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Comparison of radiotherapy infrastructure between Korea and Japan

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Abstract

Background: Patterns of cancer incidence and radiotherapy use are similar in Korea and Japan, with differences in radiotherapy infrastructure.

Methods: The authors surveyed the megavoltage machines in 91 radiotherapy centers in Korea and published data in Japan. The number of megavoltage machines per center was used as an indicator of the fragmentation of radiotherapy services using four as the threshold, and the number of megavoltage machines per million people was compared. The practice pattern of intensity-modulated radiation therapy was analyzed.

Results: There were 91 centers in Korea and 825 in Japan. The number of megavoltage machines per center was 1.3 in Japan and 2.3 in Korea. Radiotherapy infrastructure showed fragmentation in Korea and hyperfragmentation in Japan. In Japan, 75% of radiotherapy centers operated with one megavoltage machine, whereas in Korea, 47% megavoltage machines per center was 3.2 in Seoul, while that in the non-capital area was 1.8, constituting a mixed pattern of centralization and fragmentation. In Japan, megavoltage machines per center in Tokyo, Kanagawa and Osaka, was 1.5, 1.3 and 1.2, respectively, indicating no concentration in the metropolis. The number of megavoltage machines per million in Korea was 4.0, whereas that in Seoul was 8.7, constituting capital concentration. In Japan, the number of megavoltage machines per million was 8.7, whereas in Tokyo, Kanagawa and Osaka, it was is 9.3, 6.3 and 9.0, showing uniform distribution. intensity-modulated radiation therapy utilization is increasing, accounting for 15% and 23% of radiotherapy patients in Japan and Korea, respectively.

Conclusions: The fragmentation of radiotherapy services in Korea and Japan might affect radiotherapy quality.

Key words: radiotherapy infrastructure, Korea, Japan, equipment, facilities, IMRT

Introduction

Radiotherapy is an effective and widespread method for treating cancer. The number of patients receiving radiotherapy in Korea and Japan has shown a steady increase, and cancer patients are expected to increase in number as the population ages and screening becomes more popular (1–3). Therefore, the steady demand for radiotherapy services is growing in both countries. In countries with a well-developed radiotherapy infrastructure, 45–55% of patients with cancer receive radiotherapy, and about 20–25% of these will have more than one course of treatment (4). In Japan, 25–30% of cancer patients are treated with radiotherapy and in Korea, this rate has steadily increased from 25% to 30% (1, 5). In Korea, stomach cancer is the most common cancer in men, followed by lung and then colorectal. In women, breast, colorectal and stomach cancer are the most common in that order. This pattern is similar in Japan (6–8). Indeed, patterns of cancer incidence and radiotherapy treatment are very similar between the two countries. However, there are some differences in radiotherapy infrastructure and organization patterns (2, 3, 9).

Recent advances in radiotherapy technology, such as stereotactic radiosurgery, intensity-modulated radiation therapy (IMRT), and image-guided radiotherapy, require extensive human resources and infrastructure. Rosenblatt et al. (10) classified radiotherapy infrastructure in terms of centralization and fragmentation according to the number of megavoltage machines (MVMs) per center (10). The fragmentation of radiotherapy services can increase the economic burden and quality of radiotherapy. According to Nakamura et al. (2), the radiotherapy infrastructure of Japan is the most fragmented of all high-income countries, and the percentage of large radiotherapy centers is the smallest among countries with a well-developed radiotherapy infrastructure (2). In contrast, Huh reported that the radiotherapy service in Korea showed a mixed pattern of centralization in metropolitan areas and fragmentation in non-metropolitan areas (3).

The purpose of the present study was to compare the patterns and characteristics of radiotherapy infrastructure between the two countries, focusing on treatment machines, distribution of facilities and practice patterns of IMRT.

Materials and methods

The Korean authors surveyed the number of MVMs, particle accelerators and Gamma Knife units in 91 radiotherapy centers in Korea in October 2018, whereas the Japanese authors surveyed and summarized the number of MVMs and particle accelerators in 825 radiotherapy centers, as well as the number of Gamma Knife units, using the report on radiotherapy machine infrastructure in Japan in October 2018 (11–15). However, the Gamma Knife, which is managed exclusively by neurosurgeons in both countries, was excluded from the present study, as was the particle accelerator, because there were too many differences between the two countries to allow comparison in these cases (Table 1).

The authors compared the number of MVMs per center and the number per million inhabitants between the two countries as indicators of the degree of fragmentation of radiotherapy services and radiotherapy infrastructure, as suggested by Rosenblatt et al. (10). A high number of MVMs per center indicated centralization, with most machines located in only a few centers, whereas a low number of MVMs per center indicated high fragmentation, with many centers operating only one or two machines each. The number of MVMs per million was another key indicator. The geographical distribution of facilities in the capital and non-capital areas was compared between the two countries using the population data of both nations (16, 17). We also compared the number of MVMs per center and per million with the radiotherapy capacity of high-income countries (those with a gross national income of $30 000 or more per capita) and China using the Directory of Radiotherapy Centers (DIRAC) database of the International Atomic Energy Agency (18).

As IMRT utilization is increasing worldwide, we compared the practice patterns of IMRT between the two countries. Data from the national structure surveys of radiotherapy facilities, which were carried out by the Japanese Society for Radiation Oncology (JASTRO), were referenced to survey IMRT utilization in Japan (19, 20). In Korea, big data from the health insurance review and assessment service (HIRA), as well as from a paper by Rim et al. were analyzed (21, 22).

Results

There are 91 radiotherapy centers in Korea and 825 in Japan. The number of MVMs per radiotherapy center was 1.3 in Japan and 2.3 in Korea (Table 1). The number of MVMs per center in both countries was below the European mean of 2.5 (10). With a benchmark of four MVMs per center as the threshold, below which fragmentation of radiotherapy facilities occurs, as suggested by Rosenblatt et al. (10), radiotherapy infrastructure showed fragmentation in Korea and hyperfragmentation (i.e. fewer than two machines per center) in Japan. Furthermore, 619 of 825 (75%) radiotherapy centers in Japan operated with only one teletherapy machine, whereas in Korea, 43 of 91 centers (47%) did so (Table 2). In Korea, nine out of 91 (10%) centers operated four of more MVMs, whereas in Japan, 16 out of 825 centers (1.9%) did so (Table 2). However, in Seoul, the capital of Korea, the number of MVMs per center was 3.2, while the number in non-capital areas was 1.8, showing a mixed pattern of centralization in the capital and fragmentation in non-capital areas. In Japan, where the number of MVMs per center was 1.3, the numbers in Tokyo, Kanagawa and Osaka, the three biggest cities, were 1.5, 1.3 and 1.2, respectively, indicating no centralization of radiotherapy infrastructure in the metropolis.

Table 1. Number of radiotherapy (RT) centers, megavoltage machines (MVMs), particle accelerators and Gamma Knife units in Korea and Japan in 2018

	Number of RT Centers	RT centers per million population	Number of MVMs	Number of MVMs per RT center	Particle accelerator	Gamma Knife
Korea	91	1.8	205	2.3	2 proton	22
Japan	825	6.5	1105	1.3	24 (18 proton and 6 carbon ion)	54

Table 2. Number and percentages of radiotherapy (RT) centers in terms of the number of MVMs and the utilization of IMRT in each country

	RT center total	1 MVM per center	2 MVMs per center	3 MVMs per center	4 or more MVMs per center	Use of IMRT*
Korea	91	43 (47%)	26 (29%)	13 (14%)	9 (10%)	23%
Japan	825	619 (75%)	156 (18.9%)	34 (4.1%)	16 (1.9%)	15%

*Utilization of IMRT in Japan in 2017 and in Korea in 2016.

Table 3. MVMs and cancer burden in Korea and Japan in 2018

	Gross domestic product per capita (US$)	Population (in millions)	Projected cancer incidence	MVMs	Incident cancer per MVM	MVMs per million inhabitants
Korea	29 744	51.6	204 909	205	1000	4.0
Japan	38 428	127.2	1 013 600	1105	917	8.7

Table 4. Number of radiotherapy centers, MVMs and MVMs per one million population in Western and Asian countries

	MVMs	Radiotherapy centers	MVMs per center	MVMs per million
USA	3794	2113	1.8	11.8
France	509	179	2.8	7.9
Germany	551	286	1.9	6.8
Canada	289	51	5.7	8.0
UK	353	70	5.0	5.5
China	1647	1075	1.5	1.2
Japan	1105	825	1.3	8.7
Korea	205	91	2.3	4.0

Japan and Korean data from 2018. Other countries' data from the Directory of Radiotherapy Centers (DIRAC) database of the International Atomic Energy Agency (18).

The number of MVMs per million in Korea was 4.0, whereas that in Seoul was 8.7 and that in the non-capital areas was 2.9, showing a concentration of radiotherapy facilities in the capital with geographical disparities within the country. In Japan, the number of MVMs per million was 8.7; in Tokyo, Kanagawa and Osaka it was 9.3, 6.3 and 9.0, respectively, all below the median of 9.4, indicating a much more uniform distribution than in Korea. The projected cancer incidence per MVM was 917 in Japan and 1000 in Korea (Table 3). However, the number of MVMs per million was higher in Japan (8.7 vs. 4.0), as was the number of radiotherapy centers per million (6.5 vs. 1.8; Tables 1 and 3). Among high-income countries and China, Japan has one of the highest numbers of MVMs per million (Table 4).

According to the data of the national structure surveys of radiotherapy facilities, carried out by JASTRO, IMRT utilization in Japan was 15% in 2017. In Korea, it was 23% in 2016 based on the big data of the HIRA (19, 22). IMRT was mostly used to treat prostate, head and neck and central nervous system (CNS) tumors in Japan, according to the Japanese radiation oncology database report of 2018 (20). According to the big data of the HIRA, IMRT use has steadily increased in Korea, with an annual increase estimate of 38% from 2011 to 2016; it was most commonly used to treat breast, lung and prostate cancer, in that order, in 2018 (21).

Discussion

The capacity of a teletherapy machine is limited to 450–500 treatment courses per year in Western countries (23). As radiotherapy is required in 45–55% of cancer patients, 1000 new cancers annually per radiation machine will likely have a shortfall (25). However, In Japan and Korea, only 25–30% of cancer patients are treated with radiotherapy, which is almost half of the rate of countries with a well-developed radiotherapy infrastructure in Europe and the Americas (1, 2). The projected cancer incidence per MVM was 917 in Japan and 1000 in Korea. Therefore, teletherapy machines in Japan may be in slight excess supply and there is no shortage in Korea either. The utilization rate of radiotherapy increased significantly for breast, lung, liver and prostate cancer recently in Korea and this trend is expected to continue to rise (1).

The number of MVMs per center was 1.3 in Japan and 2.3 in Korea, which is below the European mean of 2.5. With four machines per radiotherapy center as the threshold, below which fragmentation of radiotherapy facilities occurs, as suggested by Rosenblatt et al. (10), then both countries showed fragmentation, whereas Japan showed hyperfragmentation. In Nordic countries, the UK, and The Netherlands, radiotherapy services are usually centralized in a few large cancer centers that use all types of radiotherapy techniques, with four to ten machines per center and all the necessary equipment and personnel (10). In Japan, in the present study, 619 of 825 radiotherapy centers (75%) operated with only one teletherapy machine, whereas in Korea, 43 of 91 (47%) did so. However, in Seoul, the number of MVMs per center was 3.2, while in non-capital areas it was 1.8, showing a mixed pattern of centralization in the capital and fragmentation in the non-capital areas. In Japan, the number of MVMs per center was 1.3, whereas that in Tokyo, Kanagawa and Osaka, the three biggest cities was 1.5, 1.3 and 1.2, respectively, meaning that there was no concentration in the metropolises. The patterns of cancer incidence, utilization of radiotherapy and number of MVMs per million were very similar between the two countries.

The capital concentration observed in Korea compared to the more even distribution of facilities observed in Japan was a big difference between the two countries.

According to recent reports, the number of MVMs per million is 11.8 in the USA, 8.0 in Canada, 7.9 in France, 6.8 in Germany and 5.5 in the UK (Table 4) (18). Rosenblatt et al. (10) suggested that the European average of 5.9 machines per million is the desirable density and that a density of four machines per million was the minimum requirement. Among the Organization for Economic Cooperation and Development (OECD) countries, Japan belongs to the highest-level group with regards the number of MVMs per million (8.7). The number of MVMs per million in Korea (4.0) still lags behind the highest-level group. However, in Seoul, the number of MVMs per million was 8.7, which does belong within the highest-level group, while that in the non-capital area was 2.9, showing that radiotherapy facilities are concentrated in the capital, with geographical disparities within the country. Korea's supply of machines has increased in recent years and the number of MVMs per million in 2018 was about twice that in 2006 (3).

The concentration of medical resources and radiotherapy facilities in the capital and metropolitan areas, where nearly half of the whole national population lives, is an important issue in Korea. A total of 22 of the 43 advanced general hospitals and 47 of the 91 radiotherapy centers are in capital areas, including Seoul, Incheon and Gyeonggi province. With regards to IMRT in 2018, 69% of new patients (22 197/32 099) were treated in the capital and metropolitan area. The main cause of the need for medical travel to metropolitan areas among radiotherapy patients was the concentration of facilities, which is partly due to Korea's advanced public transport system, which includes an expansion of the high-speed train lines. In 2014, 45% of radical prostate cancer surgeries were conducted in Seoul among non-Seoul residents, and a large proportion of travel for medical care occurred irrespective of the patients' direct distance from Seoul (26). On the other hand, in Japan, the number of MVMs per million was 8.7, whereas the numbers in Tokyo, Kanagawa and Osaka were 9.3, 6.3 and 9.0, respectively, all of which were below the median of 9.4. This indicated that a more uniform distribution and number of MVMs per center in the metropolis does not necessarily entail the concentration of radiotherapy infrastructure. To improve the economic efficiency of radiotherapy services, and to ensure higher quality, centralization seems the better approach (10). From the point of view of patients, especially rural patients, a more fragmented approach might be preferable to curtail the need for medical travel to the metropolitan area.

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, the outcome of cancer treatment in Japan is the same or better than in the United States (27). According to Numasaki et al. (27), in Japan under the situation of highly decentralized radiotherapy infrastructure, to make up for the shortage of manpower most radiation oncologists in university hospitals serving as a hub of radiotherapy in provinces participate in radiotherapy practice at affiliated hospitals. This can contribute to maintain the quality of radiotherapy level and may impede fostering of specialization of radiation oncologists.

The rate of IMRT utilization to treat cancer in Japan was 15% in 2017, whereas it was 23% in Korea in 2016 (19, 22). IMRT is most commonly used to treat prostate, head and neck and CNS tumors in Japan (20). In Korea, since 2015, the national health insurance has covered IMRT for all solid tumors. In Korea, IMRT is most commonly used to treat breast, lung and prostate cancer in 2018, in that order (21). In Korea, the use of IMRT to treat breast cancer is steadily increasing to spare organs at risk, particularly the heart, in patients with left breast cancer. Conversely, the American Society for Radiation Oncology (ASTRO) recommended, in its 'Choosing Wisely' campaign, that IMRT not be routinely used to deliver whole-breast radiation as part of breast conservation therapy. Thus, although IMRT may be beneficial in select cases with unusual anatomy, no studies have yet demonstrated that its routine use provides a significant clinical advantage (28). Furthermore, the cost-effectiveness of IMRT is still unclear, because it has a high cost. In Japan, IMRT is only reimbursed by the national health insurance system when the following personnel are present: (i) two full-time radiation oncologists with five or more years of radiotherapy experience, (ii) a full-time radiotherapy technician dedicated solely to radiotherapy, with five or more years of experience and (iii) an individual responsible solely for precision control of the radiotherapy devices, irradiation plan verification and assistance with the irradiation plan (e.g. a radiotherapy or other technician). Better cancer treatment outcomes may be achieved when the procedures are performed in high-volume institutions. It was beyond the scope of the present study to investigate whether differences in equipment and organization affect cancer outcomes, but further research should investigate how to optimize the efficiency of radiotherapy services.

In conclusion, the present comprehensive comparison analysis, carried out in Korea and Japan, showed fragmentation with capital concentration in the Korean radiotherapy infrastructure, as well as hyperfragmentation in Japan. Close networking and referral systems between provincial medical centers and major hospitals in metropolitan areas should be developed in Korea. The infrastructure in both countries should be optimized in the near future. Although the present report compared radiotherapy infrastructure between the two countries, it did not address quality issues. The quality of the infrastructure and manpower should be assessed separately in the future.

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