

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

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

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**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 75<sup>th</sup> percentile values of volume CT dose index 16 (CTDI<sub>vol, 16</sub>) 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<sub>16</sub>) 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<sub>vol, 16</sub> and DLP<sub>16</sub> 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 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<sub>vol</sub> values from 164 facilities and 955 displayed DLP values from 157 facilities were available for data analysis. A total of 32 cases involving CTDI<sub>vol</sub> 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  $\leq 1$  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<sub>vol</sub> on CT systems***

970 displayed CTDI<sub>vol</sub> 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 75<sup>th</sup> percentile values of CTDI<sub>vol</sub> from



routine protocols. The 75<sup>th</sup> percentile CTDI<sub>vol</sub> 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<sub>vol</sub> 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 75<sup>th</sup> percentile values of DLP obtained from routine protocols. The 75<sup>th</sup> 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 75<sup>th</sup> percentile of CTDI<sub>vol</sub> and DLP values with other surveys***

Tables 3 and 4 show the comparison between CTDI<sub>vol</sub> 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 75<sup>th</sup> percentiles of the CTDI<sub>vol</sub> 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 75<sup>th</sup> percentile of the CTDI<sub>vol</sub> 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 75<sup>th</sup> percentile of the CTDI<sub>vol</sub> 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<sub>vol</sub>***

The relationship between the tube voltage and 75<sup>th</sup> percentile of the displayed CTDI<sub>vol</sub> 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<sub>vol</sub> 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<sub>vol</sub> for a tube voltage of 80 kV and that for a tube voltage of 120 kV.

Table 5 details the CTDI<sub>vol</sub> and DLP values proposed as DRLs for pediatric CT in Japan by our group in reference to the CTDI<sub>vol</sub> 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 75<sup>th</sup> percentile value of the CTDI<sub>vol</sub> for pediatric CT in our survey were higher than these in the survey conducted by the IAEA [10]. Furthermore, the 75<sup>th</sup> percentile values of DLP were markedly higher than those reported in other countries [8–11]. In other words, our results imply that CTDI<sub>vol</sub> 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<sub>vol</sub> 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,  $CTDI_{vol}$  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.

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### **Conflict of interest**

The authors declare that they have no conflict of interest.

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## **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 75<sup>th</sup> percentile values of the CTDI<sub>vol</sub> from routine protocols in the three pediatric age groups

**Table 2** The minimum, maximum, median and 75<sup>th</sup> percentile values of the DLP obtained from routine protocols

**Table 3** Comparison of 75<sup>th</sup> percentile of the CTDI<sub>vol</sub> for pediatric CT scans with other surveys

**Table 4** Comparison of 75<sup>th</sup> percentile of the DLP for pediatric CT scans with other surveys

**Table 5** The CTDI<sub>vol</sub> and DLP values proposed as DRLs for pediatric CT scans in Japan

Table 1

| CTDI <sub>vol</sub><br>(mGy) | Age Group  | Minimum | Maximum | Median | 75 <sup>th</sup><br>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<br>(mGy·cm) | Age Group  | Minimum | Maximum | Median | 75 <sup>th</sup><br>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

| 75 <sup>th</sup> percentile<br>of CTDI <sub>vol</sub><br>(mGy) | Head       |              |               | Chest      |              |               | Abdomen    |              |               |
|--|------------|--------------|---------------|------------|--------------|---------------|------------|--------------|---------------|
|  | <1<br>year | 1-5<br>years | 6-10<br>years | <1<br>year | 1-5<br>years | 6-10<br>years | <1<br>year | 1-5<br>years | 6-10<br>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<sub>vol, 16</sub> by doubling CTDI<sub>vol, 32</sub>

Table 4

| 75 <sup>th</sup> percentile<br>of DLP<br>(mGy·cm) | Head       |              |               | Chest      |              |               | Abdomen    |              |               |
|---|------------|--------------|---------------|------------|--------------|---------------|------------|--------------|---------------|
|   | <1<br>year | 1-5<br>years | 6-10<br>years | <1<br>year | 1-5<br>years | 6-10<br>years | <1<br>year | 1-5<br>years | 6-10<br>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<sub>16</sub> by doubling DLP<sub>32</sub>

Table 5

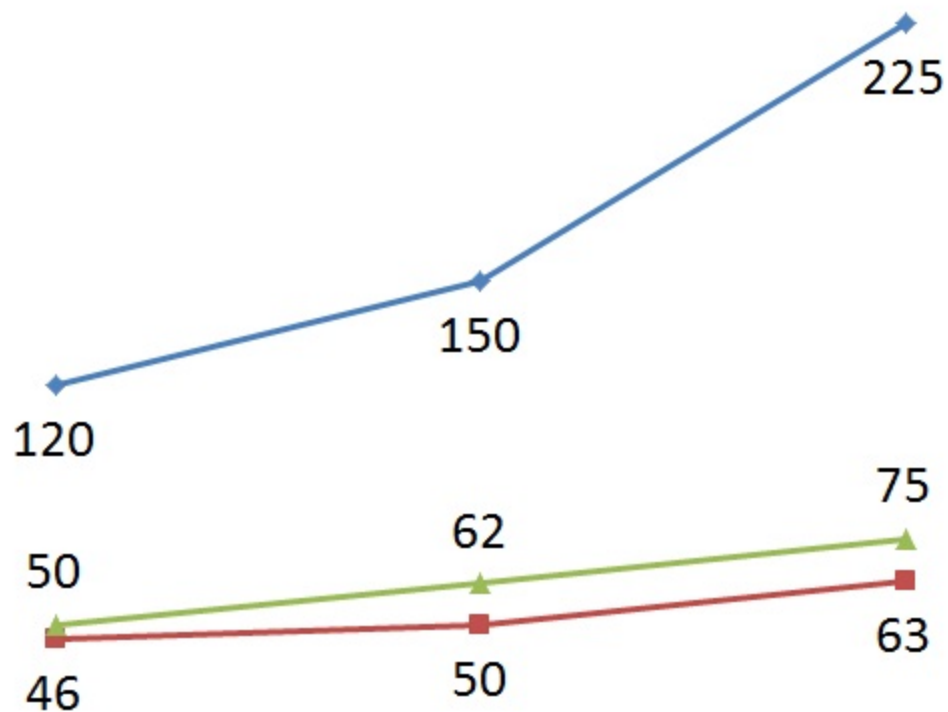
| Body region | Proposed DRLs             | <1 year   | 1–5 years | 6–10 years |
|-------------|---------------------------|-----------|-----------|------------|
| Head        | CTDI <sub>vol</sub> (mGy) | 38        | 47        | 60         |
|             | DLP (mGy·cm)              | 500       | 660       | 850        |
| Chest       | CTDI <sub>vol</sub> (mGy) | 11 (5.5)  | 14 (7)    | 15 (7.5)   |
|             | DLP (mGy·cm)              | 210 (105) | 300 (150) | 410 (205)  |
| Abdomen     | CTDI <sub>vol</sub> (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

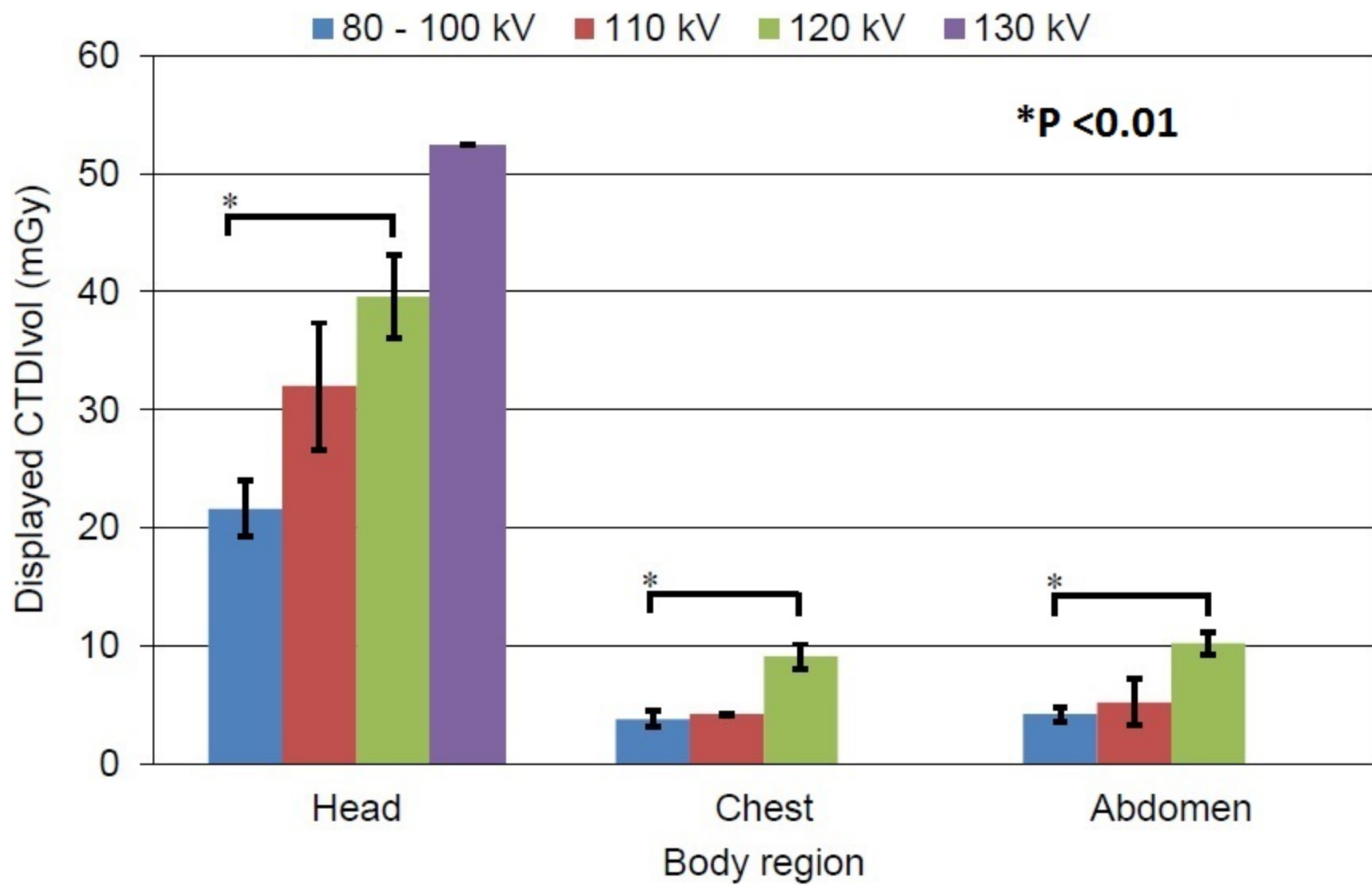
Tube current-time product



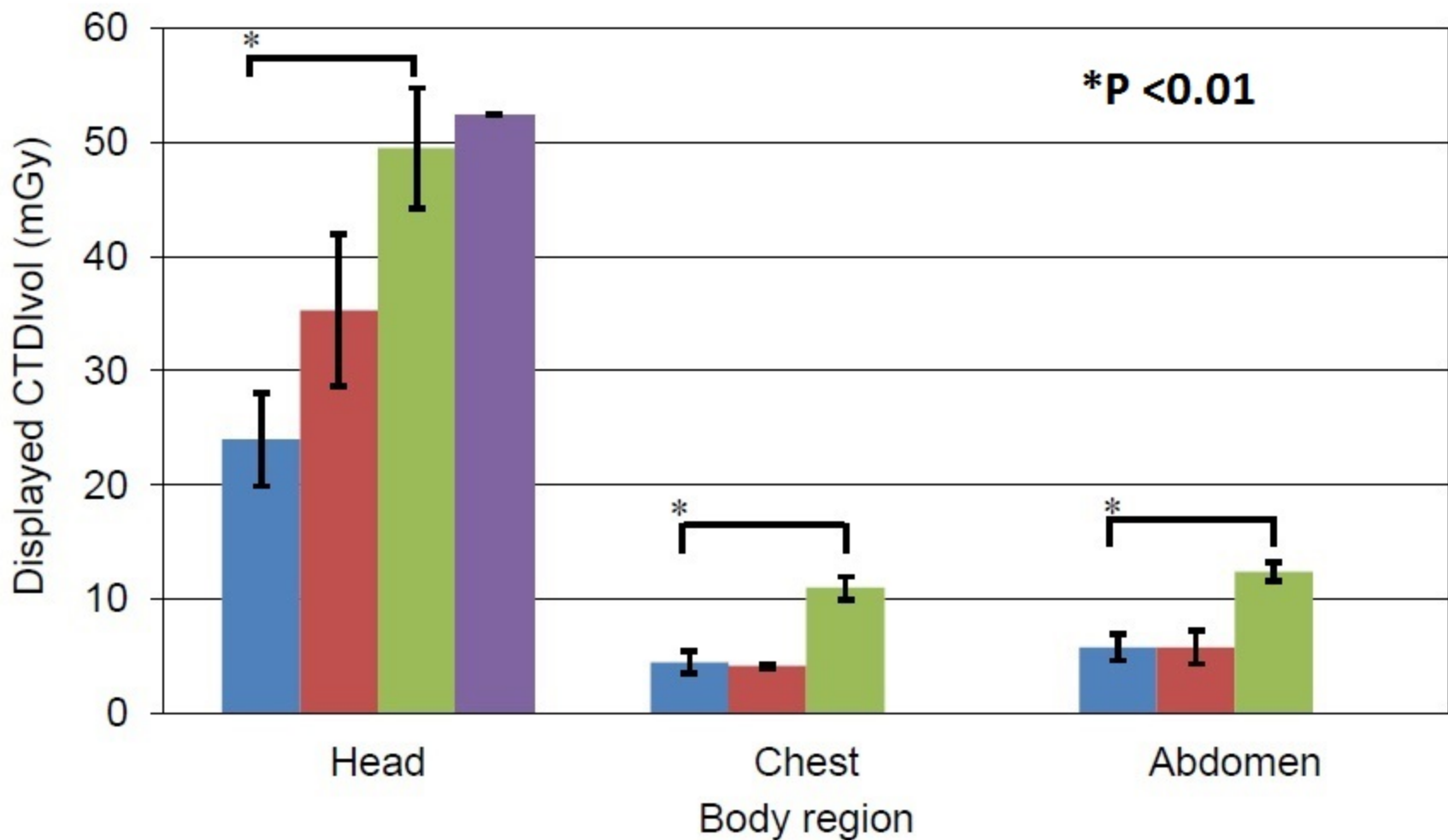
< 1 year

1-5 years

6-10 years



80 - 100 kV 110 kV 120 kV 130 kV



80 - 100 kV 110 kV 120 kV 130 kV

