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Dosimetric comparison of different multileaf collimator leaves in treatment planning of intensity-modulated radiotherapy for cervical cancer

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ABSTRACT

To study the effect of multileaf collimator (MLC) leaf widths (standard MLC [sMLC] width of 10 mm and micro-MLC [mMLC] width of 4 mm) on intensity-modulated radiotherapy (IMRT) for cervical cancer. Between January 2010 and August 2010, a retrospective analysis was conducted on 12 patients with cervical cancer. The treatment plans for all patients were generated with the same machine setup parameters and optimization methods in a treatment planning system (TPS) based on 2 commercial Elekta MLC devices. The dose distribution for the planning tumor volume (PTV), the dose sparing for organs at risk (OARs), the monitor units (MUs), and the number of IMRT segments were evaluated. For the delivery efficiency, the MUs were significantly higher in the sMLC-IMRT plan than in the mMLC-IMRT plan (802 ± 56.9 *vs* 702 ± 56.7; $p < 0.05$). The number of segments in the plans were 58.75 ± 1.8 and 59 ± 1.04 ($p > 0.05$). For the planning quality, the conformity index (CI) between the 2 paired IMRT plans with the mMLC and the sMLC did not differ significantly (average: 0.817 ± 0.024 *vs* 0.810 ± 0.028; $p > 0.05$). The differences of the homogeneity index (HI) between the 2 paired plans were statistically significant (average: 1.122 ± 0.010 *vs* 1.132 ± 0.014; $p < 0.01$). For OARs, the rectum, bladder, small intestine, and bony pelvis were evaluated in terms of V_{10}, V_{20}, V_{30}, and V_{40}, percentage of contoured OAR volumes receiving 10, 20, 30, and 40 Gy, respectively, and the mean dose (D_{mean}) received. The IMRT plans with the mMLC protected the OARs better than the plans with the sMLC. There were significant differences ($p < 0.05$) in evaluated parameters between the 2 paired IMRT plans, except for V_{30} and V_{40} of the rectum and V_{10}, V_{20}, V_{40}, and D_{mean} of the bladder. IMRT plans with the mMLC showed advantages over the plans with the sMLC in dose homogeneity for targets, dose sparing of OARs, and fewer MUs in cervical cancer.

Introduction

Cervical cancer shows high incidence and mortality for women worldwide.[1] For women with advanced or high-risk disease, concurrent chemoradiotherapy (CCRT), with or without surgery, is the standard method,[2,3] and therefore radiotherapy (RT) is the mainstay of treatment for cervical cancer.[4]

To achieve optimal treatment effect, it is crucial to minimize the dose sparing of the organs at risk (OARs) while maintaining adequate dose coverage to the target volume. In the last decade, intensity-modulated radiotherapy (IMRT) has proved to have various advantages over 3-dimensional conformal therapy not only in physical dosimetry but also in clinical practice. Moreover, clinical evaluation by radiobiological tools (*i.e.*, the equivalent uniform dose [EUD] or the local tumor control probability) has allowed further improvements in clinical practice. This has become not just an academic question in the area of IMRT, or modern rotational IMRT, when radiation oncologists commonly use a differential dose per fraction to deliver graded doses in the same treatment time.[5,6] IMRT plans could further reduce OAR doses or permit higher target doses, or both, thereby improving the therapeutic efficiency.[7] Interest in IMRT for gynecologic malignancies has grown considerably in the past 5 years.[8] For patients with cervical cancer, IMRT reduced doses to the bowel, rectum, bladder, and bone marrow (BM) in physical dosimetry[3,9] and decreased gastrointestinal, genitourinary, and hematologic toxicity in clinical practice.[9–12]

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Nevertheless, alarmingly high gastrointestinal, genitourinary, and hematologic complications were documented in patients who underwent CCRT. If patients could not tolerate it, the treatment process had to be suspended, and the curative effects would be sharply disvalued.[12] Therefore, it is necessary to further reduce the dose sparing of OARs.

The introduction of the multileaf collimator (MLC) has spurred the RT process, although target conformity is limited by the discrete step size of the leaves. For some kinds of tumors, the targets and OARs are so close in anatomy that it is very difficult to determine the boundaries between them. The MLC leaf width may affect the dose distribution in targets and OARs, and how a single MLC conforms to the outline of targets is closely related with the leaf width of the corresponding MLC. Recently, a few researchers evaluated the effects of MLC leaf width on treatment planning for several kinds of tumors, and the results are rather controversial.[13–15] Lu Wang *et al.*[15] compared IMRT plans with 2 MLC leaf widths (4 *vs* 10 mm) for prostate cancer and concluded that the 4-mm MLC significantly improved critical organ protection compared with the conventional 10-mm MLC. Previously, we examined the effects of MLC leaf widths on the IMRT planning for nasopharyngeal cancer (NPC)[13] and upper thoracic esophageal cancer (UTEC).[14] The result showed that the IMRT plans with micro-MLC (mMLC) had significant advantages in dose coverage for targets with fewer monitor units (MUs) in treatment for NPC but failed to reduce dose sparing of OARs. In IMRT planning for UTEC, when compared with the standard MLC (sMLC), the mMLC not only showed the fewer MUs and more optimal targets coverage but also reduced the dose sparing of OARs. The 2 studies were the reference in clinical treatment for NPC and UTEC in our center. Therefore, it is reasonable to conduct studies on further improving the dose coverage of targets and reducing the dose sparing of OARs by comparing the effects of MLC leaf widths (10 mm for sMLC and 4 mm for mMLC) on the IMRT planning for cervical cancer. We tried to find a better choice to guide in clinical in treatment for cervical cancer.

Methods and Materials

Patient data

Twelve women (median age 46 years, ranging from 36 to 58 years) with pathologically confirmed postoperative cervical cancer, who were admitted to our hospital between January 2010 and August 2010 and underwent hysterectomy and pelvic lymphadenectomy, were staged according to the 2009 International Federation of Obstetricians and Gynaecologists staging system[16] (Table 1). This study was approved by the Ethics Committee of West China Hospital of Sichuan University.

MLC

The Elekta MLCi, which is equipped in the Elekta Precise Treatment System (Elekta Oncology System, Sweden)[13] with a leaf width of 10 mm, was used as the sMLC device in 7 patients. It has 40 pairs of leaves with a travel range of 32.5 cm in the y-direction covering a 40 cm × 40 cm field.

The Elekta Beam Modulator (Elekta Oncology Systems, Crawley, UK),[13,17] which is equipped in the Elekta Synergy Treatment System (Elekta Oncology System, Sweden) with a leaf width of 4 mm, was used as the mMLC device in 5 patients. It has 80 individually controlled leaves with a travel range above 21 cm.

The sMLC has additional backup jaws and a source to sMLC distance of 37.3 cm. The mMLC has unmovable backup jaws and a source to mMLC distance of 46.28 cm. The total transmission of the sMLC calculated in the treatment planning system (TPS) would be the fixed-jaw transmission factor (backup-jaw transmission factor 0.11) multiplied by the MLC transmission factor (0.003), whereas only a MLC transmission factor (0.007) would be applied in treatment planning of the mMLC.[18]

Target delineation and dose prescription

All patients were immobilized in the supine position with abdomen body thermoplastic masks and underwent a spiral computed tomography (Siemens Sensation 4) of 3-mm slice thickness. Computed tomography images were transferred to and registered in the TPS) using the same method.

The clinical target volume (CTV) included the upper 3.0 cm of the vagina, paravaginal soft tissue lateral to the vagina, and regional lymph nodes (common, internal, external iliac, and presacral nodes). Inguinal nodes were treated in women with involvement of the inferior third of the vagina.[19] Based on a previous study[7] and our observation on organ motion and setup uncertainty, we applied a 7-mm uniform planning margin around the CTV to delineate the planning target volume (PTV). Critical normal structures were contoured as OARs, including the rectum, bladder, small intestine, right and left femoral heads, and bony pelvis.

For each patient, 45-Gy irradiation was delivered to PTV in 25 fractions. The prescribed dose covered at least 95% of the PTV. The restricted doses to the OARs were as follows: rectum (V_{40} [percentage of volume receiving 40 Gy] $<$ 40%, Maximum dose $\leq$ 50 Gy), bladder (V_{40} $<$ 40%, Maximum dose $\leq$ 50 Gy), small intestine (V_{30} $<$ 40%, Maximum dose $\leq$ 50 Gy), right femoral head (V_{50} $<$ 5% and V_{40} $<$ 10%), left femoral head (V_{50} $<$ 5% and V_{40} $<$ 10%), and bone pelvis (V_{10} $<$ 90% and V_{20} $<$ 75%).[20]

Planning system

Inverse IMRT plans were generated and evaluated using the TPS (Pinnacle3, version 9.0; Philips, Fitchburg, WI). The step-and-shoot beam type of the IMRT was used. Each plan was based on a beam arrangement with equidistant gantry angles

Table 1
Patient information and tumor characteristics

Patient number	Age	Histology	Grade	FIGO stage	PTV volume (cm^3)	Concurrent chemotherapy
1	40	Squamous cell carcinoma	G2	IB2	949.303	Yes
2	38	Squamous cell carcinoma	G3	IA2	932.435	No
3	50	Squamous cell carcinoma	G2	IB1	960.63	No
4	42	Squamous cell carcinoma	G2	IB2	1109.85	Yes
5	43	Squamous cell carcinoma	G3	IB1	1025.42	Yes
6	36	Squamous cell carcinoma	G2	IA2	1092.31	No
7	50	Squamous cell carcinoma	G3	IA2	1022.31	No
8	46	Squamous cell carcinoma	G3	IB2	1360.45	Yes
9	55	Squamous cell carcinoma	G2	IB2	1156.86	No
10	58	Squamous cell carcinoma	G3	IA2	1091.18	No
11	45	Squamous cell carcinoma	G2	IA2	1049.34	No
12	48	Squamous cell carcinoma	G3	IB2	1126.2	Yes

FIGO = International Federation of Obstetricians and Gynaecologists.

Table 2
Comparisons of MUs and segments in paired plans in 12 patients with cervical cancer ($n = 12$)

Patient number	Number of MUs		Number of segments	
	10 mm	4 mm	10 mm	4 mm
1	706	703.4	58	59
2	796	676.3	59	60
3	808	670.5	60	58
4	802	693.1	54	59
5	753	636.4	60	60
6	728	629.1	59	60
7	885	762.6	58	58
8	887	702.2	57	58
9	867	840.3	60	59
10	791	689.8	60	60
11	804	689.8	60	60
12	801	731.5	60	57
mean ± SD	802 ± 56.90	702.0 ± 0.08	58.75 ± 1.80	59 ± 1.04
p Value	0.0001		0.6670	

SD = standard deviation; 10 and 4 mm = multileaf collimator leaf width of 10 and 4 mm.