

# Dosimetric Impact of the Jaw-Tracking Technique in Volumetric Modulated Arc Therapy

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## Abstract

**Objective:** The jaw-tracking technique has been developed to reduce the radiation beam transmission in the regions blocked by multileaf collimator (MLC). The aim of this study is the dosimetric evaluation of the jaw-tracking technique in Volumetric Modulated Arc Therapy (VMAT).

**Material and Methods:** 31 VMAT cases treated with the jaw-tracking technique were employed and re-planned with fixed jaw to analyze the dosimetric influences of the planning target volume (PTV) and organs at risk (OARs) volume. The treatment sites were liver, lung, and pancreas. All plans were optimized and calculated under jaw-tracking and fixed jaw conditions to cover the prescription dose to 95% of PTV (D95%) using the treatment planning system. The dosimetric verification of the treatment plans, the uniformity of the target dose distributions, the partial volume doses in OARs, and the low-dose volume were evaluated to verify the dosimetric impact of the jaw-tracking.

**Results:** The jaw-tracking technique appeared to be able to provide some clinical advantages compared to the fixed-jaw technique. The dose uniformities in targets were similar between in jaw-tracking technique and in fixed jaw. It appeared that the jaw-tracking technique could significantly reduce the partial volume dose of OARs, for the kidney ( $p=0.008$ ) and duodenum ( $p=0.028$ ) in liver cancer cases, for the esophagus ( $p=0.015$ ) in the lung cancer cases, and for the normal liver ( $p=0.005$ ) and kidney ( $p=0.005$ ) in the pancreatic cancer cases. The low-dose volumes with the jaw tracking technique were calculated to be smaller than those with fixed jaw setup when the effective maximum field dimension were 1.5 cm larger than the equivalent spherical diameter of the PTVs.

**Conclusions:** The partial volume dose of OARs and the low-dose volume could be significantly reduced by application of the jaw-tracking technique without any adverse effect of the dosimetric parameter for targets in VMAT.

**Keywords:** Jaw-tracking; Volumetric modulated arc therapy; Dose uniformity; Low dose region

## Introduction

In cancer treatment, the radiotherapy has been made more and more emphasis on their clinical importance and the accompanying technology has been rapidly developed. In particular, the utilization of dynamically modulated beam could dramatically improve the dosimetric conformities of targets to reduce the doses of Organs at Risk (OARs). Intensity Modulated Radiation Therapy (IMRT) using the dynamic motions of Multileaf Collimator (MLC) delivers the prescribed dose to the tumor much more precisely and associates with much less treatment-related toxicity, thus reducing the side effects of treatment [1,2]. Recently, the Volumetric Modulated Arc Therapy (VMAT) technique was introduced to utilize the dynamic beams produced by the modulation of the dose rate and gantry angle as well as the MLCs [3]. Several reports have been published the VMAT plan was shown their superiorities to static IMRT for various types of cancer in term of clinical efficiency [4-9].

However, it is expected the nontrivial low doses due to the use of multi-directional beams and the block transmissions for MLCs can

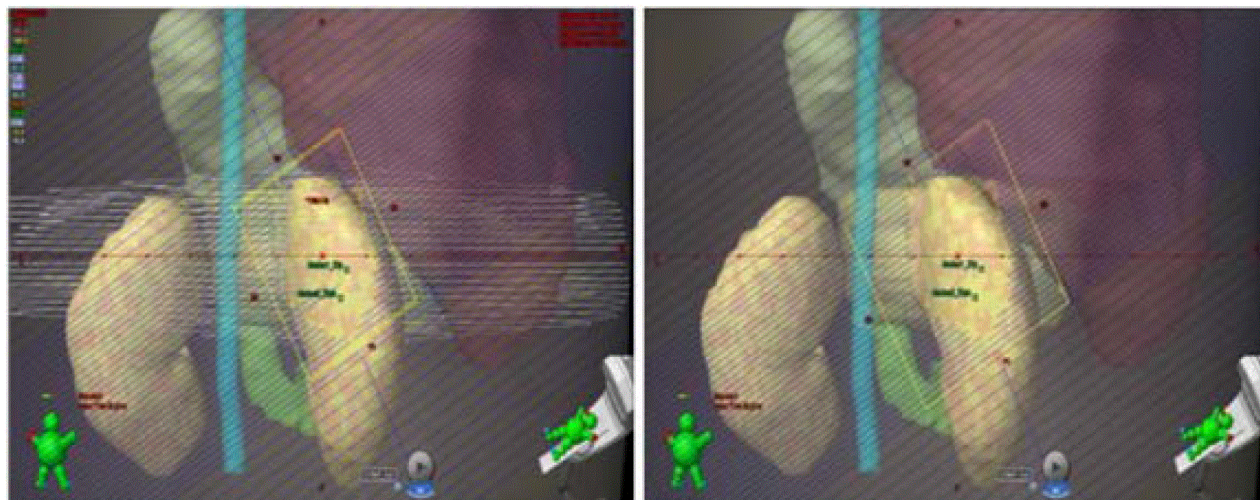
result in the increase of the chronic radiation complication probabilities [10]. It is well known that low doses delivered to normal organs can provoke secondary cancers. The plans of both VMAT and IMRT could be limited by these dosimetric problems.

In general, the treatment field is designed with the jaw apparatus, and the detailed beam shape for target volume was made by MLCs. The jaw apparatus is fixed on the maximum field size of MLC during radiation therapy, and this can cause leakage and transmission of the MLC in the IMRT or VMAT plan. Whereas, if the jaws are moved to the edge of the MLC field according to the position of the MLC (this is termed "jaw-tracking"), as shown in Figure 1, it can be expected that the radiation transmitted by the MLC and the dose delivered to normal tissue will be reduced.

However, when Joy et al. [11] investigated the dosimetric effects of jaw tracking in step-and-shoot IMRT, they found that the clinical benefit of this technique was insufficient due to experimental limitations. Meanwhile, the newly introduced TrueBeam STx system (Varian Medical System, Palo Alto, CA, USA) provides the jaw-tracking technique. Moreover, this machine is designed to deliver flattened filter and Flattening Filter Free (FFF) beams. In particular, the maximum dose rate is 2,400 MU per minute in the FFF mode. It is expected that the dose delivered out of the field can be decreased due

to reduced head scatter and residual electron contamination [12-14]. However, these advanced technique should be verify. The present study was conducted to examine the dosimetric impact of dose distribution

in the VMAT plan when using the jaw-tracking technique with TrueBeam STx system.



**Figure 1:** Jaw movement using the jaw-tracking method (left) and the fixed-jaw method (right).

## Materials and Methods

The TrueBeam STx platform is an integrated system that was designed to provide respiratory gating, real-time tracking, and accurate treatment beam delivery. This means that the latest treatment techniques can be used with this system, including SBRT, RapidArc, and Gated RapidArc. The HD120 MLC that is installed in this machine is a high-definition MLC that provides 2.5 mm leaf width. The maximum intensity modulated field size is  $22 \text{ cm}^2 \times 40 \text{ cm}^2$  at the isocentric plane. This machine provides the flattening filter free mode (6X FFF, 10X FFF), which reduces the treatment time and low-dose area. The respiratory gating technique can also use in the VMAT plan as using the TrueBeam system. To evaluate the dosimetric impact when the jaw-tracking technique is used in the radiation treatment planning (RTP, Eclipse v10) system, 31 treatment plans of patients who were treated with the TrueBeam system were extracted at random. These treatment sites were liver (n=11), lung (n=10), and pancreatic (n=10) cancer. The prescribed doses of these plans ranged from 28 Gy to 45 Gy for the liver cases, from 27.3 Gy to 60 Gy for the lung cases, and from 24 Gy to 28 Gy for the pancreas cases. The prescribed dose for all plans was normalized to cover 95% of the Planning Target Volume (PTV) (D95%).

The VMAT technique was applied to all treatment plans, which were initially, optimized using the jaw-tracking method. The dose distribution was calculated by the anisotropic analytical algorithm. The plans were re-optimized with fixed jaw technique in the same conditions (number of fractions, the number of arcs, constraint for PTV and normal tissue) to compare with the plans which were created with jaw-tracking technique. Preferentially, the VMAT plans for eight cases of liver cancer were verified. The aim was to investigate the beam delivery and positioning accuracy of the MLC for each plan because the VMAT plan controls the photon fluence by using the MLC aperture.

Pair of verification plans for each case, one with the jaw-tracking technique and one with the fixed-jaw technique, was created for the

Multicube phantom on the treatment planning system. The 2D-array dosimetric (I'mRT MatriXX, IBA) detector was used for evaluation. It consists of 1020 ionization chambers in an active area of  $24 \text{ cm}^2 \times 24 \text{ cm}^2$ . A warm-up time exceeding 15 min and 1000 MU of pre-irradiation before beam delivery were performed as recommended by the manufacturer. The correction factor (kuser) for the detector had to be measured because the 2D-array detector depends on the selected Linac, energy type, pressure and temperature. The kuser factor was measured at the maximum depth and SSD 100 cm for used energy. The measured dose distributions for each plan were verified by gamma analysis (3% and 3 mm criteria). The dose Uniformity Index (UI) of the target volume was used to describe the target dose homogeneity of the plans. UI was defined as the ratio of dose that covers 5% and 95% of the PTV ( $\text{UI} = \text{D5\%/D95\%}$ ) in the dose-volume histogram (DVH) [15]. To compare the dose distributions obtained when using the jaw-tracking and fixed-jaw techniques, OARs that were located near the target volume were defined. In the abdominal regions, we investigated the dose distributions for the spinal cord, liver, kidney, stomach, and duodenum. The dose distributions of the lung, spinal cord, and esophagus were examined in the case of lung cancer. Dosimetric evaluation of the doses to the OARs was performed by using the Quantitative Analysis of Normal Tissue Effects in Clinics (QUANTEC). We measured the dose for the critical volume of each structure and analyzed the dose differences between the jaw-tracking and fixed jaw methods on the DVH. The volumes of body received 1 Gy ( $V_1 \text{ Gy}$ ) were considered to assess the low dose volume, and data analysis was carried out with SPSS (Version 18, Chicago, IL).

## Results

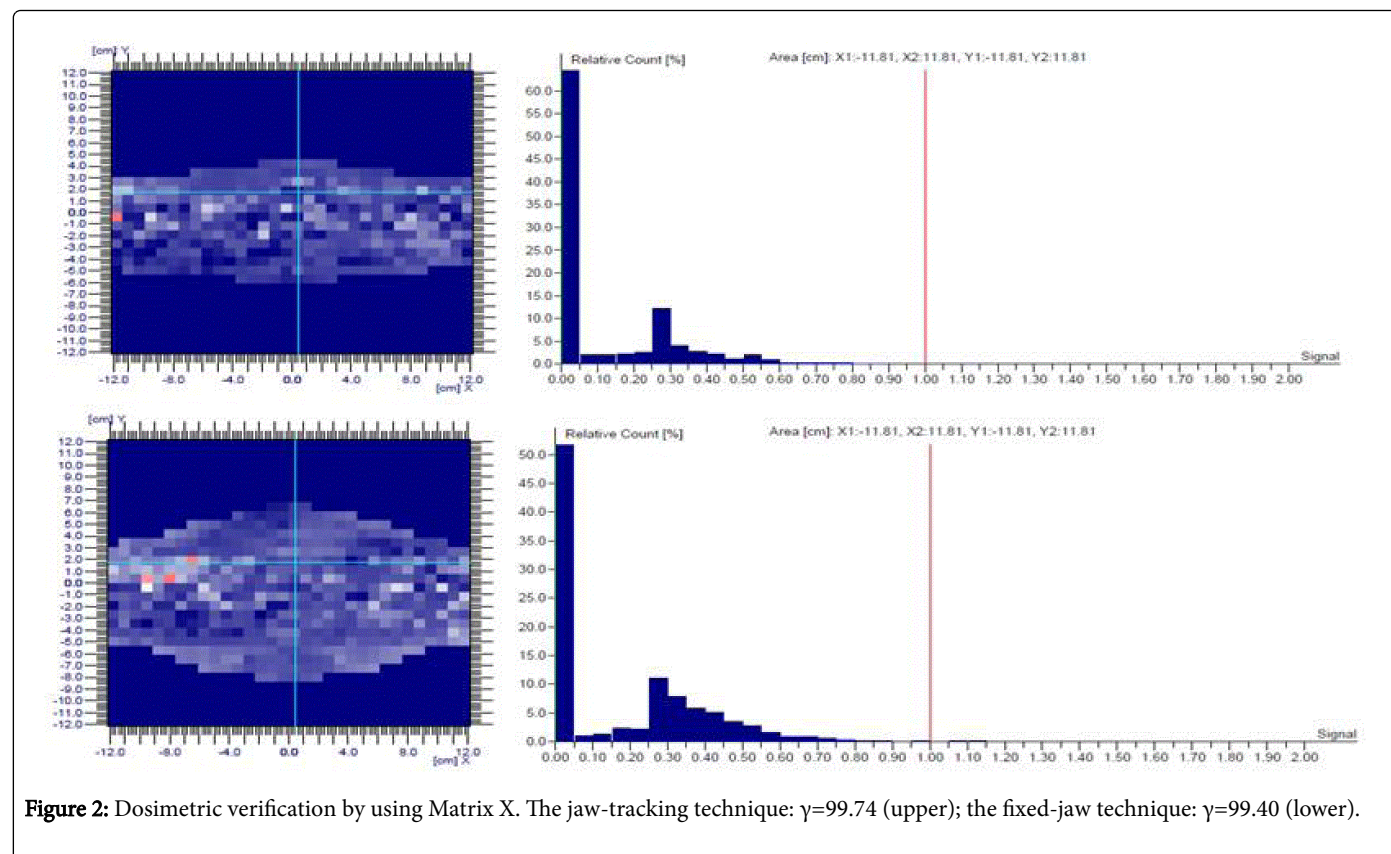
### Verification of dose delivery

The 8 pairs of VMAT treatment plans were compared between jaw-tracking technique and fixed jaw by gamma analysis, and the correlation between the two techniques in terms of dose uniformity for

PTV was analyzed by using the Wilcoxon signed rank test. The measured dose distributions by the jaw-tracking and fixed-jaw technique agreed well with the dose distributions calculated on the treatment planning system (Figure 2).

The average gamma passing rates for the verification plans with the jaw-tracking and fixed-jaw techniques were  $97.98 \pm 3.17$  and  $97.52 \pm 4.14$ , respectively. There is no significant difference in the dose delivery verification results between two techniques ( $p=0.310$ ).

Meanwhile, the dose distributions of a few plans used the fixed-jaw technique were spread more extensively than those with the jaw-tracking technique. Therefore, we can expect that the dose received by OARs at the border of the target volume will be decreased when the jaw-tracking technique is applied to the plan.



### Dose uniformity in the PTV

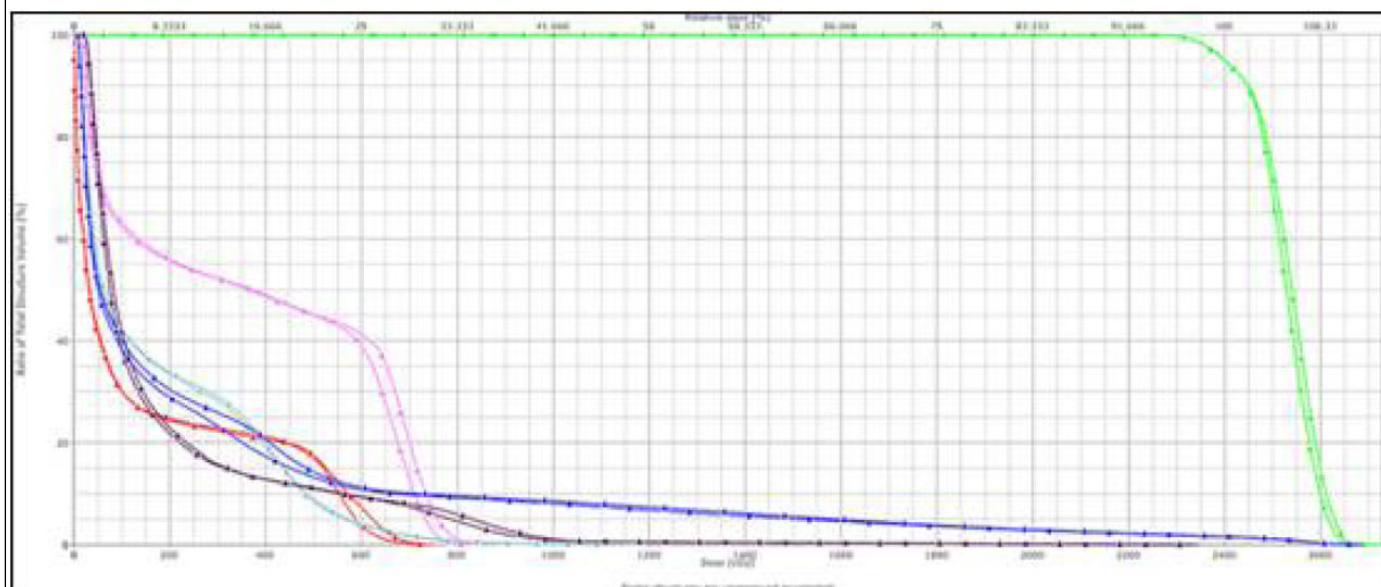
The dose uniformity of the PTV was calculated on the dose-volume histogram for each pair of the plan (Figure 3). Since the jaw-tracking technique was applied to the VMAT plans using the same conditions, the dose uniformity was somewhat better than when the fixed-jaw

technique was employed, and some dose difference for the normal tissue occurred on the DVH.

However, the VMAT plans by the jaw-tracking and fixed-jaw techniques did not differ significantly in terms of average uniformity for the target volumes (Table 1).

Dose conformity		UI	p-value
Liver	Jaw tracking	$1.09 \pm 0.05$	0.657
	Fixed jaw	$1.09 \pm 0.05$	
Lung	Jaw tracking	$1.08 \pm 0.02$	0.959
	Fixed jaw	$1.08 \pm 0.03$	
Pancreas	Jaw tracking	$1.07 \pm 0.02$	0.646
	Fixed jaw	$1.07 \pm 0.02$	

**Table 1:** Uniformity Index for planning target volume when the jaw-tracking and fixed-jaw techniques were used in the liver, lung, and pancreatic cancer cases. Uniformity Index (UI) =  $D_{5\%}/D_{95\%}$ . P-values were generated by using Wilcoxon signed rank test.

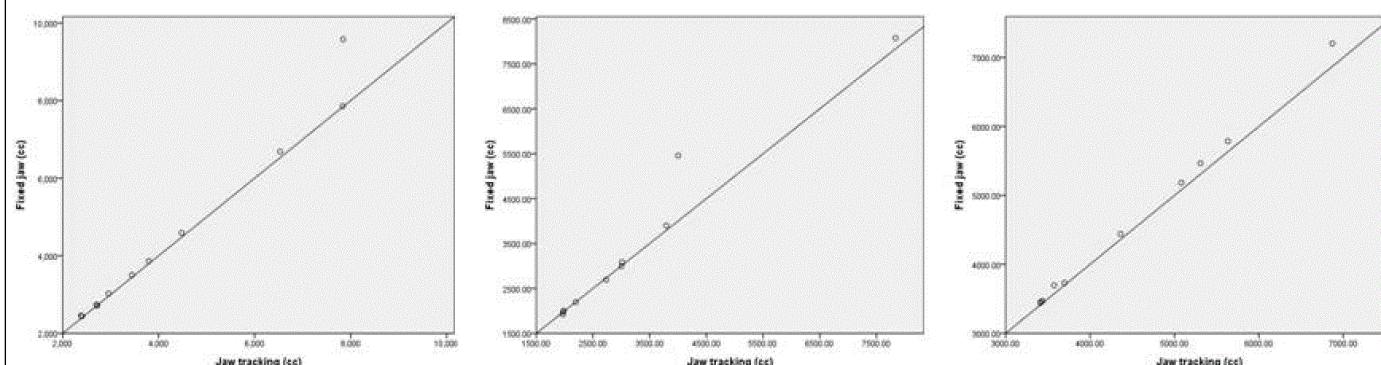


**Figure 3:** Dose-volume histogram of the planning target volume and normal organs when the jaw-tracking (dot line) and fixed-jaw (solid line) techniques were used.

### Low-dose volume

Initially, to analyze the effect of the two jaw techniques on the low-dose area, the body volumes that received 1 Gy ( $V_1$  Gy) were measured. For the liver and lung cancer cases, there are no statistical

differences by the two techniques in  $V_1$  Gy ( $p=0.191$  and  $p=0.203$ , respectively (Figure 4). However, for the pancreatic cancer treatment plans, there was a clinical difference between the two techniques in  $V_1$  Gy ( $p=0.005$ ).



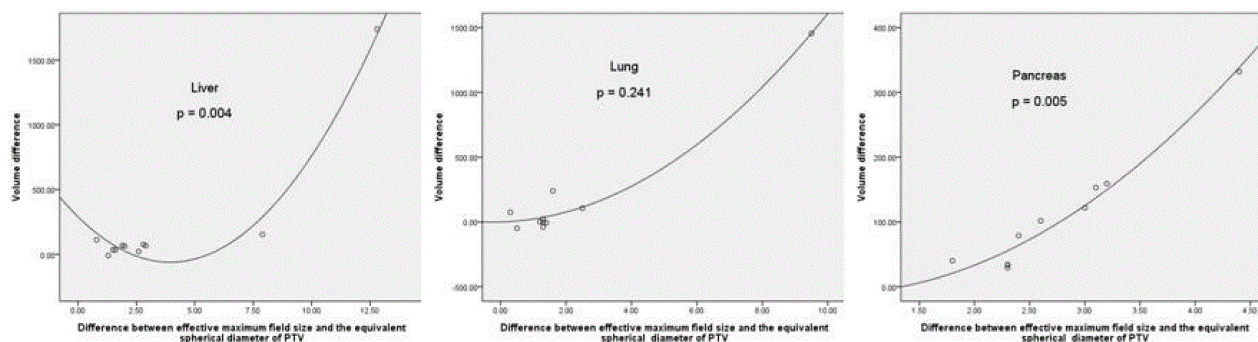
**Figure 4:** Volume differences that received 1 Gy ( $V_1$  Gy) when the jaw-tracking and fixed-jaw techniques were applied in the liver (left), lung (middle), and pancreatic (right) cancer cases.

Another way to measure the effect of the two jaw techniques on the low-dose area was to measure the difference between the effective maximum field size and the equivalent spherical diameter of the PTV and to compare that to the volume difference in the low-dose area by the two techniques.

For the liver and pancreatic cancer cases, there was a clinical difference between the two techniques ( $p=0.004$  and  $p=0.005$ ,

respectively; Figure 5). Whereas, this was not observed for the lung cancer cases ( $p=0.241$ ).

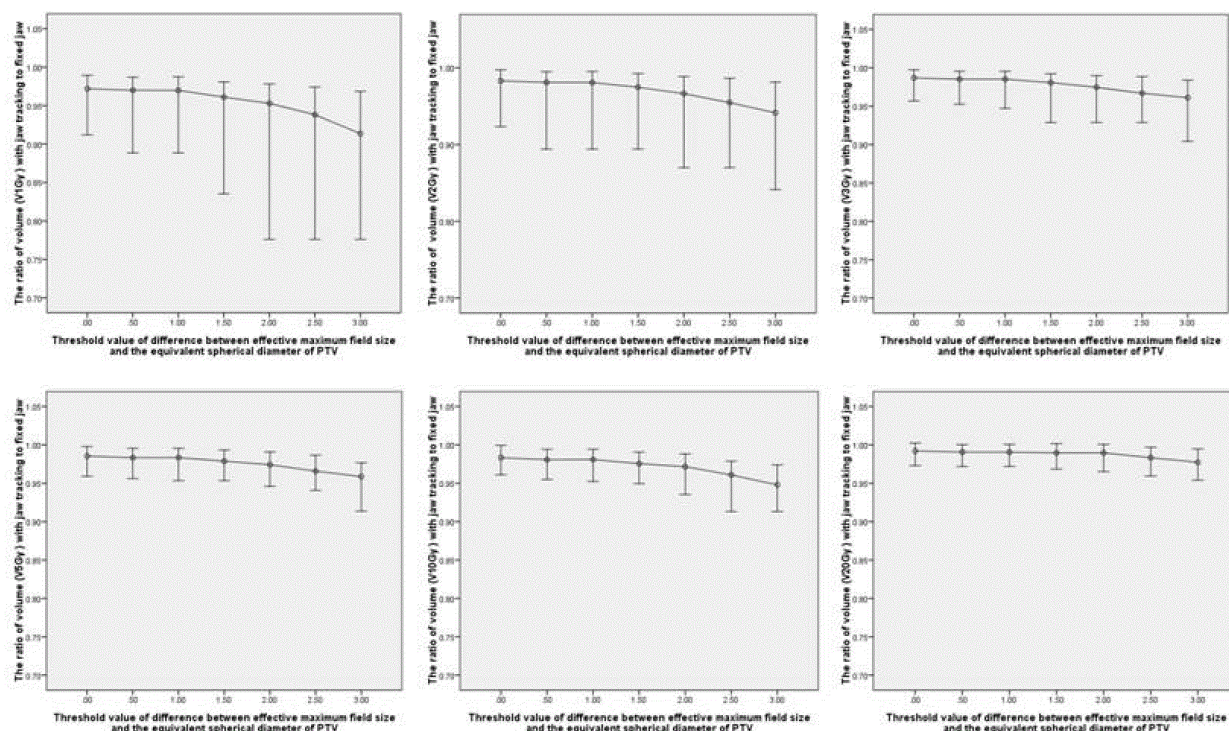
Our statistical results indicated that when there was difference of more than 1.5 cm between the effective maximum field size and the equivalent spherical diameter of the PTV, there was a low-dose area volume difference.



**Figure 5:** Volume differences by the difference between effective maximum field size and the equivalent spherical diameter of planning target volume in low dose area when the jaw-tracking and fixed-jaw techniques were applied (liver, lung, and pancreatic cancer cases).

The body volumes that received 1, 2, 3, 5, 10 or 20 Gy ( $V_1$  Gy,  $V_2$  Gy,  $V_3$  Gy,  $V_5$  Gy,  $V_{10}$  Gy, or  $V_{20}$  Gy, respectively) when each technique was used were then measured and expressed as jaw-tracking volume to fixed-jaw volume ratio. These ratios were then plotted against various threshold values of the difference between the effective maximum field size and the equivalent spherical diameter of the PTV in the low-dose

area (Figure 6). The ratio tended to decrease as the threshold value increased. In particular, there was a large difference (5%) between the two techniques in terms of  $V_1$  Gy when the threshold value was 2.5 cm. Thus, we can expect that the jaw-tracking technique may reduce radiation therapy side effects such as secondary cancer and developmental disorders in children.

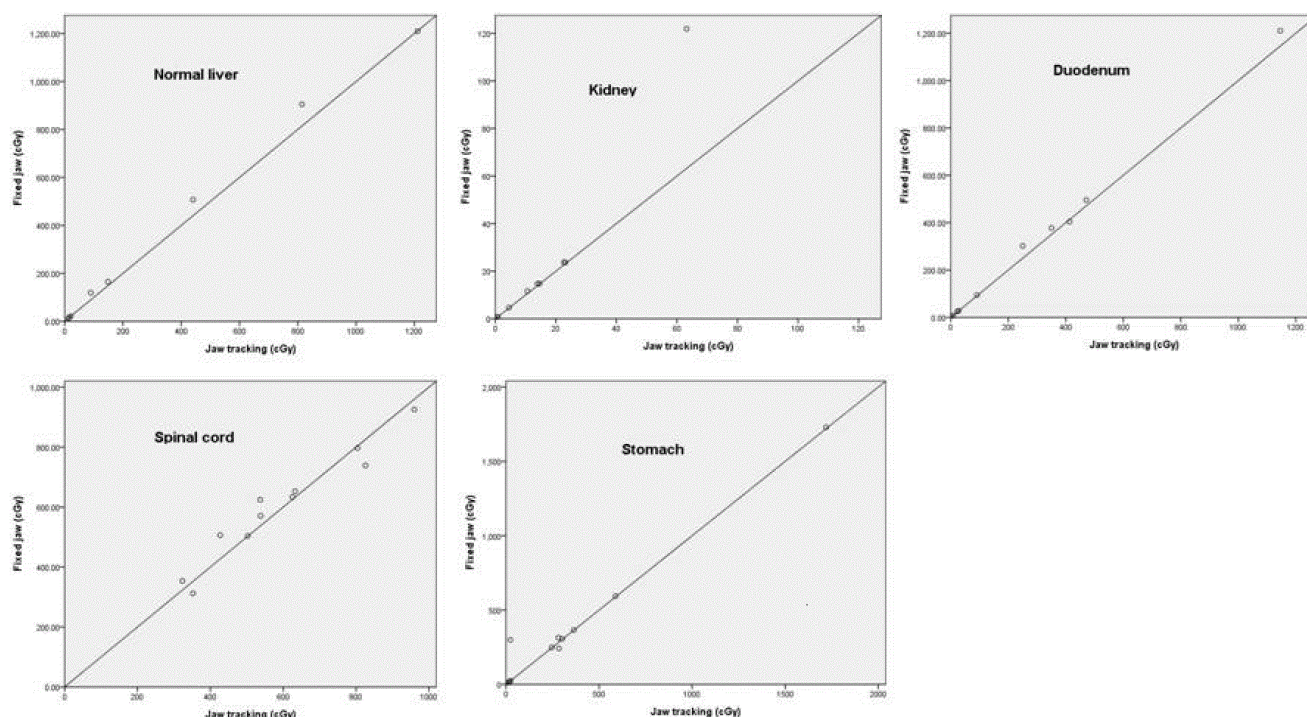


**Figure 6:** The ratio of body volumes that received 1, 2, 3, 5, 10 and 20 Gy ( $V_1$  Gy,  $V_2$  Gy,  $V_3$  Gy,  $V_5$  Gy,  $V_{10}$  Gy, or  $V_{20}$  Gy, respectively) by threshold values of difference between effective maximum field size and the equivalent spherical diameter of the planning target volume.

## Organs at risk

The dose that was delivered to specific critical volumes of normal tissue close to the target volume was analyzed. Figure 7 shows the dose that was delivered by each technique to various critical OAR volumes in the liver cancer cases. Compared to when the fixed-jaw technique

was used, the jaw-tracking technique reduced the doses of OARs by a maximum of 29.6 cGy for the normal liver, 58.7 cGy for the kidney, 64.7 cGy for the duodenum, and 276.2 cGy for the stomach. However, the jaw-tracking technique did not affect the dose received by the spinal cord in these cases.



**Figure 7:** The dose differences that were delivered by the jaw-tracking and fixed-jaw techniques in the liver cancer cases. The organs at risk in liver cancer are the normal liver, kidney, duodenum, spinal cord, and stomach.

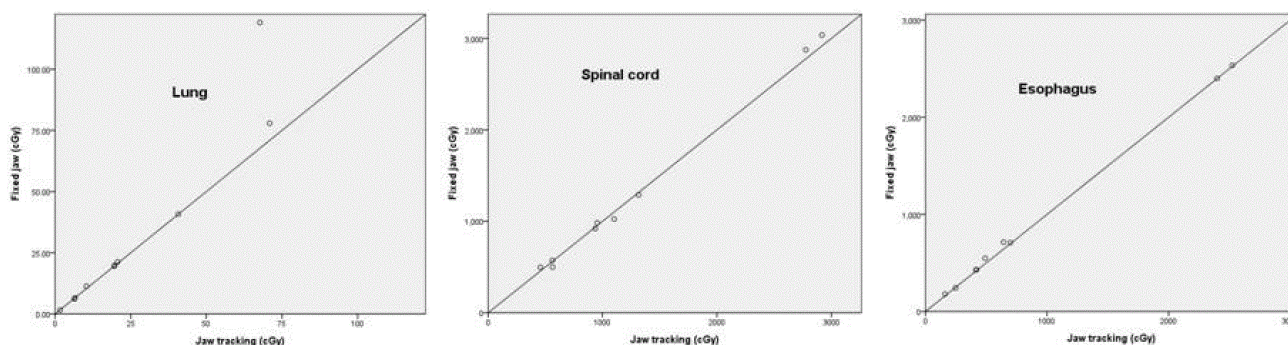
Figures 8 and 9 shows the dose differences for OARs in the lung and pancreatic cancer cases, respectively. In the cases of lung cancer, the jaw-tracking technique reduced the dose of OARs by a maximum of 51.4 cGy for the normal lung, 119.0 cGy for the spinal cord, and 72.6 cGy for the esophagus. In the pancreatic cancer cases, the jaw-tracking technique reduced the dose of OARs by a maximum of 34.3 cGy for the normal liver, 20.8 cGy for the kidney, 69.5 cGy for the duodenum, and 50.59 cGy for the stomach.

However, when the jaw-tracking technique was used, the spinal cord received more of the delivered dose than when the fixed-jaw technique was used (maximum of 55.5 cGy).

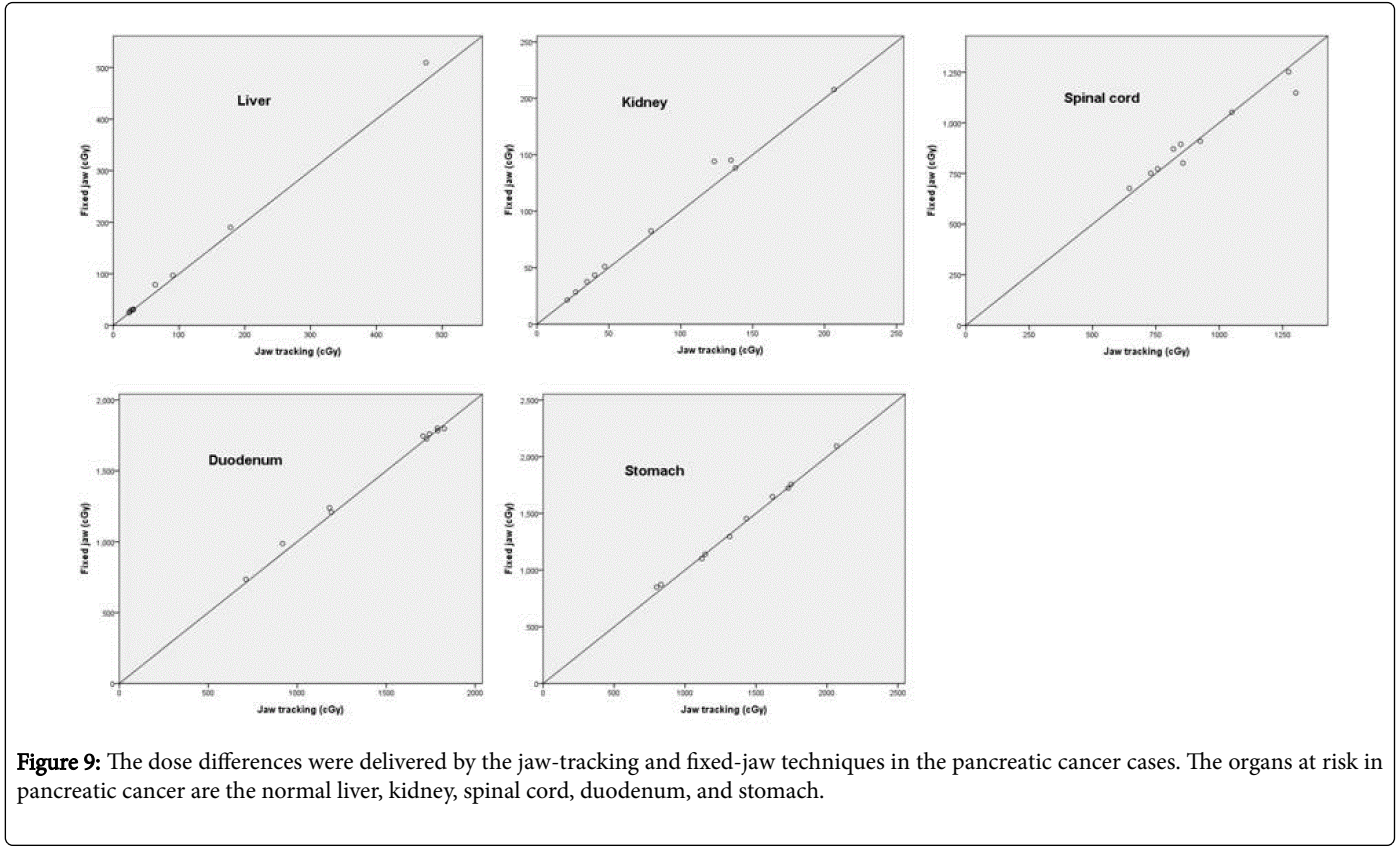
Table 2 shows result of statistical significance test between the tracking-jaw and fixed-jaw techniques in terms of the dose received by organs at risk in the liver, lung, and pancreatic cancer cases.

In the liver cancer cases, there are significant differences for all OARs except the spinal cord when the jaw-tracking technique was used. In the lung cancer cases, there is difference for the esophagus when the jaw-tracking technique was used.

In the pancreatic cancer cases, there are statistical difference for liver and kidney when the jaw-tracking technique was used.



**Figure 8:** The dose differences were delivered by the jaw-tracking and fixed-jaw techniques in the lung cancer cases. The organs at risk in lung cancer are the lung, spinal cord, and esophagus.



Cancer	Organ	Critical volume	p-value
Liver	Normal liver	D <sub>700cc</sub>	0.05
	Kidney	D <sub>200cc</sub>	0.008
	Duodenum	D <sub>5cc</sub>	0.028
	Spinal Cord	D <sub>0.25cc</sub>	0.594
	Stomach	D <sub>10cc</sub>	0.05
Lung	Lung	D <sub>1500cc</sub>	0.114
	Spinal cord	D <sub>0.25cc</sub>	0.594
	Esophagus	D <sub>5cc</sub>	0.015
Pancreas	Liver	D <sub>700cc</sub>	0.005
	Kidney	D <sub>200cc</sub>	0.005
	Duodenum	D <sub>5cc</sub>	0.074
	Spinal Cord	D <sub>0.25cc</sub>	0.878
	Stomach	D <sub>10cc</sub>	0.114

**Table 2:** Statistical significance of differences between the tracking-jaw and fixed-jaw techniques in terms of the dose received by organs at risk in the liver, lung, and pancreatic cancer cases. P-values were generated by using Wilcoxon signed rank test.

Discussion

In recent years, advanced radiation treatment machines and highly accurate treatment techniques have been developed. However,

radiotherapy still has side effects such as skin disease, malfunction and edema [16]. Although IMRT technique was developed to reduce these side effects, it has longer treatment times than the conventional treatment technique because since this technique involves a larger

number of beam directions. To overcome this problem, VMAT technique was developed. This technique is similar to IMRT in that it effectively spares normal tissue and strongly delivers the dose to the planned target volume; moreover it has a shorter treatment time and can reduce intra-fraction position error.

The leaf position accuracy of the HD 120 MLC (32 mm × 2.5 mm and 28 mm × 5.0 mm leaves) that is installed in the TrueBeam system is less than 1 mm at the isocenter. This allows the dose to be directed to a delicate three-dimensional tumor shape, thus improving the accuracy of dose delivery. The TrueBeam system can also provide the respiratory gated radiation therapy with VMAT technique, a high dose rate with the FFF mode and real-time tracking. These functions reduce the treatment time and prevent potential toxicity. Besides, the dose distributions of normal organs are expected to be reduced.

The TrueBeam system can apply the jaw-tracking technique to IMRT and VMAT. The jaw-tracking technique involves the movement of the jaws to the edge of the MLC field during radiation treatment. This technique thus reduces the radiation that is transmitted through the MLC aperture.

Several studies have evaluated the efficiency of this technique. Prasad reported that for treatment fields shaped by a MLC, the dose per MU was improved by a maximum of 5% when collimator jaw settings were used [17]. Chapek et al. [18] investigated the effects of collimator angle and jaw tracking for the dose delivered to the rectal wall while Schmidhalter et al. [19] evaluated the dosimetric effects of jaw tracking for the transmitted radiation through the multileaf collimator. Kim et al. [20] reported that the deliverability and reproducibility of VMAT plan with jaw tracking are validated, and the availability of jaw tracking was evaluated for prostate and H&N cases. Feng et al. [21] also evaluated the jaw tracking method with various cases.

In our study, we have considered the volume differences by the difference between effective maximum field size and the equivalent spherical diameter of planning target volume in the various lesions. Thus efficiency of jaw tracking could be determined.

Low-dose radiation has stochastic effects as it deposits less energy into the cell along the radiation path. Thus, low-dose radiation is considered to be less destructive per radiation track than high-dose radiation. However, low-dose radiation still causes side effects such as secondary cancer and hereditary diseases. And Nikitaki et al. [22] raised the effect of ionizing radiation in out-of-field, and investigated in clinical terms.

The present study was performed to evaluate the dosimetric impact of the jaw-tracking technique using the TrueBeam system. It was expected that the jaw-tracking technique would reduce the dose distribution received by the normal organs adjacent to the target volume compared to the fixed-jaw technique and improve the treatment target coverage. Indeed, the jaw-tracking technique did reduce the low-dose volume.

One limitation of this study was that the target volumes of the selected cases were all small and the same conditions were applied to all VMAT plans in an optimization process. The reduction of MLC transmission depends on the relative distribution of the field sizes. Therefore, the effects of the jaw-tracking technique should also be evaluated for large fields such as "Head and Neck cancer case". Another relevant factor is the position where the OARs are located relative to the PTV. The jaw-tracking technique is likely to be particularly useful

for reducing the low-dose volume of normal organs adjacent to the target volume.

## Conclusions

The recently developed linear accelerators for radiation therapy provide a variety of functions. In this study, we report that the jaw-tracking technique has some, albeit limited, dosimetric impact compared to the fixed-jaw technique. In particular, the jaw-tracking technique was found to have a clinical advantage in terms of the volume difference in low-dose volume ( $V_1$  Gy) relative to the difference between the effective maximum field size and the equivalent spherical diameter of PTV. When the jaw-tracking technique was employed, average volume differences of 214.5 cc and 108.3 cc were observed in the liver and pancreatic cancer cases, respectively. The average difference between the effective maximum field size and the equivalent spherical diameter of PTV was 3.4 cm, 2.1 cm and 2.7 cm in the liver, lung, and pancreatic cancer cases, respectively. The maximum difference for the equivalent spherical diameter of PTV was 12.8 cm, and the volume difference was 1738 cc ( $V_1$  Gy for body volume). We obtained a positive value in the region of greater than 1.5 cm difference between the effective maximum field size and the equivalent spherical diameter of PTV. To assess target coverage and sparing of OAR more accurately, more treatment plans should be assessed. These plans have to be established with the advanced technique of the TrueBeam system (which allows jaw tracking and respiratory gating with VMAT), after which Monte Carlo treatment planning must be established and performed with dosimetric measurement for these treatment plans.

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