Dosimetric Effect of Jaw Tracking in Volumetric-Modulated Arc Therapy

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Abstract

The aim of this study was to investigate the potential of jaw tracking with the volumetric-modulated arc therapy (VMAT) to reduce the normal tissue dose. Plans of nasopharynx, lung, and prostate cancers (10 plans for each) were used to perform VMAT with and without jaw tracking. The dose reduction was evaluated in terms of organ doses and integral doses. Organ-dose reduction with jaw tracking was statistically significant in the volume receiving a dose of 5 Gy (V_5) of bladder, rectum, and lung, the volume receiving a dose of 10 Gy (V_{10}) of bladder, rectum, and lung, and the mean dose of lung ($P < 0.05$). Integral-dose reduction with jaw tracking was statistically significant in almost all the treatment plans ($P < 0.05$). For organ-dose reduction, jaw tracking in VMAT plan was effective in reducing V_5 and V_{10}. For integral-dose reduction, jaw tracking in VMAT plan is an efficient method for decreasing V_5.

Keywords: Integral-dose reduction, jaw tracking, organ-dose reduction, volumetric-modulated arc therapy

Introduction

The purpose of radiation therapy is to deliver a prescribed dose to a tumor while minimizing doses to normal organs and surrounding tissues. Advanced radiation delivery techniques have been developed to optimize this purpose, such as intensity-modulated radiation therapy (IMRT) and volumetric-modulated arc therapy (VMAT).[1-5] However, IMRT and VMAT still deliver a low dose to normal organs because of interleaf leakage of multileaf collimators (MLCs).[6-11] Movement of collimator jaw in addition to MLCs during treatment was developed to decrease interleaf leakage to the patient.[12] VMAT with jaw tracking was developed in a recent model of linear accelerator (TrueBeam, Varian, Palo Alto, CA), as well as its corresponding commercial treatment planning system (TPS), Eclipse V.10.0, and newer versions. Collimator scattering during jaw moving was taken into account in the dose calculation algorithm at each control point for the Eclipse TPS.[13]

Many studies have shown the potential of jaw tracking in reducing radiation doses to normal organs by using different radiation delivery techniques. Joy *et al.*[14] evaluated the dosimetric effect of jaw tracking in step-and-shoot IMRT. Schmidhalter *et al.*[15] showed that dynamic IMRT with jaw tracking can decrease the integral dose. Kim *et al.*[16] evaluated the potential of VMAT with jaw tracking for reducing the dose to normal organs for nasopharynx plans. Snyder *et al.*[17] studied the advantage of jaw tracking in reducing doses to normal organs in IMRT and VMAT for spine stereotactic radiosurgery.

The purpose of this study was to investigate the potential of jaw tracking with the VMAT to reduce the normal tissue dose in nasopharynx, prostate, and lung treatment plans. In addition, this study provided a method for verifying an accuracy of TPS calculation for VMAT with jaw tracking by contouring a rectangular shape target volume to generate jaw tracking.

Subjects and Methods

The study was performed on a TrueBeam linear accelerator (Varian Medical Systems, Palo Alto, CA) equipped

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with a millennium 120 MLC and was planned on Eclipse TPS V.10.0 (Varian Medical Systems, Palo Alto, USA).

Dose verification for jaw tracking

The accuracy of dose calculation for jaw tracking in the TPS was verified in terms of point dose and dose distribution before using the TPS to determine the reduction of the normal organ doses. Computed tomography (CT) images of an IMRT phantom (IMRT phantom, IBA Dosimetry, Germany) was acquired with a slice thickness of 3 mm, and then, the dose distribution was calculated on the CT images. For this purpose, we created rectangular shape of target volume in the IMRT phantom with a size of 16 cm × 17 cm × 4 cm (width × length × depth), as shown in Figure 1a. In the dose calculation, we used the rectangular shape target volume to generate the maximum jaw-tracking distance in the x-jaws and y-jaws of the collimator. The investigation was performed by using 10 MV photon with VMAT beam delivery with and without jaw-tracking methods. RapidArc plans were optimized by using two full arcs for each plan (Plan#1 and Plan#2) to verify the effect of collimator scattering in different jaw positions (x-jaw and y-jaw). A summary of the x-jaw and y-jaw moving distances for each plan are listed in Table 1. Figure 1b shows a collimator rotation to generate jaw tracking in x-jaw and y-jaw directions. For x-jaw tracking (Plan#1), the collimator was rotated to 30° and 330° for the first and second arc, respectively. For y-jaw tracking (Plan#2), the collimator was rotated to 70° and 300° for the first and second arc, respectively.
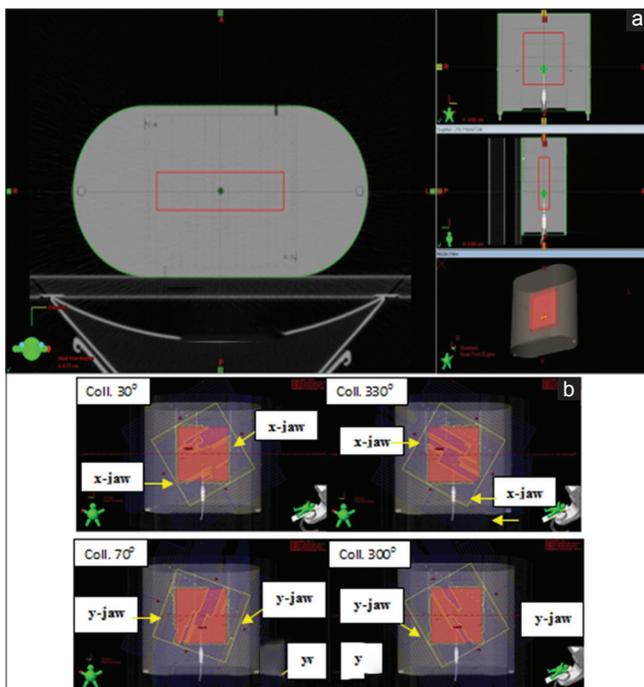

Figure 1: (a) The rectangular shape target volume for volumetric-modulated arc therapy with jaw tracking to generate the x-jaw and y-jaw traveling, (b) Collimator rotations of 30°/330° for x-jaw tracking and 70°/300°for y-jaw tracking

Point-dose measurement

A 0.6 cm³ ionization chamber (PTW Freiburg GMBH, Germany) was inserted in the IMRT phantom for the measurement of point doses. The dose measurement was compared with the TPS calculation to determine the difference.

Dose distribution measurement

The dose distribution verification was performed by using portal dose image prediction (PDIP) (Varian Medical Systems, Pala alto, USA). Dose agreement between the portal dosimetry measurement and PDIP was analyzed by using gamma index[18] criteria of 2% and 2 mm. The portal dosimetry measurement was calibrated for darkfield, flood field, and dose normalization prior to use following manufacturer's recommendations.[19]

Determination of dose reduction from jaw tracking

Thirty plans were used for the organ-dose reduction evaluation: 10 nasopharyngeal cancers, 10 lung cancers, and 10 prostate cancers; plan information is listed in Table 2. In this study, we also evaluated the effect of tumor shape on dose reduction with jaw tracking by observing the jaw-tracking distance. To control the same parameters, VMAT planning was performed with and without jaw tracking using the same constraints and priorities. In addition, MU objective function was used to control the similar MU during optimization with the strength parameter of 90 (maximum 100). The dose constraints used to evaluate normal organs are listed in Table 3. The dose was normalized as 95% isodose to cover the planning target volume (PTV) for all plans.

Dose reduction was evaluated in terms of organ and integral doses. Organ-dose reduction was measured as the volume receiving a dose of 5 Gy (V_5), the volume receiving a dose of 10 Gy (V_{10}), the volume receiving a dose of 20 Gy (V_{20}), and mean dose. Organ-dose reduction was determined in the parotids for nasopharyngeal treatment plans, normal lung for lung treatment plans, and bladder and rectum for prostate treatment plans. To determine the radiation-induced secondary malignancies, the integral dose volume was calculated as the body subtracted from the PTV for each plan.[20] The integral-dose reduction was measured in terms of V_5, V_{10}, and mean dose. The data were presented as the averages of all patients followed by the standard deviation . According to the normal distribution of data, the paired *t*-test was used in this study to determine statistically dose reduction of jaw tracking compared with no jaw tracking. $P < 0.05$ is considered to be statistically significant.

RESULTS

Dose verification for jaw tracking
Point-dose measurement
The percent difference between the point-dose measurement and TPS calculation was <0.5% for x-jaw and y-jaw tracking.

Dose distribution measurement
Dose agreement between the portal dosimetry measurement and PDIP was more than 96% gamma index passing rates with gamma index criteria of 2% and 2 mm for x-jaw and y-jaw tracking.

Table 1: Summary of x-jaw and y-jaw moving distance of jaw tracking plans for dose verification

Collimator rotation (°)	Jaw moving distance (cm)	
	x-jaw	y-jaw
Plan #1		
30	10.0	0.4
330	9.8	0.4
Plan #2		
70	5.0	9.6
300	3.2	11.3

Table 2: Summary of plan information for 30 patients in nasopharynx, lung, and prostate cancers

Plans	Energy (MV)	Jaw moving distance in cm, range (average)	
		x-jaw	y-jaw
Nasopharynx	6	0-8.5 (2.73)	0-6.3 (2.26)
Prostate	10	0.7-4.8 (2.23)	0-3.6 (1.11)
Lung	6 (5 plans) 10 (5 plans)	0-5.7 (2.04)	0-4.1 (1.22)

Table 3: Dose constraints for plan evaluation

Organ	Dose constraint
Parotids	D_{mean} <26 Gy
	$D_{50\%}$ <30 Gy
Rectum	$D_{50\%}$ <50 Gy
	$D_{35\%}$ <60 Gy
	$D_{25\%}$ <65 Gy
	$D_{20\%}$ <70 Gy
	$D_{15\%}$ <75 Gy
Bladder	$D_{50\%}$ <65 Gy
	$D_{35\%}$ <70 Gy
	$D_{25\%}$ <75 Gy
	$D_{15\%}$ <80 Gy
Lung	D_{mean} <20 Gy
	V_5 <65%
	$D_{35\%}$ <20 Gy (for radiation + chemo)
	$D_{40\%}$ <20 Gy (for radiation alone)
	$D_{30\%}$ <20 Gy

V_5: Volume receiving a dose of 5 Gy

Determination of dose reduction from jaw tracking

Figure 2 shows organ-dose reduction by using jaw tracking in various normal organs.

The most prominent reduction was found in V_5 of bladder with −1.52% of the volume. For both parotids, V_5 had similar values between jaw tracking and no jaw tracking with 100% volume receiving a dose of 5 Gy. Normal lung was the only organ that had reduction for all the categories with −0.85% for V_5, −0.82% for V_{10}, −0.59% for V_{20}, and −0.23 Gy for mean dose. Table 4 shows the *P* value of organ-dose reduction by using jaw tracking in various normal organs. Dose reduction

with jaw tracking was statistically significant in V_5 of the bladder, rectum, and lung, V_{10} of the bladder, rectum, and lung, and mean dose of lung ($P < 0.05$). For right and left parotid, there was no significant difference in V_5, V_{10}, V_{20}, and mean dose ($P > 0.05$).

Figure 3 shows the integral-dose reduction by using jaw tracking in nasopharynx, prostate, and lung cancer plans. The most distinct reduction was found in the V_5 of nasopharynx cancer with −1.13% of the volume, while the smallest reduction was found in the mean dose of prostate cancer plans with −0.09% of the volume. Table 5 shows the *P* value of integral-dose reduction by using jaw tracking in nasopharynx, prostate, and lung cancer plans. Integral-dose reduction with jaw tracking was statistically significant in almost all the treatment plans ($P < 0.05$); only the V_{10} of prostate plan showed no significant difference ($P > 0.05$).

In addition, the advantage of jaw tracking over no jaw tracking in y-jaw collimator was also observed. The result was found that the jaw tracking could reduce low doses at the upper and lower regions of the PTV, as shown in Figure 4.

Discussion

For verification of the TPS calculation, a 10 MV photon was used to determine the accuracy of the dose calculation because higher energy has a greater effect on the scattered-dose calculation.[21] In this study, the method to generate the maximum jaw-tracking distance was developed by using the rectangular shape target volume which can generate jaw moving by 10 cm and 11.3 cm for x-jaw and y-jaw tracking, respectively. Jaw-tracking distances were generated in TPS verification to be as large as possible to verify the accuracy of jaw-tracking calculation in the worst scenario. The accuracy of the dose calculation for RapidArc with jaw tracking in Eclipse TPS was sufficient for our study, with a point-dose difference of <0.5% and dose-distribution agreement of more than 96% gamma index passing rates (2%/2 mm gamma index criteria).

Schmidhalter *et al.*[15] suggested that the backscattered radiation of the y-jaw would increase because the y-jaws are closer to the monitor chamber than the x-jaws. Our study showed that no significant differences were observed between x-jaw travelling and y-jaw travelling with gamma passing rates of 99.6% and 99.9% for x-jaw and y-jaw tracking, respectively. This result indicated that the collimator backscatter changes during jaw tracking were taken into account in the dose calculation.

For sensitive organs, such as lung, rectum, and bladder, a large reduction of organ dose was found in the V_5 and V_{10}; this may decrease the chance of radiation-induced secondary malignancies. For integral-dose reduction, a large reduction was found in the low-dose regions (V_5) because jaw tracking can reduce the effects of leaf transmission. The maximum jaw moving had an average distance of 2.73 cm and range
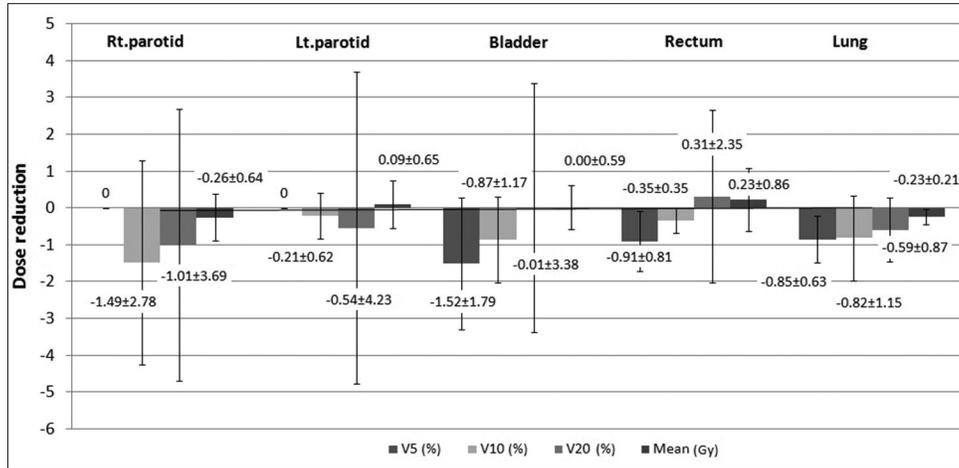
Figure 2: Organ-dose reduction for both sides of the parotid, rectum, bladder, and normal lung

Table 4: Comparison of organ dose between volumetric-modulated arc therapy with jaw tracking and volumetric-modulated arc therapy without jaw tracking

Plans	Organ	$\bar{x} \pm SD$		Difference	P
		JT	No JT		
Nasopharynx	Right parotid				
	V_5 (%)	100±0	100±0	0	0.5
	V_{10} (%)	97.93±3.28	99.43±0.80	−1.49	0.06
	V_{20} (%)	68.94±15.17	69.95±14.77	−1.01	0.21
	Mean dose (Gy)	37.93±8.54	38.20±8.26	−0.26	0.11
	Left parotid				
	V_5 (%)	100±0	100±0	0	0.5
	V_{10} (%)	97.22±5.77	97.43±5.23	−0.21	0.16
	V_{20} (%)	74.67±12.57	75.21±13.30	−0.54	0.35
	Mean dose (Gy)	40.40±9.54	40.31±9.30	0.09	0.34
Prostate	Rectum				
	V_5 (%)	87.38±18.39	88.28±18.65	−0.91	<0.05
	V_{10} (%)	78.42±17.73	78.77±17.82	−0.35	<0.05
	V_{20} (%)	59.49±21.64	59.18±22.55	0.31	0.34
	Mean dose (Gy)	31.42±8.0	31.18±8.11	0.23	0.20
	Bladder				
	V_5 (%)	82.42±21.76	83.95±21.69	−1.52	<0.05
	V_{10} (%)	75.41±24.46	76.28±24.55	−0.87	<0.05
	V_{20} (%)	60.62±22.55	60.63±23.67	−0.01	0.50
	Mean dose (Gy)	29.61±9.58	29.61±9.69	0.01	0.49
Lung	Normal lung				
	V_5 (%)	55.07±24.05	55.92±23.93	−0.85	<0.05
	V_{10} (%)	45.48±24.72	46.30±25.51	−0.82	<0.05
	V_{20} (%)	27.05±18.29	27.64±19.03	−0.59	0.053
	Mean dose (Gy)	13.72±7.97	13.95±8.17	−0.23	<0.05

V_5: Volume receiving a dose of 5 Gy, V_{10}: Volume receiving a dose of 10 Gy, V_{20}: Volume receiving a dose of 20 Gy, SD: Standard deviation, JT: Jaw tracking

from 0 to 8.5 cm [Table 2]. This was found in nasopharynx treatment plans which could reduce the maximum integral dose reduction in the V_5 by 1.13% of the volume. This indicated that integral-dose reduction depends on the tumor shape; for example, a large size difference between the anterior and lateral views in the nasopharynx tumor can create larger jaw moving.

Our study found that jaw tracking can reduce organ dose and integral dose as shown in Figures 2 and 3, which were comparable with the other study. Joy *et al.*[14] found that V_5, V_{10}, and V_{20} of normal organs can be reduced by 2% by using jaw tracking, and a large dose decrease was found in V_5. Schmidhalter *et al.*[15] found that dynamic IMRT with jaw tracking can decrease the integral dose by 1.5% and 1.8%

Table 5: Comparison of integral dose between volumetric-modulated arc therapy with jaw tracking and volumetric modulated arc therapy without jaw tracking

Plans	Integral dose	$\bar{x} \pm$ SD		Difference	P
		JT	No JT		
Nasopharynx	V_5 (%)	47.24±6.78	48.37±6.91	−1.13	<0.05
	V_{10} (%)	37.51±4.85	38.19±5.08	−0.69	<0.05
	Mean dose (Gy)	13.34±1.41	13.47±1.44	−0.13	<0.05
Prostate	V_5 (%)	22.39±6.20	22.76±6.29	−0.38	<0.05
	V_{10} (%)	16.55±5.09	17±5.06	−0.45	0.07
	Mean dose (Gy)	4.31±1.33	4.41±1.35	−0.09	<0.05
Lung	V_5 (%)	24.48±12.89	24.99±13.11	−0.51	<0.05
	V_{10} (%)	15.94±9.0	16.18±10.11	−0.24	<0.05
	Mean dose (Gy)	4.81±2.83	4.90±2.88	−0.09	<0.05

V_5: Volume receiving a dose of 5 Gy, V_{10}: Volume receiving a dose of 10 Gy, SD: Standard deviation, JT: Jaw tracking
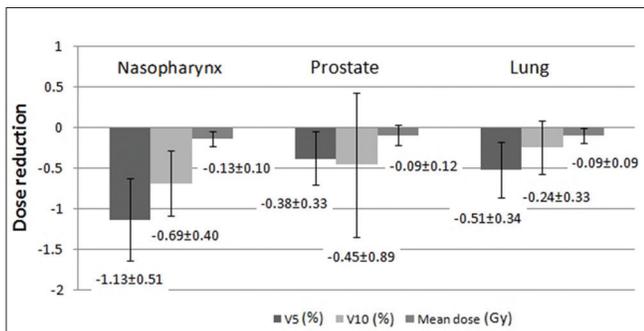

Figure 3: Integral-dose reduction in Nasopharynx, prostate, and lung plans

in nasopharynx and prostate treatment plans, respectively. They also evaluated a decrease in leaf transmission with jaw tracking in academic cases (sliding gap and chair pattern) and found decreases of 9% and 4% for the sliding gap and chair pattern, respectively. Kim *et al*.[16] showed that VMAT with jaw tracking decreased the dose to normal organs ranging from 3.7% to 8.1% for prostate plans and 4.3% to 11.9% for the nasopharynx plans. The dose reduction was more pronounced in the dose received by 80% of volume ($D_{80\%}$), the dose received by 90% of volume ($D_{90\%}$), the dose received by 95% of volume ($D_{95\%}$) than in the dose received by 5% of volume ($D_{5\%}$), the dose received by 10% of volume ($D_{10\%}$), and the dose received by 20% of volume ($D_{20\%}$) for all patients. Snyder *et al*.[17] found jaw tracking can reduce doses to normal organs in IMRT and VMAT for spine stereotactic radiosurgery. They suggested that jaw tracking can be used for decreasing the dose to the spinal cord in both IMRT and VMAT.

CONCLUSIONS

For organ-dose reduction, jaw tracking in VMAT plan was superior to no jaw tracking in reducing of low-dose regions (V_5 and V_{10}) for radiosensitive organs such as bladder, rectum, and normal lung. For integral-dose reduction, jaw tracking in VMAT plan is an efficient method for decreasing low-dose regions (V_5).
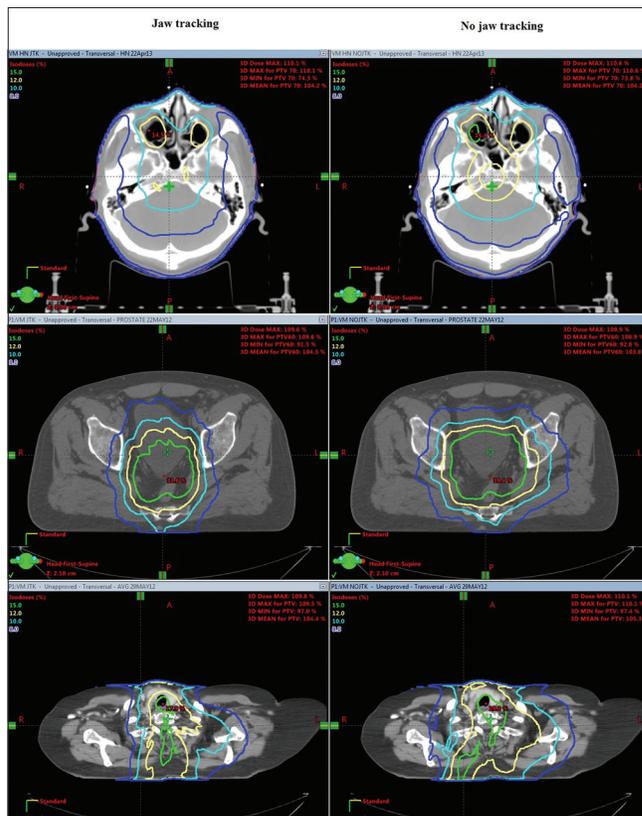

Figure 4: Comparison of low-dose distribution at upper and lower regions of planning target volume between jaw tracking and no jaw tracking in nasopharynx, prostate, and lung plans. Blue line = 8% of doses, cyan line = 10% of doses, yellow line = 12% of doses, and green line = 15% of doses

Conflicts of interest
There are no conflicts of interest.

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