Dosimetric Comparison Between Jaw Tracking and No Jaw Tracking in Intensity-Modulated Radiation Therapy

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Abstract

Purpose: This article compares the dosimetric differences between jaw tracking and no jaw tracking technique in static intensity-modulated radiation therapy plans of large and small tumors. Methods: Eight plans with large tumor (nasopharyngeal carcinoma, volume range: 510.9 to 768.0 cm³) and 8 plans with small tumor (single brain metastasis, volume range: 5.3 to 9.9 cm³) treated with jaw tracking on Varian EDGE LINAC were chosen and recalculated with no jaw tracking to study the dosimetric differences. We compared the differences of organ-at-risk doses (Dmax, Dmean), monitor units, and γ passing rate of plan verification (3mm/3%, threshold 10%; 2mm/2%, threshold 10%) between the 2 techniques. Results: The organ-at-risk doses of nasopharyngeal carcinoma cases having jaw tracking are all less than those with no jaw tracking. The Dmax and Dmean of organ-at-risks reduced 0.61% to 17.65% and 2.17% to 19.32%, P < .05, respectively. In cases with single brain metastasis, the organ-at-risk doses with jaw tracking were also lower than no jaw tracking. The Dmax and Dmean of organ-at-risk doses reduced 0.84% to 1.52% and 0.90% to 1.86%, P < .05, respectively. The monitor units for the large tumor and small tumor were increased by 2.41% and 1.1%, respectively. The γ passing rates (3mm/3%, th10%; 2mm/2%, th10%) of nasopharyngeal carcinoma plans are 99.89% ± 0.06% (jaw tracking) versus 99.56% ± 0.19% (no jaw tracking; P = .127); 97.15% ± 0.98% (jaw tracking) versus 91.90% ± 1.40% (no jaw tracking; P = .000), and the γ passing rates (3mm/3%, th10%; 2mm/2%, th10%) of brain metastasis plans are 99.97% ± 0.05% (jaw tracking) versus 99.44% ± 1.24% (no jaw tracking; P = .251), 98.65% ± 1.27% (jaw tracking) versus 93.35% ± 2.72% (no jaw tracking; P = .000). Conclusion: Jaw tracking can reduce the dose of organ-at-risks compared to no jaw tracking, and the effect is more significant for plans with large tumor. The γ passing rate of plans with jaw tracking is also higher than the plans with no jaw tracking. Although the monitor units in plans of jaw tracking will increase slightly, it is recommended to use jaw tracking in static intensity-modulated radiation therapy both in large and in small tumors.

Keywords

jaw tracking, MLC transmission, portal dosimetry, MU, static IMRT

Abbreviations

JT, jaw tracking; IMRT, intensity-modulated radiation therapy; NJT, no jaw tracking; NPC, nasopharyngeal carcinoma; MU, monitor units; OAR, organ-at-risks; MLC, multileaf collimator; PD, portal dosimetry; PTV, planning target volume; DVH, dose–volume histogram; DLG, dose leaf gap.

Introduction

Jaw tracking (JT) is a technique that was provided by Varian TrueBeam series, where the jaw can track the aperture of the multileaf collimator (MLC) to reduce the leakage and transmission and thus reduce doses of normal tissues around the...
Table 1. Target Volumes of NPC and Brain Metastasis.

|                | P1       | P2       | P3       | P4       | P5       | P6       | P7       | P8       | Mean     |
|----------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| NPC, cm³       | 751.6    | 569.0    | 562.8    | 768.0    | 632.2    | 562.2    | 510.9    | 623.5    | 622.5    |
| Brain metastasis, cm³ | 9.9      | 7.1      | 7.5      | 5.8      | 8.6      | 5.3      | 9.6      | 7.2      | 7.6      |

Abbreviation: NPC, nasopharyngeal carcinoma.

tumor. Most publications discussed the dose changes in several kinds of tumors, but very few articles studied the impact of tumor sizes and very few compared the intensity-modulated radiation therapy (IMRT) quality assurance (QA) verification results. Therefore, this study investigated the dose change in organ-at-risks (OARs), and the verification results of plans with JT both in large and in small tumors were compared to no JT (NJT), expecting the results can be beneficial for clinical treatment. In this study, we investigated the impact of JT on dose to OARs and the verification results (γ passing rates) of plans with large and small tumors.

Materials and Methods

Varian EDGE with HD120 MLC is used in the study, and the maximum field size with MLC is 40 × 22 cm. The width of MLC is 2.5 × 32 mm at the center and 5.28 mm at the peripheral. Portal Vision AS1200 with portal dosimetry (PD) is used for plan verification. AS1200 detector has an active area of 40 × 40 cm² with 1190 × 1190 pixel arrays and pixel pitch of 0.336 mm which is suitable for both large- and small-field verification. The treatment planning system is Eclipse v13.6.

In this study, 8 static IMRT cases of nasopharyngeal carcinoma (NPC) and 8 static IMRT cases of single brain metastasis were chosen. All plans used sliding window technique with 6 MV photon beam. For NPC cases, 9 coplanar fields with 40° separation were used, and for brain metastasis cases, 10 to 12 noncoplanar fields were used. In each case, the JT IMRT plan was first designed, and the NJT plan was obtained from the JT IMRT plan by recalculating MLC sequence with no JT. The maximum field size with MLC is 40 cm²/C2. MV photon beam. For NPC cases, 9 coplanar fields with 40° separation were used, and for brain metastasis cases, 10 to 12 noncoplanar fields were used. In each case, the JT IMRT plan was first designed, and the NJT plan was obtained from the JT IMRT plan by recalculating MLC sequence with no JT. The maximum field size with MLC is 40 cm²/C2. MV photon beam. 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We also compared the total MUs of JT and NJT plans. Table 5 shows the statistical results. The MUs of JT plans increased slightly compared to those of NJT plans, with the mean MU of NPC plan increased by 2.41\% and the mean MU of brain metastasis plan increased by 1.10\%.

**Table 2. OAR Dose Comparison of Cases With NPC Between JT and NJT.**

| OARs  | Items   | Jaw Tracking, cGy | No Jaw Tracking, cGy | Reduction, \% | P    |
|-------|---------|-------------------|----------------------|--------------|------|
| Brain stem | Dmax    | 4478.98 ± 393.89  | 4531.56 ± 391.94    | 1.16         | .000 |
|        | Dmean   | 2593.29 ± 286.74  | 2687.36 ± 303.35    | 3.51         | .000 |
| Spinal cord | Dmax    | 3762.26 ± 141.11  | 3889.32 ± 153.08    | 3.27         | .000 |
|        | Dmean   | 2436.77 ± 362.40  | 2521.12 ± 377.44    | 3.34         | .000 |
| Eyes   | Dmax    | 1803.55 ± 1093.11 | 1921.21 ± 1096.24   | 6.12         | .000 |
|        | Dmean   | 484.72 ± 139.43   | 577.59 ± 143.70     | 16.08        | .000 |
| Lens   | Dmax    | 445.27 ± 86.53    | 540.71 ± 98.60      | 17.65        | .000 |
|        | Dmean   | 362.04 ± 47.80    | 448.72 ± 53.35      | 19.32        | .000 |
| Optical nerves | Dmax    | 2351.25 ± 1783.81 | 2428.11 ± 1466.26   | 3.16         | .000 |
|        | Dmean   | 1045.06 ± 867.02  | 1123.91 ± 881.69    | 7.01         | .000 |
| Optical chiasm | Dmax    | 2672.16 ± 2043.14 | 2714.75 ± 2045.55   | 1.57         | .000 |
|        | Dmean   | 1449.72 ± 1038.35 | 1527.45 ± 1044.71   | 5.09         | .000 |
| Larynx | Dmax    | 6292.50 ± 407.59  | 6331.44 ± 421.79    | 0.61         | 0.003|
|        | Dmean   | 3421.59 ± 455.55  | 3497.37 ± 460.96    | 2.17         | .000 |

Abbreviations: JT, jaw tracking; NJT, no jaw tracking; NPC, nasopharyngeal carcinoma; OAR, organs at risk.

We also compared the total MUs of JT and NJT plans. Table 5 shows the statistical results. The MUs of JT plans increased slightly compared to those of NJT plans, with the mean MU of NPC plan increased by 2.41\% and the mean MU of brain metastasis plan increased by 1.10\%.

**Discussion**

The article compared the doses of OARs (mean and maximum) and the plan verification results between JT and NJT static IMRT plans in small and large tumors. We found that the mean and maximal doses of OARs in JT plans were all lower than NJT plans with the same target coverage that is consistent with the results of other articles.\(^7\)\(^\text{11}\) The transmission of Varian HD MLC is about 1.2\% for 6MV,\(^12\) and the jaw transmission is <0.5\%, so it is easier to reduce the OAR dose with JT. For small lesions, the field size is small, so the leakage to the OARs is also small. The impact of JT is more obvious in large tumors because the JT technique can block more MLC transmission in large field and reduce dose to out-of-field OARs. This finding is very helpful for plan design and can be specially applied in cases where low-dose sensitive normal tissues, such as the lung,\(^13\)\(^\text{15}\) are close to the treatment target. At the same time, JT technique can reduce the risk of secondary tumors in patients with longer survival periods, such as patients with breast cancer.\(^16\)

Plans with JT technique must be verified before treatment. In this study, we found that there was no significant difference in the γ passing rate between JT and NJT at the criteria of 3mm/3\%, th10\%, which is consistent with the result of Feng et al.\(^17\) At the criteria of 2mm/2\%, th10\%, the pass rates of plans with JT are higher than NJT plans, with the P value <.05. The γ passing rate can be affected by many factors, such as MLC dose leaf gap (DLG), MLC leakage and transmission factor, output factor, jaw moving speed, and position accuracy. In the Varian TPS model, DLG and MLC leakage and transmission factor
can be tweaked a little from the measurement value. The DLG is a parameter that accounts for Varian’s rounded MLC leaf ends and can affect the plan verification results a lot. The DLG value needs to be optimized at the stage of machine commissioning. The MLC leakage and transmission factor is an average value measured with large-volume ion chamber, such as PTW30013 with a sensitive volume of 0.6 cm³. However, it actually varies with different positions of the MLC. The difference cannot be discovered with the criteria of 3mm/3% due to its small influence, but with the criteria of 2mm/2%, the difference shows up. The JT technique can minimize the jaw size and reduce the MLC leakage and transmission so that the pass rates will increase.

Field size is smaller in JT than in NJT, and the output factor is much more difficult to measure in small field. Swinnen et al. reported that it was more accurate with the fixed field 3 × 3 cm² than JT in the very small tumor treatment. Our study showed good passing rates in brain metastasis with small fields. It could be that the volumes of our brain metastasis in this study are not so small. Because there is no output factor of field size <3 × 3 cm² in our PD model, PD can only measure the field size ≥3 × 3 cm², so the verification results are still good in our brain metastasis plans. However, the smaller the

Figure 2. Single brain metastasis dose–volume histogram (DVH) comparison of jaw tracking (JT) and no JT (NJT).

Table 3. OAR Doses Comparison of Single Brain Metastases Between JT and NJT.

| OARs       | Items     | Jaw Tracking, cGy | No Jaw Tracking, cGy | Reduction, % | P   |
|------------|-----------|-------------------|----------------------|--------------|-----|
| Brain stem | Dmax      | 1101.56 ± 997.20  | 1114.46 ± 1004.23   | 1.16         | .013|
|            | Dmean     | 295.89 ± 355.33   | 298.95 ± 356.23     | 1.02         | .000|
| Eyes       | Dmax      | 251.11 ± 165.52   | 253.24 ± 165.23     | 0.84         | .000|
|            | Dmean     | 107.72 ± 60.27    | 109.67 ± 60.23      | 1.78         | .004|
| Lens       | Dmax      | 145.06 ± 80.46    | 147.30 ± 81.22      | 1.52         | .012|
|            | Dmean     | 115.27 ± 79.76    | 116.37 ± 80.01      | 0.90         | .002|
| Optical nerve | Dmax  | 208.81 ± 79.9     | 211.92 ± 78.65      | 1.47         | .013|
|            | Dmean     | 113.30 ± 72.46    | 114.75 ± 72.47      | 1.86         | .001|
| Optical chiasm | Dmax | 229.11 ± 183.06   | 232.23 ± 182.67     | 1.34         | .005|
|            | Dmean     | 154.17 ± 134.40   | 156.62 ± 134.57     | 1.56         | .005|

Abbreviations: JT, jaw tracking; NJT, no jaw tracking; OAR, organs at risk.

Table 4. γ Pass Rate Comparison Between JT and NJT.

| Criteria       | JT      | NJT      | P   |
|----------------|---------|----------|-----|
| NPC 3mm, 3%, th10% | 99.89 ± 0.06 | 99.56 ± 0.19 | .127|
| 2mm, 2%, th10%   | 97.15 ± 0.98 | 91.90 ± 1.40 | .000|
| Brain 3mm, 3%, th10% | 99.97 ± 0.05 | 99.44 ± 1.24 | .251|
| 2mm, 2%, th10%   | 98.65 ± 1.27 | 93.35 ± 2.72 | .000|

Abbreviations: JT, jaw tracking; NJT, no jaw tracking; NPC, nasopharyngeal carcinoma.

Table 5. MU Comparison between JT and NJT.

|        | JT     | NJT     | P   |
|--------|--------|---------|-----|
| NPC    | 1413.6 ± 106.0 | 1380.3 ± 103.2 | .000|
| Brain  | 1264.6 ± 41.9  | 1250.8 ± 41.2  | .000|

Abbreviations: JT, jaw tracking; MU, monitor unit; NJT, no jaw tracking.
tumor volume, the lesser the advantage of JT in dose reduction of OARs. So, when treating very small volume tumor with the field size less than \(3 \times 3 \text{ cm}^2\), JT may not be a good choice.

In addition, we found that the MUs of JT plans were slightly higher than NJT, which was different from the article of Wu.\(^7\) Target dose can also decrease with the decrease in the MLC transmission in JT; in order to compare the dose differences in OARs with the same tumor coverage, we renormalized the target dose. Meanwhile, the output factor is smaller in JT than in NJT due to the smaller jaw size, so the MU in JT should also be higher than NJT in order to get the same tumor dose. However, the increase in MU is very slight when using JT. The increase percentage of MU in NPC and single brain metastasis is 2.41\(\%\) and 1.10\(\%\), respectively, which has little effect in the efficiency of treatment. Although the total MU is more in JT plan, the jaw size is smaller, most part of OARs is outside the field, and the jaw transmission is \(<0.5\%\), so increase in MU has little impact on OAR doses.

**Conclusion**

Jaw tracking technique can reduce the doses of OARs in static IMRT plans both in large and in small tumors, and the effect is more obvious in large tumors. The pass rates of plans with JT technique are also higher than NJT technique both in small (field size \(\geq 3 \times 3 \text{ cm}^2\)) and in large tumors. Although the MU of JT plan slightly increases, the effect in the efficiency of treatment is little, so it is recommended to use JT in static IMRT plan with the field size \(\geq 3 \times 3 \text{ cm}^2\).

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**Reference**

1. Wu L, Lu J, Ma C, et al. Application of Jaw-tracking function in VMAT for upper thoracic esophageal cancer. *Changqing Med.* 2016.
2. Chen GT, Wang Q, Liu YQ, et al. Application of TrueBeam Jaw-tracking Function in Fix Gantry IMRT and VMAT for NPC. *Chin J Med Phys.* 2014;31(3):4865-4870.
3. Feiuye S, Zhenglu B, Wei Q, Huanyu Z. Evaluation of portal dosimetry dose verification results for intensity-modulated radiotherapy plans of nasopharyngeal carcinoma by using two methods. *China Med Dev.* 2017;32(11):89-91.
4. Van Esch A, Huyskens DP, Hirschi L, Baltes C. Optimized Varian aSi portal dosimetry: development of datasets for collective use. *J Appl Clin Med Phys.* 2013;14(6):4286.
5. Surendran S. Study of feasibility of portal dosimetry in comparison with ImatriXX 2-D array system for IMRT and Rapid arc patient specific QA. *IOSR-JEN.* 2014;4(6):11-15.
6. Low DA, Moran JM, Dempsey JF, Dong L, Oldham M. Dosimetry tools and techniques for IMRT. *Med Phys.* 2011;38(3):1313-1338.
7. Wu H, Jiang F, Yue H, et al. A comparative study of identical VMAT plans with and without jaw tracking technique. *J Appl Clin Med Phys.* 2016;17(5):133-141.
8. Mani KR, Upadhayay S, Das KJ. Influence of jaw tracking in intensity-modulated and volumetric-modulated arc radiotherapy for head and neck cancers: a dosimetric study. *Radiat Oncol J.* 2017;35(1):90-100.
9. Kim JY, Kim SW, Choe BY, et al. Clinical assessment of the jaw-tracking function in IMRT for a brain tumor. *J Korean Phys Soc.* 2015;66(2):295-300.
10. Joy S, Starkschall G, Kry S, et al. Dosimetric effects of jaw tracking in step-and-shoot intensity-modulated radiation therapy. *J Appl Clin Med Phys.* 2012;13(2):3707.
11. Snyder KC, Wen N, Huang Y, et al. Use of jaw tracking in intensity modulated and volumetric modulated arc radiation therapy for spine stereotactic radiosurgery. *Pract Radiat Oncol.* 2015;5(3):e155-e162.
12. Bergman AM, Gete E, Duzenli C, Teke T. Monte Carlo modeling of HD120 multileaf collimator on Varian TrueBeam linear accelerator for verification of 6X and 6X FFF VMAT SABR treatment plans. *J Appl Clin Med Phys.* 2014;15(3):4686.
13. Kim Y, Hong SE, Kong M, Choi J. Predictive factors for radiation pneumonitis in lung cancer treated with helical tomotherapy. *Cancer Res Treat.* 2013;45(4):295-302.
14. Xiu-Mei MA, Ming YE, Li LI. An analysis of the related factors of 3D conformal radiotherapy caused pneumonitis in patients with lung cancer. *J Oncol.* 2008;14(3):197-200.
15. Tang C, Liao Z, Gomez D, et al. Lymphopenia association with gross tumor volume and lung V5 and its effects on non-small cell lung cancer patient outcomes.. *Int J Radiat Oncol Biol Phys.* 2014;89(5):1084-1091.
16. Land CE, Boice JD Jr, Shore RE, Norman JE, Tokunaga M. Breast cancer risk from low-dose exposures to ionizing radiation: results of parallel analysis of three exposed populations of women. *J Natl Cancer Inst.* 1980;65(2):353-376.
17. Feng Z, Wu H, Zhang Y, Zhang Y, Cheng J, Su X. Dosimetric comparison between jaw tracking and static jaw techniques in intensity-modulated radiotherapy. *Radiat Oncol.* 2015;10:28.
18. Chang KH, Ji Y, Kwak J, et al. Clinical implications of high definition multileaf collimator (HDMLC) dosimetric leaf gap (DLG) variations. *Prog Med Phys.* 2016;27(3):111.
19. Lujun Li, Haikun Yu, Zhicong Li, et al. Study the influence of MLC parameters to dose distribution using a verification method. *Chin J Med Dev*. 2013;26(8):21-22.

20. García-Garduño OA, Celis MA, Lárraga-Gutiérrez JM, Moreno-Jiménez S, Martínez-Dávalos A, Rodríguez-Villafuerte M. Radiation transmission, leakage and beam penumbra measurements of a micro-multileaf collimator using GafChromic EBT film. *J Appl Clin Med Phys*. 2008;9(3):2802.

21. Swinnen AC, Öllers MC, Roijen E, Nijsten SM, Verhaegen F. Influence of the jaw tracking technique on the dose calculation accuracy of small field VMAT plans. *J Appl Clin Med Phys*. 2017;18(1):186-195.