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# Clinical Feasibility of Leakage and Transmission Radiation Dosimetry Using Multileaf Collimator of ELEKTA Synergy-S Accelerator During Conventional Radiotherapy

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*Purpose*: The leakage and transmission rate (LTR) of the new-type multileaf collimator (MLC) in the Elekta Synergy-S accelerator was measured, the effects of the X-ray energy and gantry angles on the LTR, as well as the application research of LTR in clinic, were discussed. Moreover, the causes of the leakage and transmission dose (LTD) were analyzed. *Methods*: With a PTW UNIDOS dosimeter and a MP3 3D water tank, under the condition of different X-ray energies, the interleaf transmission, between-leaf leakage and leaf ends leakage at the reference position, as well as the LTR with changing the gantry angle, were measured. Moreover, the LTR change curves in the direction of gun-target (GT) and left-to-right (AB) in the isocentric plane were obtained, and the LTR was also measured at 0 mm, 50 mm and 100 mm off-axis, respectively. In clinical research, each patient was treated with the whole brain radiotherapy for both Plan 1 and Plan 2, Plan 1 was without jaws, but Plan 2 adopted jaws for shielding leakage and transmission irradiation therein, whose effects on the target volume and organs at risk (OARs, including eyes and lens) were studied. *Results*: At the reference position, the X-ray energy slightly affected the interleaf transmission, between-leaf and leaf ends leakages. Moreover, the gravity had slight effect on the between-leaf leakage; the X-ray energy had little effect on the LTD change curves in the GT and AB directions. Based on the same X-ray energy, the LTD was rather low at the point off-axis, which showed a decreased tendency following with the point further away from the axis gradually. Furthermore, different X-ray energies also had a certain effect on the LTD at the same position away from the axis, and the LTRs were larger with 10 MV and 18 MV of X-ray than that with 6 MV. Compared with Plan 1, the dose distribution of the target volume was superior, the maximum doses of eyes and lens were lower for Plan 2. *Conclusion*: The existence of interleaf leakage radiation remarkably affected the target volume and OARs, the collimator should be rotated using the jaws in accordance with the circumstances when optimizing the radiotherapy plans to protect OARs and normal tissues, which aimed to reduce the risks of irradiation.



**Keywords:** Leakage and Transmission Rate, Leakage and Transmission Dose, Multileaf Collimator, Radiotherapy, Interleaf Transmission, Between-Leaf Leakage, Leaf Ends Leakage.

## 1. INTRODUCTION

As an important device of the medical linear accelerator, the multi-leaf collimator (MLC) has been widely used in the three-dimensional conformal radiation therapy (3D-CRT) and intensity-modulated radiation therapy (IMRT) nowadays. Moreover, MLC is mainly adopted to form irregular fields instead of the blocks, and the collimator motion can be controlled by the computer in the process of irradiation to realize the goal of adjusting the static and dynamic MLC. At present, MLC is becoming the standard configuration of the medical linear accelerator. Deep understanding, as well as right grasp, on the mechanics and dosimetric characteristics of MLC is the basic task of radiation oncology physics.[1,2]

In clinic, a certain gap should be left between the adjacent leaves ensuring each leaf of MLC move independently and flexibly, which aims to avoid leaf deformation and stuck

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during movement. However, a mortise structure is necessary to be designed on the side of the leaf as this gap brings radiation leakage, and the adjacent leaves are capable of moving friendly using a tongue-and-groove design. Thus, the leaves of MLC are able to move stably and reliably then.[3,4] There are deviations of MLC position accuracy when the gantry angles of the accelerator change because of the MLC gravity, which will affect the real dose distribution remarkably.[5] The deviations are mostly neglected in current treatment planning systems, although multiple gantry angles exist in the main fields of IMRT, the MLC gravity effects on the radiation dose are commonly out of consideration.

As to the complicated target volumes, MU for single irradiation of IMRT plan may reach up to 1000 MU; furthermore, the collimator transmission and interleaf leakage seriously affect the target volume and normal tissues,[6,7] thus a quantitative measurement of MLC transmission is necessary. In this study, with the dosimeter and water tank, the leakage and transmission dose (LTD) at different X-ray energies of the Beam Modulator MLC which is internally installed in Synergy-S accelerator were measured in water, air and a RW3 solid-water phantom, respectively. In clinical application, regarding the whole brain radiotherapy, low dose, such as 500 cGy, can result in cataract as lens is highly sensitive to the rays. The effects of the whole radiotherapy are supposed to be researched since the existence of the leakage and transmission radiation. Therefore, the study on the leakage and transmission radiation effects on the target volume and OARs (including eyes and lens) is performed for the whole brain radiotherapy in this paper.

## 2. MATERIALS AND METHODS



### 2.1. Instruments and Equipment

PTW UNIDOS dosimeter, 0.125 cc thimble ionization chamber, MP3 three dimensional water tank, RW3 solid-water phantom (from PTW Inc., Germany) and Synergy-S medical linear accelerator (from ELEKTA Inc., Sweden).

### 2.2. Beam Modulator MLC

As shown in Figure 1, Elekta MLC is able to replace the upper-jaw in the direction of gun-target (GT) of the accelerator. Meanwhile a pair of back-up slice collimators is added between MLC and the lower-jaw, which move following with the MLC leaf and further strengthen the ability of MLC leaf for the radiation attenuation. Therefore, the main advantages of this collimator are that the motion range of MLC is smaller and MLC with compact structure when the leaf is close to X-ray target and the same field size is formed.

The Beam Modulator MLC shown in Figure 2 consisted of 40 pairs of leaves with 7.5 cm thick made of high-density tungsten alloy. Each individual leaf projected a width of 4 mm at the isocenter and the maximum field size of MLC was $16 \times 21$ cm$^2$. Moreover, the leaf ends were designed as arc-shape and the leaves travel along $x$-axis of the accelerator. All opposite leaves can be fully closed. In order to reduce friction during the leaf movement, there was a certain gap between two adjacent leaves, and each leaf was driven by an electric motor individually.

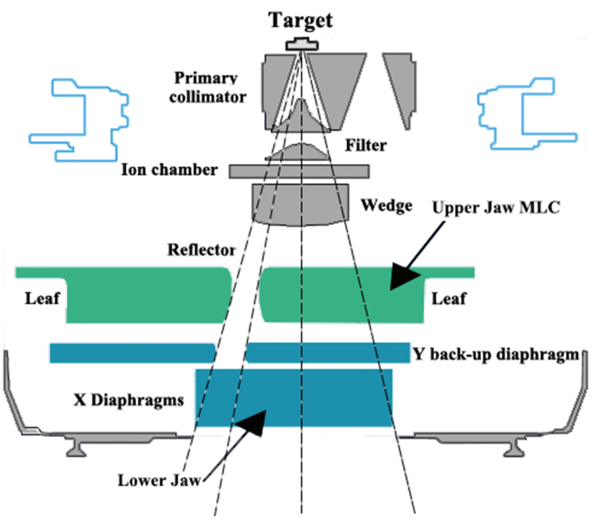


**Fig. 1.** MLC head schematic of Elekta LINAC.

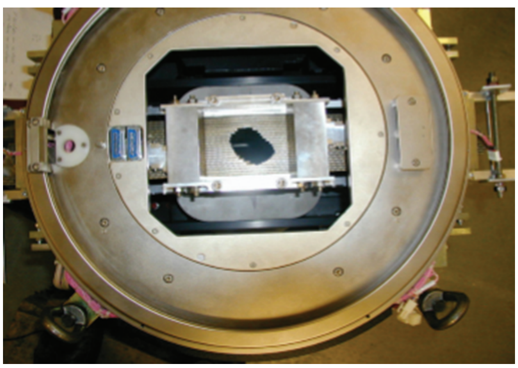

**Fig. 2.** Beam modulator of Elekta LINAC.

### 2.3. LTR at the Reference Position

The component unit of MLC is a single leaf as shown in Figure 3, the leaf width is physical width and perpendicular to the direction of both X-ray and leaf movement, which is equal to the width between the two sides; the leaf length is also physical width and parallel to the direction of leaf movement; the leaf top is the leaf surface next to X-ray target while the leaf bottom is the leaf surface near the skin of patients; the leaf height is the physical height between the leaf top and leaf bottom along the ray incident direction; the boundary of the field formed by the leaf is called leaf end. The adjacent leaves are arranged in parallel along the direction of leaf width, which are composed of each leaf group. MLC comprises two leaf groups relative to each other. Because of the structural characteristics of MLC, three types of leakage and transmission radiation were usually exited in the leaves, namely interleaf transmission, between-leaf leakage and leaf ends leakage.[8]

#### 2.3.1. LTR Measurement

The gantry and the collimator were both set to 0°, the source-to-detector distance (SDD) and the field size were 150 cm, $16 \times 21$ cm$^2$ respectively. The 0.125 cc ionization chamber was connected to a PTW UNIDOS dosimeter in air. During measuring the interleaf transmission dose, the reference position of the ionization chamber probe was supposed to be located in the middle of the projection by the leaf in the isocentric plane. Similarly, as to measure the between-leaf leakage dose, the reference position of the ionization chamber probe was supposed to be located

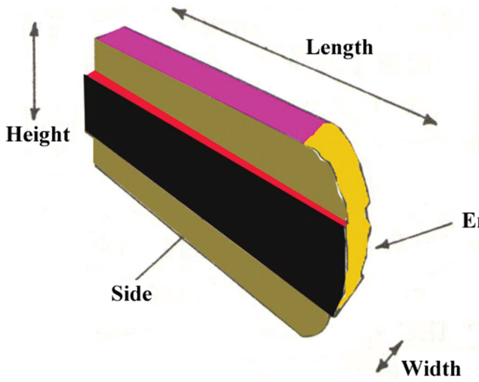


Fig. 3. Leaf structure of MLC.

in the middle of the projection by the gap of the adjacent leaves in the isocentric plane. Also, as for measuring the leaf ends leakage dose, the reference position of the ionization chamber probe was supposed to be located in the middle of the projection by the gap of the leaf ends in the isocentric plane.

Firstly, the accelerator beams on for 500 MU, and the dose rate is 300 MU/min, with 6 MV, 10 MV and 18 MV separately after all the leaves were opened. Sequently, the LTD was measured three times repeatedly at three different X-ray energies, i.e., 6 MV, 10 MV and 18 MV, respectively, to obtain mean value which was defined as $D_{\text{open}}$. Then, the accelerator beams on for 500 MU with 6 MV, 10 MV and 18 MV separately again after all the leaves were fully closed, and the LTD measured similarly were also averaged, which was called $D_{\text{blocked}}$. Therefore, the leakage and transmission radiation through the MLC was estimated as a percentage according to:[9,10]



$$\text{LTR}(\%) = \frac{D_{\text{blocked}}}{D_{\text{open}}} \times 100 \qquad (1)$$

where LTR refers to leakage and transmission rate, only changing the gantry angle according to the above methods, the values at each reference position were measured and the corresponding percentage was calculated when the gantry angles were equivalent to 30°, 60°, 90°, 120°, 150° and 180°, respectively.

#### 2.3.2. LTR Measurement with Changing the Gantry Angle Dynamically

Firstly, the gantry was set to 0°, the MLC leaves were fully opened, as well, the SDD and the field size were equivalent to 150 cm, $16 \times 21$ cm$^2$ respectively. In the 3D water tank, the 0.125 cc ionization chamber was connected to the PTW UNIDOS dosimeter, and the reference detector was placed on the diagonal line of the irradiated field. Then the isocenter point was defined as the original point, and the probe scanning motion of the ionization chamber was controlled in the ioscentric plane adopting the controller of the 3D water tank. Furthermore, the direction includes GT direction, which was perpendicular to the direction of leaf motion, and left-to-right (AB) direction, which was in line with the direction of leaf motion. Moreover, the GT direction ranges from −80 to 80 mm, while the AB direction varied from −40 to 40 mm, and it was vital to ensure the probe pass through the original point for each scanning. In the process of scanning, the values in the GT and AB directions were needed to be recorded at three different energies, i.e., 6 MV, 10 MV and 18 MV of X-ray.

Secondly, based on the above measuring methods, the values in the GT and AB directions were needed to be recorded at three different X-ray energies similarly when all the leaves were closed. Finally, the comparison and analysis on these two groups of measured values were conducted, as well the curves of LTR with changing the position were obtained the in both directions.

#### 2.3.3. LTD Measurement at the Point Away from the Central Axis

The gantry and the collimator were both set to 0°, the SSD and the irradiated field were equivalent to 200 cm, $10.4 \times 9.6$ cm$^2$ respectively. The 0.125 cc ionization chamber was placed in the RW3 solid water phantom, and the distances from the chamber to the center of irradiation field were set to 0 mm, 50 mm and 100 mm respectively. Furthermore, the measuring depth was the depth of dose maximum corresponding to these three different X-ray energies, the source to skin distance (SSD) was 200 cm and the accelerator beamed on 500 MU, then the reading in the PTW dosimeter was recorded and as a reference.

Then MLC was closed, and the ionization chamber was 0 mm, 50 mm and 100 mm away from the center of the radiation field respectively, the LTRs were measured under an irradiation of 500 MU at a depth of 1 cm for three times then, which were averaged and called the measured value of the leakage and transmission radiation, which was compared with the reference value to obtain the LTR off-axis.

#### 2.3.4. Evaluation Method for Effects of LTR on the Brain Radiotherapy

Ten patients with brain metastatic tumor were selected for the whole brain radiotherapy with the supine position, and two modes of radiotherapy plans were designed separately, namely Plan 1 and Plan 2, which adopted three-dimensional conformal radiation therapy (3D-CRT) technique with 3000 cGy of the prescription dose, and 95% of CTV is supposed to receive 95% of the prescription dose at least. As to Plan 1, MLC leaf protected eyes and lens from unnecessary irradiation. However, the jaws further protected eyes, lens and normal tissues for Plan 2 based on Plan 1, as well as, other parameters of two plans are in full accord. The effects of LTR on the whole brain for radiotherapy are performed by comparing the dosimetric parameters of the target volume and organs at risk (OARs).

Moreover, the dosimetric parameters include the mean dose of CTV ($D_{\text{mean-CTV}}$), the maximum dose of CTV ($D_{\text{max-CTV}}$), the

**Table I. LTR changing with the gantry angle at isocenter for 6 MV of X-ray.**

| Gantry angle (%) | 0° | 30° | 60° | 90° | 120° | 150° | 180° | Average |
|---|---|---|---|---|---|---|---|---|
| Interleaf transmission | 0.778 | 0.794 | 0.812 | 0.836 | 0.816 | 0.801 | 0.776 | 0.801 |
| Between-leaf leakage | 1.716 | 1.752 | 1.781 | 1.837 | 1.779 | 1.747 | 1.711 | 1.761 |
| Leaf ends leakage | 26.912 | 27.243 | 27.615 | 27.951 | 27.673 | 27.335 | 27.016 | 27.392 |

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**Table II. LTR changing with the gantry angle at isocenter for 10 MV of X-ray.**

| Gantry angle (%) | 0° | 30° | 60° | 90° | 120° | 150° | 180° | Average |
|---|---|---|---|---|---|---|---|---|
| Interleaf transmission | 0.892 | 1.026 | 1.174 | 1.322 | 1.171 | 1.029 | 0.901 | 1.074 |
| Between-leaf leakage | 1.883 | 1.926 | 2.059 | 2.176 | 2.061 | 1.917 | 1.878 | 1.986 |
| Leaf ends leakage | 27.476 | 28.554 | 29.784 | 30.641 | 29.626 | 28.511 | 27.449 | 28.863 |

minimum dose of CTV ($D_{\text{min-CTV}}$), conformal index of CTV ($CI_{\text{-CTV}}$), homogeneity index of CTV ($HI_{\text{-CTV}}$), the maximum dose of left len ($D_{\text{max-len\_L}}$), the maximum dose of right len ($D_{\text{max-len\_R}}$), the mean dose of left eye ($D_{\text{mean-Eye\_L}}$) and the mean dose of right eye ($D_{\text{mean-Eye\_R}}$). Statistical analyses were conducted using the IBM SPSS Statistic 19.0 software package. Paired $t$-test was adopted to evaluate the difference of each index, $\alpha = 0.05$, $P \leq 0.05$ were considered statistically significant. Now, the CI calculation formula[11] is

$$\text{CI} = \frac{V_{t,\text{ref}}}{V_t} \times \frac{V_{t,\text{ref}}}{V_{\text{ref}}} \tag{2}$$

where $V_t$ stands for the target volume, $V_{t,\text{ref}}$ stands for the target volume surrounded by the reference isodose surface, $V_{\text{ref}}$ stands for the volume of all areas surrounded by reference isodose surface. Here, CI ranges from 0 to 1, the higher CI, the better the conformity. Then, the HI calculation formula[12] is

$$\text{HI} = \frac{D_2 - D_{98}}{D_{\text{prescription}}} \times 100\% \tag{3}$$

where $D_2$ refers to the dose corresponding to 2% of the target volume in DVH diagram, which can be also regarded as "maximum dose," $D_{98}$ refers to the dose corresponding to 98% of the target volume in DVH diagram, which can be deemed to "minimum dose." $D_{\text{prescription}}$ is the prescription dose, the lower HI, the better the dose homogeneity of the target volume.



## 3. RESULTS

### 3.1. Effects of Gantry Angle and X-ray Energy on the LTRs

Tables I–III show the inteleaf transmission rate, between-leaf leakage rate and leaf ends leakage rate with changing the gantry angle at the reference point in the isocentric plane.

As to the effects of the gantry angles on the LTRs, the leakage and transmission dose probably increases because of the leaf sagging and slacking caused by the gravity motion. The measured results summarized in three tables show that the LTR is maximal for 90° of the gantry angle while the LTR is minimal for 0° of the gantry angle, and the LTRs are approximate equal under both 30° and 150° while the LTRs are almost equal under both 60° and 120°. It is obvious that the gravity (i.e., the gantry angle) has little influence on the LTR from the statements above.

As to the effects of X-ray energy on the LTRs, Tables I–III report that the interleaf transmission rates increase as the energy increases, which are all 1% approximately; the interleaf leakage rates for three different X-ray energies are all about 2%; the leaf ends transmission rate is from 25% to 30%, which is higher than that of the first two because of the rounded leaf ends. As to the three different X-ray energies, the transmission rate for 10 MV X-ray is relatively higher.

### 3.2. Effects of GT and AB Directions on the LTRs

The LTRs in Figure 4(a) are obtained in the GT direction of the isocenter plane at three different X-ray energies, i.e., 6 MV, 10 MV and 18 MV. The LTRs in Figure 4(b) are obtained in the AB direction of the isocenter plane at three different X-ray energies similarly, which are all normalized to the maximal irradiation field.

Figure 4(a) shows that the X-ray energy has a slight impact on the LTRs. Moreover, the LTRs for 10 MV and 18 MV are slightly higher than that for 6 MV, which is mainly caused by the different penetrating and scattering abilities of X-ray. Figure 4(b) shows that the X-ray energy has a negligible impact on the LTRs.

### 3.3. Effects of Different Off-Axis Distances on the LTRs

The LTRs were measured at 0 mm, 50 cm and 100 cm off-axis under three different X-ray energies. The data in Table IV show that the LTRs are relatively low in the two measuring positions, and decrease as the off-axis distance increases. Moreover, the LTRs for 10 MV and 18 MV X-rays are slightly higher than that for 6 MV, which is mainly caused by the different penetrating and scattering abilities of X-ray. However, the LTRs will not increase with increasing the X-ray energy as to the same off-axis point.

### 3.4. Effects of LTR on the Brain Radiotherapy

Table V shows the dosimetric parameters of two plans for each patient, which indicates $D_{\text{mean-CTV}}$, $D_{\text{max-CTV}}$ and $D_{\text{min-CTV}}$ of Plan 2 are higher while $D_{\text{max-len\_R}}$, $D_{\text{max-len\_L}}$, $D_{\text{mean-Eye\_L}}$ and $D_{\text{mean-Eye\_R}}$ are lower compared with Plan 1. Results are considered statistically significant ($P \leq 0.05$).

DVH comparison and dose distribution comparison of Plan 1 and Plan 2 for one patient are shown in Figures 5 and 6, respectively. For Plan 2 in contract with Plan 1, CTV surrounded by the isodose curve of 95% is larger, the maximum dose of lens and the mean dose of eyes are lower, as well as, the range of low dose volume is smaller relatively, which are shown in Figure 5.

For Plan 2 compared with Plan 1, the dose distribution, which is outside the scope of CTV and more than 100 cGy, is

**Table III. LTR changing with the gantry angle at isocenter for 18 MV of X-ray.**

| Gantry angle (%) | 0° | 30° | 60° | 90° | 120° | 150° | 180° | Average |
|---|---|---|---|---|---|---|---|---|
| Interleaf transmission | 0.785 | 0.912 | 1.046 | 1.192 | 1.042 | 0.931 | 0.781 | 0.9556 |
| Between-leaf leakage | 1.632 | 1.738 | 1.821 | 1.934 | 1.817 | 1.726 | 1.618 | 1.755 |
| Leaf ends leakage | 25.663 | 26.312 | 26.973 | 27.593 | 26.931 | 26.325 | 25.667 | 26.495 |

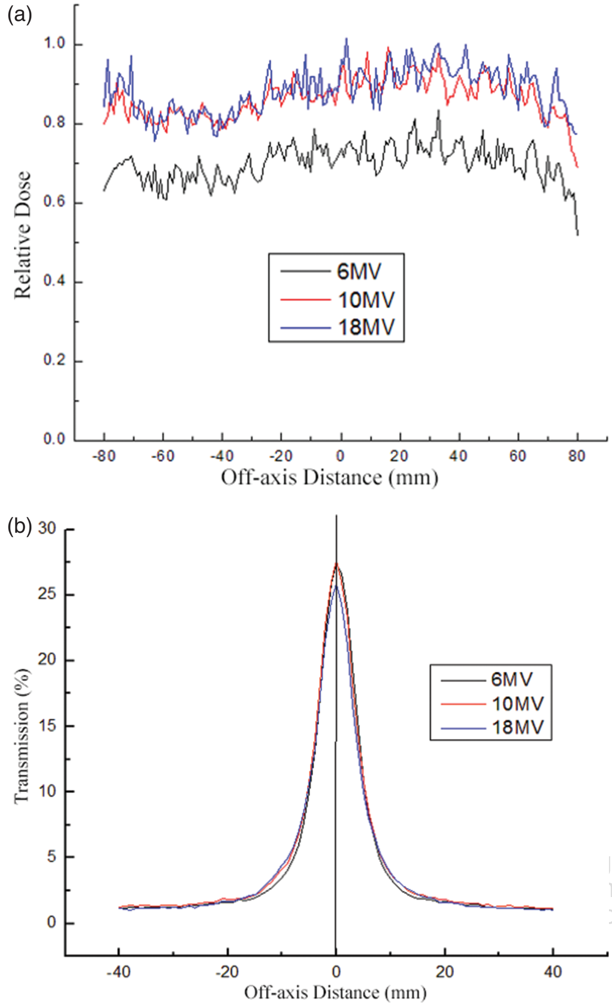


**Fig. 4.** (a) LTRs in the GT direction of the isocenter plane at three different X-ray energies. (b) LTRs in the *AB* direction of the isocenter plane at three different X-ray energies.

remarkably smaller as shown in Figure 6, which indicates that Plan 2 is capable of more protecting the normal tissues.

It can be concluded that the LTR can have remarkable effect on the target volume and OARs from the above results. Although the leakage and transmission radiation exist in Plan 1 and Plan 2, the X-ray and secondary electrons leaked and transmitted from MLC are effectively absorbed and scattered after using the jaws for Plan 2, which demonstrates that Plan 2 can significantly improve the treatment effects and immensely protect OARs.

## 4. DISCUSSION

As IMRT has become an important means of treatment for tumors, the causes such as gravity and inertia of MLC can lead to

**Table IV. LTRs at different off-axis distances and three different X-ray energies.**

| Off-axis distance (cm) | 6 MV | 10 MV | 18 MV |
|---|---|---|---|
| 0 | 0.11 | 0.076 | 0.072 |
| 50 | 0.03 | 0.05 | 0.05 |
| 100 | 0.006 | 0.02 | 0.02 |

**Table V. Dosimetric parameters comparison for two plans.**

| Parameter | Plan 1 | Plan 2 | *t* | *P* |
|---|---|---|---|---|
| CTV | | | | |
| $D_{mean}$ (cGy) | 3002.70 ± 26.69 | 3058.70 ± 17.88 | −5.12 | 0.022 |
| $D_{max}$ ($D_2$, cGy) | 3164.62 ± 21.19 | 3226.40 ± 24.57 | −1.11 | 0.037 |
| $D_{min}$ ($D_{98}$, cGy) | 2763.55 ± 13.53 | 2802.70 ± 16.27 | −5.34 | 0.028 |
| CI | 0.89 ± 0.016 | 0.90 ± 0.017 | −5.39 | 0.31 |
| HI | 0.13 ± 0.0047 | 0.14 ± 0071 | −2.30 | 0.14 |
| OARs | | | | |
| $D_{max\text{-}len\_R}$ (cGy) | 203.40 ± 21.96 | 150.90 ± 15.63 | 5.62 | 0.016 |
| $D_{max\text{-}len\_L}$ (cGy) | 188.60 ± 11.62 | 136.50 ± 9.98 | 4.82 | 0.022 |
| $D_{mean\text{-}Eye\_L}$ (cGy) | 382.90 ± 24.35 | 339.80 ± 16.15 | 2.91 | 0.001 |
| $D_{mean\text{-}Eye\_R}$ (cGy) | 281.40 ± 26.18 | 234.80 ± 27.71 | 2.85 | 0.022 |

the position errors, which will bring the dosimetry errors based on the IMRT of MLC then. Luo et al.[13] investigated the dosimetry effects caused by the position errors that is resulted from the gravity of MLC for prostate IMRT, and found out the inter-relationships between the target dose errors and the average position errors of MLC. Furthermore, if the leaf position expands 0.2 mm, the target dose will change 1%. Nevertheless, as to the dynamic IMRT. Zygmanski et al.[14] reported the leaf error of MLC is 0.05 cm around, and Woo et al.[15] found that during measuring the beam edge with ionization chamber, the leaf location will cause 13% of dose error if it is imprecise. Moreover, Sharpe et al.[16] also reported the difference of the absorbed dose can reach 16% when the leaf position error is 2 mm, while 8% with 1 mm of the position error under the condition of $1 \times 1$ cm$^2$ field. In this paper, the effects of different gantry angles on the MLC leaves can lead to dose deviations, which exists uncertainty in dose as a result of the existence of gravity. While the gantry angle is set to 0°, the motion direction of MLC leaf is perpendicular to the direction of gravity for the whole time, where the dose error caused by the MLC leaf is minimal. Therefore, in order to reduce the influence of MLC leaf on the radiation dose, it is necessary to conduct maintenance for MLC leaf on a regular basis.



The MLC transmission dose, correlating closely to the accelerator design and the ray energy, is an important part of an accelerator acceptance check and a routine content of Quality Assurance and Quality Control (QA and QC). With the application of IMRT and VMAT (Volumetric Modulated Arc Therapy), the high number of MU for a single irradiation in a field or field-in-field technique expects for a higher and higher leakage and transmission radiation requirements for MLC. Because of the high leaf ends transmission, the collimator angle of a treatment

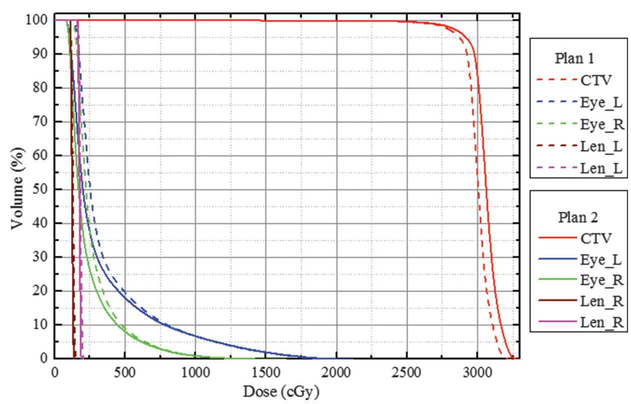


**Fig. 5.** DVH comparison of a patient for two plans.

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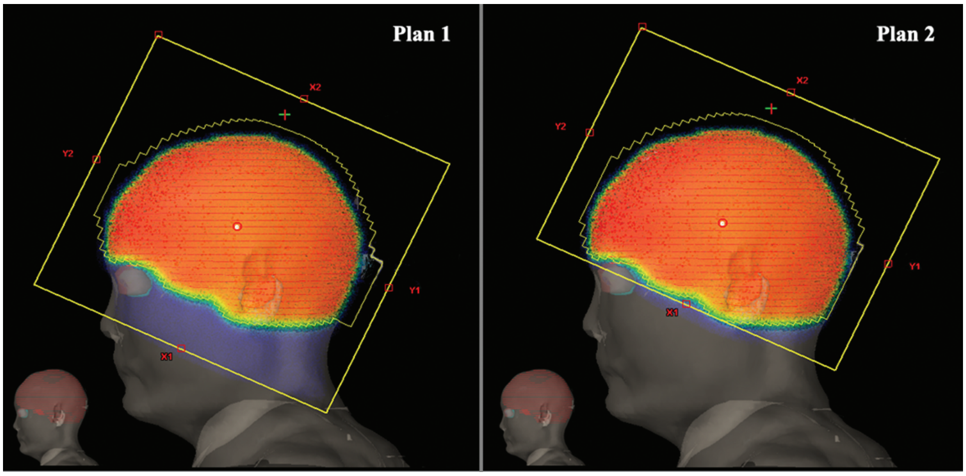


**Fig. 6.** Dose distribution comparison of two plans for one patient.

plan for different types of MLCs needs to be optimized, especially for the MLC with a 5 mm leaf gap, to protect the vital tissues and organs from the leaf ends transmission, especially for Beam Modulator MLC, which is used as an independent collimator for the absence of jaws, it is necessary to pay more attention to protect the vital tissues and organs.

Ing et al.[17] researched the effects of leakage and transmission rays on the crystal absorbed dose. However, LoSasso[18] and Liu et al.[19] studied that the LTR is about 1.5%, which is close to the results in this paper. Therefore, research on LTD is supposed to be carried out during setting the parameters in the treatment plans, as well as, further studies have shown that the bigger the irradiation field, the higher the LTD, the greater the impacts on the OARs adjacent to the target volume. Because of the gap between the leaves and the leaf width, the interleaf transmission, between-leaf and leaf ends leakages are inevitable. Thereby, the LTRs measured is needed to be fully taken into account.



The MLC leaf width directly depends on the geometric conformity between the MLC-shaped irregular field and the shape of the planning target volume (PTV); the thinner the leaf, the better the conformity, but it will rise the cost and the machining difficulties as the number of mechanical parts, such as drive motor, increase. Consequently, a rational trade-off between the conformity and the cost should be made. The MLC leaf must be at least 4–5 times the height of half-thickness to weaken the radiation intensity to be below 5%. In order to maintain the low-resistance motion between leaves, a leakage, often occurring between the leaves, reduces the effects of radiation shielding on the leaves. Thus, the leaf height needs an appropriate thickening; usually, an exceeding 5 cm thick of tungsten alloy is chosen to be the leaf. For an example, if the transmission dose is expected to fall below 2%, a 7.5 cm thick of tungsten alloy is the most common choice.[20,21]

According to the clinical application requirements, the movement of each leaf should be with independence, flexibility and low friction; the adjacent leaves are neither too close nor too far to each other, otherwise the probability of leakage will rise.[22] To resolve the contradiction, each MLC leaf has a groove on one side and a tongue on the other side; the tongue-and-groove design between two neighboring leaves can reduce the leakage based on the fact that the ray travels only in a straight line.[23] This kind of tongue-and-groove design is neither too tight nor too deep. The LTR of Beam Modulator MLC can be guaranteed to be below 2%. The radiotherapy or the automatic following function of the back-up MLC are designed for shielding the interleaf, between-leaf and leaf ends leakage rays.[24,25]

## 5. CONCLUSION

The test to MLC is based on QC of the conventional radiotherapy equipment. Therefore, before conducting QC measurement of MLC, it is vital to assure the accuracy of other accelerator parameters, such as the gantry angle, the position and isocenter accuracy of MLC, the coincidence between the light field and the irradiation field, etc. The rounded leaf ends bring a higher leakage, and the leaf ends closure often occurs in the irradiation field during the dynamic IMRT plan designing, which is supposed to pay more attention to the effects of leakage and transmission radiation on the dose precision. Any errors affecting the leaf position precision in the process of movement, such as an incomplete closure, will increase the LTD. Therefore, the daily maintenance and check on the MLC leaves should be strengthened. The MLC leakage and transmission have little change following with the gantry angle, nevertheless, because of the existence of the interleaf transmission, the jaws is indispensable to shield OARs again by rotating collimator under different conditions during optimizing a radiotherapy plan, through which the exposure risks and the damages to the vital tissues and organs are supposed to be reduced with the largest limit.

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