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# The present state of radiation exposure from pediatric CT examinations in Japan—what do we have to do?

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## ABSTRACT

The use of computed tomography (CT) has increased dramatically over the past several decades and has resulted in a concurrent increase in medical exposure to ionizing radiation. Several recent studies have examined the link between medical radiation and the risk of cancer, especially in children. The cancer risk associated medical exposure has not been definitively confirmed. However, we have to reduce unwarranted medical radiation exposure in pediatric patients. Justification and optimization are of great importance in order to minimize these risks, and the standardization of CT usage is essential. However, in Japan no clinical guidelines for the use of CT have been commonly agreed upon, especially in children. Furthermore, the CT-associated radiation exposure in Japan varies widely among the different facilities. Further studies based on a nationwide survey in Japan will be required in order to establish simple and useful clinical guidelines.

**Keywords:** CT; medical exposure; cancer risk; justification; optimization; children

## INTRODUCTION

Computed tomography (CT) is a valuable and medically beneficial imaging technology; its use is increasing in all industrial countries, where it is replacing conventional X-ray studies. The number of CT scanners per million people in Japan was the highest among developed countries according to the data from the Organisation for Economic Cooperation and Development (OECD) [1]. However, the patient is exposed to considerably high doses of ionizing radiation when undergoing CT. For example, a chest CT scan typically delivers more than one hundred times the radiation dose of a chest X-ray [2, 3]. Furthermore, the radiation exposure from CT has also increased due to rapid scanning and multiphase examinations. Radiological imaging is associated with some risk of adverse effects. The risk of cancer induction through CT scans has recently received

special attention. In particular, children are assumed to have a higher risk of developing cancer due to radiosensitivity, the relatively higher doses that are absorbed because of their smaller bodies, and because of their long lifespan after the radiation exposure. Some recent epidemiological studies have indicated that the risk of cancer was increased in children who underwent CT at relatively low doses [4–6]. Pearce *et al.* revealed increased leukemia and brain cancer risk in pediatric patients who had previously received CT. Mathews *et al.* found increased various cancer risks in pediatric patients who had been exposed to CT using a large database. However, considering the effect of confounding by indication, those results are subject to further analysis, and the effects of low-dose radiation are still unclear. At any rate, it is important to reduce the potential risk of cancer associated with CT exposure, and to draw attention to the

justification of exposure and the optimization of radiation protection. Unlike other countries, such as Germany, the USA and the UK, Japan does not have clinical guidelines for the use of CT, especially in the pediatric field. We assessed the patterns of CT practice in Japan. Recognizing the patterns of CT studies is very important for standardizing the pediatric CT practice worldwide. We would like to emphasize methods by which unnecessary medical radiation exposure can be reduced in pediatric patients.

### THE CANCER RISKS ASSOCIATED WITH CT EXPOSURE

There are various sources of public radiation, including natural sources (e.g. internal inhalation, ingestion, external cosmic rays, and terrestrial sources), medical radiation, occupational radiation, nuclear power,

and nuclear weapons. According to the United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR) 2008 report [7], ~20% of the public radiation burden is due to medical radiation. However, in comparison with the worldwide average, medical radiation accounts for a higher percentage of the public radiation burden in both the USA (~50%) [8] and Japan (>60%) [9] (Fig. 1). The use of medical radiation is associated with some risks.

Ionizing radiation is a well-established risk factor for cancer [10], and the risk in children is higher than that in adults due to the radiosensitivity of their growing and developing organs and tissues. Furthermore, their longer post-exposure life expectancy increases the lifetime risks of developing radiation-induced malignancies in comparison with adults [11, 12].

Recently, several studies have examined the link between medical radiation and the risk of cancer, especially in children.

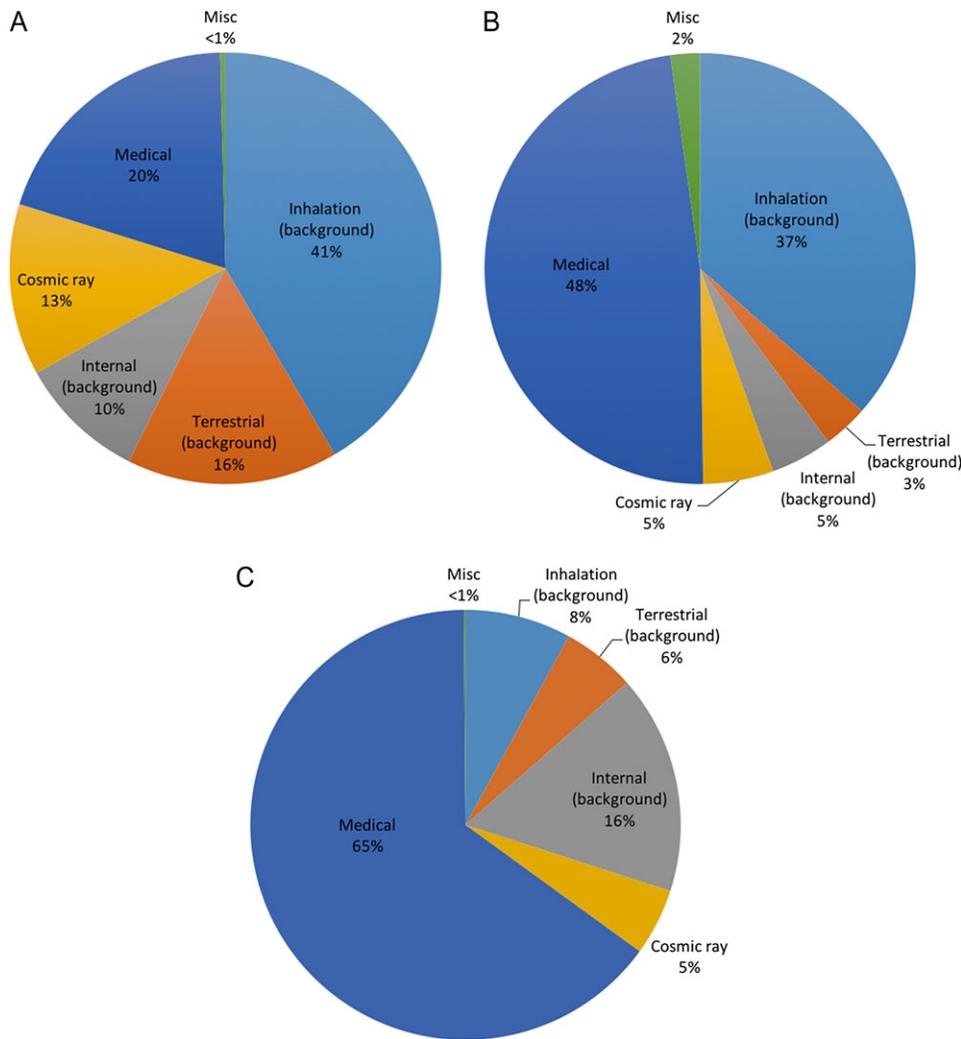


Fig. 1. A comparison of the sources of public radiation worldwide (UNSCEAR 2008) [7], in the USA (2009) [8] and Japan (2011) [9]. (A) UNSCEAR in 2008. (B) USA in 2009. (C) Japan in 2011. All of the sources that account for <1% of the total radiation burden (i.e. occupational radiation, nuclear power, and nuclear weapons) are labeled 'Misc'. The frequency of medical radiation in the USA and Japan was higher than that in UNSCEAR.

In 2001, Brenner *et al.* estimated the risks of radiation-induced fatal cancer from pediatric CT examinations [4]. The estimated lifetime increase in the cancer mortality risk attributable to the radiation exposure from a CT scan in a 1-year-old are 0.18% and 0.07% for the abdomen and head, respectively. In other words, among the ~600 000 abdominal and head CT examinations performed each year for children in the USA, roughly 500 individuals might die from cancer attributable to CT radiation.

A more recent study performed by Pearce *et al.* [5] was the first to show an increased incidence of leukemia and brain cancer in children and adolescents who had received CT. In this retrospective cohort study of 178 604 patients who underwent a CT scan between 1985 and 2002 in various hospitals in the UK, the authors reported excess rates of leukemia and brain cancer. The average follow-up period was a little under 10 years. They estimated that one excess case of leukemia and one excess case of brain cancer would occur per 10 000 head CT scans. They showed significant associations between the estimated radiation doses provided by CT scans to the red bone marrow and brain and the subsequent incidence of leukemia and brain tumors.

Similar increases or projected risks in leukemia, brain, and other solid cancers were reported in the USA [13], Taiwan [14] and Australia [6].

Methews *et al.* estimated the increased cancer risk directly by comparing the cancer incidence in over 680 000 children and adolescents exposed to CT scans in a comparison cohort of over 10 million unexposed persons of similar age [6]. Cancer incidence in CT-exposed patients was increased by 24% in comparison with that in unexposed individuals after accounting for age, sex and year of birth [incidence rate ratio (IRR) 1.24]. The IRR was greater for persons exposed at younger ages. There was an excess of 608 cancers among the CT-exposed patients (brain,  $n = 147$ ; other solid,  $n = 356$ ; leukemia or myelodysplasia,  $n = 48$ ; and other lymphoid,  $n = 57$ ). The authors showed a dose-response relationship, with the IRR increasing by 0.16 for each additional CT scan.

Boice reviewed the literature on radiation epidemiology and recent pediatric CT studies and noted a critical problem: the reasons why the examinations were performed were not known, and these reasons were the probable cause of the subsequent cancer diagnosis [15]. This is 'confounding by indication' (or 'reverse causation'), which is a major bias that frequently contaminates study populations [16]. Thus, these studies must be interpreted very carefully because analyzing the risk of medical radiation is very difficult. The cancer risk associated with CT exposure has not yet been definitively confirmed. To clarify this issue, a detailed analysis of the purpose of CT studies should be performed and the risks and benefits of radiological imaging should be determined, especially in children.

### THE NUMBER OF CT SCANNERS AND PEDIATRIC CT EXAMINATIONS IN JAPAN AND OTHER COUNTRIES

Computed tomography (CT) is an essential diagnostic tool in modern medicine. The use of CT is dramatically increasing in all industrial countries, including Japan, because of technical advances [7].

Berrington de Gonzalez and Darby compared the cancer risk from medical exposure between several developed countries [17].

They concluded that Japan had the highest attributable risks, with 3.2% of the cumulative risk of cancer attributable to diagnostic X-rays. They used the average frequency for all health-care level 1 countries in the main calculations because no data were available for the annual frequency of CT examinations in Japan. Despite this, the higher rates of X-ray examination in Japan in comparison with those in other countries might have influenced the cancer risk.

A report from the UNSCEAR in 2000 stated that there were 64 CT scanners per million people in Japan [18]. Nishizawa *et al.* conducted a nationwide survey in 2000 and concluded that there were 87.8 CT units per million people in Japan [19]. Based on the data from the Organisation for Economic Cooperation and Development (OECD), the number of CT units per million people is gradually increasing (Fig. 2) [1]. In 2014, the number of CT units per million people was 107.1, which was the highest among developed countries (Fig. 3). In the same year, a total of 13 636 medical facilities possessed CT scanners, which is equivalent to the number of convenience stores in Japan [20–22] (Fig. 4).

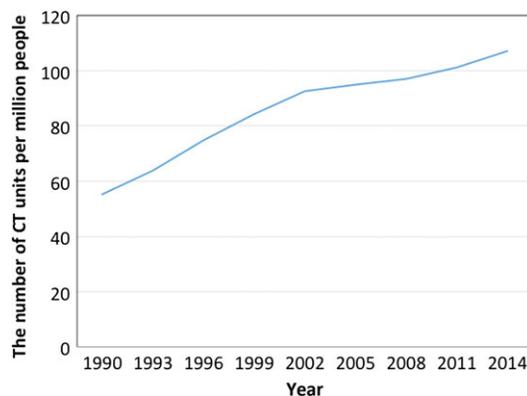


Fig. 2. The number of CT units per million people in Japan from 1990 to 2014. The number has increased year by year.

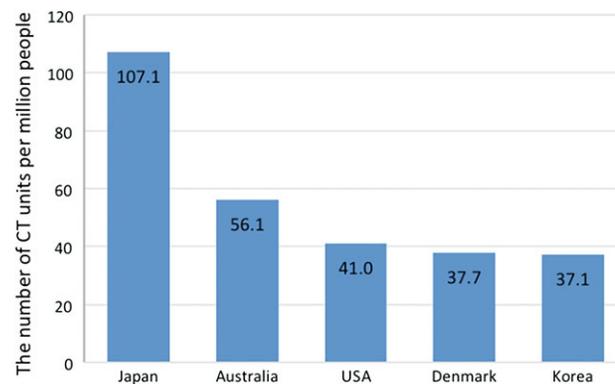
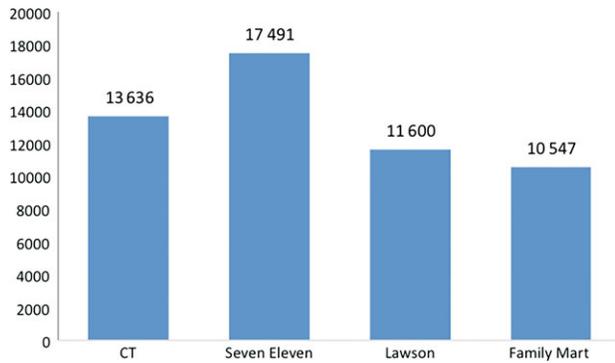


Fig. 3. The number of CT units per million people in different countries (data for 2014). There were 107.1 CT units per million people in Japan, which was the highest number among the developed countries.



**Fig. 4. A comparison of the number of CT scanners in Japan, and several convenience stores. The number of CT scanners was similar to the number of convenience stores in Japan.**

On the contrary, the number of procedures for both total CT and pediatric CT is lower in Japan than in the USA [23]. In 2006, the number of total CT procedures per thousand people was 166 in Japan and 207 in the USA. Similarly, the number of pediatric CT procedures per thousand people was 32–34 in Japan and 76–94 in the USA. In 2005, there were 64–78 pediatric CT procedures per CT unit in Japan, and 460–590 in the USA; thus, the number of procedures per CT unit in the USA was approximately seven times higher than that in Japan. Furthermore, the number of CT examinations in pediatric patients has not increased in Japan, whereas an increase has been seen in the USA.

Nishizawa estimated—based on a nationwide survey of Japan that was performed in 2000—that 1.14 million CT examinations were performed annually for patients of 0–14 years of age [19]. Miyazaki estimated that 1.22 million pediatric CT examinations were performed for children of 0–15 years of age in 2003 [24]. Ono estimated that approximately 580 000 and 600 000 CT scans were performed for pediatric patients in 2005 and 2006, respectively [23].

#### A COMPARISON OF PEDIATRIC CT BETWEEN JAPAN AND GERMANY

Recognition of the patterns in CT studies is important, not only for resolving the abovementioned issue of ‘confounding by indication’, but also for standardizing pediatric CT practices worldwide. For this purpose, we are the first to assess the pediatric CT practice patterns in Japan (Nagasaki University Hospital and Fukushima Medical University Hospital) and to compare the patterns with the German data (Mainz University Medical Center) [25]. All pediatric patients between 0 and 14 years of age who underwent a CT examination during 2008 to 2010 were included in this study. We investigated the number of CT examinations, the time of the examination and the indication. The indications were classified into several categories, which included tumor-related examinations, trauma, congenital/other typical childhood diseases, and general examination regions (‘cranium’, ‘spine’, ‘thorax’ and ‘abdomen’).

The mean number of CT examinations per patient was 1.79 in Japanese hospitals, and 1.63 in the German hospital. The overall frequency of CT examinations in Japanese university hospitals did not differ significantly from that in the German hospital. However,

differences were detected in the age distribution of the examined patients and the indications for CT. The proportion of patients of <5 years of age in Japan was significantly higher than that in Germany. The mean age in the Japanese hospitals (5.5 years) was significantly lower than that in the German hospital (7.7 years). Almost 20% of the pediatric CT examinations involved children younger than 12 months of age at the Japanese hospitals (both Nagasaki and Fukushima). In contrast, in the German hospital, fewer CT examinations were performed in patients younger than 12 months of age (2.2%).

At the Japanese hospitals, cranial indications were the most common indications for CT (42% of all CT scans), followed by tumor-related, trauma-related and abdominal indications. In comparison, trauma-related indications were the common indication for CT at the German hospital (34%), followed by cranial and tumor-related indications. The rates of cranial and abdominal CT scans at the Japanese hospitals were significantly higher in comparison with at the German hospital.

#### FUTURE PROSPECTS Justification and optimization

Several studies have examined the link between medical radiation and the cancer risk. Although there is much uncertainty about the cancer risk from CT, it is reasonable to act on the assumption that there may be some risk [12, 26]. There are two principles for reducing the radiation dose from CT: justification and optimization. According to the principle of justification, the advantages of using ionizing radiation must outweigh the disadvantages. According to the principle of optimization, the radiation dose must be kept as low as is reasonably achievable/practicable (ALARA) [27].

The principle of justification is very important but also very difficult to evaluate, because it is difficult to measure quantitatively. Thus, studies on justification are very rare. However, the inappropriate use of medical radiation is a clear violation of the principle of justification, and should be reduced.

Prior consultation before CT examination is important for reducing the inappropriate or excessive use of imaging procedures. Pediatricians and radiologists should discuss whether CT is the best study to perform [28]. These discussions can provide an opportunity to share information, such as the number of imaging tests using ionizing radiation to which the patient has been exposed [12]. A conference on radiation protection for children could be a first step in educating referring physicians [29]. It would also be useful to produce risk communication materials and education materials for parents that aim to reduce the number of unnecessary CT examinations. A previous study revealed that one-third of all CT scans were not justified by medical need [30]. Slovis asked some pediatric radiologists about the percentage of head or body CT scans that they thought they could probably do without and found that the radiologists thought that up to 30% of studies were unnecessary or could be replaced with examinations that did not involve ionizing radiation [30]. If this is true, perhaps more than 1 million children per year could be being irradiated unnecessarily in the USA. This finding suggests that unnecessary irradiation may occur and that assessments of the justification in daily practice are far from perfect. We should investigate how useful the CT findings are in Japan.

The nuclear disaster at the Tokyo Electric Power Company Fukushima Daiichi Nuclear Power Plant on 11 March 2011 resulted in the release of a large amount of radioactive materials into the atmosphere. Yoshida *et al.* investigated the number and ratio of outpatients who underwent imaging examinations (e.g. CT, X-ray, MRI, US, etc.) at Fukushima Medical University hospital before and after the accident [31]. The number of outpatients of <10 years of age who underwent CT and X-ray examinations significantly decreased after the accident. On the other hand, a significant increase was observed in the ratio of outpatients of <10 years of age who underwent US. Since the accident, information on the relatively high radiation sensitivity of children has been widely distributed. Recently, Miyazaki also investigated the number of CT examinations at the main children's hospital in Japan before and after the accident [32]. They found that the number was significantly reduced each year after the accident in comparison with the number in the year before the accident. These results suggest that public awareness of the radiation risk to children increased. Furthermore, from the viewpoint of justification, excess pediatric CT examinations might be avoided by doctors due to the recognition of the risks of radiation exposure. We hope that the increased awareness of radiation exposure has led to a turning point in Japanese pediatric radiology.

To 'optimize' medical radiation, it is very important to understand the quantitative data collected in relation to currently used devices as a starting point. In 2010, Tsushima *et al.* assessed the current situation of CT use in Japan [33]. They showed that there was very large variation in the levels of CT-associated radiation exposure among institutions. In particular, for lower abdominal CT, the radiation exposure ranged from 2.6 to 19 mSv. Many facilities use quality assessments, including consultation with a physician and assessments based on experience and the manufacturer's recommendations [34].

Tsushima *et al.* emphasized the importance of the application of reference dose levels to further reduce such institutional differences. Also, the International Commission on Radiological Protection (ICRP) recommended the use of diagnostic reference levels (DRLs) in 1996 [35]. However, DRLs were not set in Japan until 2015, when Takei *et al.* conducted a nationwide survey on radiation exposure during pediatric CT examinations and established the DRLs in Japan [36]. They found that the DLP (dose-length product) values for pediatric CT in Japan were higher in comparison with those of other countries [37–40]. We should organize a more extensive survey to collect dose data from a large cohort to establish empirical dose distributions for pediatric CT in Japan.

The automatic exposure-control option on the latest generation of scanners is also helping to reduce the CT-related radiation dose in individual patients [41]. The use of non-ionizing imaging techniques, such as ultrasonography (US) and magnetic resonance imaging (MRI), instead of CT is another approach that can be used to further reduce ionizing radiation exposure [41]. In cases of suspected appendicitis, the ACR (the American College of Radiology) recommends that ultrasonography or MRI should be performed instead of abdominal CT in pediatric patients. Another way to reduce the CT dose is to limit the number of phases. Multiple scans through the same body part can double or triple the radiation dose

to the patient. A single pass is usually sufficient for diagnostic purposes in most cases in which CT scans are indicated for pediatric patients. The most effective way to reduce the population dose from CT is simply to decrease the number of CT studies. When a CT scan is justified by medical need, the associated risk is small relative to the diagnostic information that will be obtained [41].

In particular, we believe that justification is more important than optimization. To justify the usage of ionizing radiation, the benefits must outweigh the risks. However, little has been reported on the benefits of ionizing radiation. It is necessary to quantify the benefits and risks; however, this is very difficult to accomplish because the individuals that benefit from the use of ionizing radiation in medical practice and those that are put at risk by it are usually different.

### What can we learn from the present state of radiation exposure from CT examinations in Japan and by comparing the use of CT among developed countries?

Yoshida *et al.* compared the use of pediatric CT between Japan (Nagasaki University Hospital and Fukushima Medical University Hospital) and Germany (Mainz University Medical Center). They found large differences in the frequencies of various indications for CT [25].

In Japan, the proportion of CT examinations involving pediatric patients was higher than that in Germany (5.1% vs 2.2%). The proportions of cranial and abdominal CT scans in Japan were significantly higher in comparison with those of Germany. These findings might indicate that CT is overused in Japan.

In Germany, specialized pediatric radiologists generally perform pediatric CT, whereas the CT examinations in Japan were conducted by general radiologists who did not specialize in pediatric radiology. Miyazaki *et al.* showed that, in Japan, the scanning parameters were determined by full-time radiologists in 40% of cases, and by CT technologists in 28% of cases [23]. This might partly explain the differences between Japan and Germany.

In Germany, the Radiation Protection Commission, together with clinical experts, has developed guidelines for diagnostic radiological procedures. Consequently, the low overall number of CT examinations at Mainz University Medical Center might reflect the effects of these guidelines. The American College of Radiology and the US Society for Pediatric Radiology have also produced recommendations and guidelines for pediatric CT use. Unlike other countries such as Germany, the USA and the UK, Japan does not have commonly agreed upon clinical guidelines for the use of ionizing radiation in diagnostic radiology. At the time of writing, there are no standardized clinical guidelines for pediatric CT in Japan. In 2016, the guidelines for medical imaging were published in Japan. In comparison with the 2013 guidelines, the 2016 guidelines included more content related to pediatric imaging.

From the viewpoint of 'justification', it is important to reduce inappropriate use and to standardize the usage of medical radiation. As shown in the comparison between the three Japanese University Hospitals, standardization has not been achieved in Japan. To resolve this situation, a nationwide survey on medical radiation usage should be conducted. Such a nationwide survey would also be important for 'optimization'. A nationwide survey was only recently conducted to establish the Japanese DRLs; this is roughly 10 years

behind other major developed countries and the details are still insufficient. A nationwide survey on how medical radiation is used, including the indications, consequences, and radiation dose, is necessary in order to establish standardized criteria for the appropriate use of medical radiation (for justification), and for establishing standardized imaging procedures and more detailed DRLs (for optimization).

### ETHICS STATEMENT

Approvals for the study were obtained before the beginning of the study from the Ethics Committee of Nagasaki University Hospital (No. 10042553). The study was conducted in accordance with the guidelines set out in the Declaration of Helsinki. All the data used in this study were analyzed anonymously and securely protected under the supervision of the data protection officer of each hospital.

### CONFLICT OF INTEREST

The authors have no conflicts of interest directly relevant to the content of this article.

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