JJCO Japanese Journal of Clinical Oncology

Japanese Journal of Clinical Oncology, 2018, 48(5) 476–479
doi: 10.1093/jjco/hyy031
Advance Access Publication Date: 4 April 2018
Original Article

OXFORD

Original Article

Patterns of radiotherapy infrastructure in Japan and in other countries with well-developed radiotherapy infrastructures

Katsumasa Nakamura[1,*], Kenta Konishi[1], Tetsuya Komatsu[1], Tomonari Sasaki[2], and Naoto Shikama[3]

[1]Department of Radiation Oncology, Hamamatsu University School of Medicine, Hamamatsu, [2]Department of Health Sciences, Graduate School of Medical Sciences, Kyushu University, Fukuoka, and [3]Department of Radiation Oncology, Juntendo University Graduate School of Medicine, Japan

*For reprints and all correspondence: Katsumasa Nakamura, Department of Radiation Oncology, Hamamatsu University School of Medicine, Handayama 1-20-1, Higashi-ku, Hamamatsu 431-3192, Japan. E-mail: nakam@hama-med.ac.jp

Received 8 January 2018; Editorial Decision 25 February 2018; Accepted 1 March 2018

Abstract

Background: In high-income countries, the number of radiotherapy machine per population reaches a sufficient level. However, the patterns of infrastructure of radiotherapy in high-income countries are not well known.

Methods: Among 29 high-income countries with gross national income of $25,000 or more per capita, we selected 23 countries whose total number of newly diagnosed cancer patients in 2012 was reported in the Organisation for Economic Co-operation and Development Health Statistics 2017. The numbers of radiotherapy centers and teletherapy machines in each of these 23 countries were collected using the Dictionary of Radiotherapy Centers database.

Results: The number of cancer patients per teletherapy machine was 452.35–1398.22 (median 711.66) with a three-fold variation, whereas the number of cancer patients per radiotherapy center varied even more widely, from 826.16 to 5159.86 (median 2259.83) with a six-fold variation. The average number of teletherapy machines per radiotherapy center also ranged widely, from 1.24 to 8.29 (median 3.11) with a seven-fold variation. The number of teletherapy machines in each country was almost proportional to that of cancer patients, and the number of teletherapy machines per radiotherapy center was inversely related to the number of radiotherapy centers per cancer patients. The number of teletherapy machines per radiotherapy center in Japan was 1.24, the most fragmented among the high-income countries. The percentage of large radiotherapy centers having three or more teletherapy machines in Japan was the smallest among 23 high-income countries.

Conclusions: Optimization of the radiotherapy infrastructure in Japan should be carefully considered.

Key words: radiotherapy, megavolt radiotherapy, particle accelerators

Introduction

Radiotherapy (RT) is one of the most important treatment modalities for cancer, together with surgery and chemotherapy. Although RT requires a high initial capital expenditure, such therapy is highly cost effective. Countries with low to medium levels of RT resources should develop RT services that are sustainable within the economical and human resource limitations of the country. On the other hand, in high-income countries, the number of RT machines per population has been judged to be sufficient (1). However, the patterns of RT infrastructure among countries with a high level of

Table 1. Number of cancer patients, radiotherapy centers and teletherapy machines in 23 high-income countries

	Total cancer Pts	Incidence per million population ($\times 10^3$)	RT centers	Particle centers	TT machines	Cancer Pts/TT machine	Cancer Pts/RT center	TT machines/RT center
Australia	122 031	5.37	54	0	165	739.58	2259.83	3.06
Austria	41 117	4.88	14	0	45	913.71	2936.93	3.21
Belgium	65 345	5.87	38	0	109	599.50	1719.61	2.87
Canada	182 182	5.22	53	1	286	637.00	3437.40	5.40
Denmark	36 119	6.46	7	0	58	622.74	5159.86	8.29
Finland	28 428	5.25	13	0	45	631.73	2186.77	3.46
France	349 426	5.50	177	2	491	711.66	1974.16	2.77
Germany	493 780	6.14	277	7	539	916.10	1782.60	1.95
Iceland	1449	4.54	1	0	2	724.50	1449.00	2.00
Ireland	20 808	4.54	12	0	42	495.43	1734.00	3.50
Israel	29 176	3.69	9	0	28	1042.00	3241.78	3.11
Italy	354 456	5.82	191	3	465	762.27	1855.79	2.43
Japan	703 863	5.52	754	14	938	750.39	933.51	1.24
Korea	219 520	4.39	63	2	157	1398.22	3484.44	2.49
Luxembourg	2476	4.66	1	0	4	619.00	2476.00	4.00
Netherlands	93 448	5.58	22	0	138	677.16	4247.64	6.27
New Zealand	21 337	4.84	7	0	27	790.26	3048.14	3.86
Norway	28 214	5.62	10	0	44	641.23	2821.40	4.40
Spain	215 534	4.61	119	0	249	865.60	1811.21	2.09
Sweden	50 481	5.30	17	1	76	664.22	2656.89	4.47
Switzerland	42 046	5.31	35	1	74	568.19	1136.38	2.00
United Kingdom	327 812	5.22	66	1	353	928.65	4617.07	4.97
United States	1 603 586	5.11	1941	23	3545	452.35	689.12	1.52

Pt, patient, RT, radiotherapy; TT, teletherapy.

resources have not been well studied, and it is not well known how the efficiency of RT services can best be optimized. Although the Japanese Society for Radiation Oncology (JASTRO) has conducted national infrastructure surveys of RT facilities in Japan every 1–2 years since 1990 (2), there have been few reports comparing RT structures between Japan and other countries. The purpose of this study was to clarify the patterns of RT infrastructure, focusing on the number of cancer patients per year and the distribution of RT facilities and treatment machines in Japan and other countries with well-developed RT infrastructure.

Materials and methods

A negative correlation has been demonstrated between gross national income (GNI) per capita and the annual number of cancer patients per teletherapy machine (1). In particular, in high-income countries with per-capita GNI of $25 000 or more, the number of patients treated per teletherapy machine per year (1) generally reaches the sufficient level of 400–450 patients or fewer. Therefore, we began by examining 29 countries with per-capita GNI of $25 000 or more in US$ from the World Bank 2015 database (3). We accessed the Directory of Radiotherapy Centers (DIRAC) database in 2017 and examined the number of RT centers and of teletherapy machines (4). The number of teletherapy machines was defined as the sum of linear accelerators, circular accelerators (ex. betatron or microtron) and radionuclide teletherapy units, as shown in the DIRAC database (5). X-ray generators to produce low-energy x-rays for use, and brachytherapy units were excluded from this analysis. Particle accelerators were also excluded because particle therapy is not commonly used in most of the countries in this analysis (Table 1).

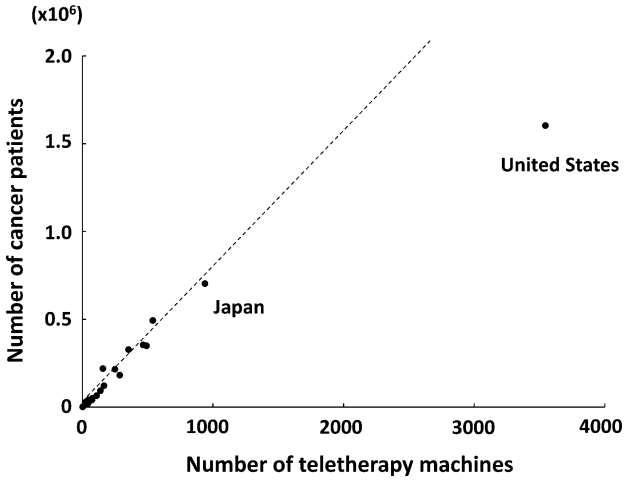

Figure 1. Relationship between the number of newly diagnosed cancer patients per year and the number of teletherapy machines in 23 countries.

The number of newly diagnosed cancer patients per year was examined for 2012 using the Organisation for Economic Co-operation and Development (OECD) Health Statistics 2017 (6). Incidence of cancer was calculated using the number of newly diagnosed cancer patients and total population in 2011 or 2012 (7). Among the 29 selected countries, six countries were excluded from this analysis because the annual numbers of cancer patients were not available in the OECD Health Statistics.

Data from the national structure surveys of RT facilities by JASTRO was also referenced to confirm the values in the DIRAC database (8).

Results

Table 1 shows the number of cancer patients, RT centers and teletherapy machines in 23 high-income countries. The numbers of cancer patients per teletherapy machine were 452.35–1398.22 (median 711.66) with a three-fold variation, whereas the numbers of cancer patients per RT center varied more widely, from 826.16 to 5159.86 (median 2259.83) with a six-fold variation. The average number of teletherapy machines per RT center also ranged widely, from 1.24 to 8.29 (median 3.11) with a seven-fold variation. The number of teletherapy machines per RT center in Japan was 1.24, the decentralized distribution among the high-income countries.

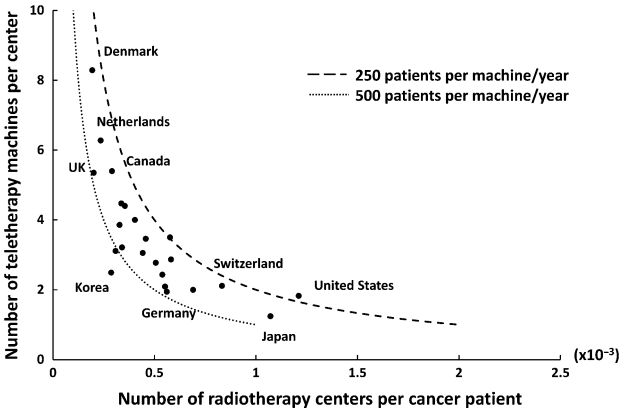

Figure 2. Relationship between the average number of teletherapy machines per center and radiotherapy centers per cancer patient in 23 countries. The relationship in inverse proportion is shown, given the assumptions that 50% of cancer patients are treated uniformly with radiotherapy and an average number of 250 patients (broken line) or 500 patients (dotted line) are treated per machine per year.

Figure 1 shows the correlation between the annual number of newly diagnosed cancer patients and the number of teletherapy machines. The number of teletherapy machines was almost proportional to that of cancer patients.

Figure 2 shows the relationship between the number of RT centers per cancer patient and teletherapy machines per RT center. The number of teletherapy machines per RT center were inversely related to the number of RT centers per cancer patients. Given the assumption that 50% of cancer patients were treated with RT, most countries lay in the range of 250–500 patients treated per machine per year.

Table 2 shows the number and percentage of large RT centers that had three or more teletherapy machines in 23 high-income countries. Except for Iceland, where there is only one RT center in the country, the percentage of large RT centers in Japan was by far the smallest among 23 high-income countries.

Discussion

RT has been rapidly evolving due to constant technological advances, and RT requires a high initial capital expenditure. Therefore, it is very important to clarify how the efficiency of RT services can best be optimized. It has been established that, in high-income countries, the number of RT machines per population is generally sufficient (1). Therefore, it is essential to investigate the patterns of RT infrastructure distribution in countries with a high level of RT resources.

Figure 1 shows that the number of teletherapy machines is almost proportional to the number of cancer patients. This is

Table 2. Numbers and percentages of radiotherapy centers according to the number of teletherapy machines per center in 23 high-income countries

	No of RT centers				Percentage of RT centers (%)		
	Total	≥3 TT machines/center	≥4 TT machines/center	≥5 TT machines/center	≥3 TT machines/center	≥4 TT machines/center	≥5 TT machines/center
Denmark	7	7	7	7	100.0	100.0	100.0
Luxembourg	1	1	1	0	100.0	100.0	0.0
Netherlands	22	19	19	13	86.4	86.4	59.1
United Kingdom	66	57	39	30	86.4	59.1	45.5
New Zealand	7	6	4	2	85.7	57.1	28.6
Canada	53	42	33	26	79.2	62.3	49.1
Sweden	17	13	7	5	76.5	41.2	29.4
Israel	9	6	4	1	66.7	44.4	11.1
Norway	10	6	5	4	60.0	50.0	40.0
Austria	14	8	5	5	57.1	35.7	35.7
Belgium	38	18	10	8	47.4	26.3	21.1
Finland	13	6	5	3	46.2	38.5	23.1
Australia	54	24	20	15	44.4	37.0	27.8
France	177	76	35	22	42.9	19.8	12.4
Ireland	12	5	4	1	41.7	33.3	8.3
Switzerland	35	13	3	2	37.1	8.6	5.7
Italy	191	68	37	15	35.6	19.4	7.9
Korea	63	19	12	7	30.2	19.0	11.1
Spain	119	32	12	3	26.9	10.1	2.5
Germany	277	55	23	11	19.9	8.3	4.0
United States	1941	352	143	63	18.1	7.4	3.2
Japan	754	34	11	6	4.5	1.5	0.8
Iceland	1	0	0	0	0.0	0.0	0.0

RT, radiotherapy; TT, teletherapy.

perhaps because RT is required in 45–55% of newly diagnosed cancer patients (9), and the capacity of a teletherapy machine is limited to 450–500 treatment courses per year (10). In Japan, only 25–30% of cancer patients are treated with RT (2), which is almost half of the rate in countries with well-developed RT infrastructure in Europe and in North America. Given this fact, the actual number of teletherapy machines in Japan may be in slight excess supply.

As shown in Fig. 2, if it is assumed that 50% of cancer patients are treated with RT, most countries treat 250–500 patients per machine per year. Because the benchmark of the linear accelerator throughput was reported to be 300–500 treatment courses per year (10, 11), it is clear that the number of teletherapy machines per center strongly depends on the number of RT centers per cancer patient among countries with a well-developed RT infrastructure.

In this report, we clarified the patterns of RT infrastructure among countries with a high level of RT resources, and revealed that the number of teletherapy machines per RT center were inversely related to the number of RT centers per cancer patients. Rosenblatt and colleagues recently reported on the status of RT capacity in European countries using the Directory of RT Centers (DIRAC) database (1). They found two main approaches to the organization of RT services in countries with a well-developed RT infrastructure: centralization and fragmentation. In some countries, RT services are centralized in a few large centers with 4–10 teletherapy machines. On the other hand, in most other European countries, RT facilities are fragmented, with many small facilities having one or two teletherapy machines. It should be noted that RT infrastructure in Japan is the most fragmented worldwide, and the percentage of large RT centers is the smallest among countries with well-developed RT infrastructure.

In terms of the goal of improving efficiency of RT services from the provider's economic point of view and enabling higher quality of RT, centralization seems to be better approach (1). From the point of view of patients—especially rural patients—seeking services, a more fragmented approach might be preferable. However, if a country has a relatively large number of RT centers per cancer patient, each center might face a greater barrier to increasing the number of teletherapy machines, as shown in Fig. 2. We believe that the results presented in the figure can also be informative for countries with low to medium levels of RT resources, because consideration of how many RT centers to aim for will be very important for the future optimization of RT services.

In Japan, the number of teletherapy machines per center was 1.24, the most fragmented among the high-income countries. One of the reasons for this fact is likely that Japan has a high per-head number of hospitals and hospital beds compared with the OECD average (12). However, Japan's number of radiation oncologists and medical physicists per capita is smaller than those in European countries and the United States (13). Japanese radiation oncologists struggle to keep up with the advances in their field given the relatively small number of staff in the highly decentralized RT infrastructure. In the situation where RT technology is developing rapidly, the training of highly specialized staff requires time and a solid educational environment. Such issues of quality control should be included in the planning for the number of RT centers per cancer patients. Optimization of the infrastructure in Japan should be carefully considered, given its twin trends of a rapidly aging population and an overall trend of population loss.

Funding

This research was in part supported by Health and Labor Sciences Research Grants (H23-Sanjigan-Ippan-007 and H29-ICT-Ippan-002) from the Ministry of Health, Labor and Welfare of Japan.

Conflict of interest statement

None declared.

References

1. Rosenblatt E, Izewska J, Anacak Y, et al. Radiotherapy capacity in European countries: an analysis of the Directory of Radiotherapy Centres (DIRAC) database. *Lancet Oncol* 2013;14:e79–86.
2. Numasaki H, Nishio M, Ikeda H, et al. Japanese structure survey of radiation oncology in 2009 with special reference to designated cancer care hospitals. *Int J Clin Oncol* 2013;18:775–83.
3. The World Bank [Internet]. Gross national income per capita 2011, Atlas method and PPP. [Cited 22 June 2017]. Available from: http://databank.worldbank.org/databank/download/GNIPC.pdf.
4. International Atomic Energy Agency [Internet]. DIRAC (DIrectory of RAdiotherapy Centres). [Cited 22 June 2017]. Available from: http://www-naweb.iaea.org/nahu/dirac/default.asp.
5. Description of the equipment contained in DIRAC. [Cited 22 June 2017]. Available from: https://dirac.iaea.org/Home/Equipment.
6. OECD.stat [Internet]. Health Status: cancer. [Cited 22 June 2017]. Available from: http://stats.oecd.org/
7. OECD.stat [Internet]. Population Statistics: population. [Cited 02 February 2018]. Available from: http://stats.oecd.org/.
8. Japanese Society for Radiation Oncology Data Center (in Japanese) [Internet]. [Cited 22 June 2017]. Available from: http://www.jastro.or.jp/aboutus/datacenter.php
9. Atun R, Jaffray DA, Barton MB, et al. Expanding global access to radiotherapy. *Lancet Oncol* 2015;16:1153–86.
10. Slotman BJ, Cottier B, Bentzen SM, et al. Overview of national guidelines for infrastructure and staffing of radiotherapy. ESTRO-QUARTS: work package 1. *Radiother Oncol* 2005;75:349–54.
11. Bentzen SM, Heeren G, Cottier B, et al. Towards evidence-based guidelines for radiotherapy infrastructure and staffing needs in Europe: the ESTRO QUARTS project. *Radiother Oncol* 2005;75:355–65.
12. Hashimoto H, Ikegami N, Shibuya K, et al. Cost containment and quality of care in Japan: is there a trade-off? *Lancet* 2011;378:1174–82.
13. Numasaki H, Shibuya H, Nishio M, et al. 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* 2012;82:e111–7.