A Survey of Pediatric CT Protocols and Radiation Doses in South Korean Hospitals to Optimize the Radiation Dose for Pediatric CT Scanning

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Abstract: Children are at greater risk of radiation exposure than adults because the rapidly dividing cells of children tend to be more radiosensitive and they have a longer expected life time in which to develop potential radiation-induced cancer. Therefore, there have been surveyed computed tomography (CT) radiation doses and several studies have established diagnostic reference levels according to patient age or body size; however, no survey of CT radiation doses with a large number of patients has yet been carried out in South Korea.

The aim of the present study was to investigate the radiation dose in pediatric CT examinations performed throughout South Korea. From 512 CT (222 brain CT, 105 chest CT, and 185 abdominopelvic CT) scans that were referred to our tertiary hospital, a dose report sheet was available for retrospective analysis of CT scan protocols and dose, including the volumetric CT dose index (CTDvol), dose-length product (DLP), effective dose (ED), and size-specific dose estimates (SSDE).

At 55.2%, multiphase CT was the most frequently performed protocol for abdominopelvic CT. Tubular current modulation was applied most often in abdominopelvic CT and chest CT, accounting for 70.1% and 62.7%, respectively. Regarding the CT dose, the interquartile ranges of the CTDvol were 11.1 to 22.5 (newborns), 14.6 to 41.7 (2–5 years), 23.5 to 44.1 (6–10 years), and 31.4 to 55.3 (11–15 years) for brain CT; 1.3 to 5.7 (≤1 year), 3.9 to 13.8 (2–5 years), and 7.7 to 13.8 (≤15 years) for chest CT; and 4.0 to 7.5 (≤1 year), 4.2 to 8.9 (2–5 years), 5.7 to 12.4 (6–10 years), and 7.6 to 16.6 (≤15 years) for abdominopelvic CT. The SSDE and CTDvol were well correlated for patients <5 years old, whereas the CTDvol was lower in patients ≥6 years old.

Our study describes the various parameters and dosimetry metrics of pediatric CT in South Korea. The CTDvol, DLP, and effective dose were generally lower than in German and UK surveys, except in certain age groups.

INTRODUCTION

With the introduction of multidetector computed tomography (MDCT) in the late 1990s, the frequency of computed tomography (CT) examinations have substantially increased in both adult and pediatric patients. In the United States, among the more than 60 million CT examinations are performed each year, pediatric CT scans account for between approximately 4 and 7.1 million examinations.1–3 A recent study estimated that 29.9 million patients undergo CT examinations annually in Japan, with pediatric CT scans accounting for 1.43 million of these procedures.4 Accordingly, the increasing radiation exposure from CT has increased concerns about the health impact of CT scans.

Children are at greater risk of radiation exposure than adults because the rapidly dividing cells of children tend to be more radiosensitive and they have a longer expected life time in which to develop potential radiation injury.1,6 The risk of radiation-induced cancer development should be a concern in pediatric patients because it can develop after a long-latency period.5,6 While many technologies have been developed to reduce radiation exposure during CT examinations, optimization and adjustment of scan parameters for pediatric patients is required, as well as the rational use of such scans.5,6 Given this attention to radiation risks in pediatric patients, several studies have suggested guidelines to optimize the radiation safety pediatric CT scans.

Some studies have surveyed CT radiation doses and several studies have established diagnostic reference levels according to patient age or body size but regional, national, and local authorized bodies should be considered before their introduction. However, no survey of CT radiation doses with a large number of patients has yet been carried out in South Korea. Thus, the purpose of our present study was to collect information regarding the radiation dose of pediatric CT scans from various hospitals throughout South Korea.
MATERIALS AND METHODS

Approval
The design of this retrospective study was approved by the Asan Medical Center Institutional Review Board. They waived the requirement for informed consent because this study was regarded as a minimal risk study.

Study Group
We retrospectively reviewed brain, chest, and abdominopelvic CT scans from various hospitals in South Korea. These scans were referred to and registered in a picture archiving communication system (PACS) in a tertiary hospital to obtain a second opinion from pediatric radiologists in the tertiary hospital. Using the PACS, we collected all uploaded outside brain, chest, and abdominopelvic CT scans from the patients who had visited our hospital between March 2010 and November 2011, and a total of 512 CT scans were found (222 brain CT, 105 chest CT, and 185 abdominopelvic CT scans). The dates of CT scans performed at outside hospitals are as follows: brain CT scans obtained between March 2008 and November 2011, chest CT scans obtained between February 2010 and November 2011, and abdominopelvic CT scans obtained between January 2009 and November 2011. All CT protocols and dose reports were blindly reviewed by a radiologist (J-YH) without hospital information. After selecting only those CT scans containing dose report sheets, 243 CT scans (47.5%) were enrolled in our CT dose survey. These comprised 97 brain CT, 59 chest CT, and 87 abdominopelvic CT scans.

We obtained data on the patient’s age in each case at the time of examination, sex, the level of the hospital, and the manufacturer, model name, and type of CT scanner from the Digital Imaging and Communications in Medicine (DICOM) header information or electronic medical record system. The manufacturer and model name of the CT scanners were obtained to determine the reference phantom size if it was not provided on the dose report sheet. If we could not get appropriate information about the type and channel number of the CT scanner in the DICOM header information, we consulted the Korean Institute for Accreditation of Medical Image (KIAMI) to obtain the data from the registry of CT scanners of South Korea. Age groups were constructed as follows: newborn (age < 1 month), age < 1 years old, age < 5 years old, age < 10 years old, and age ≤ 15 years old.9 We classified hospitals into 4 groups as follows: university hospital, general hospital with more than 100 beds, secondary referral hospital with more than 30 beds but < 100 beds, and private clinic.

CT Scan Protocols and Dosimetry
Some information about CT scans were obtained from the displayed value in the dose report sheet as follows: kilovolt peak (kVp), number of scans (single-phase scan or multiphase scan), application of automatic exposure control (AEC), volume CT dose index (CTDIvol; mGy), and dose-length product (DLP; mGy cm). If an examination was performed with a multiphase protocol, data were recorded for the phase that used the larger CTDIvol or DLP. We used the displayed CTDIvol and DLP from the CT dose report sheet to evaluate the radiation dose. We recorded the size of the reference phantom for CTDIvol when the dose report sheets provided the phantom size; otherwise, we asked manufacturers about the default phantom size according to the protocol.

The CTDIvol and DLP were summarized as follows according to the body region. The CTDIvol and DLP were summarized for dosimetrics based on a 16-cm phantom (CTDIvol16, DLP16). To convert the CTDIvol and DLP based on a 32-cm phantom (CTDIvol32, DLP32) into metrics based on a 16-cm phantom (CTDIvol16, DLP16), each metric was multiplied by 2. The effective dose (ED) was calculated by multiplying the DLP by the appropriate conversion factor. We used an already tabulated conversion factor calculated by Deak et al.16 This table contains ED/DLP ratios that take into account tube voltage, body region, patient’s age, and International Commission on Radiological Protection (ICRP) weighting factors.

TABLE 1. Number of Patients Included in the Analysis of CT Protocols and Radiation Dose

| Age, y | Brain | Chest | Abdominopelvic |
|--------|-------|-------|----------------|
| Newborn | 10    | 3     | 4              |
| ≤ 1    | 24    | 18    | 15             |
| 2–5    | 12    | 17    | 14             |
| 6–10   | 26    | 10    | 27             |
| ≤ 15   | 25    | 11    | 27             |
| Total  | 97    | 59    | 87             |

CT = computed tomography.
Conversion factors according to the ICRP 103 weighting factor were used in our present study.

In addition, a size-specific dose estimation (SSDE) was performed, as suggested by the American Association of Physicists in Medicine (AAPM) task group 204 to improve dosimetry accuracy in the chest and abdominopelvic CT. According to the report by the AAPM, the SSDE can be achieved from the following formula:

\[
\text{SSDE} = \frac{\text{conversion factor}}{C^2_{\text{CTD Ivol}}}
\]

The effective diameter was calculated in each of our present study patients to estimate the SSDE, and the effective diameter of each patient was calculated as follows:-

\[
\text{Effective diameter} = \sqrt{\text{Anteroposterior diameter} \times \text{Lateral diameter}}
\]

The anteroposterior and lateral diameters of each patient were measured on an axial image by using the digital caliper of our PACS system. These values were measured at the center of the scan length.

**Statistical Analysis**

Descriptive statistics were performed to summarize the demographic features and characteristics of the examinations and CT scanners, CT protocols, and CT dosimetric parameters.

**TABLE 2. Summary of the CTDI\textsubscript{vol16} and DLP**

| CT Protocol | CTDI\textsubscript{vol16}, mGy | DLP\textsubscript{16}, mGy cm |
|-------------|-------------------------------|-----------------------------|
| Brain       |                               |                             |
| Newborn     | 18.8 ± 18.2                   | 225.0 ± 177.9               |
| ≤1 y        | 29.3 ± 17.9                   | 439.0 ± 313.6               |
| 2–5 y       | 29.6 ± 15.3                   | 401.0 ± 164.7               |
| 6–10 y      | 38.1 ± 18.0                   | 645.0 ± 318.0               |
| ≤15 y       | 44.0 ± 15.0                   | 728.0 ± 270.4               |
| Chest       |                               |                             |
| Newborn     | 3.2 ± 2.2                     | 37.0 ± 20.8                 |
| ≤1 y        | 3.6 ± 2.3                     | 720.0 ± 5.7                 |
| 2–5 y       | 5.3 ± 2.2                     | 128.00 ± 6.81               |
| 6–10 y      | 7.2 ± 3.9                     | 205.0 ± 9.35                |
| ≤15 y       | 11.4 ± 5.9                    | 375.0 ± 199.5               |
| Abdominopelvic |                    |                             |
| Newborn     | 5.1 ± 4.5                     | 93.0 ± 74.8                 |
| ≤1 y        | 5.6 ± 2.4                     | 162.0 ± 7.5                 |
| 2–5 y       | 6.7 ± 2.9                     | 249.0 ± 137.8               |
| 6–10 y      | 10.1 ± 5.5                    | 412.0 ± 246.5               |
| ≤15 y       | 13.1 ± 7.1                    | 607.0 ± 371.5               |

CTDI\textsubscript{vol16} = volumetric CT dose index based on the 16, cm phantom. DLP\textsubscript{16} = dose-length-product based on the 16, cm phantom.

* Interquartile range was not calculated due to insufficient number of patients.
Statistical analyses were performed using MedCalc for Windows, version 12.5 (MedCalc Software, Ostend, Belgium).

RESULTS

Study Group and CT Scanners

CT scans were performed in 158 hospitals throughout South Korea. Of the 512 CT scans, almost all CT scans were performed in a university hospital or general hospital (n = 437; 85.4%), whereas few CT scans were performed in private clinics (n = 17; 3.3%). Figure 1(A) summarizes the distribution of the contributing hospitals. Most CT scanners were multirow detector in design (n = 487; 95.1%) and more than half were higher than 16-channel (n = 277; 54.1%). Only a few single-slice CT scanners contributed to this study (n = 20; 3.9%). Figure 1(B) shows the distribution of the type of enrolled CT

FIGURE 3. Mean value of the CTDIvol for brain (A), chest (B), and abdominopelvic (C) CT in each age group and body region. CT = computed tomography, CTDIvol = volumetric CT dose index.
scanners. Dose report sheets were available in 219 of the 304 CT scans from university hospitals (72%), 18 of the 133 CT scans from general hospitals (13.5%), 2 of the 58 CT scans from secondary referral hospitals (3.4%), and 4 of the 17 CT scans from private clinics (23.5%). Table 1 lists the number of the patients according to the age group and body region.

FIGURE 4. Mean value of the DLP for brain (A), chest (B), and abdominopelvic (C) CT in each age group and body region. CT = computed tomography, DLP = dose-length product.

CT Protocols

Depending on the body region, of the 243 CT scans with dose report sheets, a low kVp protocol (≤100 kVp) was applied in 20 of the brain CT scans (20.6%), 37 of the chest CT scans (62.7%), and 39 of the abdominopelvic CT scans (44.8%). Figure 2 shows the use of low kVp protocol according to the
FIGURE 5. Mean value of the ED for brain (A), chest (B), and abdominopelvic (C) CT in each age group and body region. CT = computed tomography, ED = effective dose.
body regions and age groups. Multiphase scans were performed most frequently for abdominopelvic CT, accounting for 48 CT scans (55.2%), followed by chest CT and brain CT, which accounted for 23 (39.0%) and 11 (11.3%), respectively. AEC was applied in 17.5% of the brain CT scans, 59.3% of the chest CT scans, and 70.1% of the abdominopelvic CT scans.

CT Dosimetry

Table 2 compares the CTDIvol and DLP values for each age group and body region with those of previously conducted surveys from Germany\(^9\) and the UK\(^8\) in 2006 and 2003, respectively. In the brain CT, the CTDIvol values of most age groups were lower than those of the German and UK surveys, except for children younger than 1 year old, whereas the CTDIvol was lower than in the German and UK surveys in all age groups for the chest and abdominopelvic CT scans. However, it appeared that the DLP in our South Korean patients was slightly higher when compared with the above 2 studies.

Figures 3–5 compare the CTDIvol, DLP, and ED values with those of the previously conducted studies. Ratio of the maximum CTDIvol to the minimum CTDIvol ranged from 4.3 to 16.0 for the brain CT, from 3.2 to 9.0 for the chest CT, and from 2.3 to 8.3 for the abdominopelvic CT.

Table 3 lists the third quartiles of the CTDIvol, DLP, and ED. The third quartiles of the CTDIvol in the children younger than 1 year old were generally lower for the brain and chest CT than in the German survey, except for brain CT in children younger than 1 year old and younger than 5-year-old groups. In terms of the abdominopelvic CT, the CTDIvol in the children younger than 1-year-old and younger than 5-year-old groups were higher than in the German survey. Similar to the CTDIvol quartiles, the third quartiles of the DLP were slightly higher in some age groups for brain and abdominopelvic CT.

Table 4 shows the SSDE and CTDIvol of each age group and body region for the chest and abdominopelvic CT scans and Figures 6 and 7 shows the relationship between the CTDIvol and SSDE. The SSDE and CTDIvol appeared to be

### Table 3. Third Quartile Distribution by Age Group and Body Region

| CT Protocol | CTDIvol16, mGy | DLP16, mGy cm | Effective Dose, mSv |
|-------------|----------------|---------------|---------------------|
| | Our Study | German Study | UK Study | Our Study | German Study | UK Study | Our Study | German Study | UK Study |
| Brain | | | | | | | | | |
| Newborn | 22.5 | 26.1 | 28 | 243 | 275 | 270 | 2.1 | 2.7 | 3.0 |
| ≤1 y | 39.1 | 33.6 | | 545 | 393 | | 3.3 | 2.8 | |
| 2–5 y | 41.7 | 49.0 | 43 | 508 | 611 | 465 | 1.8 | 2.6 | 1.9 |
| 6–10 y | 44.1 | 58.0 | 51 | 792 | 711 | 619 | 2.1 | 2.5 | 2.0 |
| ≤15 y | 55.3 | 64.5 | | 947 | 920 | | 1.8 | 2.7 | |
| Chest | | | | | | | | | |
| Newborn | –* | 4.2 | 12 | –* | 47 | 204 | –* | 2.1 | 7.9 |
| ≤1 y | 5.7 | 6.9 | | 53 | 93 | | 2.8 | 2.6 | |
| 2–5 y | 6.8 | 8.4 | 13 | 121 | 137 | 228 | 2.6 | 3.2 | 4.1 |
| 6–10 y | 9.3 | 11.9 | 17 | 160 | 257 | 368 | 2.6 | 3.9 | 4.8 |
| ≤15 y | 13.8 | 16.0 | | 473 | 488 | | 3.1 | 4.4 | |
| Abdominopelvic | | | | | | | | | |
| Newborn | –* | 4.6 | | –* | 81 | | –* | 4.6 | |
| ≤1 y | 7.5 | 6.8 | | 196 | 164 | | 5.0 | 4.9 | |
| 2–5 y | 8.9 | 8.3 | | 338 | 261 | | 5.9 | 5.6 | |
| 6–10 y | 12.4 | 13.7 | | 513 | 477 | | 6.3 | 7.2 | |
| ≤15 y | 16.6 | 20.2 | | 780 | 804 | | 6.0 | 8.0 | |

CTDIvol16 = volumetric CT dose index based on the 16, cm phantom, DLP16 = dose-length-product based on the 16, cm phantom.

Interquartile range was not calculated due to insufficient number of patients.

### Table 4. Comparison of the Mean Values of the CTDIvol and SSDE by Age Group and Body Region

| Age Group, y | Chest | Abdominopelvic |
|--------------|-------|-----------------|
| | CTDIvol16, mGy | SSDE, mGy | | CTDIvol16, mGy | SSDE, mGy |
| ≤1 | 3.6 | 4.0 | 5.6 | 6.1 |
| 2–5 | 5.3 | 5.3 | 6.7 | 6.8 |
| 6–10 | 7.2 | 6.1 | 10.1 | 9.0 |
| ≤15 | 11.4 | 8.9 | 13.1 | 10.5 |

CTDIvol16 = volumetric CT dose index based on the 16, cm phantom, SSDE = size-specific dose estimates.
well correlated for the patients in our current series under 5 years old, whereas the CTDIvol was lower in patients 6 years or older.

**DISCUSSION**

With the increasing use of CT scanning in pediatric patients, concerns about radiation exposure have been growing in recent decades. Several studies have been conducted to estimate these radiation exposure levels,\(^8\)\(^{-11},^{13,18}\) but no survey of CT radiation dose had previously been conducted in South Korea. Although our present survey was indirectly conducted based on CT referrals to a tertiary center, it represents the first survey of the radiation exposure of pediatric CT scans from various hospitals throughout South Korea. However, as more than 80% of CT examinations included in our present study were performed in university or general hospitals, this could have introduced a selection bias when collecting a study group. However, we considered that it would not be a considerable problem because most pediatric CT scans in South Korea are performed at large hospitals. In addition, radiation exposure from pediatric CT scans can be minimized with specific protocols, up-to-date techniques for reducing radiation, and competent radiologists and technicians. It is probable that these resources for reducing the radiation dose from CT scans would

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**FIGURE 6.** Scatter diagrams of the size-specific dose estimates (SSDE) of the chest CT.
be more available in university or general hospitals than in smaller hospitals or private clinics in South Korea.

Compared with nationwide surveys from Germany and the UK, the DLP of chest and abdominopelvic CT appeared to be higher in our present study than in those previous surveys, even though the CTDI_{vol} we measured was generally lower than in previous surveys. Since the DLP is the product of the CTDI_{vol} and scan length, it may be inferred that the scan length of pediatric chest and abdominopelvic CT scans tend to be longer in South Korea than that in the German survey. An appropriate scan length is another essential solution to reduce radiation exposure during CT scans, as well as to reduce radiation output from the CT scanner.

The dose report sheet contains the CT scan parameters and radiologists can obtain certain information about the number of scans, kVp, mAs, CTDI_{vol}, DLP, and reference tube current if AEC was applied. In addition, the sheet can be used to simply estimate the ED by multiplying the DLP by the appropriate conversion factor provided in the dose report sheet. Consequently, it can be a good and convenient tool for supervising and managing the CT radiation dose, and monitoring the dose report sheet can trigger concerns about the radiation exposure in the practice. In our study, however, the dose report sheet was available in only 47.5% of the CT scans, even though most CT scans were performed in university and general hospitals. This finding may indicate that many hospitals in South Korea are still

FIGURE 7. Scatter diagrams of the size-specific dose estimates (SSDE) of the abdominopelvic CT.
indifferent to radiation exposure from CT scans, even in pediatric patients.

The kVp is an important factor that controls the radiation dose, as well as the modulation of the tube current. Reducing the kVp can reduce the radiation output of the CT scanner and can be a good option for decreasing the radiation dose, as indicated in other studies. Since the body habitus of pediatric patients is smaller than that of adults, children are a good indication for a low kVp CT scan protocol. In our present study series, 62.7% of chest CT and 44.8% of abdominal CT scans were performed using a kVp of 80 kVp. The proportion of low kVp protocols <100 kVp appeared to be lower than reported previously. Generally, a peak tube voltage of 80 or 100 can be considered when selecting the optimal kVp for patients under weight of 45 kg and a peak tube voltage of 100 or 120 can be recommended for routine chest and abdomen CT in adolescents.

The displayed CTDIvol and DLP represent the X-ray output of the CT scanner, not the patient dose. Since these values are calculated using standardized phantoms with diameters of 16-cm or 32-cm, the CTDIvol displayed in the dose report sheet cannot represent changes in the size of individual patients. For instance, if the displayed CTDIvol is based on the 32-cm phantom, the measured CTDIvol in a patient size less than or more than 32-cm will be higher or lower than the displayed value. In 2011, an AAPM task group published dedicated correction factors to provide a more correct dose estimation according to the patient size. In 2013, another study published diagnostic reference ranges for pediatric abdominal CT by using the SSDE. In our present study, the CTDIvol showed acceptable correlation with the SSDE in patients younger than 5 years old. However, the CTDIvol underestimated the patient dose in patients 6 years old or older. We believe that the SSDE can provide accurate and direct patient doses according to the patient size in pediatric patients. Furthermore, it enables the precise control of radiation dose during pediatric CT scans.

There are several noteworthy limitations to our study. First, because our analysis was retrospective, we could not obtain information on several parameters that possibly influence the radiation dose (e.g., beam collimation, rotation time, pitch). Second, we did not assess the CT scan indications. Hence, the parameters of these CT scans may not represent the routine protocols of the respective institutions. Third, since our analysis was conducted on patient groups of single institutions, bias could have been introduced, even though the CT scans we obtained were from various hospitals throughout South Korea.

CONCLUSION

Our present study describes the various parameters and dosimetry metrics in South Korea for pediatric CT scanning of the brain, chest, and abdominal pelvic region. Although the CTDIvol, DLP, and ED were generally lower than those seen in earlier German and UK surveys, except in certain age groups, this survey showed some variability regarding the protocols and radiation exposure of the pediatric CT scanning. Since our study was a preliminary national dose survey, further investigation with more solid data obtained through a larger sample of patients and hospitals should be performed to establish a diagnostic reference level and to limit dose dispersion for pediatric CT scanning in South Korea.

ACKNOWLEDGMENTS

We are grateful to Dr Hwa Jung Kim (Department of Clinical Epidemiology and Biostatistics, Asan Medical Center, University of Ulsan College of Medicine, Cancer Center, Seoul, Korea) for her assistance in the statistical analysis of the data.

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