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

doi: 10.1007/s00247-015-3474-x

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, Shoichi Suzuki, Kichiro Koshida

Y. Takei (Corresponding author)

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 Tel: +81-53-435-2733. Fax: +81-53-435-2782. E-mail: ytakei-ham@umin.net

O. Miyazaki

Department of Radiology, National Center for Child Health and Development, 2-10-1 Okura, Setagaya-ku, Tokyo 157-8535, Japan

K. Matsubara, K. Koshida

Department of Quantum Medical Technology, Faculty of Health Sciences, Kanazawa University, 5-11-80 Kodatsuno, Kanazawa, Ishikawa 920-0942, Japan

Y. Shimada, K. Akahane

Medical Exposure Research Project, National Institute of Radiological Sciences,

4-9-1 Anagawa, Inage-ku, Chiba 263-8555, Japan

Y. Muramatsu

Department of Radiology, National Cancer Center East Hospital, 6-5-1 Kashiwanoha,

Kashiwa, Chiba 277-8577, Japan

K. Fujii

Radiological Technology, Graduate School of Medicine, Nagoya University,

1-1-20 Daiko-minami, Higashi-ku, Nagoya, Aichi 461-8673, Japan

S. Suzuki

Faculty of Radiological Technology, School of Health Sciences, Fujita Health University,

1-98 Dengaku-gakubo, Kutsukake, Toyoake, Aichi 470-1192, Japan

Abstract

Background: The diagnostic reference levels (DRLs) are not established in Japan.

Objective: To establish DRLs for pediatric computed tomography (CT) of the head, chest and abdomen for three pediatric age groups.

Materials and Methods: A nationwide questionnaire was sent by post to 339 facilities. Questions focused on pediatric CT technology, exposure parameters, CT protocols, and radiation doses for the three age groups.

Results: For the three age groups in the 196 facilities that responded, the 75th percentile values of volume CT dose index 16 ($CTDI_{vol, 16}$) for head, chest and abdominal CT were 39.1, 11.1 and 12 mGy, respectively (infants); 46.9, 14.3 and 16.7 mGy, respectively (small children); and 67.7, 15 and 17 mGy, respectively (children). For these groups, dose length products 16 (DLP_{16}) for head, chest and abdominal CT were 526.1, 209.1 and 261.5 mGy*cm, respectively, 665.5, 296 and 430.8 mGy*cm, respectively and 847.9, 413 and 532.2 mGy*cm, respectively.

Conclusion: Our survey showed that the majority of $CTDI_{vol, 16}$ and DLP_{16} values for the head were higher than the DRLs from other countries. To promote the optimization of pediatric CT scan protocols, we consider that it will be necessary to establish DRLs for pediatric CT in Japan.

Keywords

computed tomography, patient exposure, pediatric, diagnostic reference levels

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 operated by Tokyo Electric Power Company (TEPCO) [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.

We are responsible for providing accurate information regarding medical radiation exposure and explaining it to the public. Consequently, it is important that we have the latest data that allow for global comparison and evaluation. A a certain level of control is necessary over radiation exposure in patients, 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 computed tomography (CT) of the head, chest and abdomen, and to establish DRLs for three pediatric age groups: infants (aged <1 year); small children (aged 1–5 years) and children (aged 6–10 years) in Japan.

Materials and Methods

Ethics

Our Institutional Review Board approval from the participating institutions was not required for this retrospective nationwide questionnaire study, and did not require informed patient consent.

Selection of study facilities

Questionnaire forms complete with the URL of the website for posting the response, were sent by post to 339 facilities of members (as of March 2012) of the Japanese Society of Radiological Technology (JSRT). These were mainly university and national hospitals that form the core of community medicine in Japan. Responses to the questionnaire were received by post or through the website. We obtained approval from each facility to obtain responses to the questionnaire by including the 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 (aged <1 year); small children (aged 1–5 years); and children (aged 6–10 years). We asked participating institutions to confirm that the displayed $CTDI_{vol}$ was based on the 16-cm phantom. For devices that displayed the $CTDI_{vol}$ based on the 32-cm phantom, the participants were asked to enter the displayed $CTDI_{vol, 32}$, which was explicitly stated in the form. $CTDI_{vol, 32}$ was converted to $CTDI_{vol, 16}$ by multiplying by a factor of two [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, USA).

Results

Of the 339 facilities to which the questionnaires were sent, 196 (58%) responded. In total, 1002 displayed $CTDI_{vol}$ values from 164 facilities and 955 displayed DLP values from 157 facilities were available for data analysis. A total of 32 cases involving $CTDI_{vol}$ and 39 cases involving DLP were excluded because participants had 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 from 120 to 225 mAs for the head, 46 to 63 mAs for the chest and 50 to 75 mAs for the abdomen (Fig. 1). Current time product increased with age.

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

Displayed $CTDI_{vol}$ on CT systems

970 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 small children group, 16% (154/970), 8% (81/970) and 9% (84/970) were for head, chest and abdominal CT scans, respectively. In the children's 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 $CTDI_{vol}$ values ranged from 39.1 to 67.7 mGy for the head, 11.1 to 15 mGy for the chest, and 12 to 17 mGy for the abdomen. The $CTDI_{vol}$ values increased with age.

DLP displayed on CT systems

916 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 small children's group, 16% (145/916), 8% (76/916) and 9% (79/916) were for head, chest and abdominal CT scans, respectively. In the children's 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 ranged from 526.1 to 847.9 mGy*cm for the head, 209.1 to 413 mGy*cm for the chest and 261.5 to 532.2 mGy*cm for the abdomen. The DLP values increased with age.

Comparison of 75th percentile of $CTDI_{vol}$ and DLP 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 UK, 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 $CTDI_{vol}$ 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 are shown in Figs. 2–4. 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 details the $CTDI_{vol}$ and DLP values proposed as DRLs for pediatric CT in Japan by our group in reference to the $CTDI_{vol}$ and DLP for head, chest, and abdominal CT in each age group obtained from this 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 DLPs. This survey was carried out in relatively large medical facilities that form the core of community medicine, such as university and national hospitals. 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 in the present study 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 the relationship between the tube voltage and the $CTDI_{vol}$ was investigated, 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 the optimization of exposure in pediatric CT, the use of low tube voltage should be considered as 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]; they 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 value of the $CTDI_{vol}$ for pediatric CT in our survey were higher than these 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 performed over a wider area of the body.

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 those 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 is effective in reducing radiation exposure [17]. It is necessary to carry out appropriate education for radiological staff in Japan regarding radiation exposure in pediatric CT.

A total of 32 cases involving $CTDI_{vol}$ and 39 cases involving DLP were excluded because participants had entered values incorrectly, the entry form could not be corrected, or there were blank entries on the form.

In the present survey, responses were received from 196 facilities, and the $CTDI_{vol}$ values from 164 facilities and the DLPs from 157 facilities were available for data analysis.

However, 57% of the facilities did not provide data for at least one of the scanning conditions, CTDIvol or DLP, and for at least one of the age groups, which was the principal limitation of our questionnaire survey.

The latest MDCT systems often have a function to output $CTDI_{vol}$ and DLP values in the form of a radiation dose structure report (RDSR) formed by digital imaging and communications in medicine [18]. In the US, the RDSR is used for dose optimization by maintaining a dose index registry (DIR) via the dose index reporting application [19]. The introduction of the DIR using RDSR in the future will 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 other surveys. To promote the optimization of pediatric CT scan protocols, we consider that it will be necessary to establish DRLs for pediatric CT examinations in Japan.

Acknowledgements

We thank the members of JSRT 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 National Center for Child Health and Development grant (Japan, 26–20).

Conflict of interest

The authors declare that they have no conflict of interest.

References

1. Hashimoto S, Ugawa S, Nanko K, Shichi K (2012) The total amounts of radioactively contaminated materials in forests in Fukushima, Japan. Sci Rep 2:416.1-5
2. Ueda S, Hasegawa H, Kakiuchi H, Akata N, Ohtsuka Y, Hisamatsu S (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, DUNN M (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 Aroua A, Alamo-Maestre LT, Bochud F, Gudinchet F (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, Ahmed NA, Al-Dhuhli H, Al-Naemi HM (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 40:1324-44

13. Nishizawa K, Matsumoto M, Iwai K, Maruyama T (2004) Survey of CT practice in Japan and collective effective dose estimation. Nihon Igaku Hoshasen Gakkai Zasshi 64:151-158

14. Miyazaki O, Kitamura M, Masaki H, Nosaka S, Miyasaka M, Kashima K, Okada Y, Tsutumi Y (2005) Current practice of pediatric MDCT in Japan: survey results of demographics and age-based dose reduction. Nihon Igaku Hoshasen Gakkai Zasshi 65:216-223

15. Fukushima Y, Tsushima Y, Takei H, Taketomi-Takahashi A, Otake H, Endo K (2012) Diagnostic reference level of computed tomography (CT) in Japan. Radiat Prot

Dosimetry 151:51-57

16. Takei Y, Suzuki S, Miyazaki O Matsubara K, Muramatsu Y, Shimada Y, Akahane K, Fujii K (2014) Summary of the survey on radiation exposure of pediatric CT examination in Japan -focus on environments of CT examination-. Nihon Hoshasen Gijutsu Gakkai Zasshi 70:562-8
17. Paolicchi F, Faggioni L, Bastiani L, Molinaro S, Puglioli M, Caramella D, Bartikizzi C (2014) Optimization the Balance Between Radiation Dose and Image Quality in Pediatric Head CT: Findings Before and After Intensive Radiologic Staff Training. AJR 202:1309-1315
18. Shih G, Lu ZF, Zabih R, Kennedy D, Loftus M, Shih WJ, Osborne J, Nickoloff E, Schwartz L (2011) Automated framework for digital radiation dose index reporting from CT dose reports. 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

Figure legends

Fig. 1 Median value of the tube current to time product utilized for head, chest and abdominal CT scans as a function of patient age

Fig. 2 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 the infant age group (* P <0.01)

Fig. 3 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 the small children's age group (* 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 the children's age group (* P <0.01).

Table legends

Table 1 The minimum, maximum, median and 75th percentile values of the $CTDI_{vol}$ from routine protocols in the three pediatric age groups

Table 2 The minimum, maximum, median and 75th percentile values of the DLP obtained from routine protocols

Table 3 Comparison of 75th percentile of the $CTDI_{vol}$ for pediatric CT scans with other surveys

Table 4 Comparison of 75th percentile of the DLP for pediatric CT scans with other surveys

Table 5 The $CTDI_{vol}$ and DLP values proposed as DRLs for pediatric CT scans in Japan

Table 1

$CTDI_{vol}$ (mGy)	Age Group	Minimum	Maximum	Median	75^{th} percentile
Head	<1 year	9.4	120	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	5.4	11.1
	1-5 years	1	48	7.7	14.3
	6-10 years	2.2	33.9	8.3	15
Abdomen	<1 year	0.9	46.9	6.4	12
	1-5 years	1.5	46.9	9.7	16.7
	6-10 years	1.6	33.9	10	17

Table 2

DLP (mGy·cm)	Age Group	Minimum	Maximum	Median	75th percentile
Head	<1 year	13	2066	398.4	526.1
	1-5 years	16.7	2066	463.5	665.5
	6-10 years	16.7	2841.5	593.6	847.9
Chest	<1 year	11.1	945.4	90	209.1
	1-5 years	17.5	945.4	159.9	296
	6-10 years	24	960.3	228.6	413
Abdomen	<1 year	12.4	1980	153.5	261.5
	1-5 years	54.8	1980	251	430.8
	6-10 years	47.7	1980	275.5	532.2

Table 3

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	39.1	46.9	67.7	11.1	14.3	15	12	16.7	17
IAEA [10]	29	37.7	46.1	*14	*16.4	*20	*21.4	*26	*24
Thailand [9]	26	29	39	4.5	5.7	10	7.7	8.9	13.8
France [11]	30	40	50	*6	*7	*11	*8	*9	*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
UK [6]	30	45	50	12	13	20	20	20	30

*Converted $CTDI_{vol, 16}$ by doubling $CTDI_{vol, 32}$

Table 4

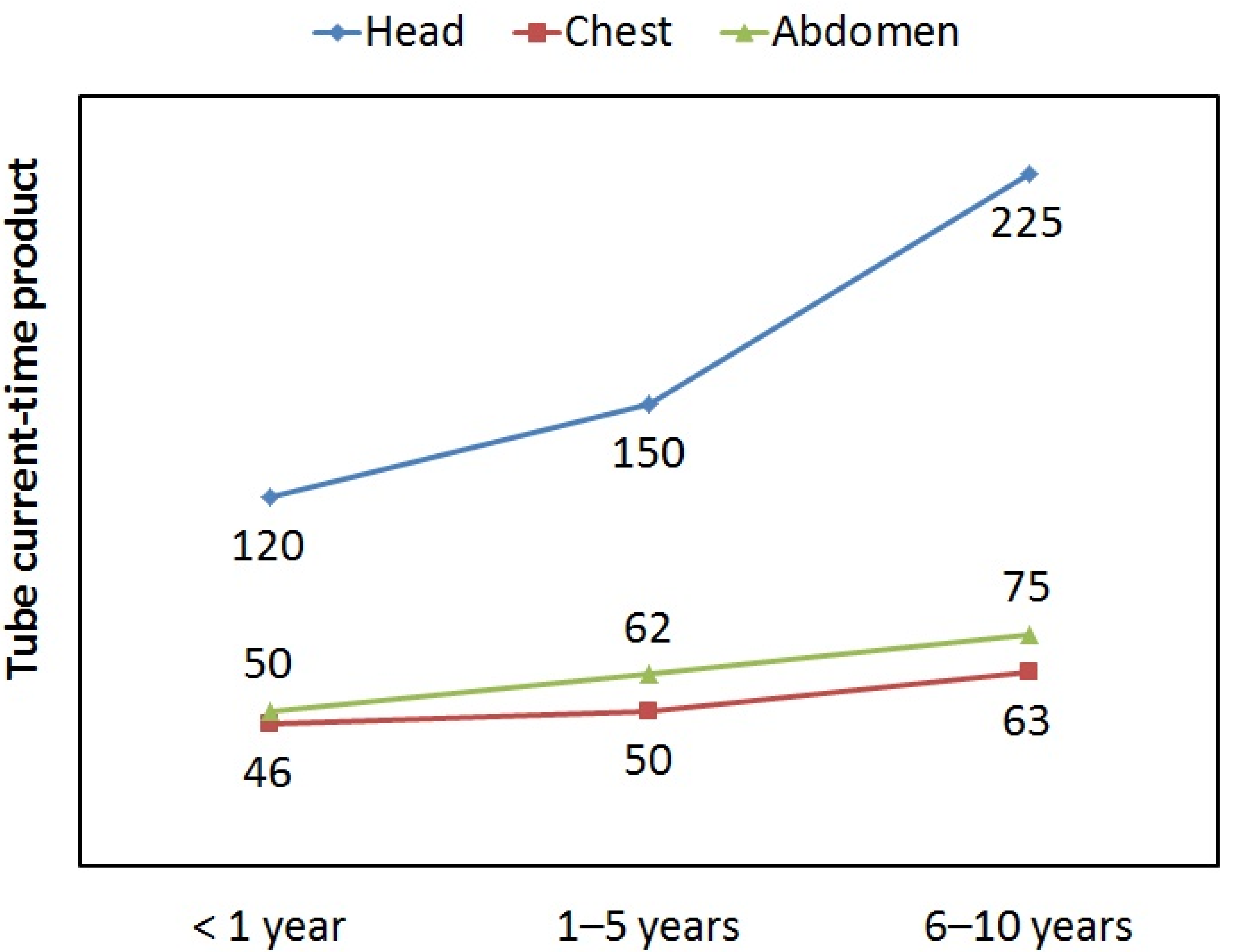
75th percentile of DLP (mGy·cm)	Head			Chest			Abdomen		
	<1 year	1-5 years	6-10 years	<1 year	1-5 years	6-10 years	<1 year	1-5 years	6-10 years
Japan	526	666	848	209	296	413	262	431	532
Thailand [9]	402	570	613	80	140	305	222	276	561
France [11]	420	600	900	*60	*126	*274	*160	*242	*490
Switzerland [8]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

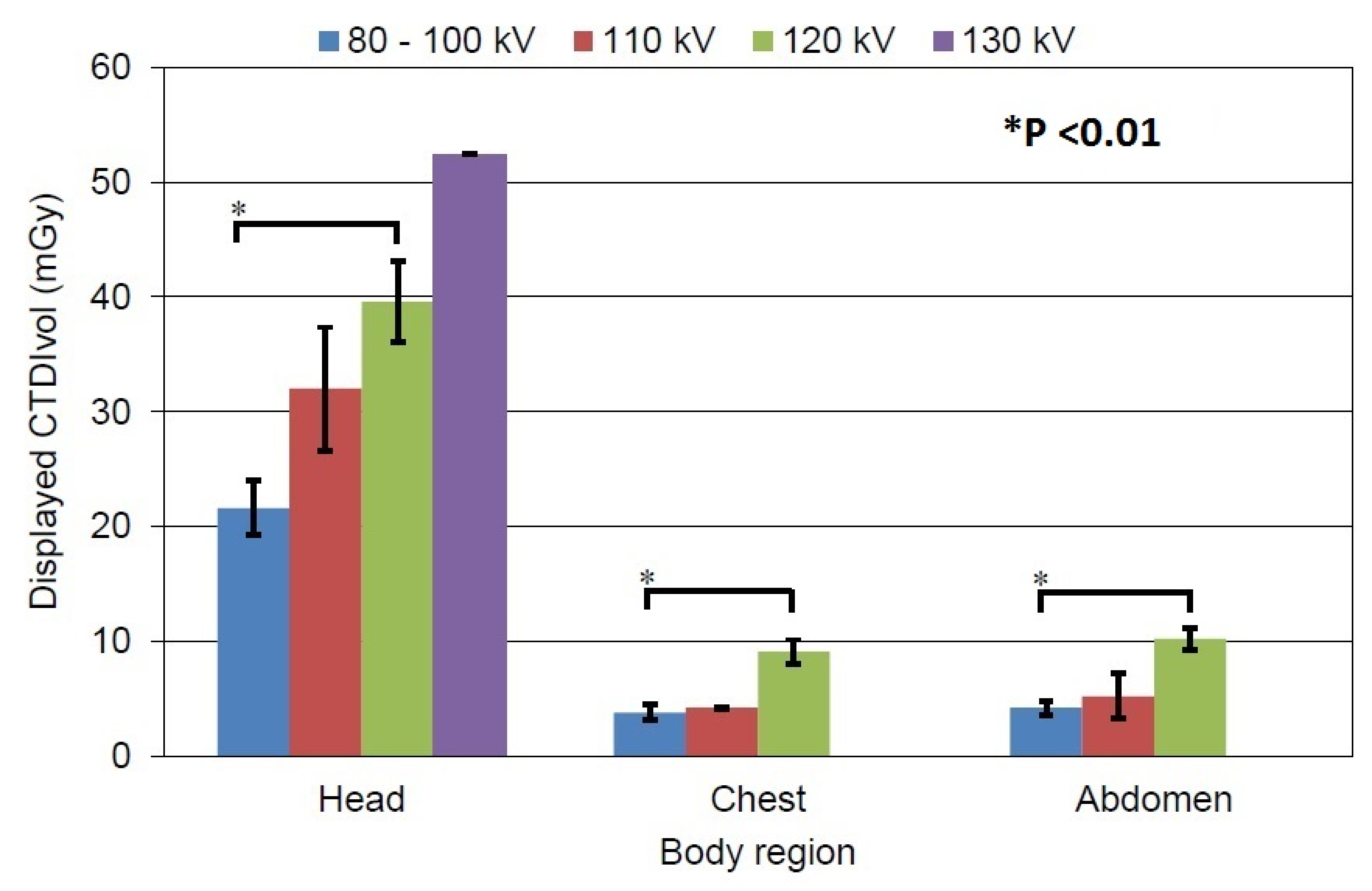
*Converted DLP_{16} by doubling DLP_{32}

Table 5

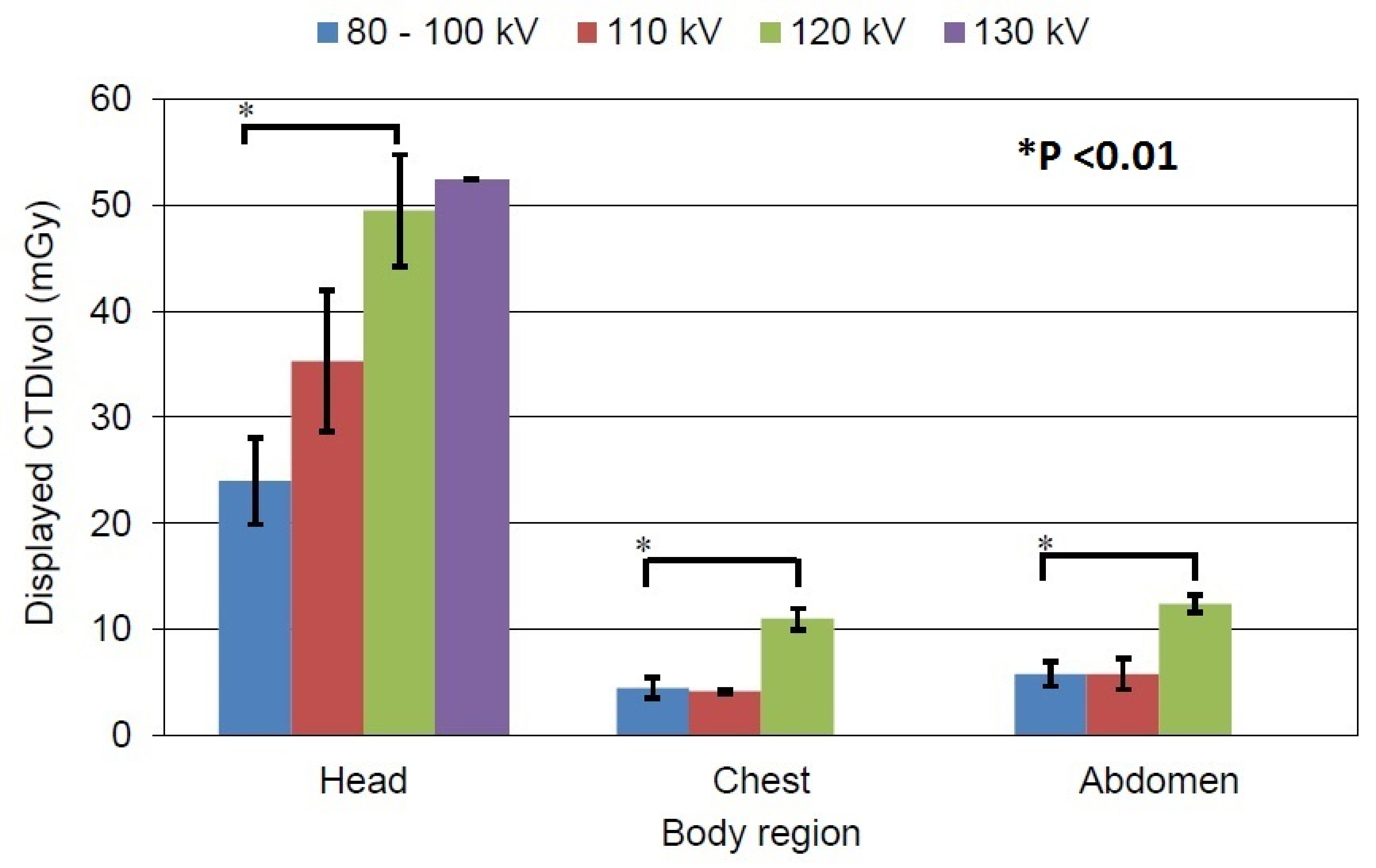
Body region	Proposed DRLs	<1 year	1–5 years	6–10 years
Head	$CTDI_{vol}$ (mGy)	38	47	60
	DLP (mGy·cm)	500	660	850
Chest	$CTDI_{vol}$ (mGy)	11 (5.5)	14 (7)	15 (7.5)
	DLP (mGy·cm)	210 (105)	300 (150)	410 (205)
Abdomen	$CTDI_{vol}$ (mGy)	11 (5.5)	16 (8)	17 (8.5)
	DLP (mGy·cm)	220 (110)	400 (200)	530 (265)

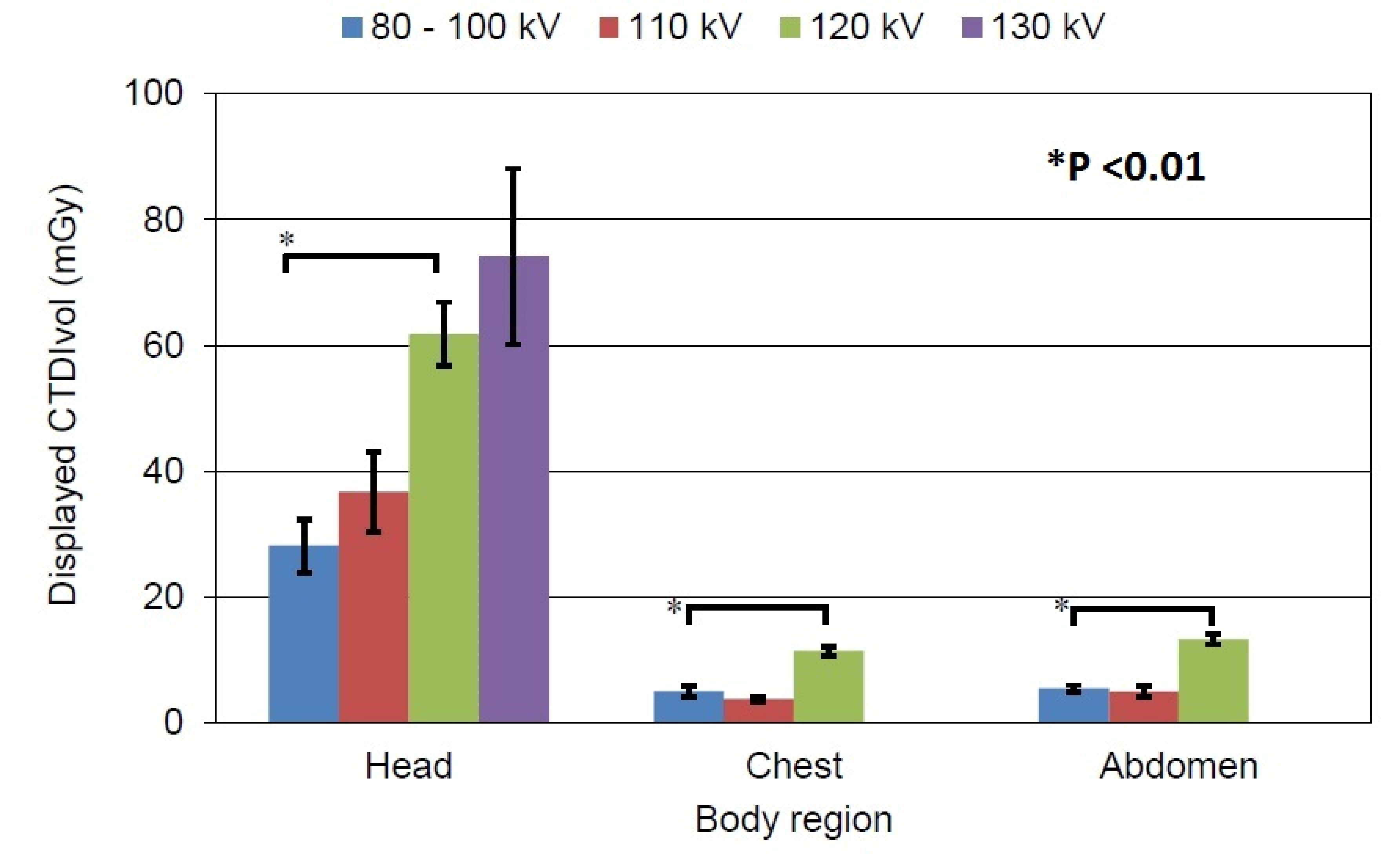
( ) are measured by 32 cm diameter PMMA phantom


Head
Chest
Abdomen
Tube current-time product
225
150
120
75
62
50
63
50
46
< 1 year
1–5 years
6–10 years



80 - 100 kV
110 kV
120 kV
130 kV
*P <0.01
Displayed CTDIvol (mGy)
60
50
40
30
20
10
0
*
*
*
Head
Chest
Abdomen
Body region


80 - 100 kV
110 kV
120 kV
130 kV
60
50
40
30
20
10
0
Displayed CTDIvol (mGy)
*
*P <0.01
*
*
Head
Chest
Abdomen
Body region


80 - 100 kV
110 kV
120 kV
130 kV
*P <0.01
Displayed CTDIvol (mGy)
100
80
60
40
20
0
*
*
*
Head
Chest
Abdomen
Body region