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Consideration of diagnostic reference levels for pediatric chest X-ray examinations

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Abstract
The use of diagnostic reference levels (DRLs) is currently recommended, and dose evaluation is considered to be important for establishing a Japanese radiological protection system in radiological medicine. Children, in particular, are sensitive to radiation, and their exposure levels must be taken into account. The DRL for the entrance surface dose (ESD) used in pediatric chest X-ray examinations in Japan is 0.2 mGy. However, the bodies of infants and young children show major changes with rapidly developing organs. Thus, the possibility that organ development may also be affected by radiation exposure should be taken into account. Therefore, radiological technologists must be conservative in setting radiographic conditions for pediatric examinations. The objective of this study was to evaluate the doses used in pediatric chest X-ray examinations at our hospital and compare them with the current DRLs, considering the assumption that setting conditions individually for different ages and subject thicknesses and performing more detailed dose evaluations will help reduce radiation exposure. The study was carried out to estimate the ESDs in 163 pediatric patients who underwent frontal or lateral chest X-ray examinations at our hospital. All doses were lower than 0.2 mGy, the dose recommended in the Japanese DRLs 2015. The doses showed a strong correlation with age, but a weaker correlation with subject thickness. These results suggest that instead of considering a common DRL for all children, the DRL should be evaluated on the basis of age.

Keywords Age · Diagnostic reference level · Entrance surface dose · Pediatric radiography

1 Introduction

Recent years have seen dramatic advances in radiographic equipment, as well as increases in the numbers of investigations and available devices. Numerous radiological investigations are performed in Japan, and medical radiation exposure levels among Japanese patients are higher than those in other countries [1].

The Japanese diagnostic reference levels (DRLs) were formulated in 2015. The International Commission on Radiological Protection (ICRP) first introduced the term "diagnostic reference level" (DRL) in Publication 73 [2]. The concept was subsequently developed further, and practical guidance was provided in 2001 [3]. DRLs are published as a tool to promote dose optimization in line with the principle of keeping the radiation dose "as low as reasonably achievable" (ALARA). In Japan, these have been summarized as DRLs 2015 by the Japan Network for Research and Information on Medical Exposure (J-RIME) [4].

DRLs are set for individual countries, regions, and institutions at the 75th percentile of the typical dose for each modality measured using a patient with an average physique or a standard phantom. In Japan, the entrance surface dose (ESD) is generally used as an index for the DRL in general radiographic examinations. It is recommended that the median ESD be used for comparisons with the DRL values [5].

Radiation exposure in pediatric patients became a focus of attention with the publication of Brenner et al.'s study in 2001, which stated that 500 of the 600,000 patients aged 15 years or under who undergo cranial or abdominal computed tomography (CT) every year in the United States of America (USA) will die of cancer [6]. However, that study was based on a relative risk model that used long-term

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follow-up data of atomic bomb victims from Hiroshima and Nagasaki, a model that remains in the realm of speculation. The numbers used in the calculations also failed to reflect the scanning conditions currently used in the USA, and they have therefore been criticized as being exaggerated [7]. Nevertheless, that study prompted discussion on the optimization and rationalization of radiation doses to control the risk of radiation exposure in pediatric medicine.

The chest is the part of the body that is most frequently examined in diagnostic X-ray examinations in children. Chest X-ray examinations account for ≥ 60% of the X-ray examinations performed in pediatric medicine every year [8]. Because chest X-ray examinations are used to diagnose and monitor conditions affecting the respiratory system, they are an essential procedure during infancy and childhood [9]. Chest radiography entails radiation exposure over a wide area, and this area includes the radiation-sensitive undeveloped breasts and thyroid. According to a report by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (which investigated 23 different types of cancer), children are highly sensitive to radiation and, in comparison with adults, are clearly at a higher risk of leukemia and cancers of the thyroid, skin, breast, and brain, which account for approximately 25% of all cancers [10].

Children's bodies are in the process of growth and development, and they are therefore highly sensitive to radiation. Great caution is, therefore, required even with regard to low-dose radiation exposure from diagnostic radiology procedures. More careful dose management is, therefore, required in pediatric radiography, and dose monitoring at regular periods is recommended. The current Japanese DRL for pediatric chest X-ray examinations is 0.2 mGy. However, indicators that take greater account of the patient's body size and age are required. The objective of this study was, therefore, to evaluate the doses used in pediatric chest X-ray scanning at our hospital and compare them with the current DRLs, with the aim of raising awareness of dose management in radiological medicine.

2 Materials and methods

The study was carried out over a 13-month period between October 2016 and October 2017, and 163 pediatric patients who underwent frontal or lateral chest X-ray examinations at our hospital were investigated. The subject population consisted of boys and girls aged up to 5 years (60% boys, 40% girls). This age range was chosen on the basis of the descriptions of infants and young children in DRLs 2015, which used the age categories of "infants" and "toddlers" as defined in the Child Welfare Act in Japan [11]. This study was approved by the Ethics Research Committee of our university (HM16–275) under the title "Study to investigate diagnostic reference levels (DRL) in general radiographic examinations." The requirement for informed consent was waived due to the retrospective nature of the study.

Subject thickness must be known to calculate the ESD. Patient subject thickness was estimated by Ichikawa et al.'s method [12] using frontal and lateral pediatric chest radiographs, with body width measured at the diaphragm level on frontal images and subject thickness measured at the level of the center of the sternum on lateral images.

The age groups assessed were 0-year-olds (0–11 months, $n = 15$), 1-year-olds (12–23 months, $n = 63$), 2-year-olds (24–35 months, $n = 28$), 3-year-olds (36–47 months, $n = 21$), 4-year-olds (48–59 months, $n = 21$), and 5-year-olds (60–71 months, $n = 15$). Subject thickness was categorized as ≤ 10.9 cm ($n = 13$), 11.0–11.9 cm ($n = 38$), 12.0–12.9 cm ($n = 56$), 13.0–13.9 cm ($n = 46$), and ≥ 14.0 cm ($n = 10$).

When estimating the ESD, the half-value layer and X-ray output at each tube voltage were measured. Radiographic condition data for the tube voltage and tube current–time product were obtained from Digital Imaging and Communications in Medicine (DICOM) tag data. The backscatter factor was obtained from the measured half-value layer and radiation field size [13]. The ESD used as the DRL value was calculated from Eq. 1.

$$D = D_{\text{air}}/mAs \times mAs \times \text{BSF} \times (\text{SCD}/\text{SSD})^2 \quad (1)$$

D ESD
D_{air}/mAs Air kerma per mAs
BSF Backscatter factor
$(\text{SCD}/\text{SSD})^2$ Distance correction
SCD Source-chamber distance
SSD Source-surface distance

The following devices were used.

- Wireless X-ray output analyzer: Piranha (RTI, MöIndal, Sweden)
- Ionization chamber dosimeter: Model 9015 (Radcal Corporation, Monrovia, CA, USA)
- X-ray high-voltage generator: KXO-80SS (Toshiba Medical Systems Co., Ltd., Japan)
- X-ray tube: DRX-3724HD (Toshiba Medical Systems Co., Ltd.)
- X-ray beam-limiting device: BLR-2000A (Toshiba Medical Manufacturing Co., Ltd., Japan)
- X-ray flat-panel detector: CALNEO smart: DR-ID1212SE (Fujifilm Corporation, Japan)

Table 1 Average and SD of subject thickness (chest depth) in each age group

Age (*n*)	Average [cm]	SD
0 years (15)	11.3	1.123
1 year (63)	12.1	0.837
2 years (28)	12.7	0.762
3 years (21)	12.8	1.022
4 years (21)	13.2	0.927
5 years (15)	13.3	0.947

SD standard deviation

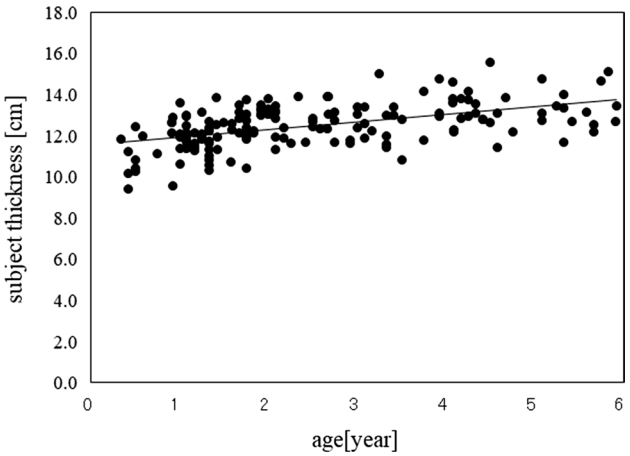

Fig. 1 Relationship between age and subject thickness

3 Results

3.1 Subject thickness measurement

Table 1 shows the mean subject thickness and its standard deviation in each age group, and Fig. 1 shows a graph of subject thickness plotted against age. Although there was some variation in the distribution, overall subject thickness tended to increase with age. Subject thickness was significantly less for 0-year-olds and 1-year-olds than for all the other age groups. It was also significantly less in 2-year-olds than in 4-year-olds or 5-year-olds (t test, $p < 0.05$). Spearman's correlation coefficient was calculated using SPSS Ver. 20 (IBM) and $r = 0.525$ ($p < 0.01$), indicating a positive correlation.

3.2 Estimation of ESD

Table 2 shows the results by age group and used tube voltage. The median ESD was 0.024 mGy for 0-year-olds, 0.030 mGy for 1-year-olds, 0.030 mGy for 2-year-olds, 0.034 mGy for 3-year-olds, 0.035 mGy for 4-year-olds, and 0.063 mGy for 5-year-olds. It was significantly lower for 0-year-olds than for all other age groups, except 2-year-olds (t test, all $p < 0.05$). It was significantly lower for 1-year-olds and 2-year-olds than for 4-year-olds and 5-year-olds, for 3-year-olds than for 4-year-olds and 5-year-olds, and for 4-year-olds than for 5-year-olds (t test, all $p < 0.05$). Patients younger than 4 years of age normally underwent examinations with a tube voltage of around 65 kV and without a grid, but if the patient age was more than 4 years, a high voltage of more than 100 kV and a grid were used for scanning. The value was below the DRL of 0.2 mGy in all age groups. There was a large difference between the maximum and minimum values in 4-year-olds and 5-year-olds. Figure 2 shows a graph of ESD by age. The distribution tended to extend further toward higher doses with increasing age, particularly for 4-year-olds and 5-year-olds. The Spearman's correlation coefficient r was 0.413 ($p < 0.01$), indicating a somewhat weak correlation.

Figure 3 shows a graph of ESD by subject thickness. As with age, the distribution tended to extend further toward higher doses with increasing subject thickness. The difference from the pattern for age is that the extension of the distribution started at as early as 11.0 cm. The Spearman's correlation coefficient r was 0.292 ($p < 0.01$), indicating a somewhat weak correlation.

Table 2 Median, average (SD), and maximal and minimal values of entrance surface dose and tube voltage used by age [mGy]

Age	0 years	1 year	2 years	3 years	4 years	5 years
n	15	63	28	21	21	15
Median	0.025	0.030	0.030	0.034	0.035	0.063
Average (SD)	0.027 (0.004)	0.032 (0.009)	0.030 (0.007)	0.033 (0.006)	0.043 (0.018)	0.063 (0.031)
Max	0.034	0.053	0.053	0.046	0.087	0.146
Min	0.024	0.021	0.024	0.023	0.020	0.022
Tube voltage [kV] (SD)	65	64.9 (1.3)	65.3 (0.7)	65.0 (1.1)	78.3 (19.9)	93.8 (25.4)

SD standard deviation, *Max* maximal, *Min* minimal

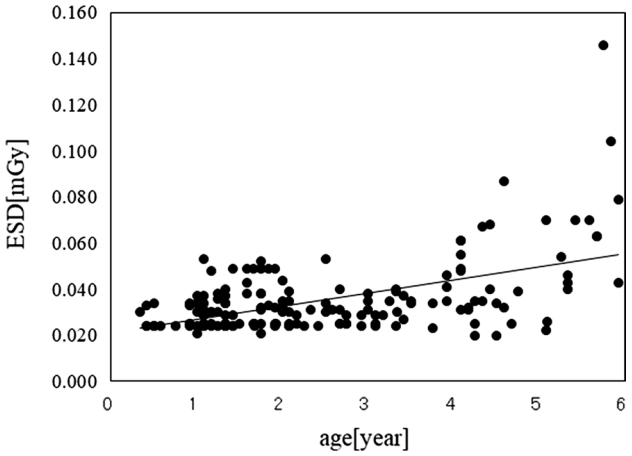

Fig. 2 Relationship between age and entrance surface dose

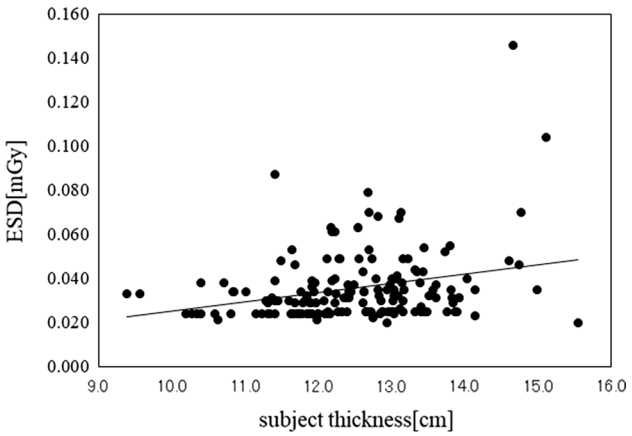

Fig. 3 Relationship between subject thickness and entrance surface dose

4 Discussion

4.1 Subject thickness measurement

Ichikawa et al.'s method of estimating subject thickness [12] was used because it has been shown to be effective in a phantom study, with a very low error (less than 1%). The standard subject thicknesses for infants and toddlers set out in DRLs 2015 are 10 cm and 15 cm, respectively. It defines infants as those aged 0 years, and in the present study, the mean subject thickness of 0-year-olds was 11.3 cm, a difference of + 1.3 cm from the standard subject thickness. This positive difference between the present result and the standard subject thickness of infants may have arisen because the present study did not include any infants aged 0–3 months, with only the results of those aged 4–11 months shown. In the present study, young children were defined as those aged 1–5 years, and their mean value was 12.6 cm, a difference of − 2.4 cm from the standard subject thickness. This negative difference between the present result and the standard subject thickness of young children was the result of a bias in the study population. Half of the data on 1–5-year-olds included in the study was concerned with 1-year-olds. Subject thickness clearly increases with increasing age, and a large proportion of 1-year-olds were in either the 11.0–11.9 cm or the 12.0–12.9 cm categories. This effect of the 1-year-old group resulted in the overall value being somewhat low. However, in another study, the average infant chest thickness was 10.7 cm and that in children aged 1-5 years was 12.1 cm [14]. Therefore, we think that the assumptions made in this study are proper. We think that that 15-cm value for the child's chest in DRLs 2015 is too high.

4.2 Estimation of ESD

The median ESD values for both infants and young children were well below the DRL because, in our hospital, we do not use automatic exposure control (AEC). In pediatric investigations, the AEC sensors do not properly cover all the regions of the patient's body. Although some authors maintain that AEC can help reduce the radiation dose [15], Publication 135 of the ICRP recommends that manual scanning rather than AEC be used for pediatric patients [5]. In our hospital, other than under exceptional circumstances, scanning of pediatric patients is carried out manually, without the use of AEC. As a result, scanning is performed individually for each patient. However, this may result in the use of an excessively high or low dose.

There was a large difference between the maximum and minimum doses used for 4-year-olds and 5-year-olds. This was because scanning was normally performed with a tube voltage of around 65 kV and without a grid, but if the subject was thicker, a high voltage of ≥ 100 kV and a grid were used for scanning. According to Watanabe et al. [16], ESD is significantly higher when a grid is used than when it is not.

The ESDs in this study were well below those recommended in DRLs 2015. The values given in DRLs 2015 do not consider the difference between computed radiography (CR) and flat-panel detector (FPD) radiography, but a detailed examination of the data [4] has shown that CR involves a higher dose than does FPD radiography. Since CR and FPD have different detective quantum efficiencies, FPD radiography may require a dose half or lower than that of CR to provide equivalent resolution [17], and the use of different receiver systems may thus have a major effect on the changes in dose. Asada et al. [18] also suggested that the use of FPDs may reduce the radiation exposure dose. The fact that only FPD radiography was used in the present study may have increased the difference between the present results and the

DRLs 2015 recommended doses. In international terms, however, the value of 0.2 mGy stipulated in Japan is somewhat high. In the European guidelines [19], the ESD for 5-year-olds is set at 100 μGy. In a 2008 European survey [20], the mean ESD was 0.135 mGy (0.062–0.353 mGy). In some countries, the value is set even lower for infants, at 0.08 mGy [21] or even 0.055 mGy [22]. Some countries also stipulate values by body weight and age. In terms of age, some countries set different DRLs for different subcategories of pediatric patients, dividing them at ages of 0, 1, 5, 10, and 15 years [22]. There are obvious differences between Japan and other nations in terms of both physique and scanning methods, meaning that these conditions must be specified individually. Therefore, it is recommended that individual countries set their own DRLs, which can be used with reference to the conditions set in those countries.

Studies of DRLs for pediatric radiology are difficult to perform in many hospitals. DRL studies should include at least 20 patients, but only a small number of pediatric patients undergo radiological investigations. Moreover, body weight, including a consideration of physique, should be used in surveys of pediatric patients, but the addition of weight data to scanning records is not a standard practice. Since patient weight is not included in scanning records, these records are difficult to use in regular studies. In this study, age and subject thickness were correlated with ESD, and these parameters have the advantage of being easier to use than weight. The present results also showed that the correlation was greater for age than for subject thickness, and it is easier for medical radiological technologists to be aware of age during scanning. Establishing finely graded DRLs for different ages would make it easier to establish conditions that facilitate awareness of changes in subject thickness and weight, and thus taking into account the patient's physique. Future studies should, therefore, use age as a simple tool that enables easy comparisons. However, patient age categories have been used in the past to define groups of children for the purpose of establishing pediatric DRL values, and it has become apparent that age alone is not a good indicator. Weight categories are preferred, and should be used whenever possible [5]. Considering these aspects, we think that patient weights should be recorded in the future because of the correlation between ESD and weight as shown in Table 3.

Table 3 Correlation of parameters with ESD

$n=24$	ESD
Age	0.565
Weight	0.587
Subject thickness	0.644

Significant at $p<0.01$

5 Conclusion

In this study, the radiation doses used in our hospital for X-ray imaging of children, who are highly sensitive to radiation and whose bodies are in the process of growth and development, were evaluated, and the results were compared with the DRLs. The actual doses were well below the DRL of 0.02 mGy, but the results indicate that DRLs should be identified for different age groups in the future to enable more careful and regular dose evaluation.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest related to this paper.

Ethical approval This study was retrospective in nature and hence did not require informed consent. For this type of study, formal consent is not required in our Institution.

Informed consent We provided a means to opt out in the study to use diagnosed images only.

References

1. Akabane K. The present situation of medical exposure. Innervision. 2010;25:46–9 **(in Japanese)**.
2. ICRPPublication73. Radiological protection and safety in medicine. Ann ICRP 1996;26(2).
3. ICRP Supporting Guidance 2 (2001) Radiation and your patient: a guide for medical practitioners. Ann ICRP 2001;31(4).
4. Diagnostic reference levels based on latest surveys in Japan—Japan DRLs 2015–http://www.radher.jp/J-RIME/report/DRLhoukokusyo.pdf.
5. Diagnostic Reference Levels in Medical Imaging Publication135. Ann ICRP. 2017;46(1).
6. Brenner D, Elliston C, Hall E, Berdon W. Estimated risks of radiation-induced fatal cancer from pediatric CT. AJR Am J Roentgenol. 2001;176:289–96.
7. Nancy SR. Taking care of children. AJR Am J Roentgenol. 2001;177:715–7.
8. Iacob O, Diaconescu C, Isac R. Patient exposure in paediatric radiology. In: European IRPA congress 2002 proceedings. 2002; p. 8–11.
9. Wadzanai B, Cynthia K, Farirayi K, Josephat B. Radiation doses received by paediatric patients during chest X-ray examinations at a central hospital in Harare, Zimbabwe. Int J Sci Basic Appl Res. 2015;24:361–72.
10. UNSCEAR Report. Effects of radiation exposure of children. 2013; Volume II Annex B.
11. Child Welfare Act in Japan. https://elaws.e-gov.go.jp/search/elawsSearch/elaws_search/lsg0500/detail?lawId=322AC0000000164#C.

12. Ichikawa T, Ono K, Asada Y. Evaluation of entrance surface dose in chest radiography using clinical images: estimation of subject thickness using two-direction radiography. J Radiol Technol. 2018;74:661–6 **(in Japanese)**.
13. Kato H. Method of calculating the backscatter factor for diagnostic X-rays using the differential backscatter factor. J Radiol Technol. 2001;57:1503–10.
14. Research Institute of Human Engineering for Quality Life "Body sizes database of children". https://www.hgl.jp/database/cat/size/children.
15. Kim HB, Do KH, Goo WH, et al. National survey of radiation doses of pediatric chest radiography in Korea: analysis of the factors affecting radiation doses. Korean J Radiol. 2012;13:610–7.
16. Watanabe H, Seki M, Nitta M, et al. Propose for the benchmark dose (BD) for the optimization of protection in medical exposure in general radiography. J Radiol Technol. 2018;74:443–51.
17. Kishimoto K, Ariga E, Ishigaki R, et al. Study of appropriate dosing in consideration of image quality and patient dose on the digital radiography. J Radiol Technol. 2011;67:1381–97 **(in Japanese)**.
18. Asada Y, Suzuki S, Kobayashi K, et al. Investigation of patient exposure doses in diagnostic Radiography in 2011 questionnaire. J Radiol Technol. 2013;69:371–9 **(in Japanese)**.
19. EC. European guidelines on quality criteria for diagnostic radiographic images in paediatrics EUR-16261. Brussels, Luxembourg; 1996.
20. Smans K, Vaño E, Sanchez R, et al. Results of a European survey on patient doses in paediatric radiology. Radiat Prot Dosim. 2008;129:204–10.
21. Roch P, Aubert B. French diagnostic reference levels in diagnostic radiology, computed tomography and nuclear medicine 2004-2008 review. Radiat Prot Dosim. 2012;154:52–75.
22. Billinger J, Nowontny R, Homolka P. Diagnostic reference levels in paediatric radiology in Austria. Eur Radiol. 2010;24:1572–9.