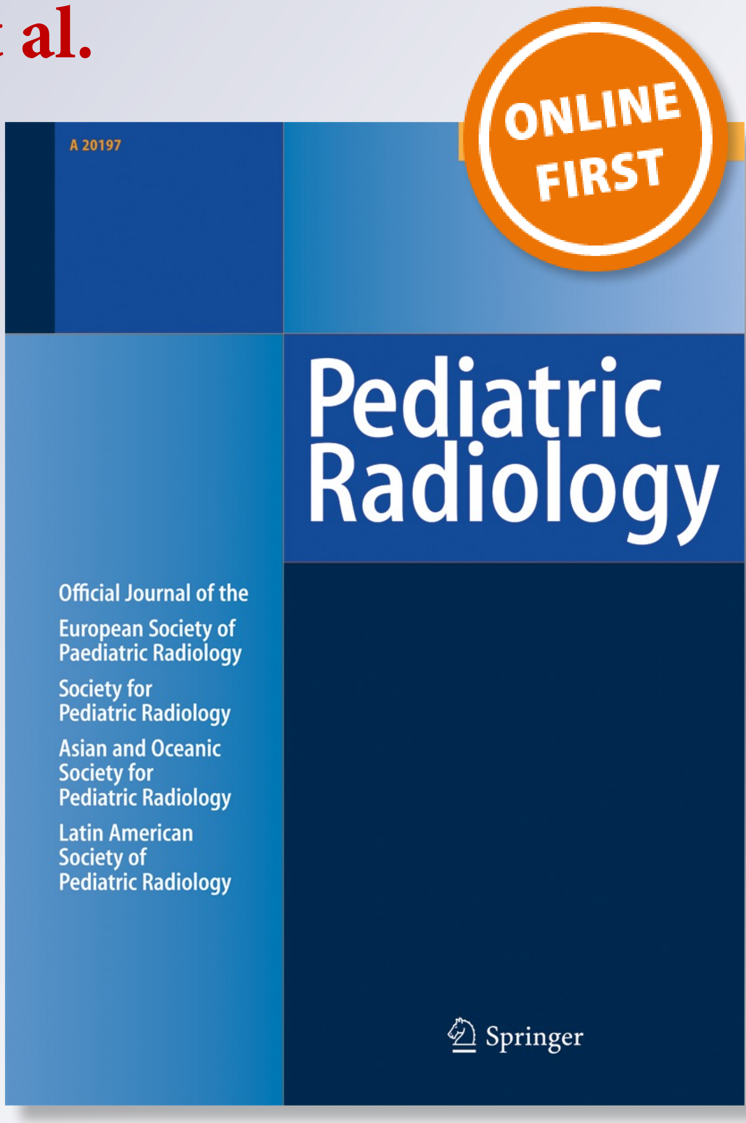
Nationwide survey of radiation exposure during pediatric computed tomography examinations and proposal of age-based diagnostic reference levels for Japan

Yasutaka Takei, Osamu Miyazaki, Kosuke Matsubara, Yoshiya Shimada, Yoshihisa Muramatsu, Keiichi Akahane, Keisuke Fujii, et al.

Pediatric Radiology

ISSN 0301-0449

Pediatr Radiol
DOI 10.1007/s00247-015-3474-x



Pediatr Radiol
DOI 10.1007/s00247-015-3474-x

ORIGINAL ARTICLE

Nationwide survey of radiation exposure during pediatric computed tomography examinations and proposal of age-based diagnostic reference levels for Japan

Yasutaka Takei[1] · **Osamu Miyazaki**[2] · **Kosuke Matsubara**[3] · **Yoshiya Shimada**[4] · **Yoshihisa Muramatsu**[5] · **Keiichi Akahane**[4] · **Keisuke Fujii**[6] · **Shoichi Suzuki**[7] · **Kichiro Koshida**[3]

Received: 6 April 2015 / Revised: 2 July 2015 / Accepted: 7 October 2015

Abstract
Background Diagnostic reference levels (DRLs) have not been established in Japan.
Objective To propose DRLs for CT of the head, chest and abdomen for three pediatric age groups.
Materials and methods We sent a nationwide questionnaire by post to 339 facilities. Questions focused on pediatric CT technology, exposure parameters, CT protocols, and radiation doses for age groups <1 year, 1-5 years, and 6-10 years.
Results For the three age groups in the 196 facilities that responded, the 75th percentile values of volume CT dose index based on a 16-cm phantom ($CTDI_{vol}$ 16 [mGy]) for head, chest and abdominal CT were for infants 39.1, 11.1 and 12.0, respectively; for 1-to 5-year-olds 46.9, 14.3 and 16.7, respectively; and for 6-to 10-year-olds 67.7, 15.0 and 17.0, respectively. The corresponding dose–length products (DLP 16 [mGy · cm]) for head, chest and abdominal CT were for infants 526.1, 209.1 and 261.5, respectively; for 1-to 5-year-olds 665.5, 296.0 and 430.8, respectively; and for 6-to 10-year-olds 847.9, 413.0 and 532.2, respectively.
Conclusion The majority of $CTDI_{vol}$ 16 and DLP 16 values for the head were higher than DRLs reported from other countries. For risk reduction, it is necessary to establish DRLs for pediatric CT in Japan.

✉ Yasutaka Takei
ytakei-ham@umin.net

1 Department of Quantum Medical Technology, Division of Health Sciences, Graduate School of Medical Science, Kanazawa University, 5-11-80 Kodatsuno, Kanazawa, Ishikawa 920-0942, Japan

2 Department of Radiology, National Center for Child Health and Development, Tokyo, Japan

3 Department of Quantum Medical Technology, Faculty of Health Sciences, Kanazawa University, Ishikawa, Japan

4 Medical Exposure Research Project, National Institute of Radiological Sciences, Chiba, Japan

5 Department of Radiology, National Cancer Center Hospital East, Chiba, Japan

6 Radiological Technology, Graduate School of Medicine, Nagoya University, Aichi, Japan

7 Faculty of Radiological Technology, School of Health Sciences, Fujita Health University, Aichi, Japan

Keywords Child · Computed tomography · Diagnostic reference levels · Patient exposure · Pediatric

Introduction

As a result of the East Japan earthquake on March 11, 2011, large amounts of radioactive substances were released into the environment by the Fukushima Daiichi nuclear power plant [1, 2]. This accident has led to widespread public unease concerning radiation, and many hospitals have received numerous queries from patients with regard to medical radiation exposure.

Radiologists have a duty of providing accurate information regarding medical radiation exposure and explaining it to the public. Consequently, it is important to have current data that allow for global comparison and evaluation. A certain level of control is necessary over radiation exposure in patients;

Published online: 22 October 2015

therefore the International Commission on Radiological Protection (ICRP) has recommended the use of diagnostic reference levels (DRLs) [3]. However in Japan DRLs have not been set for diagnostic radiology.

The purpose of this study was to conduct a nationwide questionnaire survey concerning radiation exposure during pediatric CT of the head, chest and abdomen, and to propose DRLs for three pediatric age groups: infants (ages <1 year), young children (ages 1–5 years) and children (ages 6–10 years) in Japan.

Materials and methods

Ethics

Institutional review board approval was not required for this retrospective nationwide questionnaire study, and this study did not require informed patient consent.

Selection of study facilities

We sent questionnaire forms — including a website address for posting responses — by post to 339 facilities of members (as of March 2012) of the Japanese Society of Radiological Technology. These were mainly university and national hospitals that form the core of community medicine in Japan. We received responses to the questionnaire by post or through the website. We obtained approval from each facility to collect responses to the questionnaire by including this sentence: "Your response will not be used for anything other than calculating and analyzing the radiation dose and will be managed appropriately" in the questionnaire form.

Survey items

In the questionnaire, parameters regarding the scanning conditions included the assessment criteria for the pediatric CT protocol. These included tube voltage, tube current time product and rotation time, volume CT dose index ($CTDI_{vol}$) and dose–length product (DLP) displayed on the CT systems during head, chest and abdominal CT. The children were classified into three age groups: infants (ages <1 year), young children (ages 1–5 years) and children (ages 6–10 years). We asked participating institutions to confirm that the displayed $CTDI_{vol}$ was based on a 16-cm phantom. For devices that displayed the $CTDI_{vol}$ based on a 32-cm phantom, the participants were asked to enter the displayed $CTDI_{vol}$ 32, which was explicitly stated in the form. We converted $CTDI_{vol}$ 32 to $CTDI_{vol}$ 16 by multiplying by a factor of 2 [4, 5].

Data analysis

The CT scanning conditions, $CTDI_{vol}$ and DLP, obtained from the questionnaire were summarized and compared among facilities. Statistical significance was determined using Student's *t*-test, and the significance level was set at $P<0.05$. Calculations were performed using Microsoft Excel version 2010 (Microsoft, Redmond, WA).

Results

Of the 339 facilities to which the questionnaires were sent, people at 196 (58%) responded. In total, 1,002 displayed $CTDI_{vol}$ values from 164 facilities and 955 displayed DLP values from 157 facilities were available for data analysis. This was because 32 cases involving $CTDI_{vol}$ and 39 cases involving DLP were excluded because participants entered values incorrectly, the entry form could not be corrected, or there were blank entries on the form.

Tube voltage

For all age groups and scanned areas, the most frequently used tube voltage was 120 kV, which was used in 90% (522/578) of head CT scans, 79% (265/334) of chest CT scans and 82% (277/339) of abdominal CT scans. A low tube voltage of 80–100 kV was not used frequently; it was only used in 7% (42/578) of head CT scans, 18% (61/334) of chest CT scans, and 16% (55/339) of abdominal CT scans.

Tube current time product (mAs)

The median value of the tube current time ranged 120–225 mAs for the head, 46–63 mAs for the chest and 50–75 mAs for the abdomen (Fig. 1). Current-time products increased with age.

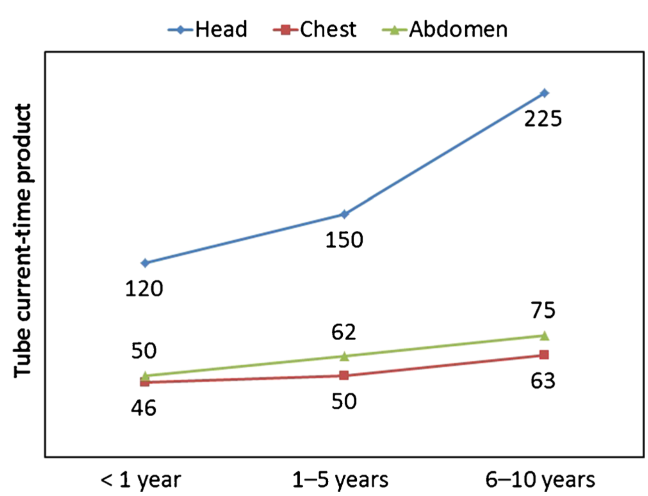


Fig. 1 Median tube current-time product for head, chest and abdominal CT scans by age group based on data from the Japanese national survey

Rotation time

For head examination, the most frequent rotation time used for children of all age groups was 1.0 s (41–48% of protocols) followed by 0.5 s (17–29% of protocols). For the chest, 0.5 s was used in 50–65% of protocols, 0.4 s in 20–30%, and 0.3 s in 1–7%. For the abdomen, 0.5 s was used in 65–73% of protocols, 0.4 s in 17–23%, and 0.3 s in 1–4%.

Pitch values

The pitch values were reported between 0.3 and 1.6 for different examinations and age groups. For head examination, a pitch of ≤1 was used in 94–97% of protocols, depending on the age groups. The most frequent pitch for all age groups was 0.7, used in 38–44% of protocols. For chest examination, a pitch between 0.9 and 1.6 was used in 89–91% of protocols, depending on the age group. The most frequent pitch for all age groups was 0.9, used in 31–35% of protocols. Similarly, for the abdominal examination, a pitch between 0.9 and 1.6 was used in 85–92% of protocols. The most frequent pitch for all age groups was 0.9, used in 22–24% of protocols.

Displayed $CTDI_{vol}$ on CT systems

Nine hundred seventy displayed $CTDI_{vol}$ values were obtained at 164 facilities. In the infant group, 16% (152/970), 8% (79/970) and 8% (74/970) were for head, chest and abdominal CT scans, respectively. In the young-children group, 16% (154/970), 8% (81/970) and 9% (84/970) were for head, chest and abdominal CT scans, respectively. In the children group, 17% (164/970), 9% (89/970) and 10% (93/970) were for head, chest and abdominal CT scans, respectively.

Table 1 shows minimum, maximum, median and 75th percentile values of $CTDI_{vol}$ from routine protocols. The 75th percentile $CTDI_{vol}$ [mGy] ranged 39.1–67.7 for the head, 11.1–15 for the chest, and 12–17 for the abdomen. The $CTDI_{vol}$ values increased with age.

Dose–length product displayed on CT systems

Nine hundred sixteen displayed DLP values were obtained at 157 facilities. In the infant group, 16% (143/916), 8% (73/916) and 7% (68/916) were for head, chest and abdominal CT scans, respectively. In the young-children group, 16% (145/916), 8% (76/916) and 9% (79/916) were for head, chest and abdominal CT scans, respectively. In the children group, 17% (157/916), 9% (85/916) and 10% (90/916) were for head, chest and abdominal CT scans, respectively.

Table 2 shows the minimum, maximum, median and 75th percentile values of DLP obtained from routine protocols. The 75th percentile DLP values [mGy · cm] ranged 526.1–847.9 for the head, 209.1–413.0 for the chest and 261.5–532.2 for the abdomen. The DLP values increased with age.

Comparison of 75th percentile of $CTDI_{vol}$ and dose-length product values with other surveys

Tables 3 and 4 show the comparison between $CTDI_{vol}$ and DLP values obtained in the present study with those from other published surveys from the United Kingdom, Germany, Switzerland, Thailand and the International Atomic Energy Agency (IAEA) [6–10]. All age-based 75th percentiles of the $CTDI_{vol}$ values for the head were 1–2 times higher and DLP values for the head were 0.9–1.9 times higher in the Japanese survey than in the other published surveys. The 75th percentile of the $CTDI_{vol}$ values for the chest were 1.4–3.2 times higher and the DLP values for the chest were 1.4–3.8 times higher in the Japanese survey than those reported from the German, Swiss, Thai and French surveys [7–9, 11] and nearly equal to the results reported for the British and IAEA surveys [6–10]. The 75th percentile of the $CTDI_{vol}$

Table 1 The minimum, maximum, median and 75th percentile values of the computed tomography dose index volume ($CTDI_{vol}$) from routine protocols in three pediatric age groups

$CTDI_{vol}$ (mGy)	Age group	Minimum	Maximum	Median	75th percentile
Head	<1 year	9.4	120.0	30.7	39.1
	1–5 years	9.4	109.3	36.1	46.9
	6–10 years	6.1	155.3	47.8	67.7
Chest	<1 year	0.6	48.0	5.4	11.1
	1–5 years	1.0	48.0	7.7	14.3
	6–10 years	2.2	33.9	8.3	15.0
Abdomen	<1 year	0.9	46.9	6.4	12.0
	1–5 years	1.5	46.9	9.7	16.7
	6–10 years	1.6	33.9	10.0	17.0

Table 2 The minimum, maximum, median and 75th percentile values of the dose–length product (DLP) obtained from routine protocols

DLP (mGy·cm)	Age group	Minimum	Maximum	Median	75th percentile
Head	<1 year	13.0	2,066.0	398.4	526.1
	1–5 years	16.7	2,066.0	463.5	665.5
	6–10 years	16.7	2,841.5	593.6	847.9
Chest	<1 year	11.1	945.4	90.0	209.1
	1–5 years	17.5	945.4	159.9	296.0
	6–10 years	24.0	960.3	228.6	413.0
Abdomen	<1 year	12.4	1,980.0	153.5	261.5
	1–5 years	54.8	1,980.0	251.0	430.8
	6–10 years	47.7	1,980.0	275.5	532.2

Table 3 The 75th percentiles of the computed tomography dose index volume ($CTDI_{vol}$) for pediatric CT scans in this study, by age and body part, compared with other surveys

75th percentile of $CTDI_{vol}$ (mGy)	Head			Chest			Abdomen		
	<1 year	1–5 years	6–10 years	<1 year	1–5 years	6–10 years	<1 year	1–5 years	6–10 years
Japan (this study)	39.1	46.9	67.7	11.1	14.3	15	12	16.7	17
IAEA [10]	29	37.7	46.1	[a]14	[a]16.4	[a]20	[a]21.4	[a]26	[a]24
Thailand [9]	26	29	39	4.5	5.7	10	7.7	8.9	13.8
France [11]	30	40	50	[a]6	[a]7	[a]11	[a]8	[a]9	[a]14
Switzerland [8]	20	30	40	5	8	10	7	9	13
Germany [7]	33	40	50	3.5	5.5	8.5	5	8	13
United Kingdom [6]	30	45	50	12	13	20	20	20	30

[a] Converted $CTDI_{vol\ 16}$ by doubling $CTDI_{vol\ 32}$

values for the abdomen were 1.2–2.4 times higher and the DLP values for the abdomen were 1.1–2 times higher in the Japanese survey than in the German, Swiss, Thai and French surveys [7–9, 11] and lower than in the British and IAEA surveys [6–10].

Relationship between tube voltage and the displayed $CTDI_{vol}$

The relationship between the tube voltage and 75th percentile of the displayed $CTDI_{vol}$ for the head, chest and abdominal CT scans in each age group is shown in Figs. 2, 3, and 4. The Student's *t*-test for statistical significance was performed between the tube voltage and displayed $CTDI_{vol}$ for the head, chest and abdominal CT scans in each age group. For all scanning areas and all age groups, a significant difference of $P<0.01$ was observed between the $CTDI_{vol}$ for a tube voltage of 80 kV and that for a tube voltage of 120 kV.

Table 5 compares the $CTDI_{vol}$ and DLP values proposed as DRLs for pediatric CT in Japan to the $CTDI_{vol}$ and DLP for head, chest, and abdominal CT in each age group obtained from our survey.

Discussion

The aim of this study was to conduct a nationwide survey of radiation exposure during pediatric CT examinations and to establish DRLs in Japan. The survey conducted by our research group has revealed, for the first time, the details of pediatric CT radiation exposure in Japan such as the scanning conditions, $CTDI_{vol}$ and dose–length product. This survey was carried out in relatively large medical facilities, such as university and national hospitals, which form the core of community medicine in Japan. Consequently, it is likely that the results are an accurate representation of pediatric CT activities in Japan.

Many facilities are using a tube voltage of 120 kV as a scanning condition for pediatric CT in Japan — ~90% of the facilities surveyed used this voltage. In contrast, only a few facilities are using a low tube voltage of 80–100 kV, which is useful for reducing pediatric CT radiation exposure [12]. When we investigated the relationship between the tube voltage and the $CTDI_{vol}$, we found that the $CTDI_{vol}$ for facilities using a tube voltage of 80 kV was significantly lower than that for facilities using 120 kV. Using a low tube voltage, the $CTDI_{vol}$ can be reduced in pediatric CT. When considering

Table 4 Comparison of 75th percentile of the dose–length product (DLP) for pediatric CT scans in this study, by age and body part, compared with other surveys

75th percentile of DLP (mGy·cm)	Head			Chest			Abdomen		
	<1 year	1–5 years	6–10 years	<1 year	1–5 years	6–10 years	<1 year	1–5 years	6–10 years
Japan (this study)	526	666	848	209	296	413	262	431	532
Thailand [9]	402	570	613	80	140	305	222	276	561
France [11]	420	600	900	[a]60	[a]126	[a]274	[a]160	[a]242	[a]490
Switzerland [8]	270	420	560	110	200	220	130	300	380
Germany [7]	390	520	710	55	110	210	145	255	475
United Kingdom [6]	270	470	620	200	230	370	330	360	800

[a] Converted to DLP_{16} by doubling DLP_{32}

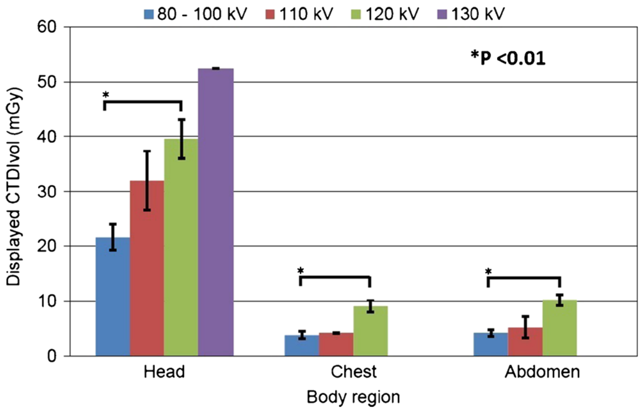


Fig. 2 Relationship between the CT tube voltage and the 75th percentile displayed as the $CTDI_{vol}$ on CT systems in head, chest and abdominal CT scans in infants ($P<0.01$)

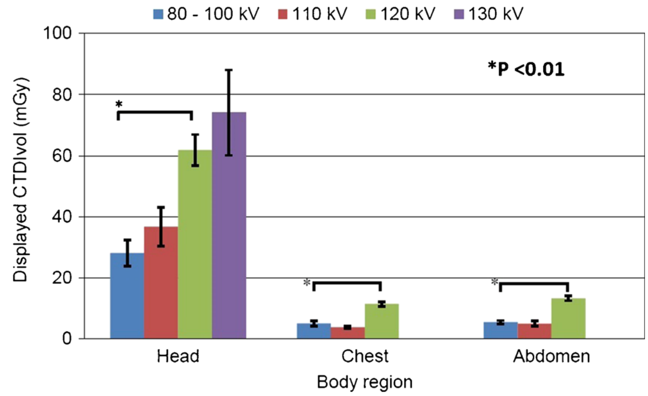


Fig. 4 Relationship between the scanning tube voltage and the 75th percentile displayed as the $CTDI_{vol}$ on CT systems in head, chest and abdominal CT scans in 6-to 10-year-olds

the optimization of exposure in pediatric CT, the use of low tube voltage is an important feature.

Previous studies on radiation exposure in pediatric patients, who are particularly vulnerable to the effects of radiation, have been conducted [13, 14]; these studies focused on calculation of the population dose and the evaluation of exposure in terms of mAs. Fukushima et al. [15] conducted a survey on the radiation exposure involved in CT examination within Gunma Prefecture and reported that the DLP for pediatric head CT was higher than that used in other countries. Thus, pediatric CT radiation exposure in Japan was expected to be higher than that in other countries.

Our survey also found that the DLP values for pediatric CT in Japan were higher than in other surveys [8–11]. The 75th percentile values of the $CTDI_{vol}$ for pediatric CT in our survey were higher than those in the survey conducted by the IAEA [10]. Furthermore, the 75th percentile values of DLP were markedly higher than those reported in other countries [8–11]. In other words, our results imply that $CTDI_{vol}$ of pediatric CT is higher in Japan than in other countries and that scanning is being conducted over a wider area of the body.

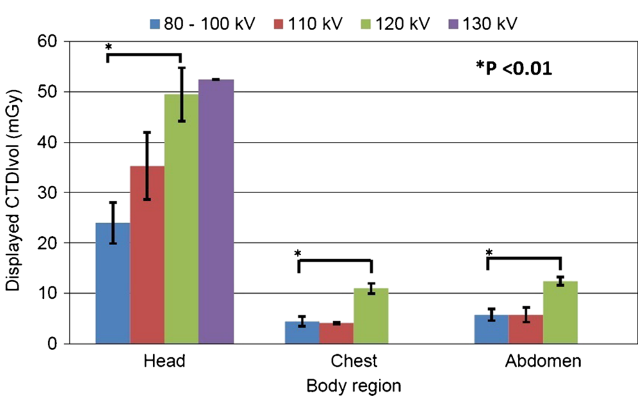


Fig. 3 Relationship between the CT tube voltage and the 75th percentile displayed as the $CTDI_{vol}$ on CT systems in head, chest and abdominal CT scans in 1-to 5-year-olds ($P<0.01$)

In Japan, pediatric CT protocols are assessed according to image quality and dose. However, many facilities use other quality assessments such as consultation with a physician and assessments based on experience and manufacturer recommendations [16]. No clear standard on image quality for pediatric CT has been established; therefore the scanning conditions adopted have been at the discretion of the physician or radiologic technologist at the clinical site. Consequently, the standard scanning conditions for pediatric CT scans have not necessarily been set appropriately. Thus there is room for improvement in optimizing the balance between image quality and radiation exposure in pediatric CT examination in Japan. Radiologic staff training has been found to be effective in reducing radiation exposure [17]. Therefore it is necessary to carry out appropriate education for radiologic staff in Japan regarding radiation exposure in pediatric CT.

Regarding our survey results, we excluded 32 cases involving $CTDI_{vol}$ and 39 cases involving DLP because participants entered values incorrectly, the entry form could not be corrected, or there were blank entries on the form. We received responses from 196 facilities; therefore after exclusions we had $CTDI_{vol}$ values from 164 facilities and the DLPs from

Table 5 The CTDIvol and DLP values proposed as age-based DRLs for pediatric CT scans in Japan

Body region	Proposed DRLs	<1 year	1–5 years	6–10 years
Head	$CTDI_{vol}$ (mGy)	38	47	60
	DLP (mGy·cm)	500	660	850
Chest	$CTDI_{vol}$ (mGy)	11 (5.5)	14 (7)	15 (7.5)
	DLP (mGy·cm)	210 (105)	300 (150)	410 (205)
Abdomen	$CTDI_{vol}$ (mGy)	11 (5.5)	16 (8)	17 (8.5)
	DLP (mGy·cm)	220 (110)	400 (200)	530 (265)

The numbers in brackets are phantom measurements (32-cm diameter PMMA phantom)

157 facilities for data analysis. However, 57% of the facilities did not provide data for at least one of the scanning conditions, $CTDI_{vol}$ or DLP, and for at least one of the age groups, which was the principal limitation of our questionnaire survey. The latest multi-detector CT systems often have a function to output $CTDI_{vol}$ and DLP values in the form of a radiation dose structure report formed by digital imaging and communications in medicine [18]. In the United States, this dose report is used for dose optimization through a dose index registry via the dose index reporting application [19]. The introduction of the registry using these dose reports in the future would facilitate the collection of more precise $CTDI_{vol}$ and DLP data from many facilities in Japan.

Based on the distribution of the $CTDI_{vol}$ for pediatric CT gathered from this survey, we have proposed DRLs for pediatric CT examinations in Japan. Although our proposed DRLs are higher than those used in other countries, it is important to encourage facilities that are conducting examinations using $CTDI_{vol}$ that are higher than the values that we have proposed to urgently reassess their scanning conditions. Regarding practical application, the results obtained in the current survey can contribute to the prompt establishment of DRLs for pediatric CT examinations to promote the optimization of pediatric CT scan protocols in Japan.

Conclusion

Our survey of pediatric CT in Japan showed that all age-based Japanese 75th percentiles of the $CTDI_{vol}$ and DLP values were higher than in surveys of other countries. To promote the optimization of pediatric CT scan protocols, it is therefore necessary to establish DRLs for pediatric CT examinations in Japan.

Acknowledgments We thank the members of Japanese Society of Radiological Technology for their cooperation in the questionnaire survey, and Mr. Yuta Matsunaga and Ms. Ai Kawaguchi for their assistance in sending and collecting the questionnaire. This research was financially supported by the Japanese Society of Radiological Technology (Scientific Research Group 2012 grant) and a Japanese National Center for Child Health and Development (grant 26–20).

Compliance with Ethical Standards

Conflicts of interest None

References

1. Hashimoto S, Ugawa S, Nanko K et al (2012) The total amounts of radioactively contaminated materials in forests in Fukushima, Japan. Sci Rep 2:416
2. Ueda S, Hasegawa H, Kakiuchi H et al (2013) Fluvial discharges of radiocaesium from watersheds contaminated by the Fukushima Dai-ichi Nuclear Power Plant accident, Japan. J Environ Radioact 118:96–104
3. International Commission on Radiological Protection (1996) Radiological protection and safety in medicine. ICRP Publication 73. Annals of ICRP(26). Pergamon Press, Oxford
4. Thomas KE, Wang B (2008) Age-specific effective doses for pediatric MSCT examinations at a large children's hospital using DLP conversion coefficients: a simple estimation method. Pediatr Radiol 38:645–656
5. McNitt-Gray MF (2002) AAPM/RSNA physics tutorial for residents: topics in CT. Radiation dose in CT. Radiographics 22: 1541–1553
6. Shrimpton PC, Hillier MC, Lewis MA et al (2006) National survey of doses from CT in the UK: 2003. Br J Radiol 79:968–980
7. Galanski M, Nagel HD, Stamm G (2006) Paediatric CT exposure practice in the Federal Republic of Germany: results of a nation-wide survey in 2005/2006. Medizinishe Hochshule, Hannover
8. Verdun FR, Gutierrez D, Vader JP et al (2008) CT radiation dose in children: a survey to establish age-based diagnostic reference levels in Switzerland. Eur Radiol 18:1980–1986
9. Kritsaneepaiboon S, Trinavarat P, Visrutaratna P (2012) Survey of pediatric MDCT radiation dose from university hospitals in Thailand: a preliminary for national dose survey. Acta Radiol 53: 820–826
10. Vassileva J, Rehani MM, Applegate K et al (2013) IAEA survey of paediatric computed tomography practice in 40 countries in Asia, Europe, Latin America and Africa: procedures and protocols. Eur Radiol 23:623–631
11. Brisse HJ, Aubert B (2009) CT exposure from pediatric MDCT: results from the 2007-2008 SFIPP/ISRN survey. J Radiol 90:207–215
12. Nievelstein RA, van Dam IM, van der Molen AJ (2010) Multidetector CT in children: current concepts and dose reduction strategies. Pediatr Radiol 40:1324–1344
13. Nishizawa K, Matsumoto M, Iwai K et al (2004) Survey of CT practice in Japan and collective effective dose estimation. Nippon Igaku Hoshasen Gakkai Zasshi 64:151–158
14. Miyazaki O, Kitamura M, Masaki H et al (2005) Current practice of pediatric MDCT in Japan: survey results of demographics and age-based dose reduction. Nippon Igaku Hoshasen Gakkai Zasshi 65: 216–223
15. Fukushima Y, Tsushima Y, Takei H et al (2012) Diagnostic reference level of computed tomography (CT) in Japan. Radiat Prot Dosimetry 151:51–57
16. Takei Y, Suzuki S, Miyazaki O et al (2014) Summary of the survey on radiation exposure of pediatric CT examination in Japan — focus on environments of CT examination. Nippon Hoshasen Gijutsu Gakkai Zasshi 70:562–568
17. Paolicchi F, Faggioni L, Bastiani L et al (2014) Optimization the balance between radiation dose and image quality in pediatric head CT: findings before and after intensive radiologic staff training. AJR Am J Roentgenol 202:1309–1315
18. Shih G, Lu ZF, Zabih R et al (2011) Automated framework for digital radiation dose index reporting from CT dose reports. AJR Am J Roentgenol 197:1170–1174
19. Morin RL, Coombs LP, Chatfield MB (2011) ACR dose index registry. J Am Coll Radiol 8:288–291