Comparison of Treatment Plans with Multileaf Collimators of different Leaf Width

Joo Young Kim, Sung Yong Park, Doo Hyun Lee, Seok Ho Lee,
Tae Hyun Kim, and Kwan Ho Cho

Research Institute and Hospital, National Cancer Center, Goyang, Korea

Purpose: To compare desimetrically intensity-modulated radiotherapy treatment plans with commercially available multileaf collimators (MLCs) of different leaf width for intracranial lesions.
Materials and Methods: Twelve patients with intracranial lesions were treated with BrainLAB's micro-MLCs (mMLCs) and performed with the BrainSCAN ver. 5.2 planning software. They were replanned using the Varian 120 and 80 MLCs. These collimators have minimum leaf width of 3 mm, 5 mm and 10 mm at isocenter, respectively. PTV was 3.3~339.2 cm^3 and the number of beams was 3~7. These three plans were compared with respect to the uniformity and the conformity indices, doses to critical organ and normal tissue.
Results: For the uniformity index of the planning target volume (PTV), there were no statistically significant differences between mMLCs and 120 MLCs (p=0.057) and between 120 MLCs and 80 MLCs (p=0.388). However, there was a difference between mMLCs and 80 MLCs ($p<0.001$). Maximum target dose to the PTV showed no dependency with respect to the leaf width. On the contrary, there were statistically significant differences in the conformity indices between mMLCs and 120 MLCs (p=0.003), between mMLCs and 80 MLCs (p=0.003) and between 120 MLCs and 80 MLCs (p=0.003). The volume of brainstem irradiated to ≥70% dose and to ≥50% dose was increased as the leaf width of MLCs increased. In particular, the volume of normal tissue irradiated is obviously changed for different leaf width. Volumetric increments for MLCs with leaf widths of 5 mm and 10 mm were 6.3% and 23.2% to the normal tissue irradiated to ≥50% dose, and 8.7% and 32.7% to the normal tissue irradiated to ≥70% dose, respectively, compared to the volume for MLCs with leaf width of 3 mm.
Conclusions: The uniformity index and maximum target dose to the PTV showed no dependency with respect to leaf width of MLCs. However, the conformity index was improved as the leaf width decreased. For the sparing of normal brain tissue, treatment plans with MLCs of 3 mm leaf width is more effective, compared to ones with MLCs of 5 mm and 10 mm leaf widths.

Key Words: Multileaf collimators (MLCs), Uniformity index, Conformity index, Sparing of critical organ and normal brain tissue

INTRODUCTION

Intensity-modulated radiotherapy (IMRT) for intracranial lesions involves the precise delivery of a dose of ionizing radiation. Because of the importance of neurological structures and their sensitivity to radiation, sparing of normal brain tissue is one of the key goals of a radio surgery/therapy procedure. Recent advances in multileaf collimator (MLC) technology have provided clinicians with the ability to shape a radio surgery/therapy beam and thereby deliver a homogeneous target dose while simultaneously sparing critical organs.

MLCs are used instead of the conformal blocks due to their efficiency in treatment delivery, although the target conformity is limited by the discrete step size of the leaves. Adams *et al.*[1] compared treatment plans, in terms of normal tissue doses

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Corresponding Author: Sung Yong Park, Center for Proton Therapy, National Cancer Center, 809 Madu 1-dong, Ilsan-gu, Goyang-si, Gyeonggi-do 411-769, Korea
Tel: 031)920-1728, Fax: 031)920-0149
E-mail: cool_park@ncc.re.kr

and tumor coverage, for fields shaped using conformal blocks and conventional MLCs and reported that the plan by MLCs showed increased volume of normal tissue being treated to > 50% and >80% of the prescription dose.

Comparisons of plans with MLCs with different leaf width have been studied previously. Kubo *et al.*[2] reported that smaller leaf width of MLCs improved conformity to the target volume and spared more bladder and rectum than larger leaf width of MLCs for prostate plans. For IMRT plans, comparison studies reported for different leaf width[3] and for different beamlet size[4] were reported. Another study for 3D-CRT plans[5] was reported recently.

Since normal tissue in the brain was sensitive to radiation, IMRT plans for intracranial lesions are needed to systematically investigate the effect for the change of leaf width of MLCs. To do this, we evaluated and compared treatment plans for different MLCs having leaf width of 3 mm, 5 mm and 10 mm, at isocenter, respectively. Three plans for each patient were compared with respect to the uniformity[6] and conformity indices, doses to critical organ and normal tissue.

MATERIALS AND METHODS

Multileaf Collimator systems

The BrainLAB micro-MLC (mMLC) system is a conveniently detachable unit to linear accelerators which does not have a built-in MLC. It has 26 pairs of leaves and a maximum field size of 10×10 cm. The leaf width at isocenter is 3 mm for the central 14 pairs, 4.5 mm for the other 6 pairs, and 5.5 mm for the outermost 6 pairs. Similar to the Varian MLCs, the BrainLAB mMLCs are compatible with Varian C series linear accelerators. The Varian 120 MLCs has a leaf width of 5 mm at isocenter for the 40 pairs, 10 mm for the other 20 pairs and a maximum field size of 40×40 cm. The Varian 80 MLCs has a uniform leaf width of 10 mm for the 40 pairs and a maximum field size of 40×40 cm.

Treatment Planning and Evaluation

For the treatment of the irregular lesions in the brain, fused image by computered tomography (CT) and magnetic resonance (MR) scans was needed, which was similar as in 3D-CRT works.[5] On this image, target and various organs such as the eyes and optic structures were delineated.

IMRT treatment planning is a computer optimization process based on a set of dose constraints on critical organs and prescribed doses to the tumor targets. There are two types of dose constraints in this planning system, PTV constraints and organ at risk (OAR) constraints. Under the restrictions of dose constraints, inverse planning process is trying to deliver suitable dose to the PTV by PTV constraints and not to deliver more doses to critical organs by OAR constraints.

After suitable dose distribution is obtained, dose-volume histograms (DVHs) for the PTV and critical organs, such as brainstem and optic chiasm are calculated and used to evaluated plan. For quantitative evaluation of plan, the uniformity and the conformity indices are used. The uniformity index to the PTV is defined as the ratio between the PTV maximum dose and D_{95}, the dose received by 95% of the target volume. The conformity index is the ratio of the total tissue volume (normal tissue volume+PTV) receiving the prescription dose to the PTV receiving the prescription dose.

Comparison between MLCs of different leaf width

Using the Varian 120 and 80 MLCs, IMRT plans previously planned using BrainLAB mMLCs were replanned. Table 1 summarized the target volume and number of beams for patients with tumors in the brain. Grid size and constraints for IMRT plans should be fixed, not to mention of the number,

Table 1. Target size and number of beams for intracranial lesions.

Patient no.	Target vol. (cc)	Number of beams
1	144.2	6
2	16.7	5
3 (1)*	20.5	5
3 (2)*	7.8	5
4	9.6	6
5	3.3	7
6	339.2	3
7	23.9	4
8	31.7	5
9	8.4	5
10	22.4	5
11	78.6	6
12	16.1	5

* Patient 3 have two isocenters

direction, and weighting of the beams and the collimator angle to treatmetn plans were replanned using Varian 120 and 80 MLCs. In order to compare treatment plans for different leaf widths, we used paraemeters such as the uniformity index and maximum target dose to the PTV, the conformity index and doses to critical organs and normal brain tissue. DVHs for critical organ (brainstem) and normal brain tissue were calculated to compare the volumes of the brainstem and normal brain tissue irradiated to $\geq$50% and $\geq$70% dose. Statistical analysis was performed according to Wilcoxon signed rank test (p value~0.05).[7]

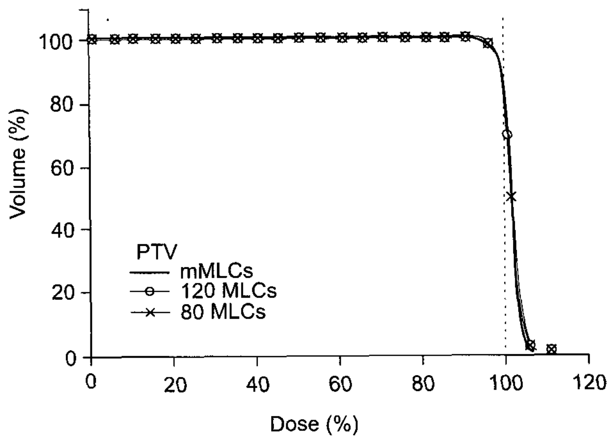

Fig. 1. DVHs for the PTV for plans with MLCs of different leaf width of patient 6.

RESULTS

Uniformity index and maximum dose to the PTV

The uniformity index for the PTV was determined from the DVHs for each plan in Fig. 1, and summarized in Table 2. There was no statistically significant difference between mMLCs with 120 MLCs (p=0.057) and between 120 MLCs and 80 MLCs (p=0.388). However, there was a difference between mMLCs with 80 MLCs ($p<0.001$). In this study, it is not enough to find the dependency to the uniformity index with respect to the leaf width of MLCs.

The maximum target dose to the PTV was also summarized in Table 2, and which was normalized to the prescribed dose for each case. No significant differences were found between three MLCs (mMLCs : 120 MLCs (p=0.388), mMLCs : 80 MLCs (p=0.227), 120 MLCs : 80 MLCs (p=0.774)).

Conformity index

The conformity index was also determined from DVHs for

Table 2. Uniformity index and maximum target dose to the PTV for plans with MLCs of different leaf widths.

Patient no.	Uniformity index			Maximum target dose (%)		
	m3	120-leaf	80-leaf	m3	120-leaf	80-leaf
1	1.05	1.10	1.08	106	111	109
2	1.07	1.06	1.08	107	106	106
3 (1)	1.12	1.16	1.15	110	114	113
3 (2)	1.08	1.09	1.09	106	107	107
4	1.05	1.06	1.07	106	107	108
5	1.04	1.03	1.04	102	101	102
6	1.26	1.23	1.27	116	113	116
7	1.19	1.22	1.21	105	105	104
8	1.07	1.09	1.10	108	108	107
9	1.09	1.13	1.13	108	111	108
10	1.11	1.12	1.16	107	106	108
11	1.10	1.14	1.15	106	109	108
12	1.07	1.12	1.13	108	113	114
Mean	1.10	1.12	1.13	107	109	108
SD	0.06	0.06	0.06	3.2	3.8	3.9

Table 3. Conformity index for plans with MLCs of different leaf widths.

Patient no.	Conformity index		
	m3	120-leaf	80-leaf
1	1.22	1.23	1.31
2	1.44	1.63	1.85
3 (1)	1.64	1.72	1.83
3 (2)	2.64	2.69	3.26
4	1.53	1.67	1.77
5	1.84	2.12	2.25
6	1.15	1.17	1.18
7	1.00	1.00	1.00
8	1.30	1.35	1.40
9	1.77	1.80	1.93
10	1.23	1.59	2.52
11	1.34	1.21	1.16
12	1.42	1.62	1.70
Mean	1.50	1.60	1.78
SD	0.42	0.45	0.63

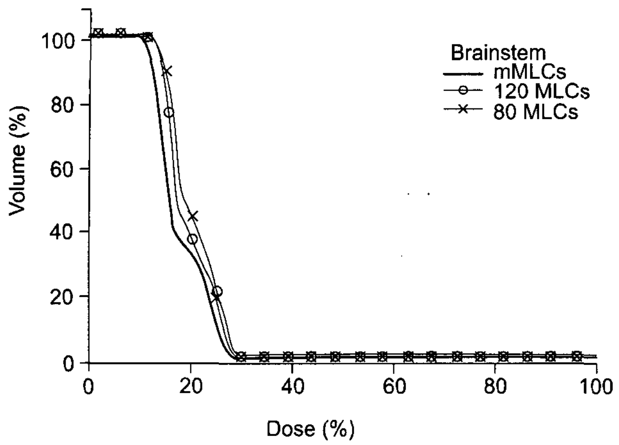

Fig. 2. DVHs for critical organ (brainstem) for plans with MLCs of different leaf width of patient 6.

the PTV and normal tissue. There were statistically significant differences in the conformity indices between mMLCs and 120 MLCs (p=0.003), between mMLCs and 80 MLCs (p=0.003) and between 120 MLCs and 80 MLCs (p=0.003). As seen in Table 3, the mean value of conformity indices for mMLCs was 1.50±0.42, for 120 MLCs was 1.60±0.45, for 80 MLCs was 1.78±0.63. This shows that the conformity is improved as the leaf width decreases.

Dose to critical organ

DVHs for critical organ (brainstem) were shown in Fig. 2, and volumes of brainstem irradiated for each MLCs leaf width were summarized in Table 4. Only cases in which % volume of critical organ was above 2% were included in this table. Volumes of brainstem irradiated to ≥70% dose and ≥50% dose were increased as the leaf width increased. However, data for patient 6 and 7 were not good because number of beams were so small that dose to critical organs was strongly dependent on beam direction (See Table 1.).

Dose to normal brain tissue

Table 5 showed volumes of normal brain tissue irradiated to ≥ 70% dose and ≥50% dose for plans with MLCs of different leaf width. As expected in Table 3 related to conformity index, volumes of normal brain tissue irradiated are increased as the leaf width increased. Volumetric increments for MLCs with leaf widths of 5 mm and 10 mm were 6.3% and 23.2% to the normal tissue irradiated to ≥50% dose, and 8.7% and 32.7% to the normal tissue irradiated to ≥70% dose, respectively, compared to the volume for MLCs with leaf width of 3 mm. This means that the smaller leaf width of MLCs provides better sparing for normal tissue. However, data for patient 1 and 6 in Table 5 shows that this result is not correct for the cases of too large target volume compared to the scale of leaf width of MLCs (See Table 1).

Table 4. Volumes of critical organ (brainstem) irradiated to ≥70% dose and ≥50% dose for plans with MLCs of different leaf widths.

Patient no.	% vol.≥70% dose			% vol.≥50% dose		
	m3	120-leaf	80-leaf	m3	120-leaf	80-leaf
4	2.43	3.56	8.61	6.93	9.36	16.10
6	26.29	29.41	32.35	71.13	64.71	67.65
7	20.78	22.66	27.66	39.84	70.00	70.00
12	9.41	11.38	15.10	17.29	19.91	24.29
Mean	14.73	16.75	20.93	33.80	41.00	44.51

Table 5. Volumes of normal brain tissue irradiated to ≥70% dose and ≥50% dose for plans with MLCs of different leaf widths.

Patient no.	% vol.≥70% dose			% vol.≥50% dose		
	m3	120-leaf	80-leaf	m3	120-leaf	80-leaf
1	26.45	25.27	33.52	46.87	45.62	56.38
2	6.64	8.16	9.81	11.47	13.83	16.77
3	7.43	8.53	10.62	13.75	14.87	18.72
4	3.39	4.18	5.25	5.84	7.36	9.12
5	1.66	2.30	3.37	3.07	3.87	5.57
6	33.17	31.22	33.55	70.46	64.91	67.04
7	5.92	6.20	7.28	14.25	15.79	17.98
8	6.08	7.67	10.54	12.61	15.07	19.23
9	3.59	5.25	7.27	7.20	10.13	13.52
10	6.63	9.47	12.38	13.81	18.01	22.52
11	11.93	13.05	14.60	25.06	26.75	29.71
12	4.04	5.75	6.78	8.14	10.99	12.28
Mean	9.74	10.59	12.91	19.38	20.60	24.07

DISCUSSION

The uniformity index for the PTV, which used a measure of qualitative evaluation of treatment plans for dose gradient to the PTV, was seen no dependency with respect to the target volume, but was seen dependency with respect to the number of beams as Hunt *et al.*[6] reported that the uniformity index for the PTV improved as the number of beams increased. For the patient 6 and 7 (number of beams was 3 and 4, respectively), the uniformity index for mMLC was 1.26 and 1.19 respectively, as seen in Table 2. For other patients, however, the mean value of the uniformity index for mMLC was 1.08. To find the relation between uniformity index and number of beams precisely, more work needs to be done.

Our results showed that the conformity index was improved as the leaf width decreased, which are consistent with those of Kubo *et al.*[2] for radiosurgery with a low number of beams, and Fiveash *et al.*[3] of CNS case for IMRT. These two studies measured conformity by the radio of the planning isodose volume to the target volume (PITV). Comparison study between MLCs with leaf width of 3 mm and of 5 mm for 3D-CRT plans[5] showed more consistent results not for the conformity index but for volumetric increments of irradiated normal tissue, since conformity index is closely related to the volume of irradiated normal tissue.

Previous works reported that smaller leaf width of MLCs spared critical organs better for 3D-CRT plans[2,5]. For IMRT works of CNS cases,[3] however, it was reported that only in the moderate dose range, less dose was delivered to the critical organs with plans of smaller leaf width. In his study, it did not show sufficient result for the relation between leaf width of MLC and sparing of critical organ. In order to make clear the dependency of dose to critical organs with respect to the leaf width of MLC, cases for treatment plans with sufficient number of beams are carefully selected.

Although we have found some benefits for smaller leaf width of MLCs, we need further careful analysis to parameters (for example, the patient diagnosis and target volume) to immediately apply these results to the clinics. However, that smaller leaf width of MLCs has some advantages for conformity for target volume and saving of normal tissue is worth reporting, when clinicians choose the type of MLC to prescribe for patients.

CONCLUSIONS

We studied IMRT treatment plans with MLCs of different leaf width for intracranial lesions. Leaf width dependency for different MLCs was not found for the uniformity index and the maximum dose to the PTV. However, the conformity index was improved as the leaf width decreased. Volumes of critical organ (brainstem) and normal tissue irradiated to $\geq$ 70% dose and $\geq$50% dose were increased as the leaf width of MLCs was increased. From this study, we suggest that for the sparing of normal tissue, treatment plans with MLCs of 3 mm leaf width are more effective, compared to ones with MLCs of 5 mm and 10 mm leaf widths.

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Leaf width가 다른 다엽 콜리메터에 의한 치료계획 비교

국립암센터, 양성자치료센터

김주영 · 박성용 · 이두현 · 이석호 · 김태현 · 조관호

목적: Leaf width가 다른 다엽 콜리메터(MLCs)를 이용, 두개내 병변에 관하여 각각의 세기조절방사선치료(IMRT) 계획을 수립하여, 이를 선량학적으로 비교하였다.

재료 및 방법: BrainSCAN ver. 5.2. 소프트웨어를 사용하여 micro-MLC로 이미 치료가 수행된 12명의 환자를 Varian사의 120 MLC와 80 MLC로 다시 치료계획하였으며 이 다엽 콜리메터들은 중심에서의 leaf width가 각각 3 mm, 5 mm, 10 mm이다. 이 때, 계획용 표적체적은 3.3~339.2 cc였고, 조사된 빔의 수는 3~7개이다. 이들을 uniformity index, conformity index, 결정장기와 정상조직 내 선량으로 서로 비교하였다.

결과: 계획용 표적체적의 uniformity index 경우, mMLCs와 120 MLCs 사이에서 (p=0.057) 120 MLCs와 80 MLCs 사이에서(p=0.388) 통계적으로 차이가 없었다. 그러나 mMLCs와 80 MLCs 사이에서 차이를 보였다(p<0.001). 계획용 표적체적에 대한 최대 목표선량은 leaf width와 연관성이 없었다. 반면에, conformity index의 경우는 mMLCs와 120 MLCs (p=0.003), mMLCs와 80 MLCs (p=0.003), 80 MLCs와 120 MLCs (p=0.003) 사이에서 통계적인 차이를 보였다. 처방선량의 70%와 50% 이상 조사되는 뇌간의 부피는 다엽 콜리메터의 leaf width가 증가함에 따라 증가하였다. 특히, leaf width의 변화에 따라 방사선에 조사되는 정상 뇌조직의 부피가 분명하게 변하였다. Leaf width가 3 mm인 다엽 콜리메터와 비교하였을 때, leaf width가 5 mm, 10 mm인 다엽 콜리메터의 부피 증가는 처방선량의 50% 이상 조사되는 정상조직의 경우, 각각 6.3%, 23.2%였고, 처방선량의 70% 이상 조사되는 정상조직의 경우, 각각 8.7%, 32.7%였다.

결론: 계획용 표적체적의 uniformity index와 최대 목표선량은 leaf width와 연관성이 없었다. 그렇지만 conformity index는 leaf width가 감소함에 따라 향상되었다. 두개내 병변 치료시, 정상 뇌조직의 보존에 있어 leaf width 5 mm, 10 mm인 다엽 콜리메터를 이용한 치료계획보다 leaf width 3 mm인 다엽 콜리메터를 이용한 치료계획이 보다 효과적임을 알 수 있었다.

중심단어: 다엽 콜리메터(MLCs), Uniformity index, Conformity index, 결정장기와 정상 뇌조직의 보존