characterized by deeper building up area and more suitable for tumor cases in deep position.[27]

4.5. *Optimum radiotherapy mode selection*

In this study, both CL_{PTV} and HL_{PTV} in the radiotherapy plan with 15 MV were superior to that with 6 MV, which manifests that high-energy X-rays has advantages over low-energy X-rays in the deeper position of pelvic cavity from the point of dose distribution of PTV. It is noteworthy that neutrons can be produced by collimator scattering and transmission as well as high-energy X-rays will additionally increase the irradiation dose, which is particularly neglected and can raise the potential of secondary malignant tumor in clinical practice.[28,29] Kry *et al.*[30] investigated the possibility of secondary cancer caused in IMRT plan for prostate cancer and the results showed that the possibility of secondary cancer caused by higher-energy X-rays is slightly higher than that by low-energy X-ray. Schneide *et al.*[31] reported the same results were obtained by applying proton and high-energy X-rays.

As with MU and T, a mean increase of 8.3% was calculated for group A compared with group B (Table 5). Likewise, the computed mean decrease of $D_{\text{mean-PTV}}$ and HI_{PTV} was 1.4% and 53.4% for group A compared with group B, respectively (Table 5). The computed mean increase of CL_{PTV} was 5.8% under conditions of ensuring PTV and OARs meeting the dose requirements for group A compared with group B (Table 5). Finally, the computed mean decrease of $D_{\text{max-small intestine}}$, $D_{\text{max-rectum}}$, $V_{50\text{-bladder}}$ and $D_{\text{max-femoral heads}}$ was 4.4%, 2.2%, 109.1% and 1.5% for group A compared with group B, respectively (Table 5). The results in this study fully illustrate group A is more suitable for post-operative cervical cancer for 5F-IMRT technique than group B.

5. Conclusion

It is demonstrated by the experimental results that for 5F-IMRT, it is superior to select the treatment mode composed of prone position, AAA algorithm, SW of MLC motion mode and 15 MV X-rays for post-operative cervical cancer patients; thus better meeting the requirements of PTV dose distribution at the expense of more

dose delivered to the normal tissues. Moreover, it remains to be investigated that these data apply to other commercially available planning systems.

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