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Evaluation of Beam-Matching Accuracy for 8 MV Photon Beam between the Same Model Linear Accelerator

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동일 기종 선형가속기간 8 MV 광자선에 대한 빔 매칭 정확도 평가

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Abstract This study aimed to assess of beam-matching accuracy for an 8 MV beam between the same model linear accelerators(Linac) commissioned over two years. Two models were got the customer acceptance procedure(CAP) criteria. For commissioning data for beam-matched linacs, the percentage depth doses(PDDs), beam profiles, output factors, multi-leaf collimator(MLC) leaf transmission factors, and the dosimetric leaf gap(DLG) were compared. In addition, the accuracy of beam matching was verified at phantom and patient levels. At phantom level, the point doses specified in TG-53 and TG-119 were compared to evaluate the accuracy of beam modelling. At patient level, the dose volume histogram(DVH) parameters and the delivery accuracy are evaluated on volumetric modulated arc therapy(VMAT) plan for 40 patients that included 20 lung and 20 brain cases. Ionization depth curve and dose profiles obtained in CAP showed a good level for beam matching between both Linacs. The variations in commissioning beam data, such as PDDs, beam profiles, output factors, TF, and DLG were all less than 1%. For the treatment plans of brain tumor and lung cancer, the average and maximum differences in evaluated DVH parameters for the planning target volume(PTV) and the organs at risk(OARs) were within 0.30% and 1.30%. Furthermore, all gamma passing rates for both beam-matched Linacs were higher than 98% for the 2%/2 ㎜ criteria and 99% for the 2%/3 ㎜ criteria. The overall variations in the beam data, as well as tests at phantom and patient levels remains all within the tolerance (1% difference) of clinical acceptability between beam-matched Linacs. Thus, we found an excellent dosimetric agreement to 8 MV beam characteristics for the same model Linacs.

Key Words: Percentage depth dose, Dose profile, Commissioning, Dose volume histogram, Delivery accuracy
중심 단어: 심부선량백분율, 선량분포, 사용준비, 선량체적히스토그램, 전달 정확성

Ⅰ. Introduction

Linear accelerators(Linacs) are the most common treatment machines in radiation therapy. Radiation oncology centers are equipped with more than one Linac, depending on the number of patients treated. Depending on the situation, equal model Linacs from the same vendor are used in many centers. To facilitate the treatment workflow in unexpected situations such as sudden breakdown of any Linac or the increase in

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patient load, two Vital Beam Linacs (Varian Medical Systems, Palo Alto, USA) are used in our center. These Linacs were sequentially installed and commissioned over two years. "Beam-matching" between these Linacs is performed to improve the treatment flexibility and efficiency during the customer acceptance procedure (CAP). Generally, beam-matching is a concept that includes tuning the beams of another unit with a reference Linac. Thus, beam-matching between Linacs can be represented by one set of beam parameters in treatment planning system(TPS)[1].

Many publication articles for beam matching were reported for various Linacs as well as the same model Linac[1-5]. These studies reported that the depth of the maximum dose along the central axis could be adjusted within 1.5 mm and that the difference in percentage depth dose(PDD) at 10 cm depth could be reduced to within 0.5% through Varian's fine-beam matching of the photon beam. However, most previous studies compared beam characteristics and evaluated beam matching accuracy for a 6 MV beam. To my knowledge, no studies have yet evaluated beam matching for an 8 MV beam of the same model Linacs. Therefore, we aimed to evaluate the accuracy of beam matching in the same model of linear accelerator for 8 MV beam which is not mentioned much in the previous paper.

II. Materials and methods

1. Beam matching producer

Two VitalBeam(VB) Linacs equipped with the Varian millennium 120 multi-leaf collimator(MLC) system were used in this study. Per vendor's acceptance criteria, the second Linac(VB2) installed last year was beam-matched with the first Linac(VB1). To match treatment beams between both these Linacs, the beam matching criteria are based on depth ionization curves as well as in-line and cross-line profiles measured in the vendor-defined prescribed geometry. Scanning setup for measuring photon depth of ionization and field profiles includes several requirements; 1) water surface must be at 100 ㎝ target skin distance(TSD), 2) the probe (0.13 cc volume) effective center must be accurately positioned. For photon depth of ionization, the depth of maximum intensity(Id_{max}) and the beam intensity at 10 ㎝ depth(Id_{10}) along the central axis for a 10 × 10 ㎠ field were measured in a water phantom using by Semi-Flex ionization chamber (IBA Dosimetry, Germany). For field flatness and symmetry, the radial and transverse profile field intensity, relative to central axis were measured at a depth of 10 ㎝ for 10 × 10 and 40 × 40 ㎠ fields and normalized to 100% in the 80% of the field width. The flatness was used the following equation

$$Flatness(\%) = \frac{D_{max} - D_{min}}{D_{max} + D_{min}} \times 100\%,$$

where D_{max} and D_{min} are maximum and minimum doses. Even if the measurements were within the vendor-defined criteria adjustments were made to improve the match between each accelerator and the first accelerator, chosen as a reference during the customer acceptance procedure(CAP).

2. Comparison of commissioning beam data

For 8 MV beam, commissioning beam data such as percentage depth doses(PDDs), beam profiles, output factors, MLC leaf transmission factors, and dosimetric leaf gap(DLG), were measured with both Linacs. The PDDs and dose profiles were normalized prior to their further comparison. PDDs were normalized to their maximum, and dose profiles were normalized to the central axis value. The depth of maximum dose(d_{max}), 10 ㎝ and 20 ㎝ depths for PDDs for were compared for different field sizes ranging from 5 × 5 ㎠ to 30 ×30 ㎠. The flatness and the symmetry of beam profiles measured at d_{max} and 10 ㎝ depths were compared for five fields such as field size of 3 × 3, 5 × 5, 10 × 10, 20 × 20 and 30 × 30 ㎠. The output factor, transmission factor(TF), and DLG were also compared. The output factor was measured at a 10 ㎝ depth and a 100 ㎝ source-to-axis distance(SAD) for different field sizes

ranging from 3 × 3 ㎠ to 30 × 30 ㎠. The relative output factor, normalized to the value measured for a 10 × 10 ㎠ field was calculated. Per procedure offered by vendor[5], TF and DLG were measured at a blue water phantom.

3. Test of beam modelling in treatment planning system

To evaluate of beam modelling in TPS, measured commissioning beam data of both Linacs were fed into the Eclipse TPS. As recommended in the American Association of Physicists in Medicine Task Group 53 (AAPM TG-53)[6], the point dose variations between both Linacs were compared at different regions of interest (ROI) such as inner, outer, buildup, and penumbra regions, as shown in Fig. 1. For this, three different open field sizes of 3 × 3, 5 × 5, 10 × 10, and 25 × 25 ㎠ were placed in virtual water phantom and calculated with a fixed dose of 100 MU. In addition, modulated radiation therapy commissioning tests were performed and evaluated, as specified in TG-119[7, 8]. Doses of isocenter and 2.5 ㎝ posterior for PTV were compared on VMAT plan for mork prostate and C shape test case, as shown in Fig. 2. The variation of the specified points between both Linacs was analyzed.

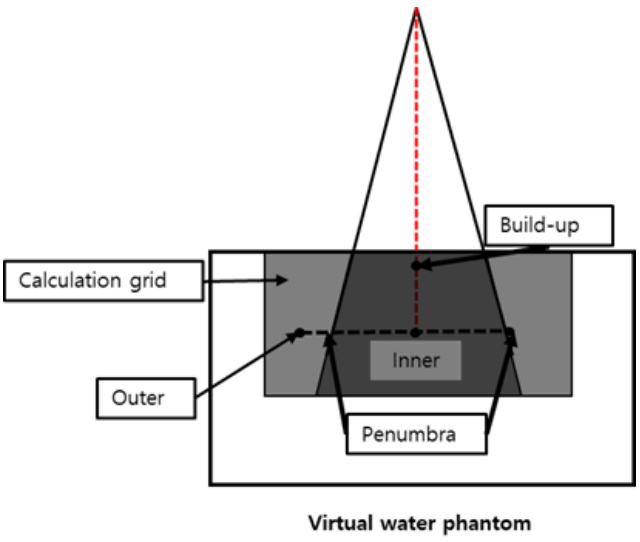

Fig. 1. Different four regions for 2 ㎝ away from the field edge (outer) and 0.5 ㎝ outside each beam (penumbra) at 5 ㎝ depth (inner) and 1 ㎝ depth (build-up) on the central axis, as recommended in the TG-53

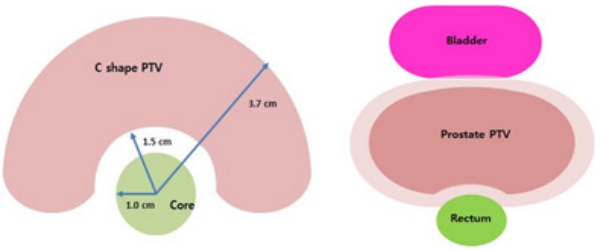

Fig. 2. Mock C-shape and prostate PTV, as specified in the TG-119

4. Clinical VMAT planning and dose measurements

This study was approved by the institutional review board (IRB approval number; B-2001-591-101). Forty patients, including 20 lung cancers and 20 brain tumors, who had been treated with the VB1 Linac at our institution were selected to evaluate treatment planning and beam delivery. All VMAT plans were generated with Eclipse TPS (version 13.7.16, Varian Medical System, Palo Alto, CA, USA) using a 8 MV beam. The optimization process was performed with a photon optimizer algorithm. All doses were calculated by using the Acuros XB(AXB) with heterogeneity correction and a dose calculation gird size of 2.5 ㎜. To compare dosimetric parameters for plans between beam-matched Linacs, we recalculated the parameters by changing only the Linac without re-optimization for the previous treatment plan. Based on the location of lung cancer and brain tumor, we accomplished the VMAT plans with 8 MV beam by using two partial arcs. The prescribed dose to the PTV was 66 Gy in 30 fractions for lung cancer and 60 Gy in 30 fractions for brain tumor. The dose was prescribed to 100% isodose and generally, the prescription dose encompassed ≥ 95% of the PTV, largely depending on the location and the proximity to critical organs. The OARs, such as lungs (ipsilateral and contralateral), spinal cord, esophagus and heart, were included.

In order to evaluate the difference in dosimetric parameters for the PTV and the OARs between two beam-matched Linacs, we calculated cumulative dose-volume histograms(DVHs) for each plan. For PTV, $D_{95\%}$ and $D_{5\%}$, which represent the dose to 95% and 5% of the volume, were analyzed. Furthermore, conformity index(CI), conformity number(CN), and homogeneity index(HI) were evaluated. For each OAR, the dosimeteric

parameters included the maximum dose(D_{max}), the mean dose(D_{mean}), and a set of $D_{x\%}$ which is the maximum dose received by an x% volume of the organ. In the brain case, the Dmax for eyes, lenses optic chiasm, optic nerve, and brain stem and D_{max} and D_{mean} for both hippocampus were evaluated. The dosimetric parameters in the lung case were included D_{mean}, $D_{20\%}$, and $D_{10\%}$ for the contralateral and the ipsilateral lung, and D_{max} for the spinal cord.

All VMAT plans performed patient-specific dosimetric quality assurance(DQA) by using the Electronic Portal Image Device(EPID, Varian PortalVision aS1200), which has the advantages of being integrated into most Linacs with sub-millimeter spatial resolution, linearity in the dose and the dose rate, and excellent dose measurement accuracy[9]. The planar doses using EPID were compared with those calculated using the TPS through absolute dose gamma evaluations using criterions of dose-difference(DD) and in distance-to-agreement(DTA) of 2%/3 ㎜ and 2%/2 ㎜. The passing rate of global-index was calculated for analyzing the delivery accuracy between both Linacs. For evaluation of the beam-matching for both Linacs, the portal dose image prediction(PDIP) plans generated by VB1 Linac are delivered on VB2 Linac through machine override without re-calculation, and the patient-specific QA results acquired by both Linacs were compared.

Ⅲ. Results

1. Accuracy of beam-matched data

At CAP, the ionization curve and profiles of in-plane and cross-plane measured with both VB Linacs were showed in Table 1. Difference of Id_{max} and Id_{10} for ionization depth curve were −0.01 mm and 0.25%. All differences of flatness and symmetry for dose profiles were all within 0.5% for 10 × 10 ㎠ and 40 × 40 ㎠ fields. The maximum difference for dose profiles was −0.41% in symmetry of in-plane for a 10 × 10 ㎠ field size.

2. Difference of commissioning beam data

The variations in commissioning beam data, such as PDDs, beam profiles, output factors, TF, and DLG are summarized in Tables 2-5. Differences of dosimetric parameters in PDDs for four field sizes were all within 1 ㎜ in d_{max} and within 0.2%, except−0.5% in the 20 × 20 ㎠ field of PDD_{20} (percentage depth dose at 20 ㎝ depth). In addition, no differences in the $PDD_{20/10}$ (the ratio of the percentage depth dose at 20 and 10 ㎝), which indicates the beam quality, were observed for both beam-matched Linacs. For flatness and symmetry of dose profiles at d_{max} and 10 ㎝ depth for four field sizes, all differences between beam-matched units were less than −1.0%. The maximum differences in flatness and symmetry were −0.61% at d_{max} and −0.33% at 10 ㎝ depth for the 30 × 30 ㎠ field.

For output factors, percentage differences for all field sizes were all within 0.5%. The maximum difference was observed, as −0.46% for the 20 × 20 ㎠ field. Difference in the MLC transmission and the DLG was 0.06 ㎜ and 0.06%, respectively.

Table 1. Comparison of the ionization depth curves and dose profiles measured by both Linacs during CAP

Linac	Ionization depth curve		Dose profiles							
			In-plane (10 × 10 ㎠)		Cross-plan (10 × 10 ㎠)		In-plane (40 × 40 ㎠)		Cross-plan (40 × 40 ㎠)	
	Idmax (㎝)	Id10 (%)	Flatness (%)	Symmetry (%)	Flatness (%)	Symmetry (%)	Flatness (%)	Symmetry (%)	Flatness (%)	Symmetry (%)
VB1	2.01	70.8	2.30	1.00	2.20	0.40	1.70	0.40	1.60	0.50
VB2	2.00	71.1	2.64	0.59	2.41	0.73	1.60	0.55	1.34	0.49
VB2-VB1 diff.	-0.01	0.25	0.34	-0.41	0.21	0.33	-0.10	0.15	-0.26	-0.01

CAP : customer acceptance procedure, VB : VitalBeam

Table 2. Comparison of the dosimetric parameters between beam-matched Linacs for four field sizes of 8 MV beam.

Dosimetric parameters	Field size (㎠)	8 MV		
		VB 1	VB 2	VB2-VB1 Difference
dmax (㎝)	5	1.98	2.06	0.08
	10	1.90	1.90	0.00
	20	1.70	1.74	0.04
	30	1.70	1.65	-0.05
PDD10 (%)	5	67.57	67.69	0.12
	10	70.55	70.44	-0.11
	20	73.01	72.87	-0.14
	30	73.99	73.92	-0.07
PDD20 (%)	5	39.53	39.57	0.04
	10	43.03	42.9	-0.13
	20	47.05	46.55	-0.50
	30	48.32	48.44	0.12
PDD20/10	5	0.59	0.58	0.00
	10	0.61	0.61	0.00
	20	0.64	0.64	-0.01
	30	0.65	0.66	0.00

dmax : the depth of maximum dose, PDD10, PDD20: the percentage depth doses at 10 and 20 ㎝, PDD20/10: the ratio of the percentage depth doses at 20 and 10 ㎝

Table 3. Differences in flatness and symmetry of dose profiles at d_{max} and 10 ㎝ depth for four field sizes of 8 MV beams.

Dosimetric parameters	Field size (㎠)	8 MV				VB2-VB1 Difference	
		VB 1		VB 2			
		Flatness (%)	Symmetry (%)	Flatness (%)	Symmetry (%)	Flatness(%)	Symmetry(%)
d_{maz}	3	3.66	0.15	3.60	0.18	-0.06	0.03
	10	0.79	0.18	0.91	0.34	0.12	0.16
	20	1.35	0.41	1.01	0.24	-0.34	-0.17
	30	2.72	0.45	2.11	0.56	-0.61	0.11
10 ㎝	3	4.47	0.29	4.27	0.22	-0.20	-0.07
	10	2.15	0.24	2.38	0.30	0.23	0.06
	20	1.44	0.17	1.71	0.22	0.27	0.05
	30	1.16	0.58	1.39	0.28	0.23	-0.3
	20	1.94	0.42	2.34	0.50	0.40	0.08
	30	2.13	0.60	2.28	0.27	0.15	-0.33

d_{max} : the depth of maximum dose, VB : VitalBeam

Table 4. Comparison in output factors between two beam-matched Linacs for different field sizes and two beam energies.

Field size (㎠)	8 MV		VB2-VB1 Difference (% Difference)
	VB 1	VB 2	
3	0.853	0.854	0.001 (0.12%)
6	0.935	0.935	0.000 (0.00%)
10	1.000	1.000	0.000 (0.00%)
15	1.052	1.048	-0.004 (-0.38%)
20	1.088	1.083	-0.005 (-0.46%)
30	1.136	1.131	-0.005 (-0.44%)

VB : VitalBeam

Table 5. Differences in the dosimetric leaf gap and transmission factor of a multi-leaf collimator between two beam-matched Linacs.

Parameters	8 MV		
	VB 1	VB 2	VB2-VB1 Difference
DLG (㎜)	0.159	0.1646	0.0056
TF (%)	1.66	1.6	-0.06

DLC: dosimetric leaf gap, TF: transmission factor, VB : VitalBeam

3. Accuracy of beam modelling in treatment planning system

Differences of the specified point doses between both Linacs at phantom levels for TG-53 and TG-119 test shown in Tables 6-7. In TG-53 recommended test, all differences at four regions of interesting(ROIs) for three field sizes were less than 1.0 cGy, expect -1.0 and -1.2 cGy for buildup and penumbra region of a 25 × 25 ㎠ field. In addition, the differences and percentage differences at isocenter and 2.5 ㎝ posterior of PTV for prostate and C shape test were all within 1.2 cGy and 1.00%.

4. Dosimetric parameters and passing rates on VMAT plans

For the treatment plans of brain tumor and lung cancer for each patient using the same fluence and MU, summary data on the differences in evaluated DVH parameters for the PTV and the OARs between two beam-matched Linacs were recorded and are shown in Tables 8-9. Fig. 3 and 4 show the comparison of dose distribution and DVH in the brain VMAT plan using 8 MV beam on beam-matched Linacs for any patient.

For 20 lung VMAT plans, average differences of the

Table 6. TG53 point dose and difference at four different regions for both VB Linacs.

Region of measurement	Field size (㎠)	VB1 (cGy)	VB2 (cGy)	VB1 vs VB 2 VB2-VB1 Difference (cGy)
Buildup	3 × 3	86.8	86.1	-0.7
	10 × 10	95.2	94.5	-0.7
	25 × 25	104.2	103.2	-1.0
Inner	3 × 3	79.0	78.9	-0.1
	10 × 10	88.2	88.1	-0.1
	25 × 25	95.1	94.5	-0.6
Outer	3 × 3	0.4	0.4	0.0
	10 × 10	0.8	0.8	0.0
	25 × 25	8.0	8.0	0.0
Penumbra	3 × 3	34.8	34.7	-0.1
	10 × 10	55.3	55.0	-0.3
	25 × 25	67.1	65.9	-1.2

VB : VitalBeam

Table 7. Difference of TG119 point doses at different regions on volumetric modulated arc therapy technique for both VB Linacs.

Test case	Technique	Location	VB1 (cGy)	VB2 (cGy)	VB2-VB1 Difference (cGy) (% Difference)
Prostate	VMAT	Isocenter	201.5	200.8	-0.7 (-0.19%)
		2.5 ㎝ posterior	147.1	146.0	-1.1 (-0.66%)
C shape	VMAT	Isocenter	200.2	199.8	-0.4 (-0.20%)
		2.5 ㎝ posterior	126.7	125.6	-0.6 (-0.86%)

evaluated DVH parameters for PTV and OARs was all within 0.3% between beam-matched Linacs. The average differences in HI, CI, and CN which present the plan quality were all within 0.02%. The maximum differences were observed in Dmean of ipsilateral lung, as -0.05%. The D95% and the D5% of the PTV were not statistically significant (P=0.201 and 0.090), respectively, but the other parameters for the OARs showed statistically significant low difference (P<0.05)

For 20 brain VMAT plans, no notable differences

Table 8. Comparison of dosimetric parameters between VB1 (reference) and VB2 for 20 lung plans

DHV parameter		VB1 MeanSD	VB2 MeanSD	VB2-VB1 Difference (%)			*P*-value
				Average	Minimum	Maximum	
PTV	D95%	64.52 ± 1.06	64.48 ± 1.11	-0.06	0.09	0.77	0.201
	D5%	68.63 ± 1.56	68.57 ± 1.48	-0.08	0.06	0.73	0.025
	HI	0.09 ± 0.05	0.07 ± 0.10	-0.02	0.00	0.18	<0.001
	CI	1.05 ± 0.09	1.03 ± 0.07	-0.02	0.00	0.14	0.005
	CN	0.91 ± 0.08	0.92 ± 0.10	0.01	0.01	0.10	<0.001
Contralateral lung	D10%	31.07 ± 4.52	31.14 ± 4.66	0.02	0.31	0.85	0.011
	D20%	21.14 ± 2.98	21.20 ± 3.10	0.02	0.30	0.96	0.002
	Dmean	12.85 ± 2.59	12.88 ± 2.44	0.07	0.36	1.00	0.032
Ipsilateral Lung	D10%	50.87 ± 5.92	50.91 ± 6.05	0.08	0.06	1.02	0.020
	D20%	37.13 ± 3.89	37.20 ± 4.11	0.20	0.02	0.88	0.009
	Dmean	21.53 ± 3.59	21.57 ± 3.55	0.18	0.03	1.05	0.029
Spinal Cord	Dmax	19.51 ± 5.82	19.56 ± 5.35	0.24	0.06	1.02	0.028
Heart	Dmean	13.77 ± 6.12	13.81 ± 6.21	0.29	0.05	0.88	0.005

VB : VitalBeam, DVH : dose volume histogram, PTV : planning target volume

Table 9. Comparison of dosimetric parameters between VB1 (reference) and VB2 for 20 brain plans

DHV parameter		VB1 Mean SD	VB2 Mean SD	VB2-VB1 Difference (%)			*P*-value
				Average	Minimum	Maximum	
PTV	D95%	60.55 ± 0.15	60.60 ± 0.22	0.08	0.00	0.31	0.139
	D5%	62.31 ± 0.85	62.26 ± 0.95	-0.08	0.00	0.74	0.030
	HI	0.11 ± 0.02	0.11 ± 0.03	-0.09	0.00	-1.02	<0.001
	CI	1.09 ± 0.09	1.09 ± 0.07	-0.01	0.00	0.11	0.022
	CN	0.93 ± 0.08	0.93 ± 0.10	-0.11	0.00	-0.33	0.043
LT Eye	Dmax	24.48 ± 5.49	24.4 ± 3.55	-0.19	0.08	1.30	0.129
	Dmean	19.18 ± 1.02	19.28 ± 1.05	0.21	0.01	0.62	0.011
RT Eye	Dmax	27.46 ± 4.88	27.43 ± 4.92	-0.10	0.06	1.08	0.136
	Dmean	10.75 ± 0.95	10.72 ± 1.04	-0.25	0.12	0.57	0.015
LT optic nerve	Dmax	34.13 ± 1.53	34.11 ± 1.51	-0.09	0.09	0.62	0.022
RT optic nerve	Dmax	34.62 ± 1.98	34.59 ± 1.95	-0.07	0.05	0.59	0.042
Optic chiasm	Dmax	42.18 ± 2.02	42.13 ± 2.07	-0.12	0.10	0.89	0.015
Brainstem	Dmax	42.18 ± 0.54	43.48 ± 0.59	-0.11	0.11	0.99	0.002
LT hippocampus	Dmax	38.82 ± 0.39	38.79 ± 0.44	-0.06	0.02	0.64	0.025
	Dmean	27.34 ± 0.54	27.29 ± 0.63	-0.05	0.05	1.13	0.018
RT hippocampus	Dmax	32.02 ± 0.44	32.00 ± 0.59	-0.08	0.05	0.79	0.012
	Dmean	22.08 ± 0.53	22.07 ± 0.63	-0.18	0.07	1.24	0.009

VB : VitalBeam, DVH : dose volume histogram, PTV : planning target volume

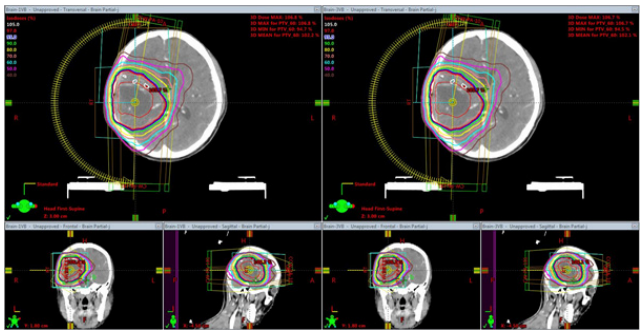

Fig. 3. Comparison of the dose distributions for the axial, sagittal, and coronal directions for brian VMAT plans using beam-matched Linacs.

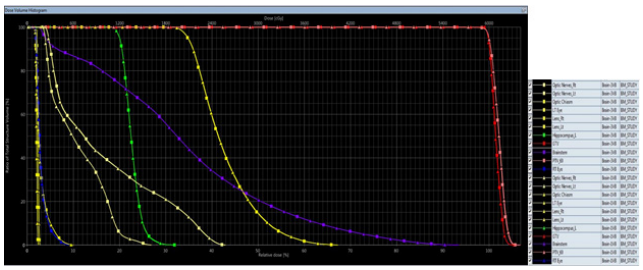

Fig. 4. Comparison of the dose volume histograms(DVHs) in brain volumetric modulated arc therapy(VMAT) plans of any patient for beam-matched Linacs.

were observed in the dosimetric comparison and the DVH variation between beam-matched Linacs for any particular patient. All differences in the evaluated parameters for the PTV and all structures were within 1.0%, except Dmean for the right and left hippocampus (1.24% and 1.13%). The average difference was within 0.02% for the D95% of the PTV, and the D_{max} for left and right eye were not statistically significant (P=0.139, 0.129, and 0.136, respectively). On the other hand, the other parameters for PTV and all OAR were statistically significant as the P-values were all less than 0.05.

For all lung and brain VMAT plans, the gamma passing rates of each plan delivered on beam-matched Linacs were acquired through comparing the dose calculated by using the TPS. Table 10 summarizes the average and the maximum differences in passing rates between the calculated and the measured planar doses for lung and brain VMAT plans through absolute dose gamma evaluations by using criterion of the 2%/2 mm and the 2%/3 mm. For the two beam-matched Linacs, all average passing rates of the EPID measurements were higher than 98% and 99% for the 2%/2 mm and the 2%/3 mm criteria. Average differences in the passing rates from two Linacs were all within 0.20% for both treatment sites. The maximum difference was 1.82% in lung VMAT plan using the 2%/2 mm criterion. The passing rates for both criteria had P-values more than 0.05 and were not statistically significant differences for both treatment sites, as shown in Table 10.

Ⅳ. Discussion

We have been tuned the 8 MV beam of the other Linac(VB2) with those of reference Linac(VB1) during CAP. Beam matching for ionization depth curve and dose profiles showed a good level as shown in Table 1. In commissioning beam data, the evaluated dosimetric beam data of beam-matched Linacs showed very similar dosimetric characteristics within 0.6% difference as shown in Tables 2-6. This illustrates that these beam matched Linacs can be represented by one set of beam parameters for 8 MV beam. Although a 6 MV beam, not

Table 10. Average and maximum difference in the passing rates between the calculated and the measured planar doses on each 20 volumetric modulated arc therapy plan for lung cancer and brain tumor.

Treatment sites	Gamma criterion	Gamma passing rate		VB1 vs VB2 (Difference+SD)	Max Difference	P-value
		VB1	VB2			
Lung	2%/2 mm	99.05%	99.21%	0.150.83%	1.82%	0.147
	2%/3 mm	99.55%	99.53%	-0.020.39%	1.31%	0.066
Brain	2%/2 mm	98.15%	98.35%	0.200.96%	1.75%	0.122
	2%/3 mm	99.25%	99.23%	-0.020.55%	1.01%	0.083

VB : VitalBeam, DVH

a 8 MV, many papers were reported to beam-matching results in Linacs for various vendors such as Varian, Elekta, and Siemens Linacs[3, 10-14]. Ashokkumar et al. reported that the comparison of dosimetric parameter like PDDs, profiles, and output factor shows the reproducibility (within 3%) of photon beam in beam-matched Linacs[10]. Xu et al. that the average differences in commissioning beam data among three beam-matched Elekta machines were within 1%[11]. Bhangle et al. reported that all evaluated dosimetric factors from two Siemens Linacs were within 1%, indicating good agreement between matched beams[14]. Our evaluated dosimetric results were the same or slightly better than those of the previous studies. The reason is probably due to the result of dosimetric parameters from beam matching of the same model Linacs.

Beam-matched Linacs can be represented by one set of dosimetric parameters in the TPS. Using AAPM TG-53 and TG-119 protocol, we found that the TPS calculated point doses show good agreement (<1.0 cGy) between both VB liancs for TG-53 specified regions and TG-119 specified points. These results mean that commissioning beam data of the beam-matched Linacs are well modeled in the TPS.

The calculated dose at TPS must have a satisfactory agreement in the DVH parameters between the beam-matched Linacs. As shown in Figure 1 and 2, the dose distribution of lung and brain VMAT plans for any patient was relatively similar to both liancs on visual inspection. The average differences in evaluated DVH parameters were less than 0.3%. Most of maximum differences in evaluated DVH parameters plans were less than 1.0%, expect for some OARs such as ipsilateral lung, spinal cord, eyes and hippocampus. This means that the plans using a 8 MV beam were not different for the beam-matched Linacs. In this study, our results of the evaluated DVH parameters showed better agreement than those of non-beam-matched Varian Linacs, regardless of the beam energies and the treatment sites. Krishnappan et al. reported dosimetric variation among six non-beam-matched Varian Linacs using different techniques for H&N and pelvis cases[15]. They showed maximum variations up to 2.6% for H&N VMAT plans and 2.1% for pelvis VMAT plans among the six Linacs.

Verification of dose delivery to the treatment plans is also essential for evaluation of beam matching between both Linacs. Therefore, the dose calculated in the TPS was verified by portal dosimetry using EPID. The advantage of portal dosimetry was a less time and material-consuming system and gave minimal deviation, as mentioned in the previous studies[9, 16-18]. This may be due to the easy EPID calibration and setup for verifying the treatment delivery. All passing rates for lung and brain treatment sites in beam-matched Linacs were more than 99% and 98% for gamma criterion of the 3%/2 ㎜ and 2%/2 ㎜, indicating accurate beam modeling and dose delivery. Small differences (<0.1%) in the passing rates for the lung VMAT plans when using the 6 MV beam were observed between beam-matched Linacs for both criterion.

The limitation of this study is that there are not enough clinical cases to evaluate beam matching. For more detailed analysis, it is necessary to evaluate various treatment sites. For more detailed analysis, it is necessary to evaluate various treatment sites. In this study, we mentioned the results of brain and lung cases, which are treated the most with 8 MV in our institution. It will be applied to other clinical cases in the future. Another limitation is that beam matching for both two VB Linacs was evaluated in only VMAT technique. Of course, the VMAT technique is the most delicate and complex technique, but it seems to be necessary to analyze the 3D CRT and IMRT techniques to perform the accurate evaluation for beam matching.

Ⅴ. Conclusion

The overall dosimetric variations in the beam data, as well as tests at phantom and patient levels remains all within the tolerance (1% difference) of clinical acceptability between beam-matched Linacs. Thus, we found an excellent dosimetric agreement for 8 MV photon beam characteristics for Linacs of the same model. Therefore a patient can be used the same model Linac if the treated Linac is happened the problems.

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