博 士 学 位 論 文

強度変調放射線治療における照射野外吸収線量
の測定

近 畿 大 学 大 学 院
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Doctoral Dissertation

MEASUREMENT OF ABSORPTION DOSE OUTSIDE IRRADIATION FIELD IN IMRT

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論文題目

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MEASUREMENT OF ABSORPTION DOSE OUTSIDE IRRADIATION FIELD IN IMRT

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The absorption dose outside the irradiation field for prostate intensity-modulated radiation therapy was measured and evaluated by comparison with calculated values of radiation treatment planning system (TPS). The values of TPS calculated were using Varian CLINAC21EX/Eclipse and TomoTherapy Planning System for constant irradiation time. The absorption dose was measured by placing a glass-element dosemeter in a human-bone enclosure phantom with a planning target volume inside the irradiation field. The organs at risk were the rectum, spinal cord, thyroid, eyeball and the left lung. The calculated values of TPS, Varian CLINAC21EX/Eclipse and TomoTherapy Planning System were calculated, up to 17 and 55 cm from the isocenter, respectively. The absorbed dose outside the irradiation field diverged with increased distance from the isocenter (Varian/Eclipse: $p = 0.03$, TomoTherapy Planning System: $p = 0.25$). The calculated values for the absorbed dose outside the irradiation field were underestimated.

INTRODUCTION

In recent years, with the spread of high-precision radiation treatments such as intensity-modulated radiation therapy (IMRT), increased secondary radiation rather than the desired direct radiation has been reported[(1)]. This behavior is attributed to the tendency of IMRT to have longer irradiation time.

The IMRT settings, such as the irradiation time or the total monitor unit (MU), vary according to the treatment plan, even for the same prescribed dose. Further, the secondary radiation is also thought to be influenced by the radiation conditions. However, there is almost no mention of irradiation conditions on irradiation time (Beam-on-Time)[(1–5)] in the previous research on this topic, with the exception of the recent report by Ruben *et al.*[(6)]. The irradiation conditions are determined on the basis of the treatment plan computed by the radiation treatment planning apparatus. Previously, the dose calculated using a method incorporating conventional inhomogeneity correction was compared with that calculated using the Monte Carlo method, which is now gaining popularity[(7)]. However, the dose outside the irradiation field cannot be regarded as being adequately calculated by the radiation treatment planning apparatus. Recently, the occurrence of second primary cancer or myelodysplastic syndrome (MDS) induced by radiation treatment has been reported[(8)]. Furthermore, secondary radiation outside the irradiation field has also been reported to affect blood-forming myeloid tissues, even though lesser radiation is used for radiation treatment targeting prostate glands and the breast[(9, 10)].

In the present study, actual measurement of the absorbed dose both inside and outside the irradiation field is conducted by setting the radiation conditions to standardized values using the IMRT benchmark[(11)] specified by the Quality Assurance Review Center. Hence, the absorbed dose outside the irradiation field, which is believed to be the cause of the reported second primary cancer or MDS, is evaluated. Further, the measured values are comparatively verified against those calculated by the radiation treatment planning apparatus. Note that the irradiation time is considered, which has been overlooked in previous research.

EQUIPMENT AND METHOD

In the present study, two systems were employed together: the Clinac 21 EX (Varian Medical Systems, Palo Alto, CA, USA) radiotherapy apparatus and the Eclipse Ver. 8.6 (Varian Medical Systems, Palo Alto, CA, USA) radiation treatment planning apparatus, along with a second set of two systems: TomoTherapy (Accuray Inc., Madison, WI, USA) and the Planning Station 5.0.5.18 19-Nov-2014 (Accuray Inc., Madison, WI, USA) radiation treatment planning apparatus. These systems were used to measure the absorbed dose inside the irradiation zone, which was achieved by placing a GD-302 glass-element dosemeter[(12, 13)] (Asahi Techno Glass Corporation, Shizuoka) inside an SB-4 human-body-equivalent phantom (Kyoto Kagaku, Kyoto, Japan). A GD-1000 reader (Asahi Techno Class Corporation, Shizuoka) was used as the reading device. To fix and support the phantom, on the couch with the Hip-fix system, which includes the PelvicBoard, Spread Leg Vac-lok cushion (CIVCO Medical Solutions, Kalona, IA, USA) was used, which was placed on top of the treatment bed.

In this article, the Clinac 21EX and Eclipse Ver 8.6 combination is denoted as 'Varian/Eclipse' and that of the TomoTherapy with Planning Station 5.0.5.18 19-Nov-2014 is denoted as 'TomoTherapy'.

Irradiation settings

The irradiation outline and conditions were set according to the IMRT benchmark, assuming prostate glands in 2 Gy of prescription dose. The radiation treatment planning apparatus was used to prepare the planning target volume (PTV) and organs at risk (OAR)[14, 15] in the areas corresponding to the pelvis and prostate of the human-body-equivalent phantom specified in the IMRT benchmark. For the OAR, a central cylinder with 2-cm diameter was assumed; then, a half-cylinder surrounding the central cylinder with a 0.3-cm gap was created as the PTV. The outer and inner circumferential radii were 3.8 and 1.3 cm, respectively. The *Z* axis (craniocaudal direction) was set to 5.4 cm (Figure 1).

In addition to the three irradiation condition constraints determined by the IMRT benchmark, irradiation plans fulfilling the maximum dose point conditions were created in the PTV, using the respective radiation treatment systems (Table 1).

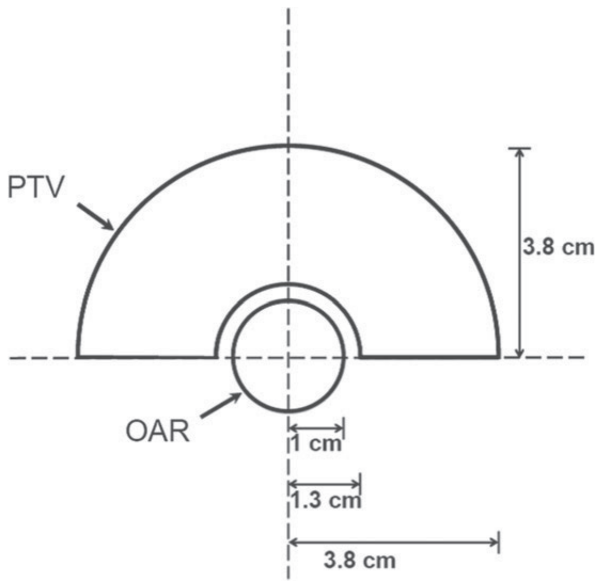

Figure 1. PTV and OAR settings based on IMRT benchmark. The left-right (*X* axis) and ventrodorsal (*Y* axis) directions were created according to the specified values and the *Z* axis (craniocaudal direction) was set to 5.4 cm.

The Varian/Eclipse plan used 10-MV X-rays with nine beams, with a source–axis distance of 100 cm and a total dose of 962 MU, planned for 300 MU/60 s. The PTV of Varian/Eclipse treatment plan was received PTV 1.93 Gy fix as below 2 Gy prescription dose. The TomoTherapy system employed 6-MV X-rays and provided helical irradiation for 209.1 s with a bed moving amount of 8.3 cm and a total dose of 2885 MU. The PTV of TomoTherapy system treatment plan was received PTV 1.92 Gy fix as below 2 Gy of prescription dose. The irradiation time was adjusted to yield ±5% for 192.4 s in the Varian/Eclipse case and for 209.1 and 200 s for the TomoTherapy case, where 197.47 s (max.: 445.4 s; min.: 121.2 s, standard deviation (SD): ±94.55) was considered as a standard. We created several kinds of treatment plan. We chose the one that satisfies the constraints and has almost same irradiation time (within 5%).This time period is the average value for 21 cases in which TomoTherapy was clinically applied for the IMRT treatment of prostate patients in the period of January–July 2015 at Otsu Red Cross Hospital. In addition, Tables 2 and 3 show other equipment-wise parameters concerning irradiation. Figure 2 shows the dose distribution of the coronal plane passing through the isocenter for both systems.

In the Varian/Eclipse case, the analytical anisotropic algorithm method was used[16, 17]. For the TomoTherapy case, the Planning Station[18] special treatment planning apparatus attached to Tomo Therapy was used.

The phantom used in this study was divided into 28 portions, from the femoral neck to the head portion in the caudocranial direction, that both ends were not included in measuring location.

Other than these are used as measurement locations, which were numbered from 1 to 26. Further, in this study, Phantom portion number (P-Nos.) was used to indicate the measurement locations on the phantom. The positions without numbers correspond to the glass-element measurement positions.

Measurement locations

Two categories of measurements were conducted overall. Measurement ① compared the dose distribution in the coronal plane of the human body with the actually measured absorbed dose, while measurement ② considered the at-risk tissue, followed by evaluation. All measurements of both categories ① and ② were conducted three times; the average value and SD were then obtained for each category.

Measurement ①-1: dose distribution comparison in phantom

For the absorption dose measurement locations, glass dosemeters were set in the coronal plane on

Table 1. Criteria for IMRT benchmark.

Criteria	Varian/Eclipse	TomoTherapy
1. 95% of the PTV must receive at least 95% of the prescribed dose (190 rad).	96.5% (193 rad)	96.0% (192 rad)
2. No more than 5% of the PTV shall receive a dose greater than 115% (230 rad) of the prescribed dose.	113.4% (2.268 rad)	113.1% (2.262 rad)
3. No more than 5% of the OAR shall receive a dose greater than 60% (120 rad) of the prescribed dose.	1.8% (3.64 rad)	1.5% (2.996 rad)

Table 2. Irradiation parameters for Varian/Eclipse treatment system, with 9-beam irradiation and a selected dose rate of 300 MU/60 s. Irradiation time: 192.4 s.

Varian/Eclipse	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9
Gantry Rtn (deg)	180	80	115	140	280	245	220	340	20
Coll, Couch Rtn (deg)	0	0	0	0	0	0	0	0	0
Field X (cm)	10.3	7.1	7.7	9.3	7	7.7	9.3	9.8	9.8
X1 (cm)	5	3.3	3.5	4	3.7	4.2	5.3	5.3	4.5
X2 (cm)	5.3	3.8	4.2	5.3	3.3	3.5	4	4.5	5.3
Field Y (cm)	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
Y1 (cm)	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Y2 (cm)	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
SSD (cm)	90.9	85.4	85.6	86.3	85.1	85.3	86.2	93.4	93.7
MU	133	75	99	137	73	99	138	101	107

Table 3. Irradiation parameters for TomoTherapy treatment system. Helical irradiation of 2.512-cm width was selected when the irradiation conditions were set.

TomoTherapy in 2 Gy of prescription dose	
Field width	2.512 cm, fixed
Pitch	0.43
Sinogram segments	2.4
Planning modulation factor (actual)	3.5 (2.044)
Plan calculation grid	FINE ($0.195 \times 0.195\,cm^2$)
Duration (s)	209.1
Gantry rotations	7.7
Gantry period (s)	27.2
Expected MU	2885
Couch travel (cm)	8.3

isocenter. Overall, dosemeters were placed at a total of 50 locations, as shown in Figure 3.

Measurement ①-2: intersections between sagittal plane and coronal plane on the isocenter

To understand the distance relationship outside the irradiation field from the results obtained for measurement ①-1 above, only those locations arranged linearly on the intersection of the sagittal plane with respect to the isocenter and the coronal plane were considered. The deviation value was obtained for each machine by using the following equation:

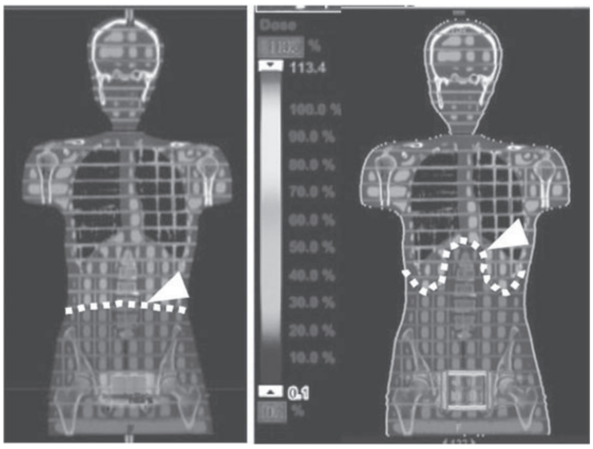

Figure 2. Dose distribution diagram (*left*: Varian/Eclipse, *right*: TomoTherapy). The relative coronal plane dose distribution is shown, after normalization conducted by considering the prescribed 2-Gy dose passing through the isocenter as 100%. The distribution of the 0.1% (dotted line) portion (white arrow) was relatively flat in the Varian/Eclipse case, whereas for the TomoTherapy system, the widening of the boundary portion differed along the spine.

$$\text{Deviation} = \frac{\text{Calculated value} - \text{Measured value}}{\text{Measured value}} \times 100, \quad (1)$$

where, deviation is indicated the percent. The deviation between measured value and calculated value

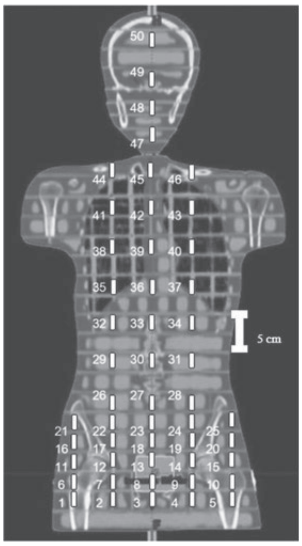

Figure 3. Measurement ①: Schematic diagram of measurement locations. The glass-element arrangement is shown, where the bottom left element is No. 1, and the numbers increase consecutively to the right (white numbers). Numerous glass elements (including the PTV) were arranged, including P-Nos. 2 and 3 and P-Nos. 1, 4 and 5, to facilitate careful measurements.

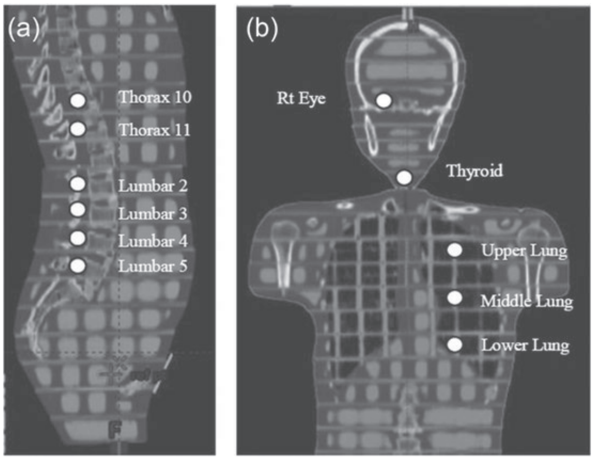

Figure 4. Measurement ②: Schematic diagram of measurement locations for risk tissue evaluation. (a) Spinal cord: one element each at lumbar levels 2–5 and thorax levels 10 and 11, and (b) five locations: the upper, lower and middle lung regions of the left lung field (P-Nos. 16, 14 and 12), inside the coronal plane passing through the isocenter, along with a thyroid portion (P-No. 19) and a right eyeball portion (P-No. 24) (All measurement locations are indicated by white circles.).

gives a suggest of the accuracy of calculation from each radiation treatment planning system[19].

Measurement ②: risk tissue evaluation

The measurement locations included PTV (P-Nos . 2–3), which is a standard for the prescribed dose. Measurements were performed by introducing the following: elements at three locations in PTV (1 glass-element each at the isocenter, ±2 cm from the isocenter along the craniocaudal direction); one element each from OAR in the sagittal plane and the spinal cord (1 element each at lumber levels 2, 3, 4 and 5, and one element each at thorax levels 10 and 11) (Figure 4a); and one element each at the thyroid portion and right eyeball. In addition, measurements were also performed at the upper, middle and lower lung, by considering the left lung field (Figure 4b).

Comparative verification

The measured absorption dose values at the 50 measurement locations (Measurement ①) and the values calculated by the radiation treatment planning apparatus were obtained for each of the two systems. For both treatment systems, a significance level of 5% (2.5% on each side) was set and the 2-sided Mann Whitney U verification was performed. In order to compare the interior and exterior of the irradiation field, the Z axis range of the PTV was assumed to be within the irradiation field. Verification was conducted at 10 and 40 locations inside and outside the irradiation field, respectively. Further, the risk tissue evaluations of each treatment system were compared. SPSS (Version 10, Chicago, IL, USA) was used for the verification.

RESULTS

Dose distribution in phantom comparison

① *Comparison of measured and planning-apparatus-calculated absorption dose values for each radiation system*

Figures 5–7 and Table 4 show the radiation treatment results obtained by measurement method ①-1, for the Varian/Eclipse and TomoTherapy cases, respectively. Even at the location farthest from the edge of the irradiation field (No. 50 at 65 cm from Isocenter), an absorption dose of 1 mGy was measured. Note that, in the Varian/Eclipse case, no calculated values were available beyond No. 34 at 23 cm from Isocenter. In the TomoTherapy case, calculations were performed up to No. 48 at 55 cm from Isocenter.

The calculated values (△) in Figure 5 were not obtained up to a substantial range outside the irradiation field and, thus, there are no calculated values beyond No. 34. The dotted-line portion shows the range of the major PTV axis. The error bars attached to the measured values corresponds to the SD.

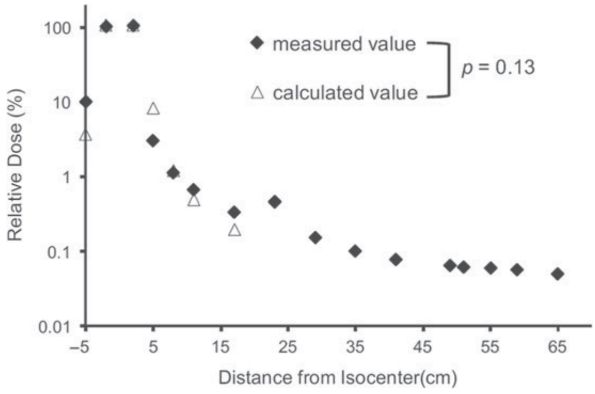

Figure 5. Comparison of calculated values (normalized by considering 2-Gy value prescribed for Varian/Eclipse as 100%) with measured values.

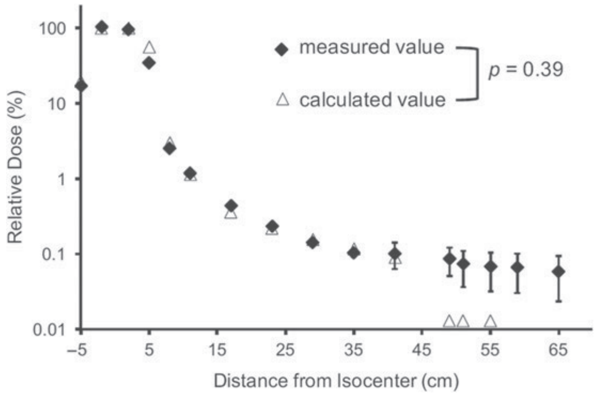

Figure 6. Comparison of calculated values (normalized by considering the 2-Gy value prescribed for TomoTherapy as 100%) with measured values.

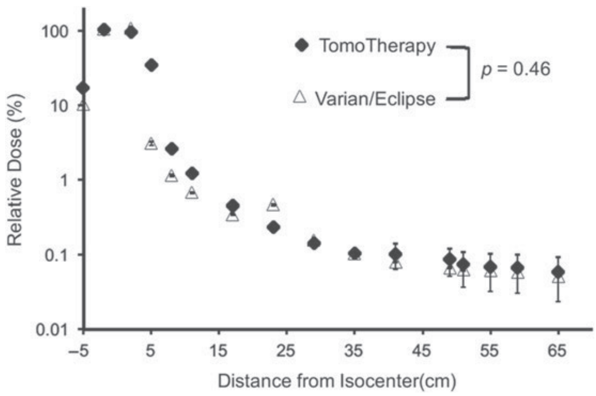

Figure 7. Comparison of measured values for both radiation treatment apparatus types, normalized by considering the prescribed value of 2 Gy as 100%.

For the Varian/Eclipse case, 2-sided Mann Whitney *U* verification was performed with 5% significance for a group of calculated values and a group of measured values, yielding $p = 0.13$.

As can be seen from Figure 6, calculated values (△) were obtained up to No. 48 for the TomoTherapy case, but the greater the separation of the glass element no. from the edge of the irradiation field, the greater the diversion from the measured value (◆). As previously, the dotted-line portion shows the major-axis range of the PTV and the error bars attached to the measured values show the SD. Two-sided Mann Whitney *U* verification of the differences between the values calculated by the TomoTherapy device and the total measured values, with 5% significance level, yielded $p = 0.39$.

When the measured and calculated values were compared for glass elements separated from the edge of the irradiation field, such as those at locations No. 35 and upwards, the difference was small (Figure 7). In Figure 7, the dotted line portion and error bars have the same meanings as previously. The difference between the two radiation systems was assessed using the 2-sided Mann Whitney *U* verification with a 5% significance level, yielding $p = 0.46$.

The results of measurement method ①-2 (Eq. (1)), concerning the deviation between the measured and calculated results for each apparatus, are shown in Figure 8. For the Varian/Eclipse case, deviations of 0.1% were calculated up to locations separated from the isocenter by 17 cm (No. 32). In the TomoTherapy case, deviations of 0.01% were calculated up to the parietal region measurement location (No. 48), which was separated by 55 cm from the isocenter.

Figure 8 shows the deviation results obtained using Eq. (1). In the Varian/Eclipse case, the deviation was large up to a distance of 17 cm from the isocenter, whereas it was large up to a distance of 47 cm in the TomoTherapy (◇) case. This difference occurs because there are no calculated values from the Varian/Eclipse (▲) beyond the 17-cm distance.

Absorption dose of risk-tissue

Table 5 shows each of the absorption dose of risk-tissue for the two examined systems. For the PTV results, the error was up to 8% for the prescribed dose of 2 Gy. For the OAR results, the error was below the dose specified by the IMRT benchmark. Regarding the thyroid region separated by 49 cm from the isocenter, the absorbed doses were 1.43 ± 0.01 mGy and 1.22 ± 0.08 mGy for the Varian/Eclipse and TomoTherapy systems, respectively. Further, at the right eyeball portion, separated by 59 cm from the isocenter, the absorbed doses for the Varian/Eclipse and TomoTherapy systems were 1.27 ± 0.02 mGy and 0.95 ± 0.07 mGy, respectively. As regards the spinal cord, the absorbed dose reduced with increased

Table 4. The radiation treatment results obtained by measurement ①-1, for the Varian/Eclipse and TomoTherapy cases, respectively. Even at the location farthest from the edge of the irradiation field (No. 50), an absorption dose of 1 mGy was measured. Note that, in the Varian/Eclipse case, no calculated values were available beyond No. 34. In the TomoTherapy case, calculations were performed up to No. 48.

Number of measured place	TomoTherapy		Varian/Eclipse	
	Measured value (%) ± SD	Calculated value (%)	Measured value (%) ± SD	Calculated value (%)
1	1.91 ± 0.12	1.41	2.16 ± 0.44	0.70
2	4.44 ± 0.53	4.49	4.63 ± 0.86	1.80
3	16.79 ± 1.69	19.85	10.23 ± 1.52	3.70
4	5.78 ± 0.31	6.38	5.13 ± 0.69	2.10
5	2.70 ± 0.21	3.05	2.05 ± 0.14	0.80
6	9.07 ± 0.73	8.01	8.27 ± 0.13	9.00
7	17.14 ± 1.46	17.91	21.92 ± 2.51	30.00
8	102 ± 7	100	104 ± 2	108
9	21.01 ± 1.33	23.44	32.48 ± 3.25	38.60
10	9.72 ± 0.75	8.65	10.74 ± 0.41	9.60
11	8.48 ± 0.70	6.64	6.94 ± 0.38	8.90
12	18.86 ± 1.28	16.33	22.74 ± 2.85	24.00
13	95 ± 6	100	107 ± 3	108
14	18.76 ± 1.02	21.51	37.96 ± 0.69	39.00
15	8.43 ± 0.68	8.09	11.31 ± 0.36	10.60
16	5.33 ± 0.42	4.60	1.07 ± 0.07	1.30
17	11.41 ± 0.81	9.92	1.85 ± 0.14	3.00
18	33.99 ± 2.31	56.01	3.03 ± 0.20	8.40
19	10.93 ± 0.93	11.67	2.17 ± 0.04	3.90
20	5.29 ± 0.22	4.76	1.22 ± 0.02	1.40
21	0.96 ± 0.07	0.78	0.71 ± 0.04	0.60
22	1.93 ± 0.09	1.63	0.92 ± 0.04	0.80
23	2.55 ± 0.16	2.96	1.12 ± 0.04	1.20
24	1.77 ± 0.12	1.79	0.98 ± 0.02	0.90
25	0.90 ± 0.08	0.82	0.76 ± 0.02	0.60
26	1.00 ± 0.06	0.83	0.57 ± 0.02	0.40
27	1.19 ± 0.07	1.14	0.66 ± 0.02	0.50
28	0.95 ± 0.06	0.82	0.60 ± 0.01	0.40
29	0.40 ± 0.03	0.21	0.31 ± 0.02	0.10
30	0.44 ± 0.03	0.36	0.34 ± 0.01	0.20
31	0.41 ± 0.03	0.22	0.33 ± 0.00	0.10
32	0.22 ± 0.02	0.12	0.37 ± 0.06	0.10
33	0.23 ± 0.02	0.22	0.46 ± 0.01	0.00
34	0.22 ± 0.01	0.10	0.33 ± 0.07	0.00
35	0.14 ± 0.01	0.03	0.15 ± 0.01	0.00
36	0.14 ± 0.01	0.15	0.15 ± 0.00	0.00
37	0.13 ± 0.01	0.03	0.14 ± 0.00	0.00
38	0.11 ± 0.01	0.01	0.10 ± 0.00	0.00
39	0.10 ± 0.01	0.12	0.10 ± 0.00	0.00
40	0.10 ± 0.01	0.03	0.10 ± 0.00	0.00
41	0.10 ± 0.04	0.01	0.08 ± 0.00	0.00
42	0.10 ± 0.04	0.09	0.08 ± 0.00	0.00
43	0.10 ± 0.03	0.01	0.08 ± 0.00	0.00
44	0.09 ± 0.04	0.01	0.06 ± 0.00	0.00
45	0.09 ± 0.04	0.01	0.07 ± 0.00	0.00
46	0.09 ± 0.04	0.03	0.07 ± 0.00	0.00
47	0.07 ± 0.04	0.01	0.06 ± 0.00	0.00
48	0.07 ± 0.04	0.01	0.06 ± 0.00	0.00
49	0.07 ± 0.04	0.00	0.06 ± 0.00	0.00
50	0.06 ± 0.04	0.00	0.05 ± 0.00	0.00

distance from the isocenter. For the Varian/Eclipse and TomoTherapy systems, the dose varied from 14 to 2.2 mGy and from 20 to 2.3 mGy, respectively. In a similar manner, the dose absorbed in the left lung field reduced with increased distance from the isocenter. For the Varian/Eclipse case, it varied from 3.18 to 1.19 mGy and for the TomoTherapy case, it varied from 4.01 to 1.74 mGy. The average background during the measurement was 3 μGy.

Verification results

Two-sided Mann Whitney *U* verification was performed at a 5% significance level for treatment-system-wise measured values obtained from measurement ① and those calculated from the planning apparatus. A significant difference could not be seen, with p = 0.13 (Figure 5) and p = 0.39 (Figure 6) in the Varian/Eclipse and TomoTherapy cases, respectively. Similarly, the results of a comparative verification between the measured values given by both treatment systems yielded p = 0.46 (Figure 7), with no significant difference. Moreover, a similar verification was performed for the regions inside and outside the irradiation field. The comparison for both apparatus types inside the irradiation field yielded p = 0.65 and 0.74 for the Varian/Eclipse and TomoTherapy systems, respectively; thus, there was no significant difference. However, a comparison of the results for the exterior of the irradiation field yielded p = 0.03 and 0.25 for the Varian/Eclipse and TomoTherapy devices, respectively, indicating a significant difference (Figure 7).

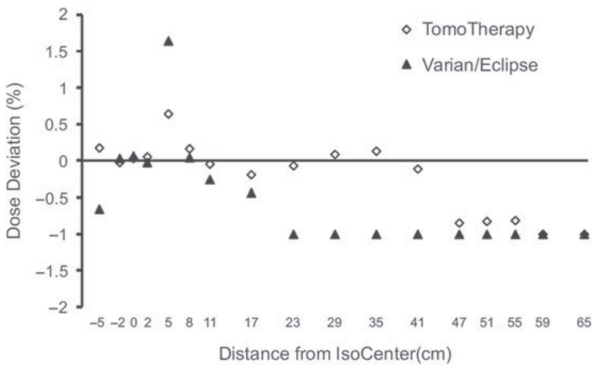

Figure 8. Deviation between measured and calculated values for both systems.

DISCUSSION

For the examined radiation treatment systems, no difference was found in the calculated values inside the irradiation field, but a difference in absorption amount at the exterior of the irradiation field was seen (Figures 6–8). As regards the planning apparatus, the effect of influence beam modeling of the uncalculated dose leakage or secondary radiation may have been

Table 5. Dose absorption results for risk tissue measurements for Varian/Eclipse and TomoTherapy systems. At each measurement location, the measurement was conducted three times and the average value and SD was obtained. The differences between the two radiation treatment systems were analyzed using 2-sided Mann Whitney *U* verification at 5% significance level. As the PTV and OAR were created according to the specified conditions, verification was not performed.

Measured place	Distance from isocenter (cm)	Varian/Eclipse absorption dose (mGy) ± SD	TomoTherapy absorption dose (mGy) ± SD	*p*-Value
PTV	−2	2039 ± 27	2042 ± 138	
	0	2070 ± 24	1923 ± 108	
	2	1995 ± 33	1901 ± 114	
OAR	−2	688 ± 11	235 ± 13	
	0	710 ± 10	200 ± 12	
	2	683 ± 18	127 ± 9	
Spine				
Thorax 10	29	2.2 ± 0.01	2.3 ± 0.1	NS
Thorax 11	26	3.46 ± 0.08	2.7 ± 0.14	<0.05
Lumber 2	18.8	6.43 ± 0.14	5.87 ± 0.28	<0.05
Lumber 3	15.8	7.03 ± 0.04	8.35 ± 0.42	<0.05
Lumber 4	13.2	9.47 ± 0.17	12.31 ± 0.7	<0.05
Lumber 5	9.8	14.15 ± 0.27	20.72 ± 1.13	<0.05
Left lung				
Lower	29	3.18 ± 0.01	4.01 ± 0.07	<0.05
Middle	35	1.74 ± 0.01	2.04 ± 0.08	<0.05
Upper	41	1.19 ± 0.01	1.74 ± 0.01	<0.05
Thyroid	46.8	1.43 ± 0.01	1.22 ± 0.08	<0.05
R-eyeball	65	1.27 ± 0.02	0.95 ± 0.07	<0.05

$p < 0.05$ was considered significant for this study. NS = not significant.

reflected. For both radiation treatment systems, calculated values could not be obtained for all ranges in the phantom outside the irradiation field. Further, the verification results showed that there was no significant difference in the TomoTherapy case, with $p = 0.25$; however, on the graph there appears to be a difference from glass element No. 35 onwards. A matter worthy of special mention is that the absorption dose results in the TomoTherapy case are higher than those for the Varian/Eclipse in the locations in the vicinity of the PTV. This may be because TomoTherapy with a jaws width of 2.5 cm was planned in this study. Therefore, for the PTV, the irradiation range may have become longer because of the direct radiation in the craniocaudal direction.

In addition, in Figure 8, which shows the differences in the dose deviation for both systems, a value that can be assumed to be an error occurred at a location 5 cm from the isocenter. This error may be considered to reflect the dose leakage from the apparatus reported in previous research[1]. The glass-element dosemeter used in the present study has been reported[12] to have an uncertainly of ~2% in the measurement, including variation in the element. Araki and Ohno[13] have reported that there is a difference in the response characteristics of the glass element to the irradiation field size , the measurement depth and energy. In this study, we compared the prescribed doses to PTV based on the standards, so we thought that the uncertainty including them is reflected in the variation. However, the variation in the measured values was larger in the TomoTherapy case than that for the Varian/Eclipse device. As the variation was more than the measurement output deviation considered in everyday maintenance, it may be considered to be a reflection of the variation between persons participating in the operation or measurement. According to Das *et al.*[20], major deviation in the prescribed and radiated doses occurs in medical facilities. This finding raises concerns regarding accuracy when comparing clinical results of IMRT. In the present study, measurements were also obtained based on clinical data; however, the IMRT benchmark was used as an index for constant radiation conditions.

In research on prostate glands, Bhojani *et al.*[21] has reported that the rate of occurrence of second primary cancer is significantly higher in radiation treatment than in surgical treatment. Recently, Radivoyevitch *et al.*[8] has reported the significant influence of radiation treatment on second primary cancer and MDS, following the radiation treatment of prostate glands. Normally, there is a lower proportion of blood-forming myeloid tissues in the irradiation field in radiation treatment targeting the prostate; therefore, the possibility of occurrence of second primary cancer and MDS from directly within the irradiation field following radiation treatment may be lower. Further, low dose exposure outside the irradiation field may have some influence. As regards reports[22, 23] indicating the influence of radiation treatment on embedded-type medical equipment such as pace makers, ICRU Report 83[24] has stated that the absorption dose for IMRT for the remaining volume at risk, may be useful for estimating the risk of carcinogenesis and, thus, evaluating the absorbed dose or dose outside the irradiation field. This will allow the dose at the time of re-irradiation to be evaluated, which includes transition to a new segment different to that first treated by radiation.

For dose measurement in megavoltage computed tomography with the irradiation time required for image guided radiotherapy, Hälg et al.[25] has shown that the radiation leakage is less when TomoTherapy is used. Further, imaging with a dose lower than other instruments has been reported. In the present study, a significant difference was seen in the risk tissue dose absorption. The number of MU is a factor but not radiation time unless it is very short (high dose rate) or very long (low dose rate) and radiobiological effects are considered. Any radiobiological effects will not be identified with dosimetric comparisons of planned dose and measured dose.

As regards future research, measurements concerning details about the contribution of secondary radiation and leakage to the radiation outside the irradiation field, along with appropriate protection and reconsideration of settings through the introduction of new dosemeter algorithms[3, 7, 26] are topics of interest.

CONCLUSION

Absorbed doses inside and outside the irradiation field for IMRT were studied using a glass-element dosemeter and compared with values calculated from two types of treatment planning apparatus. The values inside the irradiation field were equivalent for both systems; however, the calculated values for the absorbed dose outside the irradiation field were underestimated.

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