wurden die Auswirkungen von Veränderungen in der japanischen Gesundheitsfürsorge-Politik auf die Strahlungstherapie-Struktur untersucht.

Material und Methodik: Die Japanische Gesellschaft für radiologische Therapie und Onkologie hat eine Erhebung zur nationalen Struktur der Strahlungsonkologie im Jahr 2007 durchgeführt. Dabei wurden die Strukturen von 349 auf Krebsbehandlung spezialisierten Krankenhäusern und 372 anderen Strahlentherapie-Einrichtungen verglichen.

Ergebnisse: Die jeweiligen Ergebnisse in Bezug auf die Ausrüstung und das Personal in den auf Krebsbehandlung spezialisierten Krankenhäusern und anderen Einrichtungen waren: Linearbeschleuniger pro Einrichtung: 1,3 bzw. 1,0; jährliche Patientenzahl pro Linearbeschleuniger: 296,5 bzw. 175,0. Das jährliche Patientenaufkommen pro Vollzeitäquivalent-Radioonkologe betrug 237,0 bzw. 273,3. In geografischer Hinsicht stand die Anzahl der auf Krebsbehandlung spezialisierten Krankenhäuser in Relation zur Bevölkerungszahl.

Schlussfolgerung: Die Struktur der Radioonkologie in Japan war, was die Ausrüstung und insbesondere die auf Krebsbehandlung spezialisierten Krankenhäuser betrifft, ebenso ausgereift wie oder ausgereifter als in europäischen Ländern und in den Vereinigten Staaten, obwohl die medizinischen Kosten im Verhältnis zum BIP in Japan geringer sind. Es besteht weiterhin ein Mangel an Arbeitskräften. Die Erhebungsdaten haben sich als bedeutsam für ein umfassendes Verständnis des Radioonkologie-Krankenpflegesystems in Japan erwiesen.

Schlüsselwörter: **Strukturerhebung · Strahlentherapie-Einrichtung · Strahlentherapie-Personal · Strahlentherapie-Ausrüstung · Patientenaufkommen · Medizinisches Versorgungssystem**

Introduction

In developed countries in Europe, such as France, Germany, Italy, and the UK, as well as in the United States, the rates of radiotherapy use for cancer treatment are as high as 50% or more because there are sufficient radiotherapy facilities and personnel, such as radiation oncologists (ROs), medical physicists (MPs), and radiotherapy technologists (RTTs) [1, 2, 5, 11]. On the other hand, the current utilization rate of radiotherapy for new cancer patients in Japan is only 26.1% [19] and surgery is still predominant. In Japan, the Cancer Control Act has been implemented since 2007 in response to patients' urgent petitions to the government [8]. This law strongly advocates the promotion of radiotherapy. At the same time, the Ministry of Health, Labor, 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 between regional cancer care hospitals [3, 9, 13]. The Japanese Society of Therapeutic Radiology and Oncology (JASTRO) has conducted national structure surveys of radiotherapy facilities in Japan every 2 years since 1990 [18, 19]. 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 radiotherapy.

In this study, the recent structure of radiation oncology in Japan was analyzed with special reference to DCCHs in terms of equipment, personnel, patient load, and geographic distribution. The effect of changes in the cancer care policy by the Japanese government on radiotherapy structure was also investigated. Furthermore, the medical care situation in Japan was compared with European countries and the United States.

Materials and Methods

JASTRO carried out a national structure survey of radiation oncology in 2007 by administering a questionnaire in 2008 [19]. The questionnaire consisted of items related to 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. A response was received from 721 of 765 (94.2%) radiotherapy facilities in Japan. There were 377 DCCHs facilities by the end of fiscal year 2009. The surveys were not returned by 16 facilities, and 13 facilities did not have departments of radiotherapy at the time of the survey. Thus, the structures of 349 DCCHs and 372 other radiotherapy facilities were analyzed. In this survey, full-time equivalent (FTE) (40 hours/week only for radiation oncology service) data were surveyed depending on clinical working hours for radiotherapy of each staff. SAS® 8.02 (SAS Institute Inc., Cary, NC, USA) [12] was used for the statistical analysis. The statistical significance was tested by means of the X^2 test, Student's t test, or analysis of variance (ANOVA).

The Japanese Blue Book Guidelines (JBBG) [6, 7] 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) [15, 17] data.

Results

Current Situation of Radiation Oncology

Table 1 shows the current situation of radiation oncology in Japan. The numbers of new patients and total patients in all radiotherapy facilities in Japan were estimated at approximately 181,000 (170,229 × 765/721) and 218,000 (205,087 × 765/721), respectively. For DCCHs, the corresponding numbers were approximately 117,000 (112,101 × 364/349) and 141,000 (135,383 × 364/349). The number of patients in DCCHs, thus, accounted for approximately 65% of the number of patients, both new and total (117,000/181,000 and 141,000/218,000), in all radiotherapy facilities. The average numbers of new patients/facility were 321.2 for DCCHs and 156.3 for the other radiotherapy facilities, and for the average numbers of total

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

Tabelle 1. Anzahl neuer Patienten und aller Patienten (neu plus wiedereingeliefert), die der Strahlentherapie bedürfen, in auf Krebsbehandlung spezialisierten Krankenhäusern und anderen Strahlentherapie-Einrichtungen.

	Designated cancer care hospitals	Others	Total
Facilities	349	372	721
New patients	112,101[a]	58,128	170,229[b]
Average no. new patients/facility	321.2	156.3	236.1
Total patients (new + repeat)	135,383[a]	69,704	205,087[b]
Average no. total patients/facility	387.9	187.4	284.4

[a] Since the number of designated cancer care hospitals with RT was 364, the number of new patients in designated cancer care hospitals was estimated at approximately 117,000 (112,101 × 364/349), and the corresponding number of total patients (new plus repeat) at approximately 141,000 (135,383 × 364/349).

[b] Since the number of radiotherapy facilities was 765 in 2007, the number of new patients was estimated at approximately 181,000 (170,229 × 765/721), and the corresponding number of total patients (new plus repeat) at approximately 218,000 (205,087 × 765/721).

patients/facility, the corresponding figures were 387.9 and 187.4, respectively.

Facility and Equipment Patterns and Patient Load/Linac

The radiotherapy equipment patterns and related functions in Japan are shown in Table 2. In DCCHs, 453 linacs and 103 ^{192}Ir RALSs were in current use, while the corresponding data for the other radiotherapy facilities were 354 and 20, respectively. The rate of ownership of equipment at DCCHs was significantly higher than at the other radiotherapy facilities. As for the linac system in DCCHs, the dual-energy function was used in 339 units (74.8%), the three-dimensional conformal radiotherapy (3D-CRT) function in 341 (75.3%), and the IMRT function in 165 (36.4%). For the other radiotherapy facilities, the corresponding figures were 200 (56.5%), 214 (60.5%), and 70 (19.8%). The respective patient load/linac was 296.5 at DCCHs and 175.0 at the other radiotherapy facilities. The distribution of annual patient load/linac in Japan is shown in Figure 1a. The patient load at 20% of DCCHs and 6% of the other radiotherapy hospitals exceeded the JBBG warning level of 400 patients/linac. However, the average patient load/linac at the other facilities was below the guideline level. Compared with the data for 2005 [3], the rate of linac ownership and rate of installation of the various functions (dual-energy, 3DCRT, and IMRT function) in linac increased by 1.7%, 1.7%, 7.8%, and 6.4%, respectively at DCCHs. At the other radiotherapy facilities, these rates increased as well and the corresponding percentages were 1.7%, 0.2%, 7.8%, and 5.9%.

The patterns for radiotherapy planning systems (RTPs) and other equipment are shown in Table 2. X-ray simulators were installed in 69.3% of the DCCHs and in 53.0% of the other radiotherapy facilities, CT simulators in 75.7% and 56.7%, and RTPs in 96.8% and 93.8%, respectively. 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 2005 [3], X-ray simulator ownership decreased by 9.8%, while CT simulator and RTP ownership increased by 11.8% and 0.5%, respectively, at DCCHs, while

Table 2. Items of equipment, their function and patient load per unit of equipment in designated cancer care hospitals and other hospitals. Linac: Linear accelerator; IMRT: intensity-modulated radiotherapy; RALS: remote-controlled afterloading system; CT: computed tomography; 3D-CRT: three-dimensional conformal radiotherapy; RTP: radiotherapy planning.

Tabelle 2. Bestrahlungsgeräte, deren Funktion und Patientenaufkommen pro Gerät in auf Krebsbehandlung spezialisierten Krankenhäusern und anderen Strahlentherapie-Einrichtungen. Linac: Linear accelerator; IMRT: intensity-modulated radiotherapy; RALS: remote-controlled afterloading system; CT: computed tomography; 3D-CRT: three-dimensional conformal radiotherapy; RTP: radiotherapy planning.

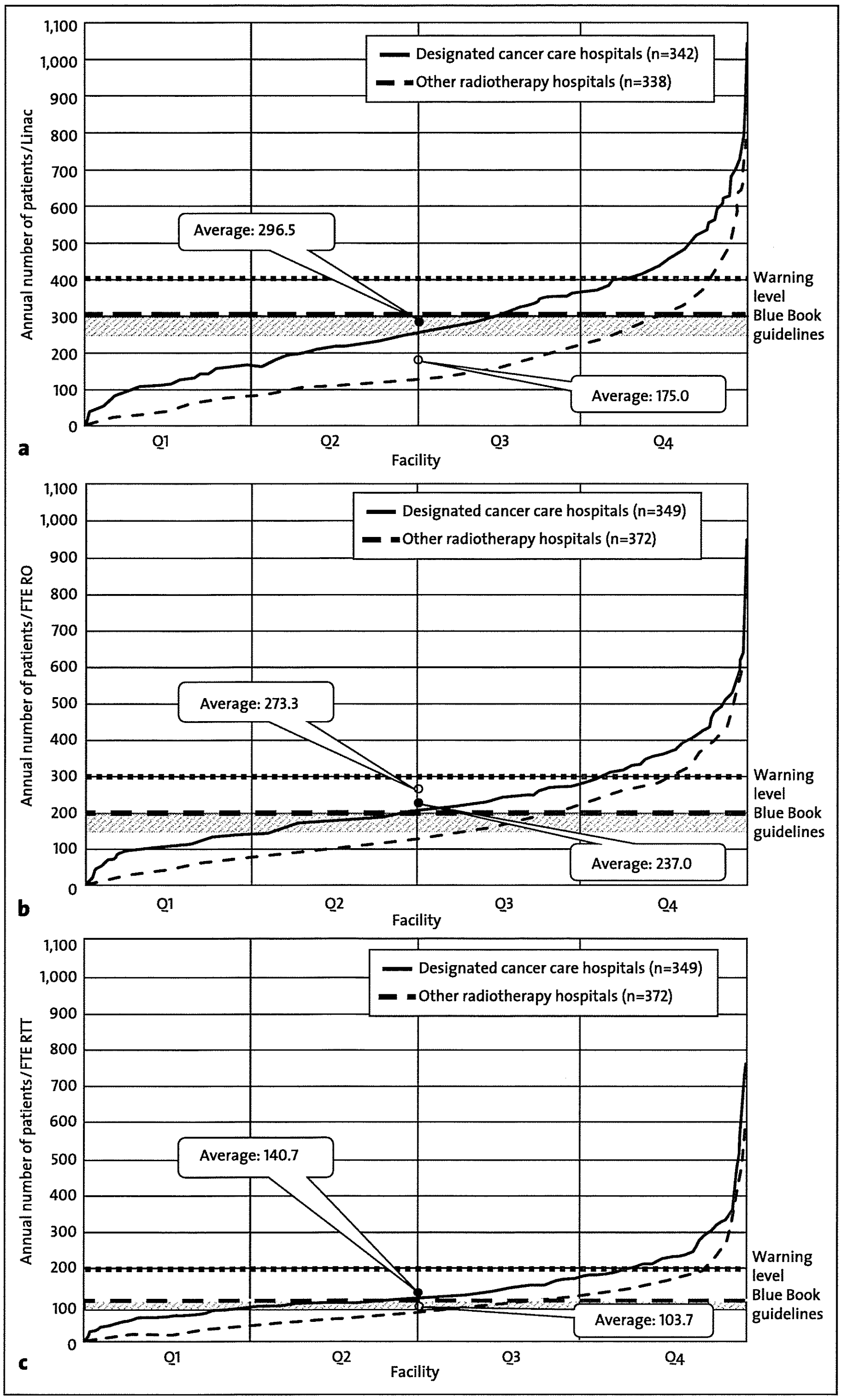
	Designated cancer care hospitals (n = 349)		Comparison with 2005	Others (n = 372)		Comparison with 2005	Total (n = 721)	
	n	%	%	n	%	%	n	%
Linac	453	98.0[a]	1.7[c]	354	90.9[a]	1.0[c]	807	94.3[a]
with dual energy function	339	74.8[b]	1.7[c]	200	56.5[b]	0.2[c]	539	66.8[b]
with 3D-CRT function (MLC width ≤1.0 cm)	341	75.3[b]	7.8[c]	214	60.5[b]	7.8[c]	555	68.8[b]
with IMRT function	165	36.4[b]	6.4[c]	70	19.8[b]	5.9[c]	235	29.1[b]
Average no. linac/facility	1.3	–	–	1.0	–	–	1.1	–
Annual no. patients/linac	296.5[d]	–	–	175.0[d]	–	–	243.2[d]	–
^{192}Ir RALS (current use)	103	29.5[a]	–	20	5.4[a]	–	127.0	17.1[a]
X-ray simulator	246	69.3[a]	–9.8[c]	199	53.0[a]	–8.7[c]	445	60.9[a]
CT simulator	277	75.1[a]	11.8[c]	220	56.7[a]	8.3[c]	497	65.6[a]
RTP computer	630	96.8[a]	0.5[c]	440	93.8[a]	3.4[c]	1,070	95.3[a]

[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 2005, calculated with the formula: *data of 2007* (%) – *data of 2005* (%)

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



Figures 1a to 1c. a Distribution of annual patient load/linear accelerator at designated cancer care hospitals and other radiotherapy facilities. Horizontal axis represents facilities arranged in order of increase in annual number of patients/treatment equipment within facilities. **b** Distribution of annual patient load/FTE RO at designated cancer care hospitals and other radiotherapy facilities. Horizontal axis represents facilities arranged in order of increase in annual number of patients/FTE RO within facilities. The number of FTE RO for facilities with FTE <1 was calculated as FTE =1 to avoid overestimating patient load/FTE RO. **c** Distribution of annual patient load/RTT at designated cancer care hospitals and other radiotherapy hospitals. Horizontal axis represents facilities arranged in order of increase in annual number of patients/RTT within facilities. The number of FTE RTT for facilities with FTE <1 was calculated as FTE =1 to avoid overestimating patient load/FTE RTT. Q1: 0–25%; Q2: 26–50%; Q3: 51–75%; Q4: 76–100%.

Abbildungen 1a bis 1c. a) Verteilung des jährlichen Patientenaufkommens pro Linearbeschleuniger in auf Krebsbehandlung spezialisierten Krankenhäusern und anderen Strahlentherapie-Einrichtungen. Die horizontale Achse stellt die Einrichtungen dar, die nach der jährlichen Anzahl der Patienten pro Behandlungsgerät innerhalb der Einrichtungen in aufsteigender Reihenfolge angeordnet wurden. **b)** Verteilung des jährlichen Patientenaufkommens pro Vollzeitäquivalent-Radioonkologe in auf Krebsbehandlung spezialisierten Krankenhäusern und anderen Strahlentherapie-Einrichtungen. Die horizontale Achse stellt die Einrichtungen dar, die in aufsteigender Reihenfolge nach der jährlichen Anzahl der Patienten pro Vollzeitäquivalent-Radioonkologe innerhalb der Einrichtungen angeordnet wurden. Bei Einrichtungen mit Vollzeitäquivalent <1 wurde die Anzahl der Vollzeitäquivalent-Radioonkologen mit Vollzeitäquivalent =1 berechnet, um eine Überschätzung des Patientenaufkommens pro Vollzeitäquivalent-Radioonkologe zu vermeiden. **c)** Verteilung des jährlichen Patientenaufkommens pro Strahlentherapie-MTA in auf Krebsbehandlung spezialisierten Krankenhäusern und anderen Strahlentherapie-Krankenhäusern. Die horizontale Achse stellt die Einrichtungen dar, die in aufsteigender Reihenfolge nach der jährlichen Anzahl der Patienten pro Strahlentherapie-MTA innerhalb der Einrichtungen angeordnet wurden. Bei Einrichtungen mit Vollzeitäquivalent <1 wurde die Anzahl der Vollzeitäquivalent- Strahlentherapie-MTAs mit Vollzeitäquivalent =1 berechnet, um eine Überschätzung des Patientenaufkommens pro Vollzeitäquivalent- Strahlentherapie-MTA zu vermeiden. Q1: 0–25%; Q2: 26–50%; Q3: 51–75%; Q4: 76–100%.

at the other radiotherapy facilities X-ray simulator ownership decreased by 8.7% and CT simulator and RTP ownership increased by 8.3% and 3.4%, respectively.

Staffing Patterns and Patient Loads

Staffing patterns and patient loads in Japan are detailed in Table 3. The total numbers of FTE ROs were 571.3 for DCCHs

Table 3. Structure and personnel of designated cancer care hospitals and other hospitals. RT: radiotherapy; RO: radiation oncologist; FTE: full-time equivalent (40 hours/week only for RT practice); JASTRO: Japanese Society of Therapeutic Radiology and Oncology.

Tabelle 3. Struktur und Personal von auf Krebsbehandlung spezialisierten Krankenhäusern und anderen Strahlentherapie-Einrichtungen. RT: radiotherapy; RO: radiation oncologist; FTE: full-time equivalent (40 hours/week only for RT practice); JASTRO: Japanese Society of Therapeutic Radiology and Oncology.

	Designated cancer care hospitals (n = 349)	Comparison with 2005 (%)	Others (n = 372)	Comparison with 2005 (%)	Total (n = 721)
Facilities with RT bed	171	–	110	–	281 (39.0)
Average no. RT bed/facility	4.3	–	2.0	–	3.1
Total (full + part-time) RO FTE	571.3	21.2[a]	255.0	–15.9[a]	826.3
Average no. FTE ROs/facility	1.6	14.3[a]	0.7	–22.2[a]	1.1
JASTRO-certified RO (full-time)	378	29.0[a]	99	–25.6[a]	477
Average no. JASTRO-certified ROs/facility	1.1	22.2[a]	0.3	–25.0[a]	0.7
Patient load/FTE RO	237.0	–5.8[a]	273.3	14.1*	248.2
Total (full + part-time) RT technologist FTE	962.2	–	671.9	–	1634.1
Average no. FTE RT technologists/facility	2.8	–	1.8	–	2.3
Patient load/FTE RT technologist	140.7	–	103.7	–	125.5
Total (full + part-time) medical physicist FTE	42.0	–	26.4	–	68.4
Total (full + part-time) RT nurse FTE	304.3	–	190.1	–	494.4

[a] Rate of increase compared with the data of 2005, calculated with the formula: $\frac{\text{data of 2007 (n)} - \text{data of 2005 (n)}}{\text{data of 2005 (n)}} \quad 100\,(\%)$

and 255.0 for the other radiotherapy facilities, while the corresponding average numbers of FTE ROs/facility were 1.6 and 0.7 and the numbers for the patient load/FTE RO 237.0 and 273.3. The distribution of annual patient load/FTE RO in Japan is illustrated in Figure 1b. More than 300 patients/RO (JBBG warning level) were treated in 22% of DCCHs and in 11% of the other facilities. In Figure 2a, the percentage of distribution of facilities by patient load/FTE RO is shown. The largest number of facilities featured a patient/FTE RO level in the 150–199 range for DCCHs and in the 100–149 range for the other radiotherapy facilities. The facilities which have less than 1 FTE RO still account for about 37.2% of DCCHs and 73.9% of the other radiotherapy facilities. In DCCHs, the average numbers of FTE ROs/facility and full-time JASTRO-certified ROs/facility increased by 14.3% and 22.2%, respectively, compared with 2005 data. In other radiotherapy facilities, however, those numbers decreased by 22.2% and 25.0%. The annual patient load/FTE RO decreased by 5.8% in DCCHs and increased by 14.1% in other radiotherapy facilities.

The total numbers of FTE RTTs were 962.2 for DCCHs and 671.9 for the other radiotherapy facilities, and the average numbers per facility were 2.8 and 1.8, respectively. The patient loads/FTE RTT were 140.7 and 103.7, respectively. The distribution of annual patient load/FTE RTT in Japan is shown in Figure 1c. More than 200 patients/RTT (JBBG warning level) were treated in 18% of DCCHs and in 8% of the other radiotherapy facilities, while Figure 2b shows the percentage of distribution of facilities by patient load/FTE RTT. The largest number of facilities featured a patient/FTE RTT level in the 100–119 range for DCCHs and in the 60–89 range for the other radiotherapy facilities. The total numbers of FTE MPs and FTE radiotherapy nurses were 42.0 and 304.3 for DCCHs and 26.4 and 190.1 for the other radiotherapy facilities.

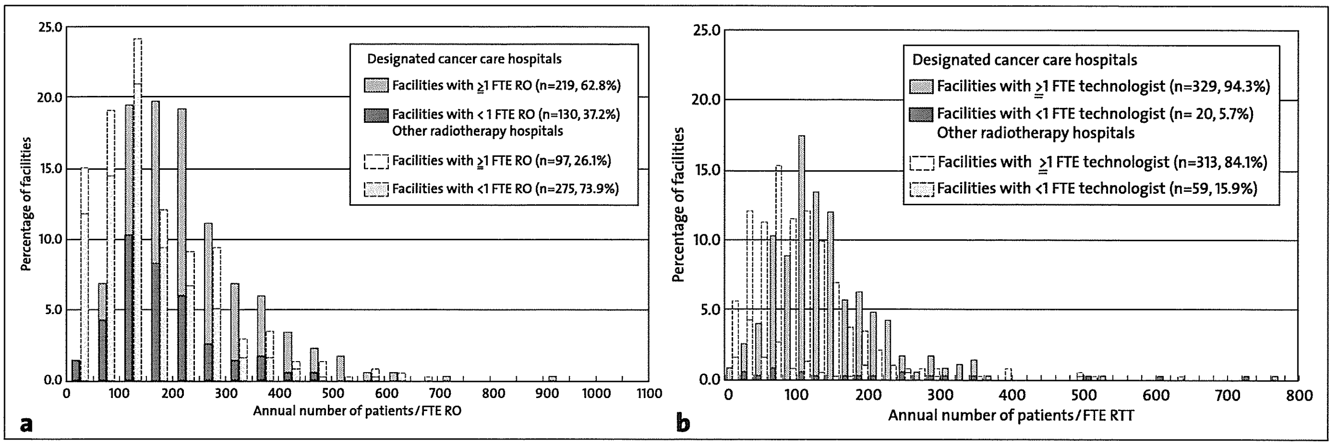
Geographic Patterns

Figure 3 shows the geographic distribution for 47 prefectures of a number of radiotherapy facilities arranged in order of increasing population for all prefectures in Japan [14]. There were significant differences in the average number of facilities per quarter for both all radiotherapy facilities and DCCHs (both: $p<0.0001$). The numbers of all radiotherapy facilities and DCCHs were strongly associated with population size (respective correlation coefficients: 0.95 and 0.82).

Discussion

The utilization rate of radiotherapy for new cancer patients in Japan is less than a half of that for developed countries in Europe, such as France, Germany, Italy, and UK, as well as for the United States. Radiotherapy is expected to play an increasingly important role in Japan because the increase in the elderly population is the highest among developed countries. In Japan, the majority of facilities still rely on part-time ROs, especially in facilities other than DCCHs. The percentage distribution of facilities by patient load/RO in DCCHs proved to be largely similar to that of the United States in 1989 [16]. However, the facilities which have less than one FTE RO still account for about 37% of DCCHs in Japan. In European countries and the United States, on the other hand, most facilities have a full-time RO.

On a regional basis, the results of this study proved that DCCHs were in appropriate locations. In the 2005 survey [9], there were not enough DCCHs in some regions with a large population because many university facilities were not



Figures 2a and 2b. a Percentage of facilities by patient load/FTE RO for designated cancer care hospitals and other radiotherapy hospitals. Each bar represents an interval of 50 patients per FTE RO. The number of FTE ROs for facilities with FTE <1 was calculated as FTE =1 to avoid overestimating patient load/FTE RO. **b** Percentage of facilities by patient load/FTE RTT for designated cancer care hospitals and other radiotherapy hospitals. Each bar represents an interval of 20 patients per FTE staff. The number of FTE RTTs for facilities with FTE <1 was calculated as FTE =1 to avoid overestimating patient load/FTE RTT.

Abbildungen 2a und 2b. a Prozentsatz der Einrichtungen nach Patientenaufkommen pro Vollzeitäquivalent-Radioonkologe bei auf Krebsbehandlung spezialisierten Krankenhäusern und anderen Strahlentherapie-Krankenhäusern. Jeder Balken stellt ein Intervall von 50 Patienten pro Vollzeitäquivalent-Radioonkologe dar. Bei Einrichtungen mit Vollzeitäquivalent <1 wurde die Anzahl der Vollzeitäquivalent-Radioonkologen mit Vollzeitäquivalent =1 berechnet, um eine Überschätzung des Patientenaufkommens pro Vollzeitäquivalent-Radioonkologe zu vermeiden. **b** Prozentsatz der Einrichtungen nach Patientenaufkommen pro Vollzeitäquivalent-Strahlentherapie-MTA bei auf Krebsbehandlung spezialisierten Krankenhäusern und anderen Strahlentherapie-Krankenhäusern. Jeder Balken stellt ein Intervall von 20 Patienten pro Vollzeitäquivalent-Mitarbeiter dar. Bei Einrichtungen mit Vollzeitäquivalent <1 wurde die Anzahl der Vollzeitäquivalent-Strahlentherapie-MTAs mit Vollzeitäquivalent =1 berechnet, um eine Überschätzung des Patientenaufkommens pro Vollzeitäquivalent-Strahlentherapie-MTA zu vermeiden.

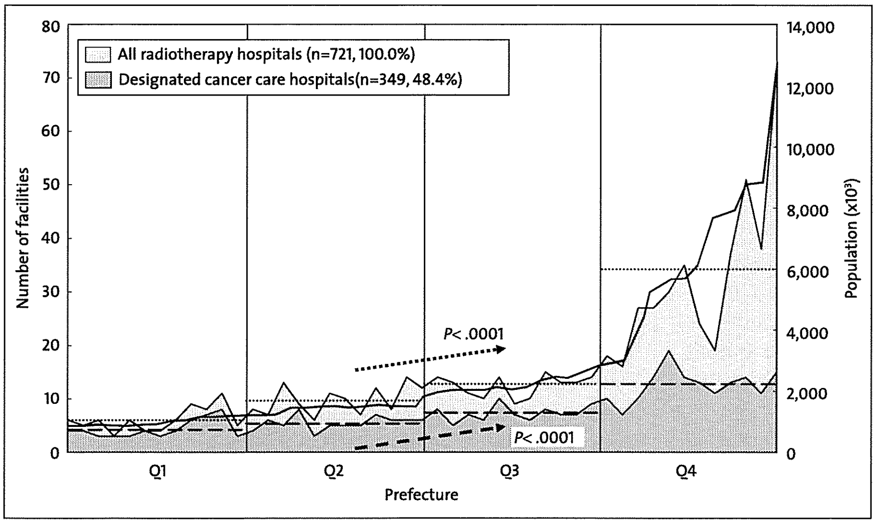


Figure 3. Geographic distribution for 47 prefectures of the number of facilities arranged in order of increase in population. The dotted line shows the average number of facilities of the prefectures per quarter for all radiotherapy hospitals and the dashed line shows the average number for designated cancer care hospitals. Q1: 0–25%; Q2: 26–50%; Q3: 51–75%; Q4: 76–100%.

Abbildung 3. Geografische Verteilung der Anzahl der Einrichtungen in 47 Präfekturen, geordnet in aufsteigender Reihenfolge nach der Bevölkerungszahl. Die gepunktete Linie zeigt die durchschnittliche Anzahl der Einrichtungen der Präfekturen pro Viertel für alle Strahlentherapie-Krankenhäuser, und die gestrichelte Line zeigt die durchschnittliche Anzahl für auf Krebsbehandlung spezialisierte Krankenhäuser. Q1: 0–25%; Q2: 26–50%; Q3: 51–75%; Q4: 76–100%.

certified as DCCHs by the Ministry of Health, Labor, and Welfare. The findings of the current survey show that some university facilities with many patients undergoing radiotherapy were certified as DCCHs. There are, thus, enough radiotherapy facilities in Japan with a nationwide distribution. The medical situation in Japan is susceptible to the effect of measures taken by local governments. Current radiotherapy potential in radiotherapy facilities other than DCCHs in Japan is underutilized because of personnel shortages.

In Japan, a new educational system is being developed to train specialists for cancer care, including ROs, MPs, medical oncologists, oncology nurses, and palliative care doctors. Although the numbers of ROs in DCCHs have increased, the numbers in the other radiotherapy hospitals have decreased. In Japan, many radiotherapy hospitals do not even have their own department of radiotherapy, while we are of the opinion that all radiotherapy hospitals, whether designated or not, need to have

Table 4. Structural features and personnel related to radiation oncology in developed countries and cost adapted from the Directory of Radiotherapy Centers of the International Atomic Energy Agency [4]. RO: radiation oncologist; GDP: Gross Domestic Product.

Tabelle 4. Strukturmerkmale und Personal im Bereich Radioonkologie in entwickelten Ländern und Kosten nach dem Strahlentherapiezentren-Verzeichnis der Internationalen Atomenergie-Organisation [4]. RO: radiation oncologist; GDP: Gross Domestic Product.

Country	RT facilities	ROs	Medical physicists	Population (million)[a]	Facilities/ Population	RO/ Population	Medical physicists/ Population	Medical costs of GDP (%)[b]
Germany	219	835	626	82.7	2.6	10.1	7.6	10.4
Italy	151	839	392	58.2	2.6	14.4	6.7	8.7
France	186	574	267	60.9	3.1	9.4	4.4	11.0
USA	2,514	2,943	1,879	303.9	8.3	9.7	6.2	16.0
Japan[c]	721	826.3[d]	68.4[d]	128.3	5.6	6.4	0.5	8.1

[a] Based on Demographic Yearbook of United Nations [20].

[b] Based on Demographic OECD Health Data 2009 [10].

[c] Based on JASTRO structure survey 2007.

[d] These data are expressed as full-time equivalent. Most ROs or other oncologists at academic facilities work part-time at affiliated hospitals. Therefore, the total numbers of ROs does not reflect the actual structure of radiation oncology personnel in Japan.

their own department of radiotherapy. It was found that MPs work mainly in metropolitan areas or academic facilities, such as university hospitals or cancer centers. At present, there is no national license 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). The number of RTTs is more satisfactory that that of ROs and MPs, but RTTs are extremely busy because they are also partially act as MPs in Japan. The average number of radiotherapy staff members in DCCHs was greater than that in the other radiotherapy hospitals. Equipment ownership in the other radiotherapy facilities increased compared with 2005, being more firmly established in DCCHs than in the other radiotherapy hospitals. Therefore, the accreditation of DCCHs is closely correlated 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 for the geographical consolidation of radiotherapy facilities in Japan.

The Directory of Radiotherapy Centers of the International Atomic Energy Agency has disclosed the member countries' data for the structure of radiation oncology [4]. Table 4 shows the data for the structure of radiation oncology in Japan, Germany, Italy, France, and the United States. The numbers of ROs and MPs per million population in Japan (6.4 and 0.5) are smaller than in France (9.4 and 4.4), Germany (10.1 and 7.6), and Italy (14.4 and 6.7). However, the number of radiotherapy facilities per million population in Japan (5.6) is larger than in France (3.1), Germany (2.6), and Italy (2.6). As for the United States, the numbers of ROs, MPs, and radiotherapy facilities per million population (9.7, 6.2, and 8.3) are all larger than in Japan. These findings do not necessarily mean that the medical care system in Japan is inferior. Even though the medical costs in relation to GDP [10] in Japan are the lowest among the aforementioned five countries, the outcome of cancer treatment in Japan is the same or better than in the other developed countries.

To evaluate medical care systems for cancer at regular intervals, it is very important to collect detailed information for all cancer care facilities. In Japan, JASTRO regularly surveys the structural information for all radiotherapy facilities and PCS has been conducted every 4 years to investigate the processes and outcomes of cancer care using radiotherapy. However, the collection of outcome information is insufficient. In the United States, a National Cancer Data Base was established and has been collecting the data for approximately 75% of cancer patients. This database is used as the quality indicator for improvements in the processes and outcomes of cancer care. We have recently established a Japanese National Cancer Database based on the radiotherapy data, and we are preparing to collect cancer care data with this system.

Conclusion

The structure of radiation oncology in DCCHs in Japan showed more maturity than that of other facilities in terms of equipment, functions, and staff. However, there is still a shortage of manpower. The survey data presented and discussed here are important and fundamental for clearly understanding the medical care system of radiation oncology in Japan. As the survey data make clear, a national policy is needed to solve the problem of the establishment of DCCHs and the shortage of manpower for cancer care.

Acknowledgments

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CLINICAL INVESTIGATION **Education and Training**

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.

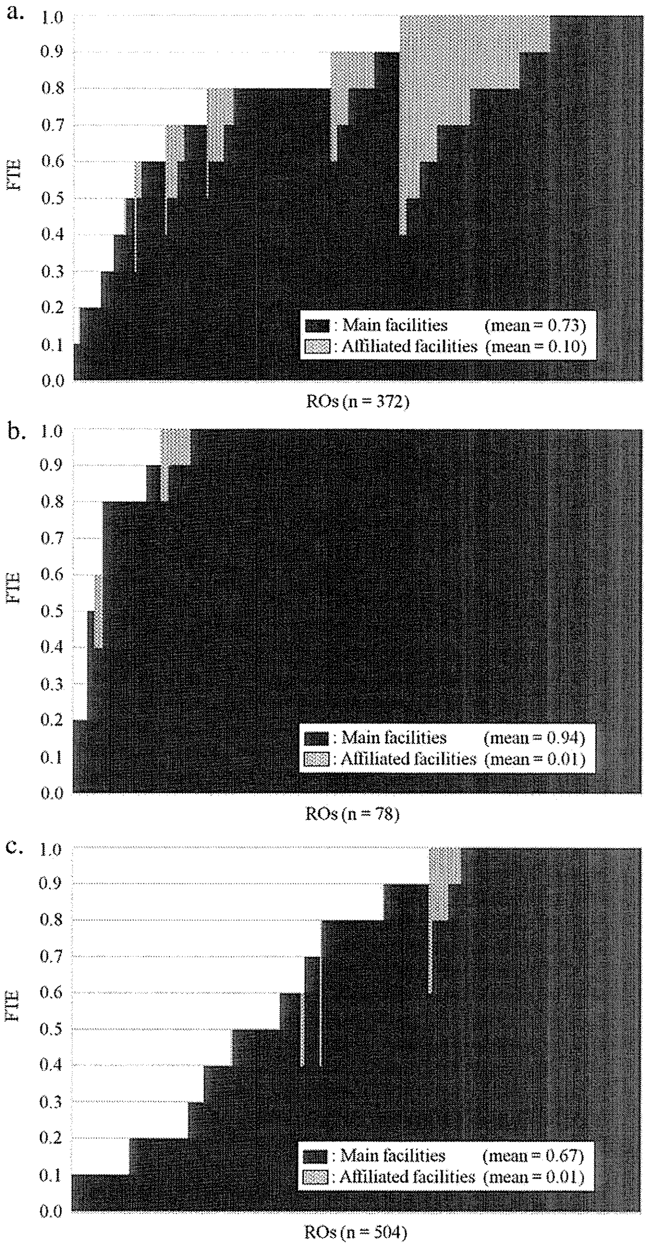

Fig. 1. Working patterns of ROs working mainly at (a) university hospitals, (b) cancer centers, and (c) other radiotherapy hospitals. Distribution of FTE ratio between main and affiliated facilities on each RO. Horizontal axis represents ROs in ascending order of own total FTE. *Abbreviations:* RO = 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

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,

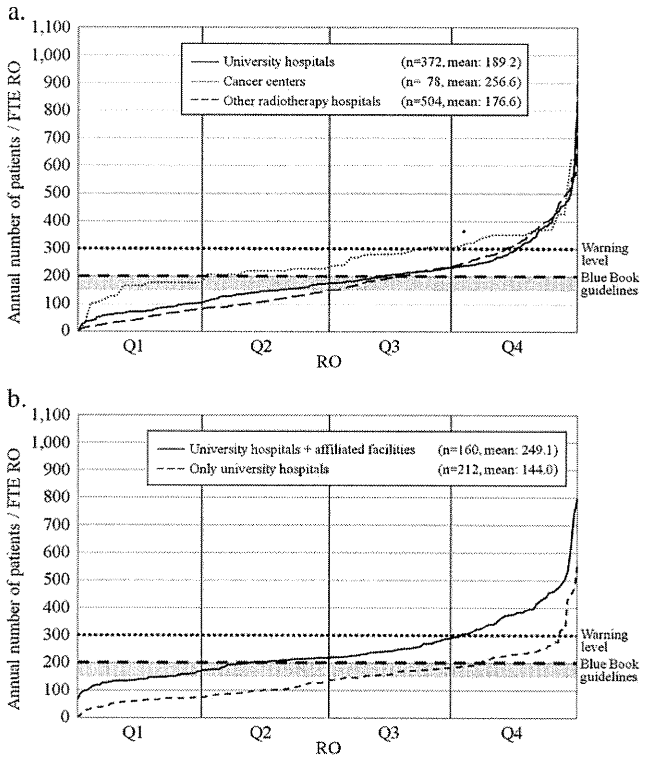

Fig. 2. Distribution of annual patient load/RO. (a) RO working mainly in university hospitals, cancer centers, and other radiotherapy hospitals. (b) RO working mainly in university hospitals. Horizontal axis represents ROs in ascending order of annual numbers of patients/RO. Q1: 0–25%, Q2: 26–50%, Q3: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

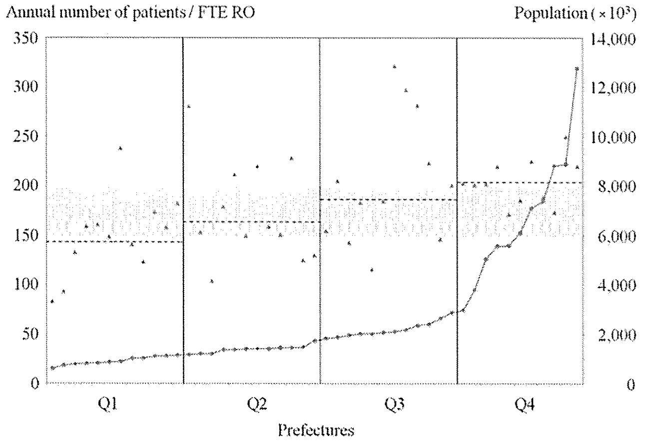

Fig. 3. Geographic distribution for 47 prefectures of annual number of patients (new plus repeat) per RO in ascending order of prefectural population. Q1: 0–25%; Q2: 26–50%; Q3: 51–75%; Q4: 76–100%. Triangles represent average annual number of patients per RO for each prefecture. Blue circles show prefectural 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

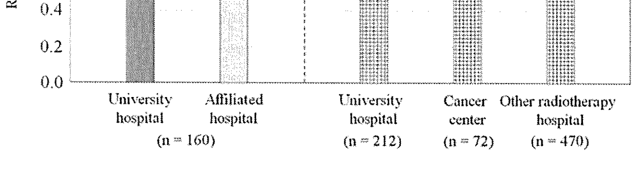

Fig. 5. Relative practice index for patients of ROs. (a) Relative practice index for patients in university hospitals and affiliated hospitals (targeted ROs were working mainly in university hospitals and part-time in affiliated hospitals). (b) Relative practice index for patients in university hospitals, 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 ($n = 1, 2, 3, \ldots, k$). 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.

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Respiratory monitoring with an acceleration sensor

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Abstract

Respiratory gating radiotherapy is used to irradiate a local area and to reduce normal tissue toxicity. There are certain methods for the detection of tumor motions, for example, using internal markers or an external respiration signal. However, because some of these respiratory monitoring systems require special or expensive equipment, respiratory monitoring can usually be performed only in limited facilities. In this study, the feasibility of using an acceleration sensor for respiratory monitoring was evaluated. The respiratory motion was represented by means of a platform and measured five times with the iPod touch® at 3, 4 and 5 s periods of five breathing cycles. For these three periods of the reference waveform, the absolute means ± standard deviation (SD) of displacement were 0.45 ± 0.34 mm, 0.33 ± 0.24 mm and 0.31 ± 0.23 mm, respectively. On the other hand, the corresponding absolute means ± SD for the periods were 0.04 ± 0.09 s, 0.04 ± 0.02 s and 0.06 ± 0.04 s. The accuracy of respiratory monitoring using the acceleration sensor was satisfactory in terms of the absolute means ± SD. Using the iPod touch® for respiratory monitoring does not need special equipment and makes respiratory monitoring easier. For these reasons, this system is a viable alternative to other respiratory monitoring systems.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Respiratory motion is one of the major causes of uncertainty in radiotherapy of lung or liver cancers. Respiration causes tumors in the thorax or abdomen to move during free breathing, so that in conventional radiotherapy large margins must be added to the clinical target volume to account for respiratory motion. As a result, an extensive planning target volume (PTV)

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is required to ensure dose delivery to the target, which means that the PTV includes excess normal tissue which leads to an increase in normal tissue toxicity. In order to compensate for these problems, respiratory gating radiotherapy and breath hold radiotherapy were developed (Vedam *et al* 2001, Ozhasoglu 2002). Gated radiotherapy, which uses a respiratory signal, irradiates only during a specific respiratory phase, while breath hold radiotherapy delivers only when the target breath hold level has been reached. With these methods, it is possible to irradiate a local area and to reduce usual tissue toxicity. However, the efficiency of these methods is determined by a patient's breathing stability and reproducibility, and previous studies have reported that free respiratory motion varies greatly from cycle to cycle and from patient to patient. Without any external intervention, therefore, patients cannot voluntarily maintain a stable breathing pattern and reproduce this pattern from day to day (Tobin *et al* 1983a, 1983b, Bruce 1996).

In order to use these methods effectively, it is necessary to deal with respiratory motion, which requires monitoring of tumor motion. This can be done by, for example, using internal fiducial markers (Shirato *et al* 2000, Shimizu *et al* 2001) or an external respiration signal and measuring changes in lung volume with a spirometer (Jonathan *et al* 2008, Zhang *et al* 2003). Fiducial markers are inserted near tumors and tracked during fluoroscopic imaging, which is useful for detecting tumor motions in real time. However, it is invasive and not easy to perform. Detection of an external respiration signal, on the other hand, is a non-invasive method and can be performed easily with, for example, the real-time position management (RPM) system (Varian Medical Systems, Palo Alto, CA) or the ExacTrac Gating/Novalis Gating system (BrainLAB AG, Feldkirchen, Germany). The RPM system is capable of tracking the vertical position of a pair of infrared reflective markers on a small lightweight marker block which is placed on a patient's thorax or abdomen. The patient views a reference waveform which is used for respiratory coaching and breathes in accordance with the waveform. This system has been most widely discussed in publications. The ExacTrac system uses external markers on the patient's skin for gating the radiation beam.

The respiratory training associated with these non-invasive methods for improving patients' breathing stability and reproducibility has been examined and proven to be effective (George *et al* 2006, Laura *et al* 2009, Masselli *et al* 2009). In these studies, the protocol of respiratory training was mainly based on monitoring of the patient's respiration and providing the patient with feedback. Respiratory monitoring was performed by measuring external or internal breathing signals such as thoracic–abdominal wall motion (e.g., with the RPM or ExacTrac system). However, because some of these respiratory monitoring systems require special or expensive equipment, respiratory monitoring can be performed only in limited facilities.

In this study, an acceleration sensor which is widely used in many engineering fields was used for respiratory monitoring. It is expected that respiratory monitoring can be performed easily with this sensor because of its low cost and universal availability. A respiratory monitoring system using this sensor was developed and its feasibility for respiratory monitoring evaluated.

2. Materials and methods

2.1. Acceleration sensor

In this study, the iPod touch® (Apple Inc., Cupertino, CA, USA) was used together with the LIS331DL acceleration sensor (ST Microelectronics, Geneva, Switzerland), which is a nano, low-power, digital output 3-axis linear accelerometer and continuously detects the gravity

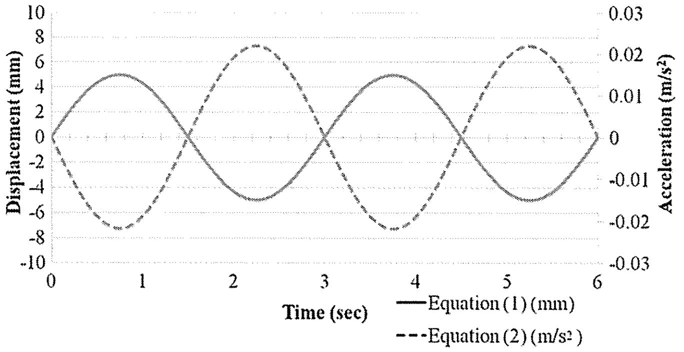

Figure 1. Graphical representation of equations (1) (solid line) and (2) (dashed line), where A is 5 mm and τ is 3 s.

acceleration. The detection sensitivity of this sensor is approximately 0.18 m s^{-2} for the three axes. There are two methods for measuring the position with the iPod touch®: (A) using variations in the acceleration, and (B) using the gradient of the iPod touch® using the gravity acceleration. Method (A) suggests that the position is detected by integrating twice and acquired. Generally, in the study with an acceleration sensor, method (A) is used. However, with method (A) it is difficult to measure respiratory motion because the LIS331DL acceleration sensor is not sensitive enough to detect the magnitude of respiratory motion. The reason for this can be shown logically as follows. Respiratory motion can be assumed to be a fixed periodical motion because a patient's respiratory motion patterns can vary in magnitude, period and regularity (Vedam *et al* 2003, Neicu *et al* 2006). In this study, the following mathematical model of the respiratory motion is assumed as

$$z(t) = A\sin(2\pi t/\tau), \tag{1}$$

where $z(t)$ is the respiratory motion at time t, A is the amplitude of the respiratory motion and τ is the period of the respiratory motion. When this equation is differentiated twice, the acceleration is obtained. The acceleration is written as

$$a(t) = -\frac{4\pi^2 A}{\tau^2}\sin\left(\frac{2\pi t}{\tau}\right), \tag{2}$$

where $a(t)$ is the acceleration at time t. Figure 1 is a graphical representation of equation (1) (solid line) and of equation (2) (dashed line) where A was 5 mm, and τ was 3 s. The maximum and minimum values of the acceleration were 0.02 and -0.02 m s^{-2}, respectively. These values suggest that sensitivity for an area sufficiently smaller than 0.02 m s^{-2} is necessary to detect the acceleration. However, because the sensitivity of the acceleration sensor used in our study is 0.18 m s^{-2}, it would be extremely difficult to measure the displacement of respiratory motion from the variation in the acceleration. On the other hand, method (B) can measure displacement of 2 mm or more by using 0.18 m s^{-2} sensitivity. For this reason, method (B) was used in this study.

2.2. Low-pass filter

Because the acceleration detected with the iPod touch® was very noisy, it was difficult to acquire a smooth respiratory waveform, so that we used a low-pass filter to reduce noise. This filter passes low-frequency signals but reduces the amplitude of high-frequency signals. The following shows a low-pass filter equation:

$$a_{l(n+1)} = a_{(n+1)} \times k + a_{l(n)} \times (1.0 - k), \tag{3}$$

where a_l is the acceleration after use of a low-pass filter, a is the acceleration measured with the iPod touch®, k is a coefficient which, in our case, was 0.1 and n is the total number of data sampled. A smoother waveform can be obtained by using a low-pass filter many times, but this is not a viable option because every time this filter is used, it weakens the signals and causes time delays. To decide the optimal frequency for using the low-pass filter, the effects of noise, weakened signals and time delays were evaluated.

First, to assess the effects of noise, the iPod touch® was placed on a flat surface and stationary. In theory, the acceleration is shown for the one axis (a_y) as 0 m s^{-2}. Because of the noise, however, accelerations did not show these values, so that the effects of the noise were evaluated under the following four conditions: (a) the low-pass filter was not used (no filtering), it was used (b) once (filtering once), (c) twice (filtering twice) and (d) thrice (filtering thrice). Accelerations were measured with the iPod touch® under each of these four conditions for a 30 s period. The range of noise variation was evaluated by using the mean acceleration ± standard deviation (SD) and the variation coefficient.

Second, weakening of signals and time delays were evaluated. For a logically consistent evaluation, equation (1) was adopted as the reference waveform, where A was kept constant at 5 mm, and τ was varied from 3 to 4 and 5 s. The conditions for assessment were the same as those for noise: (a) no filtering, (b) filtering once, (c) filtering twice and (d) filtering thrice. The waveform of 'no filtering' case is the reference one itself. Differences in the peak-to-peak displacement and time values between (a) and one of the remainders ((b), (c) and (d)) were calculated and assessed by using the absolute mean ± SD. The reference waveform was recorded at a rate of 60 Hz.

2.3. Detection procedure

The detection procedure system was developed with the iPhone software development kit. This kit is written in Objective-C and provides a variety of original applications. The actual acceleration was detected with UI Accelerometer class which is one of the functions in Objective-C and could detect the current acceleration instantaneously. Detected data were saved in iPod touch® and transmitted to the PC using original program. The accelerometer sampling rate was approximately 60 Hz. This sampling rate was limited by hardware and the created program. It was not uniform and occasionally the recording rate varied between 30 and 120 Hz. The rate of approximately 60 Hz was calculated from acquired data.

One of the three axes of the acceleration sensor was used to detect the magnitude. Figure 2 shows the schematic of this detection procedure, where g is the gravity acceleration (9.8 m s^{-2}), a_y, which detected as a function of θ, is y-axis acceleration, l is the length of an acrylic plate (the iPod touch® is placed on this plate) and h, which is calculated from θ, is the magnitude of respiratory motion. Equations are written as

$$a_y = g \times \sin\theta \tag{4}$$

$$h = l \times \sin\theta \tag{5}$$

$$h = l/g \times a_y, \tag{6}$$

where equation (6) is calculated from (4) and (5). This equation suggests that h is proportional to a_y. The magnitude was not produced by integrating the acceleration twice in this study. The

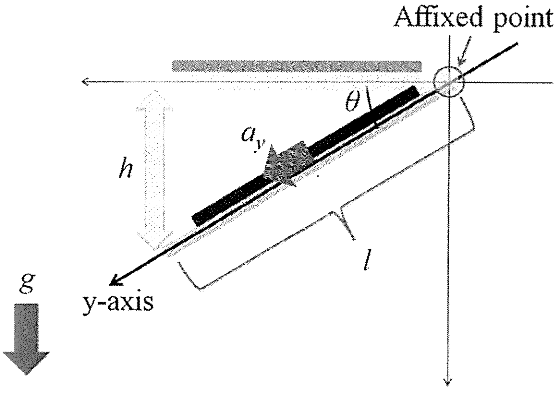

Figure 2. Procedure for detection of the magnitude of the gradient; g is the gravity acceleration (9.8 m s^{-2}), a_y, detected as a function of θ, is y-axis acceleration, l is the length of the acrylic plate (the iPod touch® was placed on this plate) and h, which is calculated from θ, is the magnitude of respiratory motion.

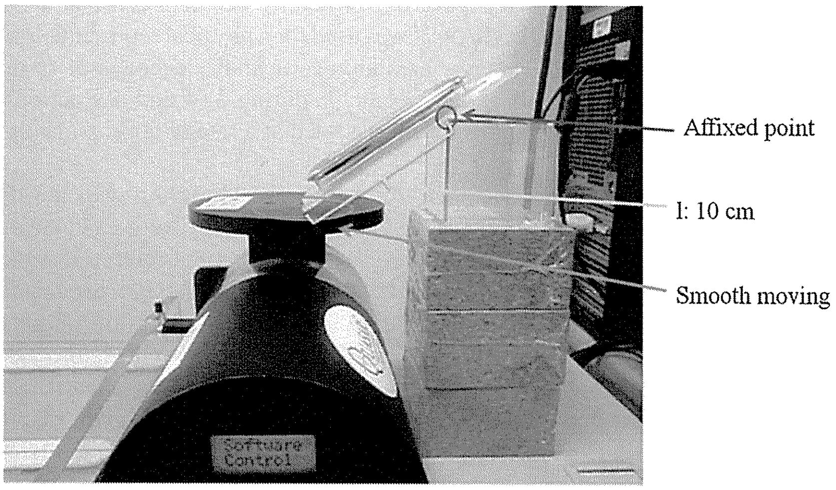

Figure 3. Detection procedure with QUASAR™. The iPod touch® is placed on the acrylic plate. One side of the plate is placed on the QUASAR™ and could slide. The other is affixed to a stand. l is 10 cm.

affixed point suggests that the acrylic plate is affixed by a hinge brace, so this position does not change.

Figure 3 shows the detection procedure using the QUASAR™ Programmable Respiratory Motion Platform (Modus Medical Devices Inc., London, Canada). QUASAR™ is driven by a motor and represents the thoracic–abdominal wall motion of a patient. The motion of QUASAR™ was configured by installing a reference waveform data. The iPod touch® was placed on an acrylic plate, one side of which was placed on the QUASAR™ and could slide. The other was affixed to a stand. With this arrangement, l was 10 cm. The displacement of the QUASAR™ could thus be monitored by measuring the gradient of the iPod touch®.