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ORIGINAL ARTICLE

Japanese structure survey of radiation oncology in 2009 with special reference to designated cancer care hospitals

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Abstract

Background The structure of radiation oncology in designated cancer care hospitals in Japan was surveyed in terms of equipment, personnel, patient load, and geographic distribution, and compared with the structure in other radiotherapy facilities and the previous survey.

Methods The Japanese Society for Therapeutic Radiology and Oncology surveyed the national structure of radiation oncology in 2009. The structures of 365 designated cancer care hospitals and 335 other radiotherapy facilities were compared.

Results Designated cancer care hospitals accounted for 50.0 % of all the radiotherapy facilities in Japan. The patterns of equipment and personnel in designated cancer

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care hospitals and the other radiotherapy facilities were, respectively, as follows: linear accelerators per facility: 1.4 and 1.0; dual-energy function: 78.6 and 61.3 %; three-dimensional conformal radiotherapy function: 88.5 and 70.0 %; intensity-modulated radiotherapy function: 51.6 and 25.3 %; annual number of patients per linear accelerator: 301.3 and 185.2; Ir-192 remote-controlled after-loading systems: 31.8 and 4.2 %; and average number of full-time equivalent radiation oncologists per facility: 1.8 and 0.8. Compared with the previous survey, the ownership ratio of equipment and personnel improved in both designated cancer care hospitals and the other radiotherapy facilities. Annual patient loads per full-time equivalent radiation oncologist in the designated cancer care hospitals and the other radiotherapy facilities were 225.5 and 247.6, respectively. These values exceeded the standard guidelines level of 200.

Conclusions The structure of radiation oncology in designated Japanese cancer care hospitals was more mature than that in the other radiotherapy facilities. There is still a shortage of personnel. The serious understaffing problem in radiation oncology should be corrected in the future.

Keywords Radiotherapy · Medical engineering · Epidemiology

Introduction

In Japan, the current utilization rate of radiotherapy (RT) for new cancer patients in Japan is only 27.7 % and surgery remains predominant [1]. This rate is very low when compared to those for western developed countries. The main reason for this is that there is not enough personnel, such as radiation oncologists (ROs), medical physicists (MPs), and radiotherapy technologists (RTTs) [2, 3]. The Cancer Control Act was implemented in 2007 in response to patients' urgent petitions to the Japanese government [4]. This law strongly advocates the promotion of RT and an increase in the number of ROs and MPs. At the same time, the Ministry of Health, Labour and Welfare began the accreditation of "designated cancer care hospitals (DCCHs)" with the aim of correcting regional differences in the quality of cancer care and strengthening cooperation among regional cancer care hospitals [5, 6]. The Japanese Society for Therapeutic Radiology and Oncology (JASTRO) has conducted national structure surveys of RT facilities in Japan every 2 years since 1990 [7]. Findings of these surveys indicate that the structure of radiation oncology in Japan has improved in terms of equipment and functioning in response to the increasing numbers of cancer patients who require RT.

In the study presented here, the structure of radiation oncology in DCCHs in Japan was analyzed in terms of equipment, personnel, patient load, and geographic distribution, and compared with these features in other RT facilities in Japan. In addition, the recent structure of RT facilities was compared with that surveyed in 2007 [2] and the medical care situation in Japan was compared with that in European countries and the USA.

Methods and materials

A national survey in the form of a questionnaire on the structure of radiation oncology in Japan in 2009 was conducted by JASTRO from March 2010 to January 2011 [1]. The questionnaire consisted of items related to the number of treatment machines and type of modality, the number of personnel by job category, and the number of patients by type and disease site. The response rate was 90.9 % (700 out of 770) from all actual RT facilities in Japan. The number of DCCHs certified by the Ministry of Health, Labor and Welfare was 375 as of April 1, 2011 [8]. Of this total, 51 were designated prefectural and 324 were designated regional cancer care hospitals. The surveys were not returned by 20 facilities, and 3 facilities did not have departments of RT at the time of the survey, so that the structures of 365 DCCHs and 335 other RT facilities were analyzed. In this survey, full-time equivalent (FTE) (40 h/week for radiation oncology work only) data were surveyed in terms of the clinical working hours for RT of each staff member. SAS® 8.02 (SAS Institute Inc., Cary, NC, USA) [9] was used for the statistical analysis and statistical significance was determined by means of the χ^2 test and Student's *t* test.

The Japanese Blue Book Guidelines (JBBG) [10, 11] were used for comparison with the results of this study. These guidelines pertain to the structure of radiation oncology in Japan based on Patterns of Care Study (PCS) [12, 13] data. The standard guidelines for annual patient load per external beam equipment were set at 250–300 (warning level 400), those for annual patient load per FTE RO at 200 (warning level 300), and those for annual patient load per FTE RT technologists at 120 (warning level 200).

Results

Current situation of radiation oncology

Table 1 shows the current situation of radiation oncology in Japan. DCCHs accounted for 50.0 % (385/770) of all the RT facilities in Japan. The numbers of new patients and total patients in all RT facilities in Japan were estimated at approximately 201,000 (182,390 × 770/700) and 240,000 (205,087 × 770/700), respectively. For DCCHs,

Table 1 Numbers of new patients and total patients (new plus repeat) requiring radiotherapy in designated cancer care hospitals and other radiotherapy hospitals

	DCCHs	Other RT facilities	*p* value (95 % CI)[a]	Total
Facilities	365	335	–	700
New patients	126,123[b]	56,267	–	182,390[c]
Average new patients/facility	345.5	168.0	<0.0001 (146.7, 208.4)	260.6
Total patients (new + repeat)	150,215[b]	67,614	–	217,829[c]
Average total patients per facility	411.5	201.8	<0.0001 (171.6, 247.8)	311.2

DCCH designated cancer care hospital, *RT* radiotherapy, *CI* confidence interval

[a] Student's *t* test

[b] The number of designated cancer care hospitals with RT was 385, and the number of new patients in DCCHs was estimated at approximately 134,000; the corresponding number of total patients (new plus repeat) was 159,000

[c] The number of radiotherapy facilities was 770 in 2009, and the number of new patients was estimated at approximately 201,000; the corresponding number of total patients (new plus repeat) was 240,000

the corresponding numbers were approximately 134,000 (126,123 × 385/365) and 159,000 (150,215 × 385/365). The number of new patients and total patients in DCCHs thus accounted for approximately 66.7 % (134,000/201,000) and 66.3 % (134,000/201,000 and 159,000/240,000) of the number of new patients and total patients in all RT facilities. The average numbers of new patients per facility were 345.5 for DCCHs and 168.0 for the other RT facilities, and for the average numbers of total patients per facility the corresponding figures were 411.5 and 201.8, respectively.

Facility and equipment patterns and patient load per linear accelerator

The RT equipment patterns and related functions in Japan are shown in Table 2. In DCCHs, 496 linear accelerators (linacs) and 116 ^{192}Ir remote-controlled after-loading systems (RALSs) were in current use, while the corresponding data for the other RT facilities were 320 and 14, respectively. The rate of equipment ownership at DCCHs was significantly higher than at the other RT facilities. As for the linac systems in DCCHs, the dual-energy function was used in 390 (78.6 %), the three-dimensional conformal radiotherapy (3D-CRT) function in 439 (88.5 %), and the IMRT function in 256 (51.6 %). For the other RT facilities, the corresponding figures were 196 (61.3 %), 224 (70.0 %), and 81 (25.3 %). The patient load per linac was 301.3 at DCCHs and 185.2 at the other RT facilities. Compared with the data for DCCHs in 2007 [2], the rate of linac ownership increased by 0.6 % while the rates of increase for installation of the various functions used with linacs were 3.8 % for dual-energy, 13.2 % for 3D-CRT, and 15.2 % for IMRT function. At the other RT facilities, the rate of linac ownership decreased by 0.4 %, while the rates of installation corresponding to those for DCCHs increased by 4.8, 9.5, and 5.5 %. The patterns for radiotherapy planning systems (RTPs) and other equipment are shown in Table 2. X-ray simulators were installed in 56.7 %, computed tomography (CT) simulators in 83.3 %, and RTPs in 97.3 % of the DCCHs, while the corresponding percentages for the other RT facilities were 44.2, 70.4, and 94.6 %. A noteworthy difference between the two types of facilities was found in the rates of X-ray simulator and CT simulator installation. Compared with the data for 2007 [3], X-ray simulator ownership at DCCHs decreased by 12.6 %, while CT simulator and RTP ownership increased by 8.2 and 0.5 %, respectively. At the other RT facilities, X-ray simulator ownership decreased by 8.8 % while CT simulator and RTP ownership increased by 13.7 and 0.8 %, respectively.

The distribution of annual patient load per linac in Japan is shown in Fig. 1. The patient load at 19.4 % of DCCHs and 4.6 % of the other RT hospitals exceeded the JBBG warning level of 400 patients per linac, but the average patient load per linac at the other facilities was below that level. Compared with the data for 2007 [2], the rate of facilities exceeding the JBBG warning level (400 patients per linac) decreased at both DCCHs (−0.8 %) and the other RT facilities (−0.7 %). However, the average number of total patients per facility increased at both DCCHs (1.6 %) and the other RT facilities (5.9 %).

Staffing patterns and patient loads

Staffing patterns and patient loads in Japan are detailed in Table 3. The figures for total FTE ROs were 666.3 for DCCHs and 273.1 for the other RT facilities, while the corresponding average numbers of FTE ROs per facility were 1.8 and 0.8 and for patient load per FTE RO 225.5 and 247.6. The distribution of annual patient load per FTE RO in Japan is illustrated in Fig. 2. More than 300 patients per RO (JBBG warning level) were treated in 23.3 % of DCCHs and in 10.7 % of the other facilities. Figure 3 shows the distribution of facilities by patient load per FTE RO, with the largest number featuring a patient per FTE RO level in the 100–149 range for DCCHs and the other

Table 2 Items of equipment, their function and patient load per unit of equipment in designated cancer care hospitals and other radiotherapy hospitals

	DCCHs ($n = 365$)		Comparison with 2007	Other RT facilities ($n = 335$)		Comparison with 2007	p value (95 % CI)	Total ($n = 700$)	
	n	%	%	n	%	%		n	%
Linac	496	98.6[a]	0.6[c]	320	90.4[a]	−0.4[c]	<0.0001[f]	816	94.7[a]
With dual energy function	390	78.6[b]	3.8[c]	196	61.3[b]	4.8[c]	<0.0001[f]	586	71.8[b]
With 3D-CRT function (MLC width ≤1.0 cm)	439	88.5[b]	13.2[c]	224	70.0[b]	9.5[c]	<0.0001[f]	663	81.3[b]
With IMRT function	256	51.6[b]	15.2[c]	81	25.3[b]	5.5[c]	<0.0001[f]	337	41.3[b]
Average no. linac per facility	1.4	–	4.7[e]	1.0	–	0.4[e]	<0.0001 (0.3, 0.4)[g]	1.2	–
Annual no. patients per linac	301.3[d]	–	1.6[e]	185.2[d]	–	5.9[e]	<0.0001 (86.8, 133.9)[g]	255.8[d]	–
^{192}Ir RALS (actual use)	116	31.8[a]	2.3[c]	14	4.2[a]	−1.2[c]	<0.0001[f]	130	18.6[a]
X-ray simulator	211	56.7[a]	−12.6[c]	150	44.2[a]	−8.8[c]	0.0009[f]	361	50.7[a]
CT simulator	324	83.3[a]	8.2[c]	251	70.4[a]	13.7[c]	<0.0001[f]	575	77.1[a]
RTP computer	854	97.3[a]	0.4[c]	417	94.6[a]	0.8[c]	0.0757[f]	1,271	96.0[a]

DCCH designated cancer care hospital, *RT* radiotherapy, *CI* confidence interval, *Linac* linear accelerator, *IMRT* intensity-modulated radiotherapy, *RALS* remote-controlled after-loading system, *CT* computed tomography, *3D-CRT* three-dimensional conformal radiotherapy, *RTP* radiotherapy planning

[a] Percentage of facilities which have this equipment

[b] Percentage calculated from the number of systems using this function and the total number of linac systems

[c] Comparison with the data of 2007, calculated using the formula: data of 2009 (%) − data of 2007 (%)

[d] Percentage calculated from the number of patients and the number of linac units. Facilities without linacs were excluded from the calculation

[e] Rate of increase compared with the data of 2007, calculated using the formula: $\frac{\text{data of 2009 }(n)-\text{data of 2007 }(n)}{\text{data of 2007 }(n)} \times 100\ (\%)$

[f] χ^2 test

[g] Student's t test

RT facilities. Facilities with less than 1 FTE RO still account for about 31.2 % of DCCHs and 65.7 % of the other RT facilities. The average numbers of FTE ROs per facility and full-time JASTRO-certified ROs per facility at DCCHs increased by 11.5 and 6.7 %, respectively, compared with 2007 data, and for the other RT facilities, those numbers increased by 18.9 and 22.3 %. The annual patient load per FTE RO, on the other hand, decreased by 4.9 % at DCCHs and 9.4 % at the other RT facilities.

The total numbers of FTE RTTs were 1175.7 for DCCHs and 660.2 for the other RT facilities, and the corresponding average numbers of RTTs per facility were 3.2 and 2.0, while the patient loads per FTE RTT were 127.8 and 102.4. The distribution of annual patient load per FTE RTT in Japan is shown in Fig. 4. More than 200 patients per RTT (JBBG warning level) were treated in 11.0 % of DCCHs and in 7.5 % of the other RT facilities, while Fig. 5 shows the distribution of facilities by patient load per FTE RTT. The largest number of facilities featured a patient per FTE RTT level in the 100–119 range for DCCHs and the other RT facilities. The total numbers of FTE MPs and FTE RT nurses were 74.6 and 392.8, respectively, for DCCHs and 43.0 and 228.4 for the other RT facilities.

Distribution of primary disease sites and palliative treatment

Table 4 shows the distribution of primary disease sites and palliative treatment at DCCHs and the other RT facilities. The most common disease site at DCCHs and the other RT facilities was the breast. Head/neck, esophagus, liver/biliary tract/pancreas, gynecologic, urogenital, prostate, hematopoietic/lymphatic, and skin/bone/soft tissue cancers were treated at higher rates at DCCHs than at the other RT facilities. The rates for other cancers were the reverse. Compared with the data for 2007, the percentage of breast cancers increased the most at DCCHs (1.4 %), and at the other RT facilities the percentage of head/neck and breast cancers increased significantly (2.4 and 2.3 %).

Brain metastasis was treated at higher rates at the other RT facilities (14.7 % of total patients) than at DCCHs (6.9 % of total patients), while the reverse was true for

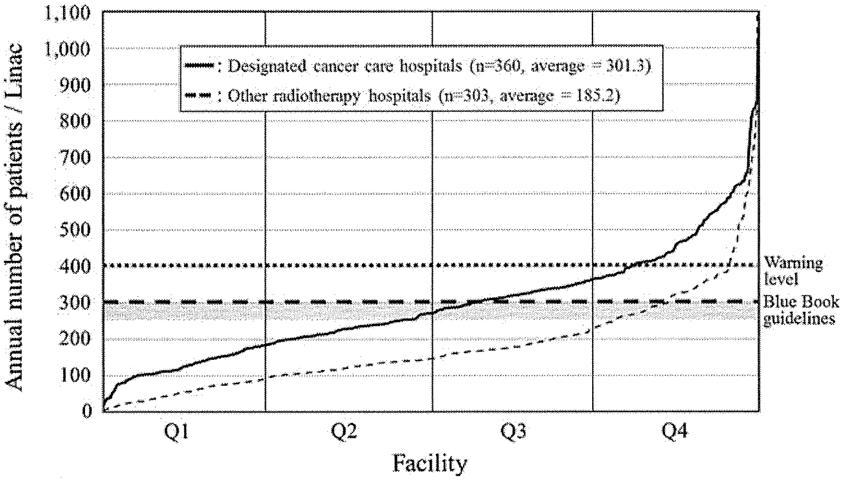

Fig. 1 Distribution of annual patient loads per linear accelerator in designated cancer care hospitals and the other radiotherapy facilities. *Horizontal axis* represents facilities arranged in order of increasing value of annual number of patients per treated equipment within facilities. *Q1* 0–25 %, *Q2* 26–50 %, *Q3* 51–75 %, *Q4* 76–100 %

Table 3 Structure and personnel of designated cancer care hospitals and other radiotherapy hospitals

	DCCHs (n = 365)	Comparison with 2007[a] (%)	Other RT facilities (n = 335)	Comparison with 2007[a] (%)	p value[b]	Total (n = 700)
Facilities with RT beds	190	–	108	–	–	298 (42.6)
Average no. RT beds per facility	4.2	−1.5	2.2	11.5	–	3.3
Total (full + part-time) RO FTE	666.3	–	273.1	–	–	939.4
Average no. FTE ROs per facility	1.8	11.5	0.8	18.9	<0.0001	1.3
JASTRO-certified RO (full-time)	422	–	109	–	–	531
Average no. JASTRO-certified ROs per facility	1.2	6.7	0.3	22.3	<0.0001	0.8
Annual no. patients per FTE RO	225.5	−4.9	247.6	−9.4	<0.0001	231.9
Total (full + part-time) RT technologist FTE	1175.7	–	660.2	–	–	1836.0
Average no. FTE RT technologists per facility	3.2	16.8	2.0	9.1	<0.0001	2.6
Annual no. patients per FTE RT technologist	127.8	−9.2	102.4	−1.3	<0.0001	118.7
Total (full + part-time) medical physicist FTE	74.6	77.7	43.0	62.9	–	117.6
Total (full + part-time) RT nurse FTE	392.8	29.1	228.4	20.1	–	621.2

DCCH designated cancer care hospital, *RT* radiotherapy, *RO* radiation oncologist, *FTE* full-time equivalent (40 h/week only for RT practise), *JASTRO* Japanese Society for Therapeutic Radiology and Oncology

[a] Rate of increase compared with the data of 2007, calculated using the formula: $\frac{\text{data of 2009 }(n)-\text{data of 2007 }(n)}{\text{data of 2007 }(n)} \times 100\ (\%)$

[b] Student's t test

bone metastasis (11.3 and 12.8 %, respectively). Compared with the data for 2007, the rate of brain and bone metastasis decreased in both DCCHs (−0.7 and −0.9 %) and the other RT facilities (−1.0 and −2.3 %).

Discussion

The utilization rate of RT for new cancer patients in Japan is less than half of that in developed countries in Europe and in the USA [14]. However, RT is expected to play an increasingly important role in Japan because the increase in the elderly population is the highest among developed countries. The distribution of facilities by patient load per RO for DCCHs proved to be largely similar to that of the USA in 1989 [15]. While the numbers of ROs in both DCCHs and the other RT hospitals in Japan has increased, the facilities which have less than one FTE RO still account for 31.2 % of DCCHs and 65.7 % of the other RT facilities. In Japan, the majority of facilities still rely on

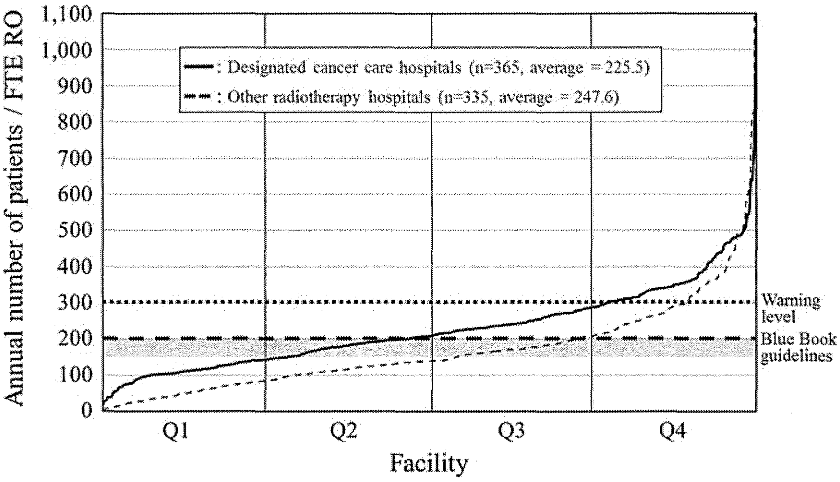

Fig. 2 Distribution of annual patient loads per FTE RO in designated cancer care hospitals and the other radiotherapy facilities. *Horizontal axis* represents facilities arranged in order of increasing value of annual number of patients per FTE RO within facilities. *Q1* 0–25 %, *Q2* 26–50 %, *Q3* 51–75 %, *Q4* 76–100 %. Number of FTE RO for facilities with FTE <1 was calculated as FTE = 1 to avoid overestimating patient loads per FTE RO

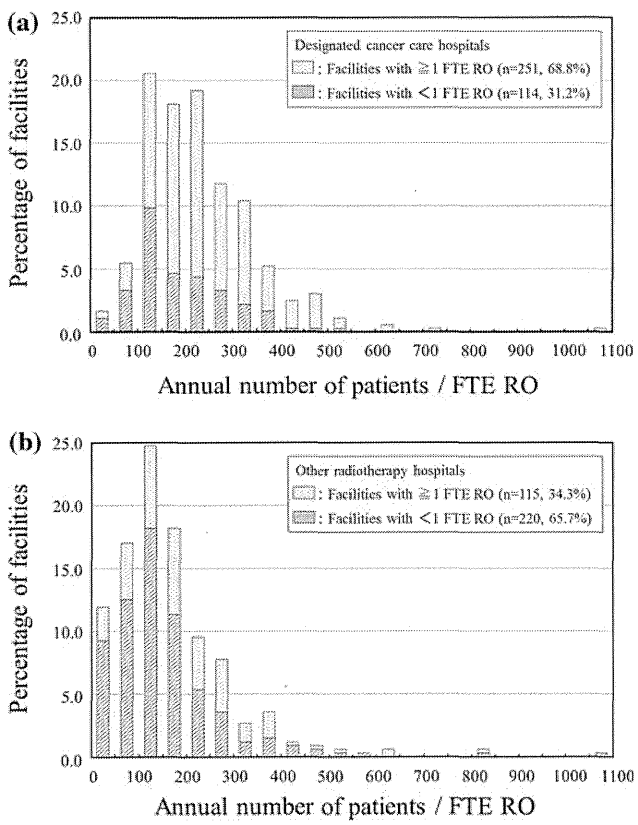

Fig. 3 Percentage of facilities by patient loads per FTE RO in designated cancer care hospitals (**a**) and in the other radiotherapy hospitals (**b**). *Each bar* represents an interval of 50 patients per FTE RO. Number of FTE RO for facilities with FTE <1 was calculated as FTE = 1 to avoid overestimating patient loads per FTE RO

part-time ROs, especially in facilities other than DCCHs, but in western developed countries, most facilities have at least 1 full-time RO. The distribution in Japan of facilities by patient load per RO for the other RT facilities in this study was similar to that in 1990 [15], so that a shortage of ROs has remained a major concern. More than 300 patients per RO (JBBG warning level) were treated in 17.6 % of all RT facilities. This is a matter of critical importance to the quality of radiotherapy.

A new educational system called "Cancer Professional Training Plan" by the Ministry of Education, Culture, Sports, Science and Technology, Japan is being developed in Japan to train specialists for cancer care, including ROs, MPs, medical oncologists, oncology nurses, and palliative care doctors. The average number of RT staff members at DCCHs was greater than that in the other RT hospitals. As noted above, there is still a shortage of Ros, although the numbers have increased. In Japan, many RT hospitals do not have an independent department for RT. One way to increase the number of ROs is to create an independent department for RT. The numbers of MPs in Japan are still smaller than those in western developed countries, and they work mainly in metropolitan areas or academic facilities, such as university hospitals or cancer centers. At present, no national license is available for MPs in Japan, but those with a master's degree in radiation technology or science and engineering can take the accreditation test for MPs administered by the Japanese Board of Medical Physics (JBMP). Compared with ROs and MPs, a sufficient number of RTTs is ensured in Japan. However, there is a significant number of hospitals with less than 1 FTE RTT in both DCCHs ($n = 13$) and the other RT hospitals ($n = 50$). In addition, many RTTs are extremely busy because they must also partially act as MPs. As for equipment, the ownership of equipment for advanced high-precision radiation therapy machines increased compared with 2007 at all RT facilities, especially DCCHs, indicating that the accreditation of DCCHs closely correlates with the maturity of the radiation oncology structure. Further accreditation of DCCHs by the Ministry of Health, Labor, and Welfare would be a move in the right direction towards a more balanced geographic consolidation of RT facilities in Japan.

The findings of this study show that, on a regional basis, DCCHs were located in the most suitable areas. There were

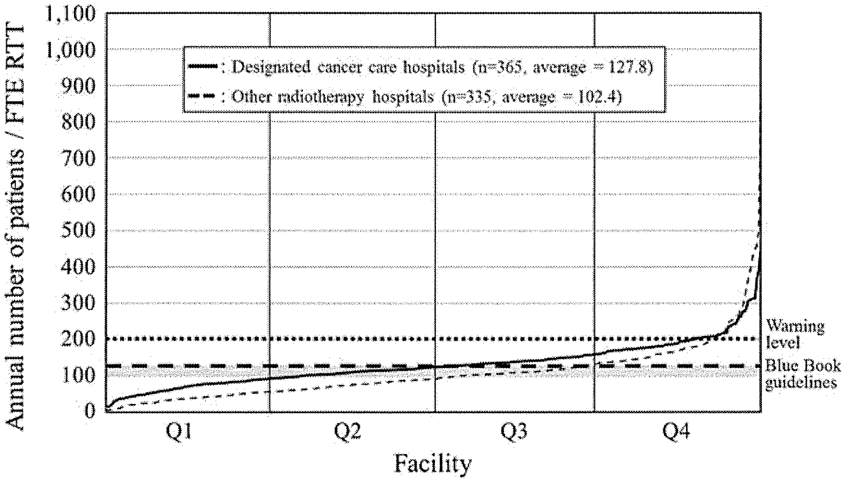

Fig. 4 Distribution of annual patient loads per FTE RTT in designated cancer care hospitals and the other radiotherapy facilities. *Horizontal axis* represents facilities arranged in order of increasing value of annual number of patients per FTE RTT within facilities. *Q1* 0–25 %, *Q2* 26–50 %, *Q3* 51–75 %, *Q4* 76–100 %. Number of FTE RTT for facilities with FTE <1 was calculated as FTE = 1 to avoid overestimating patient loads per FTE RTT

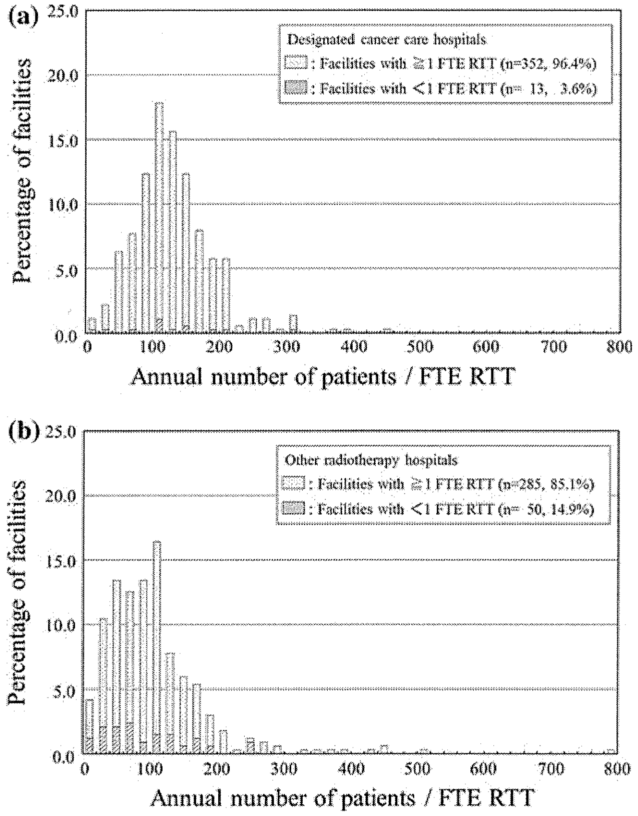

Fig. 5 Percentage of facilities by patient loads per FTE RTT in designated cancer care hospitals (**a**) and in the other radiotherapy hospitals (**b**). *Each bar* represents an interval of 20 patients per FTE RTT. Number of FTE RTT for facilities with FTE <1 was calculated as FTE = 1 to avoid overestimating patient loads per FTE RTT

388 DCCH facilities by the end of fiscal year 2011 because some further university facilities with many patients undergoing RT had been certified as DCCHs since the previous survey, while some small-scale facilities were not certified as DCCHs by the Ministry of Health, Labor, and Welfare. In terms of nationwide distribution, there seem to be enough RT facilities in Japan. On the other hand, the RT potential of RT facilities other than DCCHs in Japan remains unrealized because of personnel shortages. The most frequent primary disease site treated with RT at the other RT facilities changed from lung/trachea/mediastinum to breast, compared with the data for 2007, while at DCCHs, the most frequently treated primary disease site, the breast, remained unchanged from 2007. Finally, the number of patients with brain and bone metastasis did not increase since 2007.

To evaluate medical care systems for cancer at regular intervals, it is very important to collect detailed information on all cancer care facilities. In Japan, the structural data for all RT facilities is regularly surveyed by JASTRO. In addition, the procedures and the outcome data of cancer care for patients undergoing RT have been conducted by PCS every 4 years, but insufficient outcome data is collected. In the USA, a National Cancer Data Base was established in 1989 and since then has been collecting comprehensive data on cancer care, and this database is used as the quality indicator for improvements in the processes and outcomes of cancer care [16, 17]. We have established a Japanese National Cancer Database based on the RT data in Japan and we are preparing to use this system for the collection of cancer care data.

In conclusion, the RT structure of DCCHs in Japan showed more maturity than that of other RT facilities in terms of equipment, functions, and staff. However, there is still a shortage of personnel (ROs, RTTs, MPs, RT nurses, and so on) in radiation oncology in Japan. The structure survey data presented and discussed here seemed to be both fundamental and important for a clear and accurate understanding of the medical care system for radiation oncology in Japan. As this survey data makes clear, a

Table 4 Primary sites of cancer, brain metastasis, and bone metastasis treated with RT in designated cancer care hospitals and the other radiotherapy hospitals

Primary site	DCCHs (n = 344)		Comparison with 2007[a]	Others (n = 300)		Comparison with 2007[a]	p value[b]	Total (n = 644)	
	n	%	%	n	%	%		n	%
Cerebrospinal	4,719	3.9	0.2	4,342	8.5	−1.1	<0.0001	9,061	5.8
Head and neck (including thyroid)	13,084	10.9	−0.2	5,021	9.8	2.4	<0.0001	18,105	9.8
Esophagus	7,306	6.1	−0.4	2,288	4.5	−0.6	<0.0001	9,594	6.0
Lung, trachea, and mediastinum	21,600	18.0	−0.6	10,707	21.0	−0.5	<0.0001	32,307	19.5
Lung	19,532	16.2	−0.6	9,659	18.9	0.7	<0.0001	29,191	17.3
Breast	27,706	23.0	1.4	12,128	23.8	2.3	0.0008	39,834	21.5
Liver, biliary, tract, and pancreas	4,733	3.9	−0.1	1,908	3.7	0.3	0.0577	6,641	3.8
Gastric, small intestine, and colorectal	5,693	4.7	−0.2	2,586	5.1	−0.4	0.0029	8,279	5.1
Gynecologic	6,851	5.7	0.0	1,365	2.7	−0.6	<0.0001	8,216	4.9
Urogenital	16,641	13.8	0.7	6,409	12.6	−0.2	<0.0001	23,050	13.0
Prostate	12,830	10.7	0.9	5,089	10.0	0.6	<0.0001	17,919	9.6
Hematopoietic and lymphatic	6,176	5.1	−0.3	1,773	3.5	−0.1	<0.0001	7,949	4.8
Skin, bone, and soft tissue	3,014	2.5	−0.1	1,079	2.1	−0.7	<0.0001	4,093	2.7
Other (malignant)	1,359	1.1	−0.2	582	1.1	−0.3	0.8388	1,941	1.4
Benign tumors	1,407	1.2	−0.3	813	1.6	−0.4	<0.0001	2,220	1.6
Pediatric < 15 years (included in totals above)	900	0.7	0.0	192	0.4	−0.1	<0.0001	1,092	0.6
Total	120,289	100.0	0.0	51,001	100.0	0.0		171,290[c]	100.0
Metastasis	(n = 365)			(n = 335)				(n = 700)	
Brain	10,361	6.9	−0.7	9,973	14.7	−1.0	<0.0001	20,334	10.4
Bone	19,293	12.8	−0.9	7,613	11.3	−2.3	<0.0001	26,906	13.6

[a] Comparison with the data of 2007, calculated using the formula: data of 2009 (%) − data of 2007 (%)

[b] χ^2 test

[c] Number of total new patients is different with these data, because no data on primary sites were reported by some facilities

national policy is needed to improve the establishment of DCCHs and overcome the shortage of personnel for cancer care.

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Conflict of interest The authors declare that they have no conflict of interest.

References

1. Teshima T, Numasaki H, Nishio M et al (2011) Japanese Structure Survey of Radiation Oncology in 2009 (First Report) (in Japanese with an English abstract). Available from: http://www.jastro.or.jp/aboutus/child.php?eid=00025. Accessed 15 December 2011
2. Numasaki H, Shibuya H, Nishio M et al (2011) Japanese structure survey of radiation oncology in 2007 with special reference to designated cancer care hospitals. Strahlenther Onkol 187:167–174
3. Numasaki H, Shibuya H, Nishio M et al (2012) National Medical Care System may impede fostering of true specialization of radiation oncologists: study based on structure survey in Japan. Int J Radiat Oncol Biol Phys 82:e111–e117
4. Maeda M (2008) A review of cancer control strategy in Japan (in Japanese with an English abstract). J Natl Inst Public Health 57:304–307
5. Ishikura S (2008) Developing high quality radiotherapy service: current status and future perspectives (in Japanese with an English abstract). J Natl Inst Public Health 57:327–331
6. Sobue T (2008) Current activities and future directions of the cancer registration system in Japan. Int J Clin Oncol 13:97–101
7. Tsunemoto H (1990) Present status of Japanese radiation oncology: National survey of structure in 1990. J Jpn Soc Ther Radiol Oncol (special report) 1992:1–30
8. The Designated Cancer Hospitals, Ministry of Health, Labor and Welfare: A list of designated cancer hospitals. Available from: http://www.mhlw.go.jp/bunya/kenkou/dl/gan_byoin03.pdf. Accessed 15 December 2011
9. SAS Institute Inc (1985) SAS User's Guide: statistics. SAS Institute Inc., Cary

10. Japanese PCS Working Group. (2005) Radiation oncology in multidisciplinary cancer therapy—basic structure requirement for quality assurance of radiotherapy based on Patterns of Care Study in Japan. Ministry of Health, Labor, and Welfare Cancer Research Grant Planned Research Study, 14–6
11. Japanese PCS Working Group. (2010) Radiation oncology in multidisciplinary cancer therapy—basic structure requirement for quality assurance of radiotherapy based on Patterns of Care Study in Japan. Ministry of Health, Labor, and Welfare Cancer Research Grant Planned Research Study, pp 18–4
12. Tanisada K, Teshima T, Ohno Y et al (2002) Patterns of Care Study quantitative evaluation of the quality of radiotherapy in Japan. Cancer 95:164–171
13. Teshima T, Japanese PCS Working Group. (2005) Patterns of Care Study in Japan. Jpn J Clin Oncol 35:497–506
14. The American Society for Radiation Oncology (2004) Fast Facts About Radiation Therapy. ASTRO Fact Sheet for immediate review. http://www.waterjel.com/assets/files/pdf/ASTROFactSheet.pdf. Accessed 1 May 2012
15. Teshima T, Owen JB, Hanks GE et al (1996) A comparison of the structure of radiation oncology in the United States and Japan. Int J Radiat Oncol Biol Phys 34:235–242
16. National Cancer Data Base. http://www.facs.org/cancer/ncdb/index.html. Accessed 1 May 2012
17. Bilimoria KY, Stewart AK, Winchester DP et al (2008) The National Cancer Data Base: a powerful initiative to improve cancer care in the United States. Ann Surg Oncol 15:683–690

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NATIONAL MEDICAL CARE SYSTEM MAY IMPEDE FOSTERING OF TRUE SPECIALIZATION OF RADIATION ONCOLOGISTS: STUDY BASED ON STRUCTURE SURVEY IN JAPAN

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Purpose: To evaluate the actual work environment of radiation oncologists (ROs) in Japan in terms of working pattern, patient load, and quality of cancer care based on the relative time spent on patient care.
Methods and Materials: In 2008, the Japanese Society of Therapeutic Radiology and Oncology produced a questionnaire for a national structure survey of radiation oncology in 2007. Data for full-time ROs were crosschecked with data for part-time ROs by using their identification data. Data of 954 ROs were analyzed. The relative practice index for patients was calculated as the relative value of care time per patient on the basis of Japanese Blue Book guidelines (200 patients per RO).
Results: The working patterns of RO varied widely among facility categories. ROs working mainly at university hospitals treated 189.2 patients per year on average, with those working in university hospitals and their affiliated facilities treating 249.1 and those working in university hospitals only treating 144.0 patients per year on average. The corresponding data were 256.6 for cancer centers and 176.6 for other facilities. Geographically, the mean annual number of patients per RO per quarter was significantly associated with population size, varying from 143.1 to 203.4 ($p < 0.0001$). There were also significant differences in the average practice index for patients by ROs working mainly in university hospitals between those in main and affiliated facilities (1.07 vs 0.71: $p < 0.0001$).
Conclusions: ROs working in university hospitals and their affiliated facilities treated more patients than the other ROs. In terms of patient care time only, the quality of cancer care in affiliated facilities might be worse than that in university hospitals. Under the current national medical system, working patterns of ROs of academic facilities in Japan appear to be problematic for fostering true specialization of radiation oncologists. **© 2012 Elsevier Inc.**

Structure survey, Working pattern, Patient load, Quality of cancer care, Medical care system.

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INTRODUCTION

The medical care systems of the United States and Japan are very different, which influences the personnel cost of medical staff. In radiation oncology, too, there is thus a major difference in personnel distribution between the United States and Japan. Most radiotherapy facilities in the United States are supported by full-time radiation oncologists (ROs), whereas the majority of radiotherapy facilities in Japan still rely on part-time ROs. Radiotherapy facilities with less than one full-time equivalent (FTE) RO on their staff still account for 56% nationwide (1). The Cancer Control Act was implemented in Japan in 2007 in response to patients' urgent petitions to the government (2). This act strongly advocates the promotion of radiotherapy (RT) and an increase in the number of ROs and medical physicists. However, a shortage of ROs still remains a major concern in Japan and will remain so for the foreseeable future.

The Japanese Society of Therapeutic Radiology and Oncology (JASTRO) has conducted national structure surveys of RT facilities in Japan every 2 years since 1990 (1, 3). The structure of radiation oncology in Japan has improved in terms of equipment and its functions in response to the increasing number of cancer patients who require RT.

In this study, we used the data of the JASTRO structure survey of 2007 to evaluate the actual work environment of radiation oncologists in Japan in terms of working pattern, patient load, and the quality of cancer care based on the relative time spent on patient care.

MATERIALS AND METHODS

Between March and December 2008, JASTRO carried out a national structure survey of radiation oncology in the form of a questionnaire in 2007 (1). The questionnaire consisted of questions about the number of treatment machines and modality by type, the number of personnel by job category, the number of patients by type, and the site. The response rate was 721 of 765 (94.2%) from all actual RT facilities in Japan.

Table 1 shows the overview of radiation oncology in Japan. University hospitals accounted for 15.8% of all RT facilities and had 40.0% of the total full-time ROs and treated 29.5% of all patients. The corresponding data were 4.0%, 7.8%, and 10.2% for cancer centers, and 80.2%, 52.2%, and 60.3% for other RT hospitals, respectively. "Full-time/part-time" indicates the employment pattern of RO. In Japan, even full-time ROs must work part-time in smaller facilities such as other RT hospitals. We considered these numbers to be inappropriate for accurate assessment of personnel. For this survey, we therefore collected FTE (40 h/week for radiation oncology services only) data depending on hours worked in clinical RT of each RO. For example, if an RO works 3 days at a university hospital and 2 days at an affiliated hospital each week, FTE of the RO at the university hospital is 0.6 and at an affiliated hospital it is 0.4. The FTE of a facility that has three ROs with 0.8, 0.4, and 0.6 is calculated as 1.8 in total.

This survey collected the work situation data of a total of 1,007 full-time ROs and 534 part-time ROs. The data of full-time ROs were crosschecked with those of part-time ROs by using their identification data. Table 2 shows the result of crosschecking between data of full-time ROs and data of part-time ROs. In this study, data of 954 ROs were analyzed. Table 3 shows an overview of the analyzed data. In ROs working mainly in university hospitals, there are two ROs who worked at a maximum of six facilities (main facilities and five affiliated facilities) SAS 8.02 (SAS Institute Inc., Cary, NC) (4) was used for the statistical analysis, and the statistical significance was tested by means of the Student's t-test or analysis of variance.

The Japanese Blue Book guidelines (5, 6) for structure of radiation oncology in Japan based on Patterns of Care Study (PCS) data were used as the standard for comparison with the results of this study. PCS in Japan have been used since 1996 and have disclosed significant differences in the quality of RT by the type of facilities and their caseloads (7, 8). The standard guidelines for annual patient load per FTE RO have been set at 200 (warning level 300).

To evaluate quality of cancer care provided by ROs, the relative practice index for patients was calculated by the following expression.

$$\frac{\sum_{k=1}^{n} f_k}{\sum_{k=1}^{n} a_k} \times 200$$

in which n is the number of facilities that the RO works in ($n = 1, 2, 3, \ldots, k$), f_k is the FTE of the RO in facility k, and a_k is the annual number of patients per RO in facility k

Calculation method of coefficient "200:"

1) Number of weeks per year = (365–15)/7 = 50 weeks
   ※ Japan has 15 national holidays a year
2) 1.0 FTE = 40 h/week
3) Annual working hours of FTE 1.0 = 50 × 40 h = 2,000 h
4) Relative practice index for patients was normalized using the Blue Book guideline of 200 patients/FTE RO. For this guideline, care time per patient was set at 10 hours (2,000 h/200 patients).
5) Coefficient was 200 (2000/10).

RESULTS

Working patterns

Figure 1 shows working patterns of ROs working mainly in (a) university hospitals, (b) cancer centers, and (c) other

Table 1. Categorization of radiotherapy facilities in Japan

				Full-time ROs		Part-time ROs	
Facility category	Number of facilities	New patients	Total patients (new + repeat)	*n*	FTE	*n*	FTE
University hospital	114	50,351	60,555	403	293.0	70	21.6
Cancer center	29	16,794	20,968	78	73.7	14	2.5
Other radiotherapy hospital	578	103,084	123,564	526	351.8	450	83.7
Total	721	170,229	205,087	1,007	718.5	534	107.8

Abbreviations: RO = radiation oncologist; FTE = full-time equivalent (40 hours per week for radiation oncology services only).

Table 2. Connection between full-time and part-time RO data

Data of full-time ROs	
Total number	1,007
Number of full-time ROs excluded from this analysis*	53
Number of full-time ROs analyzed	954
Breakdown	
Number of ROs who worked as full-time staff at main facilities and as part-time staff at affiliated facilities	199
Number of ROs who conducted only radiotherapy-related work as full-time staff at individual facilities (FTE of the RO was 1.0)	275
Number of ROs who conducted radiotherapy-related and other work as full-time staff at individual facilities (FTE of the RO was less than 1.0)	480
Data of part-time ROs including duplicate ROs	
Total number	534
Number of ROs who worked as full-time staff at main facilities and as part-time staff at affiliated facilities (number of part-time ROs analyzed)	280
Number of ROs who worked as only part-time staff at the facilities (Number of part-time ROs excluded from this analysis)	254

Abbreviations: RO = radiation oncologist; FTE = full-time equivalent (40 hours per week for radiation oncology service only).

* Data of full-time ROs who worked at facilities with few patients were excluded, as were duplicated data of full-time ROs.

RT hospitals. The percentages of white parts in Figures 1 (a-c) were 17.4%, 5.0%, and 32.0%.

In university hospitals, the mean FTE RO for main facilities was 0.73 and for affiliated facilities it was 0.10. The corresponding figures were 0.94 and 0.01 for cancer centers, and 0.67 and 0.01 for other RT hospitals. For university hospitals, the ratio of ROs working only in main facilities was 16.4%, and the corresponding figures for cancer centers and other RT hospitals were 79.5% and 31.7%, respectively. The ratio of ROs working mainly in university hospitals and part-time in affiliated facilities was 44.5%. The corresponding data were 6.5% of ROs working primarily in cancer centers and 7.5% of ROs working mainly in other RT hospitals.

Patient loads

Figure 2(a) shows the patient load per RO working mainly in university hospitals, cancer centers, and other RT hospitals. Of ROs working primarily in university hospitals, 40.1% treated more than 200 patients per year. The corresponding ratios were 74.4% of ROs working primarily in cancer centers and 36.5% of those working mainly in other RT hospitals. The average number of patients treated by ROs working primarily in university hospitals was 189.2, with the corresponding figures being 256.6 patients in cancer centers and 176.6 in other RT hospitals. Figure 2(b) shows the patient load per RO working primarily in university hospitals. Of ROs working in university hospitals and affiliated facilities, 65.9% treated more than 200 patients per year, and the percentage was 19.3% of ROs working only in university hospitals. The former treated an average of 249.1 patients and the latter 144.0 patients per year.

The geographic patterns

Figure 3 shows the geographic distribution for 47 prefectures of the mean annual number of patients (new plus repeat) per RO arranged in order of increasing population by all prefectures in Japan (9). The average annual number of patients per RO per quarter ranged from 143.1 to 203.4, with significant differences among quarters ($p < 0.0001$). Figure 4 shows the top 10 prefectures with ROs who treated more than 200 patients per year in descending order: Tokyo, Osaka, Kanagawa, Hokkaido, Chiba, Aichi, Fukuoka, Hyogo, Miyagi, and Hiroshima.

Relative practice index for patients of ROs

Figure 5(a) shows the average relative practice index for patients of ROs in university hospitals and affiliated facilities (ROs working mainly in university hospitals). The average practice index of RO for patients was 1.07 at university hospitals and 0.71 at affiliated facilities for a statistically significant difference ($p < 0.0001$). Figure 5(b) shows the average relative practice index for patients of ROs working only in university hospitals, only in cancer centers, and only in other RT hospitals. The respective indices for the three categories were 1.26, 1.02, and 1.01. There were significant differences in the indices between university hospitals and cancer centers ($p = 0.0278$) and between university hospitals and other RT hospitals ($p < 0.0001$). The difference between cancer

Table 3. Overview of analyzed data

Main facility category	Number of full-time ROs working at main facilities	Number of part-time ROs working at affiliated facilities					
		First*	Second*	Third*	Fourth*	Fifth*	Subtotal
University hospital	372	160	59	14	4	2	239
Cancer center	78	5	0	0	0	0	5
Other radiotherapy hospital	504	34	2	0	0	0	36
Total	954	199	61	14	4	2	280

Abbreviation: RO = radiation oncologist.

* First: first affiliated facilities; second: second affiliated facilities; third: third affiliated facilities; fourth: fourth affiliated facilities; fifth: fifth affiliated facilities.

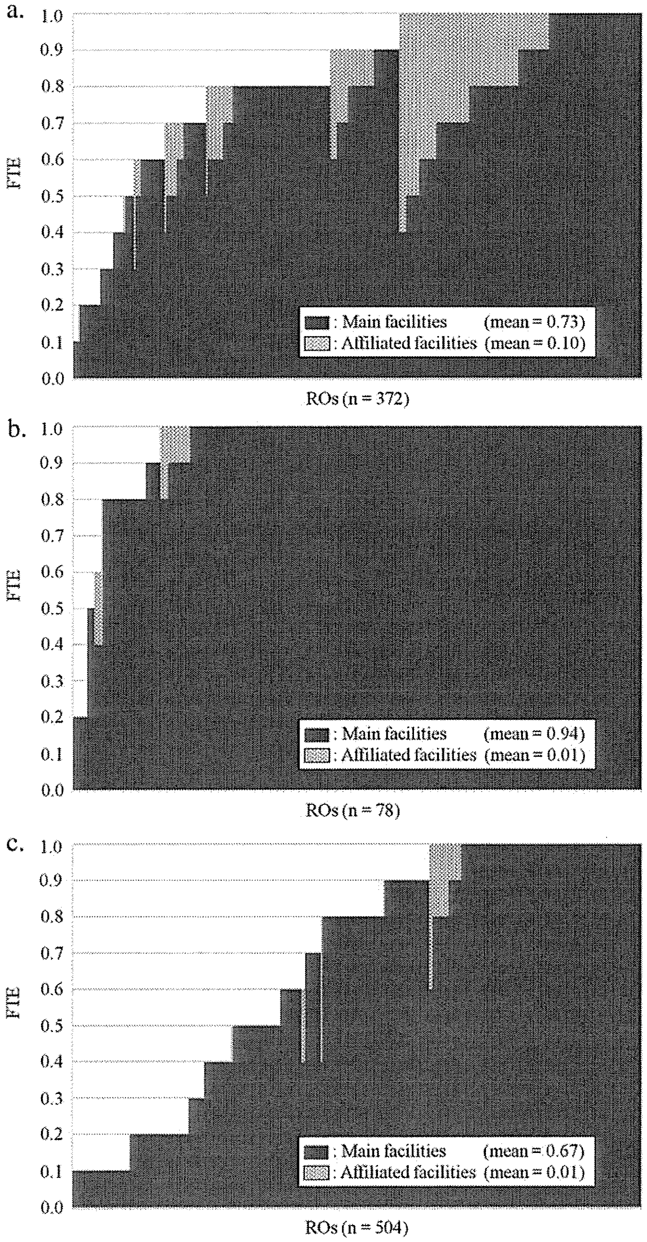

Fig. 1. Working patterns of ROs working mainly at (a) university hospitals, (b) cancer centers, and (c) other radiotherapy hospitals. Distribution of FTE ratio between main and affiliated facilities on each RO. Horizontal axis represents ROs in ascending order of own total FTE. *Abbreviations:* RO = radiation oncologist; FTE = full-time equivalent (40 hours per week for radiation oncology services only).

centers and other RT hospitals was not significant ($p = 0.9459$).

DISCUSSION

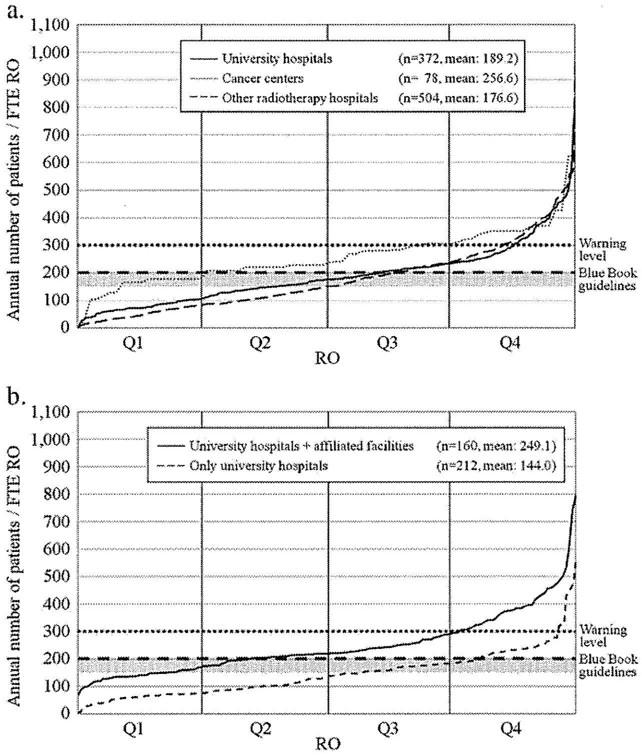

Fig. 2. Distribution of annual patient load/RO. (a) RO working mainly in university hospitals, cancer centers, and other radiotherapy hospitals. (b) RO working mainly in university hospitals. Horizontal axis represents ROs in ascending order of annual numbers of patients/RO. Q1: 0–25%, Q2: 26–50%, Q3: 51–75%, Q4: 76–100%. *Abbreviations:* RO = radiation oncologist; FTE = full-time equivalent (40 hours per week for radiation oncology services only).

In the United States, most RT facilities are supported by full-time ROs, with an FTE of 1.0 for most ROs working at their own facilities. In Japan, on the other hand, more than a half of the facilities still rely on part-time ROs. The main reason of this discrepancy is a shortage of ROs. Between 2005 and 2007, the increase in the number of cancer patients requiring RT (7.3%) was higher than that in the number of FTE ROs (6.7%) (1). To make up for the shortage of ROs, most ROs in university hospitals must work part-time at affiliated hospitals, as is evident from the date shown in Figure 1. White parts of Figure 1 (a: 17.4%, b: 5.0% c: 32.0%) represent three types of data: (a) FTE data of ROs who were not provided in the survey questionnaire; (b) FTE data of part-time ROs whose identification data could not connect to those of full-time ROs; (c) FTE data of ROs working in nonradiation oncology services. In this survey, the data of type (a) and (b) were missing data and the data of type (c) were not collected. In other RT hospitals, the FTE of most ROs working in their own facilities is low and these ROs do not work part-time at other hospitals. There are two reasons for this. First, diagnosticians partly provide RT as ROs in their own hospitals and, second, other specialists (such as brain surgeons using gamma knife) partly function as ROs to provide RT. Because those facilities have few cancer patients, their patient load is less than that of university hospitals and cancer centers. These findings are evident from Figure 2(a). There was a major difference in the working patterns of ROs between university hospitals and cancer centers. FTE at their own facilities of most ROs working in university hospitals is less than 1.0, whereas that of most ROs working in cancer centers is 1.0,

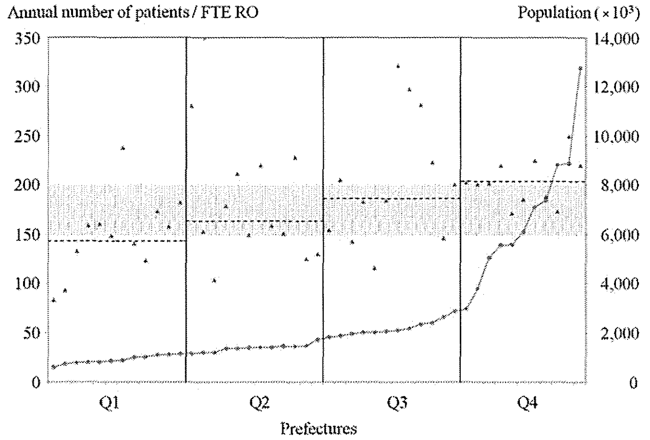

Fig. 3. Geographic distribution for 47 prefectures of annual number of patients (new plus repeat) per RO in ascending order of prefectural population. Q1: 0–25%; Q2: 26–50%; Q3: 51–75%; Q4: 76–100%. Triangles represent average annual number of patients per RO for each prefecture. Blue circles show prefectural population. Horizontal broken lines indicate the average annual number of patients per RO per quarter. The shaded area represents the Japanese Blue Book guideline (150–200 patients per RO). *Abbreviations:* RO = radiation oncologist; FTE = full-time equivalent (40 hours per week for radiation oncology services only).

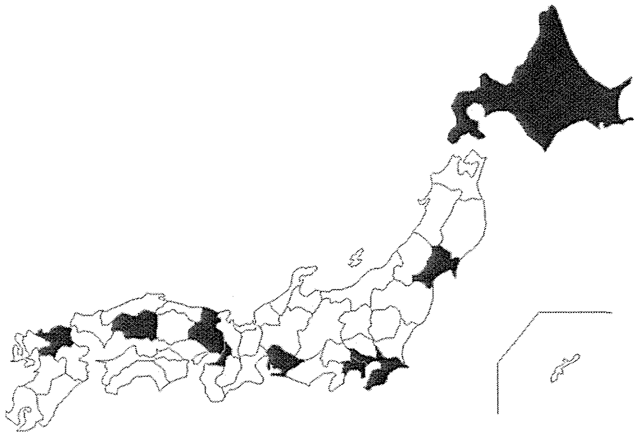

Fig. 4. The top 10 prefectures with ROs who treated more than 200 patients in descending order: Tokyo, Osaka, Kanagawa, Hokkaido, Chiba, Aichi, Fukuoka, Hyogo, Miyagi, and Hiroshima. *Abbreviation:* RO = radiation oncologist.

the same as in the United States and European countries. The shortage of ROs is not the only reason for the problems facing Japan. The pay system of ROs is another important reason. The salary of ROs in Japan is low because specialist medical fees for ROs are not covered by the Japanese healthcare insurance system. Moreover, the salary of ROs in university hospitals is lower than in other types of facilities, so that most of these ROs must work part-time at affiliated hospitals to earn a living. One advantage of this system, however, is that advanced technology is introduced sooner and faster in affiliated hospitals.

The geographic patterns demonstrated significant differences in the patient load among prefectures, ranging from 83.2 to 321.4 patients per RO. There were more ROs in metropolitan than other areas. However, the number of ROs who had more than 200 patients (new plus repeat) was strongly associated with population (correlation coefficient: 0.94), so that the number of ROs in metropolitan area remained insufficient.

Gomi *et al.* reported that the survival rate of patients treated in academic RT facilities (university hospitals and cancer centers) was better than that of those treated in nonacademic RT facilities in Japan (10). In this study, the proportion of facilities with part-time ROs in nonacademic RT facilities group was higher than that in academic RT facilities group. Part-time ROs have less care time per patient because they had a limit to working hours. On the basis of the presented evidence, the relative practice index for patients of ROs was calculated as one way to valuate quality of cancer care in this study. Concerning ROs working primarily in university hospitals, the average relative practice index for patients in affiliated facilities was less than that in main facilities (university hospitals). Teshima *et al.* reported that academic RT facilities (university hospitals and cancer centers) had better equipments and manpower than nonacademic RT facilities (1). Therefore, ROs at large-scale university hospitals might be given sufficient support because large-scale university hospitals tend to have state-of-the-art equipment, practice leading-edge medical treatment techniques, and employ enough medical staff members. On the other hand, ROs of most affiliated facilities could provide only minimal cancer care because these facilities

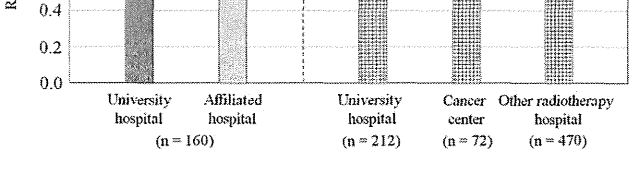

Fig. 5. Relative practice index for patients of ROs. (a) Relative practice index for patients in university hospitals and affiliated hospitals (targeted ROs were working mainly in university hospitals and part-time in affiliated hospitals). (b) Relative practice index for patients in university hospitals, cancer centers, and other radiotherapy hospitals (targeted ROs were working only in university hospitals or cancer centers only or only in other radiotherapy hospitals). *The formula used for calculating relative practice index for patients is: $\frac{\sum_{k=1}^{n} f_k}{\sum_{k=1}^{n} a_k} \times 200$ n: number of facilities that the RO works in (n = 1, 2, 3, …, k). f_k : FTE of the RO in facility k a_k : annual number of patients per RO in facility k. *Abbreviations:* RO = radiation oncologist; FTE = full-time equivalent (40 hours per week for radiation oncology services only).

tend to lack sufficient equipment and medical staff. Moreover, commuting between large-scale university hospitals and affiliated facilities resulted in a waste of time and in tiredness. Therefore, the quality of cancer care in affiliated facilities was worse than that in large-scale university hospitals. Although the annual number of patients per RO in cancer centers was higher than that in university hospitals and other RT hospitals, the average relative practice index for patients of ROs working only in cancer centers was lower than that for patients of ROs working only in university hospitals and equal to that for patients of ROs working only in other RT hospitals. It can thus be concluded that ROs in cancer centers worked efficiently.

The utilization rate of RT for new cancer patients in Japan is much lower than that in European countries and the United States. Because there are enough RT facilities distributed nationwide in Japan, an increase in the number of Ros would likely result in a spectacular improvement in the utilization rate of RT for new cancer patients. To increase the number of ROs, it is necessary to improve the work environment and conditions for radiation oncology in medical care facilities. One, feasible suggestion is for RT facilities to set up a new department of radiation oncology, so that the position of RO will be established at every such facility and the status of radiation oncology will improve as a result. In addition, the Cancer Control Act was approved in 2006 and the Basic Plan to Promote Cancer Control Program was approved by the Japanese Cabinet in 2007 to promote RT and education for ROs as well as other RT staff members. For the implementation of this law and plan, the availability of basic data of RO working conditions is essential. As a start, an education program called "Cancer Professional Training Plan" was started in April 2008 with the support of the Ministry of Education, Culture, Sports, Science and Technology.

Quality of cancer care was evaluated in this study with the aid of the relative practice index for patients. However, data concerning the processes and outcomes for cancer care using RT should be used for a more accurate evaluation of cancer care. In the United States, the National Cancer Data Base has been collecting data for cancer care. The data of National Cancer Data Base are useful for quality evaluation of cancer care (11, 12). Furthermore, PCS has been performed every 4 or 5 years since 1973 for a survey of the structure, processes, and outcomes of radiation oncology facilities (13). As PCS evolved into Quality Research in Radiation Oncology, periodic assessments of radiation oncology have been conducted for evaluation of practice quality on a national basis. In Japan, the structure, processes and outcomes for cancer care using RT have been investigated by PCS every 4 years (7, 8). The Japanese PCS has evaluated the quality of cancer care with RT and provided evidence of the disparity in quality of RT among facilities (14–18). However, these data are insufficient because PCS is a two-stage cluster sampling survey. We have recently established a database system based on available radiation oncology data and the collection of cancer care data by means of this system is now in preparation.

This study based on the JASTRO structure survey has indicated that the current national medical care system may impede fostering of true specialization of radiation oncologists in Japan because it is suffering from systemic fatigue. Although private hospitals make much money by receiving fee-for-service reimbursement, public hospitals face major deficit problems. It is therefore necessary to redistribute the burden of medical costs. On the other hand, the Japanese medical care system is beneficial for patients and national finances. Japan has had a universal health insurance system since 1961. Even though the per-capita medical costs in Japan were less than half of those in the United States and the medical costs in relation to the gross domestic product in Japan were about half of those in the United States as of 2007 (19), the outcome of cancer treatment in Japan is the same or better than in the United States. It is therefore very important to collect at regular intervals detailed information about all cancer care facilities for evaluation of quality of care and medical care systems for cancer. In Japan, the JASTRO structure survey has collected structural data of radiation oncology. Furthermore, a database system for the collection of data regarding the processes and outcomes for cancer care has recently been established in Japan as well as an information infrastructure for evaluation of the quality of care in radiation oncology.

In conclusion, our survey found that ROs working in university hospitals and their affiliated facilities treated more patients than did other ROs. In terms of patient care time only, the quality of cancer care in affiliated facilities might be worse than that in university hospitals. Under the current national insurance system, working patterns of ROs in academic facilities in Japan tend to impede the fostering of true specialization of radiation oncologists.

REFERENCES

1. Teshima T, Numasaki H, Shibuya H, *et al.* Japanese structure survey of radiation oncology in 2007 based on institutional stratification of Patterns of Care Study. *Int J Radiat Oncol Biol Phys* 2010;78:1483–1493.
2. Maeda M. A review of cancer control strategy in Japan [in Japanese]. *J Natl Inst Public Health* 2008;57:304–307.
3. Teshima T, Numasaki H, Shibuya H, *et al.* Japanese structure survey of radiation oncology in 2005 based on institutional stratification of Patterns of Care Study. *Int J Radiat Oncol Biol Phys* 2008;2:144–152.
4. SAS Institute Inc. SAS User's Guide: Statistics. Cary, NC: SAS Institute Inc.; 1985.
5. Japanese PCS Working Group. Radiation oncology in multidisciplinary cancer therapy -Basic structure requirement for quality assurance of radiotherapy based on Patterns of Care Study in Japan. Ministry of Health, Labor and Welfare Cancer Research Grant Planned Research Study 14-6, 2005.
6. Japanese PCS Working Group. Radiation oncology in multidisciplinary cancer therapy -Basic structure requirement for quality assurance of radiotherapy based on Patterns of Care Study in

Japan. Ministry of Health, Labor and Welfare Cancer Research Grant Planned Research Study 18-4, 2010.

7. Tanisada K, Teshima T, Ohno Y, *et al.* Patterns of Care Study quantitative evaluation of the quality of radiotherapy in Japan. *Cancer* 2002;95:164–171.
8. Teshima T, Japanese PCS working group. Patterns of Care Study in Japan. *Jpn J Clin Oncol* 2005;35:497–506.
9. Ministry of Internal Affairs and Communications, Statistics Bureau, Director-General for Policy Planning (Statistical Standards) & Statistical Research and Training Institute. Current population estimates as of October 1, 2007. Available from: www.stat.go.jp/english/data/jinsui/2007np/index.htm (accessed August 31, 2010).
10. Gomi K, Oguchi M, Hirokawa Y, *et al.* Process and preliminary outcome of a patterns-of-care study of esophageal cancer in Japan: Patients treated with surgery and radiotherapy. *Int J Radiat Oncol Biol Phys* 2003;56:813–822.
11. National Cancer Data Base. Available from: www.facs.org/cancer/ncdb/index.html (accessed June 30, 2010).
12. Bilimoria KY, Stewart AK, Winchester DP, *et al.* The National Cancer Data Base: A powerful initiative to improve cancer care in the United States. *Ann Surg Oncol* 2008;15:683–690.
13. Wilson JF, Owen JB. Quality research in radiation oncology: A self-improvement initiative 30 years ahead of its time? *J Am Coll Radiol* 2005;2:1001–1007.
14. Yamauchi C, Mitsumori M, Sai H, *et al.* Patterns of care study of breast-conserving therapy in Japan: Comparison of the treatment process between 1995–1997 and 1999–2001 surveys. *Jpn J Clin Oncol* 2007;38:26–30.
15. Toita T, Kodaira T, Uno T, *et al.* Patterns of radiotherapy practice for patients with cervical cancer (1999–2001): Patterns of Care Study in Japan. *Int J Radiat Oncol Biol Phys* 2008;70:788–794.
16. Kenjo M, Uno T, Numasaki H, *et al.* Radiation therapy for esophageal cancer in Japan: Results of the Patterns of Care Study 1999–2001. *Int J Radiat Oncol Biol Phys* 2009;75:357–363.
17. Uno T, Sumi M, Numasaki H, *et al.* Changes in patterns of care for limited-stage small cell lung cancer: Results of the 99-01 Patterns of Care Study—A nationwide survey in Japan. *Int J Radiat Oncol Biol Phys* 2008;71:414–419.
18. Ogawa K, Nakamura K, Onishi H, *et al.* Japanese Patterns of Care Study Working Subgroup of Prostate cancer. External beam radiotherapy for clinically localized hormone-refractory prostate cancer: Clinical significance of nadir prostate-specific antigen value within 12 months. *Int J Radiat Oncol Biol Phys* 2009;74:759–765.
19. OECD Health Data 2010. Paris: Organisation for Economic Co-Operation and Development; 2010.

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Quality assurance of MLC leaf position accuracy and relative dose effect at the MLC abutment region using an electronic portal imaging device

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We investigated an electronic portal image device (EPID)-based method to see whether it provides effective and accurate relative dose measurement at abutment leaves in terms of positional errors of the multi-leaf collimator (MLC) leaf position. A Siemens ONCOR machine was used. For the garden fence test, a rectangular field (0.2 × 20 cm) was sequentially irradiated 11 times at 2-cm intervals. Deviations from planned leaf positions were calculated. For the nongap test, relative doses at the MLC abutment region were evaluated by sequential irradiation of a rectangular field (2 × 20 cm) 10 times with a MLC separation of 2 cm without a leaf gap. The integral signal in a region of interest was set to position A (between leaves) and B (neighbor of A). A pixel value at position B was used as background and the pixel ratio (A/B × 100) was calculated. Both tests were performed at four gantry angles (0, 90, 180 and 270°) four times over 1 month. For the nongap test the difference in pixel ratio between the first and last period was calculated. Regarding results, average deviations from planned positions with the garden fence test were within 0.5 mm at all gantry angles, and at gantry angles of 90 and 270° tended to decrease gradually over the month. For the nongap test, pixel ratio tended to increase gradually in all leaves, leading to a decrease in relative doses at abutment regions. This phenomenon was affected by both gravity arising from the gantry angle, and the hardware-associated contraction of field size with this type of machine.

Keywords: MLC; IMRT; EPID; garden fence test; calibration

INTRODUCTION

Because treatment fields consist of multiple segments generated from optimization procedures and the multi-leaf collimator (MLC) leaf positions control steep dose gradient, quality assurance for MLC plays an important role in treatment planning and dose delivery in intensity-modulated radiation therapy (IMRT). Variation between the planned and actual leaf positions can lead to incorrect dose distributions [1–3]. For segmental MLC, the over- or underlapping of abutting field segments leads to hot or cold spots in the abutment regions of approximately 13% mm^{-1} and 17% mm^{-1} of the average dose for the abutting segments for 6- and 18-MV photon beams, respectively [4].

Several methods for quality assurance (QA) of MLC position in IMRT have been proposed. The garden fence test is traditionally used to verify the actual versus planned MLC stop position [5, 6]. Although this method is generally performed with radiographic film, it is time-consuming and analysis is costly. The same tests have recently been performed with electronic portal image devices (EPIDs) [7–10]. These devices facilitate the confirmation of leaf position accuracy with high precision, namely 0.4 mm per pixel of physical detector size, and at any gantry angle, even 0°. The garden fence test is accordingly performed at our department with an EPID at gantry angles of 0, 90, 180, and 270° to account for leaf positional error due to the gravity effect. Since therapeutic procedures regularly require the delivery of MLC-defined fields to patients at a wide range of gantry angles, the accuracy of these QC checks at other gantry angles has been investigated. In addition to the gravity effect, leaf positional error also affects the dose error between abutment leaves, particularly in step-and-shoot IMRT [1]. Treatment planning systems do not account for leaf positional error, however, and it is therefore not accounted for in dose calculation. Rather, dose delivery is critically dependent on the performance of MLC leaf position accuracy and on ensuring that the planned dose distribution can be achieved safely and accurately.

The publications of AAPM task groups (TG) 50 and 142 provide an excellent review of MLC design and QA issues [11, 12]. The TG-50 report provides a test for determining errors in leaf positioning that is extremely sensitive to relative position errors, but does not quantify the amount of error, identify the offending leaf or demonstrate the absolute position of the leaves with respect to the central axis of the collimator. In contrast, the TG-142 report does provide a test for leaf positioning error, but does not allow checking of the dose error generated by an incorrect leaf stop positioning error for neighboring leaves. Moreover, the relative dose effect at the MLC abutment region has not been quantitatively investigated, to our knowledge at least.

Here, we used an EPID to develop a technique to efficiently measure the absolute position of each MLC leaf from the central axis of the collimator over the range of leaf positions utilized in IMRT. Additionally, we developed a simple QA procedure to determine as the relative pixel intensity error between abutment leaves produced by an incorrect leaf position compared with the expected leaf position, and then used this technique to determine a suitable period for MLC leaf calibration using the long-term reproducibility of leaf position. The reproducibility of leaf positions was tested in the long term as a function of gantry angle.

MATERIALS AND METHODS

MLC and EPID

Exposures were done with a Siemens ONCOR Impression plus linear accelerator (Siemens Medical Systems, Concord, CA, USA). This system utilizes an MLC designed with 82 pairs of leaves, consisting of two leaves that project to 0.5-cm width at 100 cm from the source (leaves #1 and #41) and 39 leaves which project to a 1-cm width (leaves #2–40). The double-focused MLC design was initially described by Das *et al.* [13]. The leaves can travel across the beam central axis for a maximum distance of 10 cm.

A Siemens OPTIVUE 1000 EPID (Siemens Medical Systems) was used to acquire portal images. The detector has 1024 × 1024 pixels with a size of 0.40 mm. Overlaying the sensitive layer of the EPID is a 3-mm copper plate to remove low energy photons, followed by a scintillating layer of phosphor to transform incoming x-rays to visible photons, and then a pixel array implanted on the amorphous-Si panel to capture visible photons and convert them to electric charges. The charge signals are then read out and digitized by a 16-bit analogue to digital converter. Source to imager distance (SID) is changeable between 110 cm and 160 cm.

Repeated extension/retraction of the EPID

Use of the EPID to measure leaf position was tested by examining the repeatability of EPID extension and retraction. The cross wire plate, which is named XRETIC and matched to the mechanical isocenter, was inserted into a shadow tray, and exposure of one monitor unit with a field size of 20 cm × 20 cm was done 10 times, as shown in Fig. 1. Coincidence of mechanical isocenter and radiation beam center is <1 mm.

At every exposure the EPID was set without a change in field size; that is, each exposure was done without motion of the MLC. An SID of 150 cm and gantry angle of 0° were used. Because the physical center of the EPID (row: 511, column: 511) was not exactly matched to the cross point of the XRETIC plate, the shift data, which consist of the rotational and translational offset, were measured by matching the physical center of the EPID with the projected image of the XRETIC wire. Minimum resolution for this analysis was 1 pixel and 0.1°, which was the same as the minimum resolution of collimator rotation for translation and rotation, respectively. Calculated pixel size was 0.27 mm at the isocenter given that the physical pixel size at a SID of 150 cm was 0.40 mm.

Determination of EPID sag correction factors

When measurement is done at various gantry angles, EPID sag should be identified to allow for correction of both

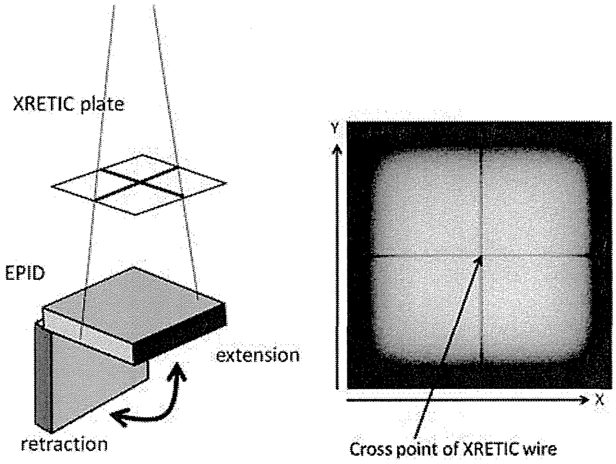


Fig. 1. Retraction and extension of the EPID. Axes in color show the physical center (row: 511, column: 511) of the portal image.

rotational offset and translational offset so that the center of the XRETIC plate can be matched with the isocenter. After the XRETIC plate was inserted into a shadow tray, exposure with a 20 cm × 20 cm X-ray field by one monitor unit was done at the gantry angles of 0, 90, 180 and 270°. The shift value needed for translation and rotation was then calculated manually.

Garden fence test

A slit field of 2 mm width by 20 cm height was made and the field center was swept from –10 cm to +10 cm at intervals of 2 cm; that is, irradiation with one monitor unit was continuously done 11 times with no extension or retraction of the EPID. This irradiation protocol was known as the garden fence test, which detects the MLC leaf position errors [14–18]. All portal images were taken at an SID of 150 cm using a 6-MV photon beam. A composite image was made as the sum of the 11 images with our in-house software. Figure 2 shows the composite image and coordinate system for this study. This is an inverted image, which means the irradiated region is white and the unirradiated region is black.

The coordinate system was defined as follows: the origin was set to the isocenter after EPID sag correction. The X-axis was directed from the X1 jaw-MLC to the X2 jaw-MLC and the Y-axis from the Y2 jaw to the Y1 jaw. For each MLC leaf the center position of the field width that the distance between 50% of the peak intensity for the pixel intensity profile (i.e. the center of full-width half-maximum) was calculated. This used the MLC edge detection method proposed by Bayouth *et al.* [19]. Although the visual inspection is basically performed in the garden fence test with or without MLC leaf position error, in this study the MLC leaf position error was defined as the distance between the calculated position and the nominal planned position. A positive deviation value meant that the error was toward the X2 side from the planned position, whereas a negative value meant that the error was toward the X1 side. These procedures were done at the four gantry angles of 0, 90, 180 and 270°.

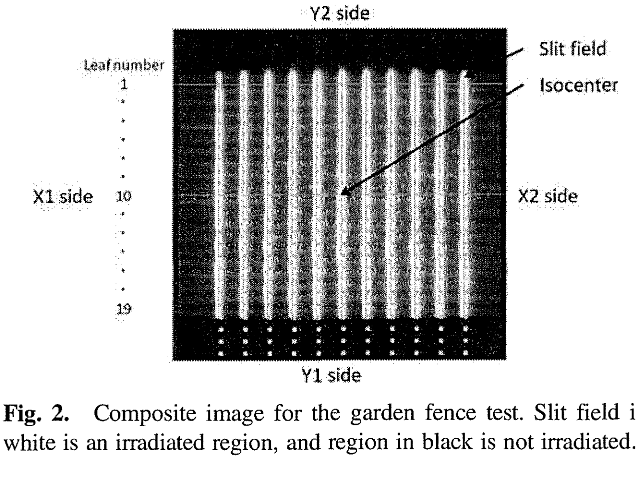


Fig. 2. Composite image for the garden fence test. Slit field in white is an irradiated region, and region in black is not irradiated.

Nongap test

A rectangular field of 2 cm × 20 cm was produced and sequentially irradiated onto the EPID at a 2-cm interval without a leaf gap 10 times, as if a 20 cm × 20 cm open field was created. As with the garden fence test, all EPID images were taken at an SID of 150 cm using a 6-MV photon beam. For each image, 10 images were acquired in our in-house software and a composite image was created. Figure 3 showed a sample image at gantry angle 0° for this test.

The integral signal in the small region of interest (ROI), which had a size of 10 mm × 5 mm, was set to position A (MLC leaf abutment: gap) and B (its neighbor: open field). Once the ROI was set in the left up corner on the composite image for either position A or B, the other ROIs were automatically defined based on the interval of leaf abutment gap of 2 cm and lead width of 1 cm. For each region, mean pixel value within the ROI was calculated at region A and B. For region B, the mean pixel value from the two regions was calculated and used, namely both sides of the gap region, in order to remove radiation field variations. A pixel value at position B was used as background intensity. The EPID image pixel values at position A were divided by an open field image at position B to reduce potential variations in beam output and symmetry and minimize the effect of local EPID response variations. The ratio of pixel value (A/B × 100) at each MLC abutment position was used to determine underdose, overdose and flattened dose regions, with a pixel ratio at position A of >100 assumed to indicate underdosing in the leaf gap, and of <100 to indicate overdosing. The multiplied factor of 100 was used to gain the value of pixel ratio. These procedures were done at gantry angles of 0, 90, 180 and 270°, respectively.

Reproducibility of the garden fence test and nongap test

To determine the change in leaf position and the relative dose intensity effect by the deviation of each leaf position,

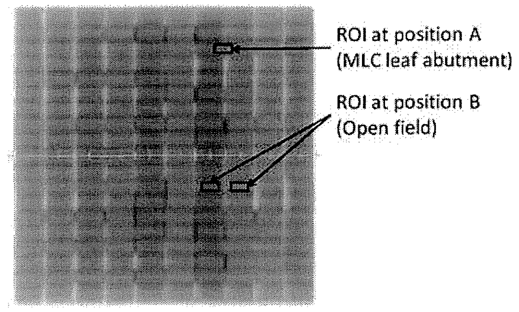


Fig. 3. Composite image for the nongap test. The size of the region of interest (ROI) was a 10-mm width and 5-mm height.

the garden fence test and nongap test were performed for a period of 1 month without MLC leaf calibration. Each test was performed four times over this period. EPID sag error was also measured and used for correction of the tests to evaluate the beam axis coordinate. With regard to the nongap test, the change in pixel ratio at each MLC abutment position (X = –8, –6, –4, –2, 0, 2, 4, 6, 8) was measured. The pixel ratio of the last data point at each abutment position was compared with that of the first data point using the paired *t*-test. Statistical significance was set at the 5% level.

RESULTS

Repeated extension/retraction of the EPID

Measurements were obtained by recording the pixel coordinates of the cross point of the XRETIC plate on the EPID image. Figure 1 shows the pixel coordinates of the cross point in both the X and Y axes. Standard deviations of the shift correction data over 10 measurements in the X and Y axes were 0.00 mm and 0.00 mm, respectively with the measurement uncertainty of 0.14 mm because the minimum pixel resolution for analysis was 0.27 mm. Maximum deviation was 0.00 mm in both axes despite repeated extension and retraction of the EPID without change in MLC leaf position. These findings indicate that the EPID could be used for the analysis of MLC leaf position.

Determination of EPID sag correction factors

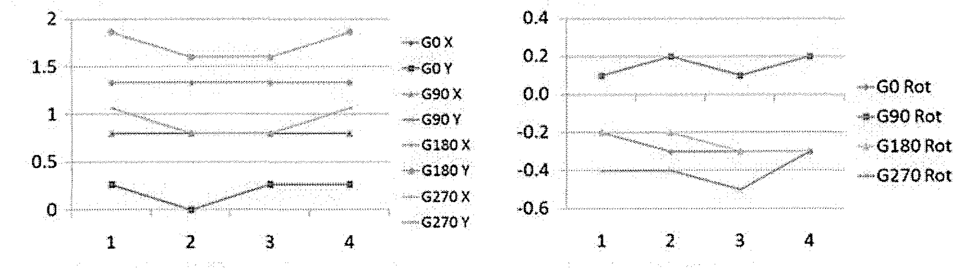
Measurements were obtained by recording the pixel coordinates of the cross point of the XRETIC plate on the EPID image at four gantry angles. Figure 4 shows the change in translational offset in millimeters and rotational offset in degrees for the cross wire at the four gantry angles on weekly measurement for 1 month.

At gantry 0, standard deviations (SDs) of the translational offset for the X and Y axes and rotational offset were 0.00 mm, 0.13 mm and 0.05°, respectively. Although there was no deviation for the translational offset at a gantry angle of 90°, 0.06° of SD was seen for rotational offset. At gantry angle 180°, SDs of translational offset were 0.00 mm and 0.15 mm for the X and Y axes, and 0.06° for rotational offset, respectively. At gantry angle 270°, the SDs of translational offset were 0.15 mm and 0.15 mm for the X and Y axes, and 0.08° for rotational offset, respectively. Although some translational and rotational shift was seen at all gantry angles, these were relatively small correction factors, and when the garden fence test and nongap test were performed, these factors were used to evaluate the results relative to the beam central axis. EPID sag was reproducible over time and the correction factors would require only occasional checking.

Garden fence test

Figure 5 shows deviations from the planned position at all four gantry angles when the center of the slit field ranged from –10 cm to 10 cm with an interval of 2 cm.

For each angle, deviation from the planned nominal MLC location was <1 mm, and thus within the tolerance level of SMLC advocated by Palta and others [20]. Average deviations calculated from each error of all leaf positions for the gantry angles of 0, 90, 180 and 270° were –0.04 mm, 0.24 mm, 0.11 mm and –0.20 mm, respectively. Compared with gantry angle 0° (–0.04 mm), orientation with gantry angle 90° (0.24 mm) and 270° (–0.20 mm) was toward the positive for gantry angle 90° and toward the negative for gantry angle 270°. Although these results were identical with the gravity effect ($P < 0.01$), the amount of deviation at gantry angle 180° was markedly small (0.11 mm), the difference was nevertheless significant ($P < 0.01$). Figure 6 shows average deviations from the planned MLC location for every gantry angle on testing once per week over 1 month. The data at the initial week was the same as that of Fig. 5. Although results for the second and subsequent measurements showed significant differences in the degree of deviation except for the data of the second week at gantry angles 180 and 270°, these were



Translational offset at 4 gantry angles

Rotational offset at 4 gantry angles

Fig. 4. Translational offset and rotational offset for four gantry angles over 1 month. The X axis is measured in weeks. (**A**) Translational offset in mm for both X and Y axes at four gantry angles of 0, 90, 180 and 270°. (**B**) Rotational offset in degree at four gantry angles of 0, 90, 180 and 270°.