Multisection computed tomography: Results from a Chinese survey on radiation dose metrics

Dan-Dan Zhoua, Pengfei Suna, Zhifang Jiab, Wanan Zhub, Guang Shic, Boyu Konga, Haifeng Wanga,
Huimao Zhanga,*

aDepartment of Radiology, The First Hospital of Jilin University, Changchun, China; bDepartment of Neurosurgery, The First Hospital of Jilin University, Changchun, China; cDepartment of Clinical Epidemiology, The First Hospital of Jilin University, Changchun, China

Abstract

Background: As multisection spiral computed tomography (MSCT) have been extensively used, it is important to consider the amounts of doses the patients are exposed during a computed tomography (CT) examination. The aim of the current study was to summarize MSCT doses in Chinese patients to establish the diagnostic reference levels (DRLs).

Methods: Radiation dose metrics were retrospectively collected from 164,073 CT examinations via the Radimetrics Enterprise Platform. Radiation dose metrics (volume CT dose index [CTDvol], dose-length product [DLP], effective dose [ED], and organ dose) and size-specific dose estimate (SSDE) were calculated for adults and children based on anatomical area and scan type.

Results: The median CTDvol and DLP values were highest in the head at 51.7 mGy (interquartile range [IQR], 33.2-51.7 mGy) and 906.5 mGy·cm (IQR, 582.4-1068.2 mGy·cm) and lowest in the chest at 7.9 mGy (IQR, 7.9-10.3 mGy) and 284.8 mGy·cm (IQR, 249.0-412.6 mGy·cm), respectively. The median SSDE values of chest and pelvis were 12.1 mGy (IQR, 10.8-14.1 mGy) and 36.3 mGy (IQR, 34.0-38.9 mGy), respectively. EDs for children were similar to adults except for an increased 1.5-, 0.77-, and 1.7-fold in the chest, neck, and pelvis, respectively (p < 0.001). Furthermore, radiation doses tended to increase with increasing slice number and decrease when exposure reduction techniques were used.

Conclusion: Our findings provide a basis for the evaluation of CT radiation doses and evidence for establishment of DRLs in China.

Keywords: Diagnostic reference levels; Dose-length product; Effective dose; Radiation dose metrics; Volume CT dose index

1. INTRODUCTION

The development of multisection (multislice) spiral computed tomography (MSCT) has led to a noticeable quantum leap in clinical performance of computed tomography (CT), enabling faster and accurate diagnosis of diseases. Nevertheless, the associated high radiation dose of CT is a major concern regarding an increased risk of carcinogenesis in the receivers, especially in multiphasic CT where the same organ is scanned multiple times (~four times) in different phases of contrast enhancement, thereby increasing the risk of carcinogenicity. Radiation doses from CT examinations are highly variable based on the scanner type and number, operation condition, examination, and protocol. The most efficient CT types are often associated with a high risk of carcinogenesis due to high radiation efficiency. Although it is mandatory to ensure safety against ionizing radiation during the procedure, general dose limits cannot be utilized for CT examinations as the potential risks and benefits must be weighed on an individual basis. European regulation and US National Council on Radiation Protection and Measurement implemented the use of specific diagnostic reference levels (DRLs), which represent the dose levels at which an investigation of appropriate dose should be initiated, rather than the absolute upper limit for a dose, which was proposed by the International Commission on Radiation Protection [ICRP] in 1996. Following this, several surveys were globally conducted to set DRLs to limit radiation exposure arising from CT procedures. The dose parameters recommended in the European guidelines are weighted CT dose index for a single slice and dose-length product (DLP) for an entire examination. Various commercial software systems can manage radiation doses, and one of them is Radimetrics, a software tool that monitors, tracks, and manages patient radiation exposures from CT. Monte Carlo techniques are used to derive the effective dose (ED) by calculating the organ doses that are further multiplied by weighting factors published in the ICRP.

Because MSCTs have been recently introduced into many developing and developed countries and have been extensively used in many studies almost replacing the conventional X-ray technique, it is important to give utmost consideration to patient doses. Given the scarcity of surveys, DRLs have not been established in China. Therefore, we aimed to summarize MSCT doses from examinations performed at our hospital to help institutions evaluate CT doses and contribute to the creation of DRLs for radiation in China.

2. METHODS

2.1. Study design and population

In this retrospective survey, radiation doses of 169,802 MSCT examinations performed by eight CT scanners between July

---

*Address correspondence: Dr. Huimao Zhang, Department of Radiology, The First Hospital of Jilin University, Changchun 130021, China.
E-mail address: huimaozhang@163.com (H. Zhang).

Conflicts of interest: The authors declare that they have no conflicts of interest related to the subject matter or materials discussed in this article.

Received: September 11, 2017; accepted: February 12, 2018.
doi: 10.1097/JCMA.0000000000000191.

Copyright © 2019, the Chinese Medical Association. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
2015 and January 2016 were analyzed to estimate the radiation dose metrics for adult and pediatric patients, which may assist the clinicians to set DRLs for Chinese patients. A total of 164,073 examinations from patients who underwent MSCT were included, after excluding CT examinations (5729 examinations) that lacked complete information on age, anatomical sites and clinical indications, clear indication, and clear definition of the scanned area; positron emission tomography/CT examinations; and MSCT examinations performed for research or interventional procedures. Examinations were grouped according to whether they were performed on teenagers and adults (aged >14 years) or children (aged ≤14 years).

The study was approved by the ethical committee of our hospital, and the requirement to obtain informed consent was waived because of the retrospective design of the study.

2.2. CT scanners
Eight CT (The General Electric Company, Waukesha, WI 53188, USA) facilities in the hospital from three manufacturers were included in this study: three from Siemens (Siemens Medical Solutions, Malvern, PA, USA), two from GE Healthcare, and three from Philips (Philips Medical Systems Nederland BV, a Philips Healthcare company, Best, The Netherlands) (Appendix 1). We divided these CT facilities into three groups based on the number of slices and whether dose-sparing techniques were used or not: CT group A (CT 1, 2, 3, 7) were 64 sliced and above, CT group B (CT 4, 5) were 16 sliced, and group C (CT 6, 8) were 64 sliced using radiation exposure reduction algorithms including Adaptive Statistical Iterative Reconstruction (ASIR, for CT6) and iDose (for CT8), which improve the image quality and allow the use of lower tube currents (data not shown). A total of 95 experienced radiologists were involved in scanning and reading of CT images.

2.3. Data collection and CT protocol
Radiation dose data from MSCT examinations were collected and downloaded from Radimetrics Enterprise Platform (Bayer Healthcare, Whippany, NJ, USA) for analysis. Radimetrics collects dose metrics from the Digital Imaging and Communications in Medicine and Picture Archiving and Communications System (PACS) and derives the size-specific dose estimate (SSDE) by calculating patient diameter from the mid-scan length. Radimetrics uses the library of Cristy phantoms20 to calculate the ED by matching patients to a particular computational phantom based on the patient’s age, weight, or diameter.

During scanning protocols with various examination parameters, a set of Monte Carlo simulations are run for every patient in the library to calculate organ doses, which are then used to derive the ED, according to the published ICRP 103 tissue-weighting factors.20 The radiation dose metrics such as volume CT dose index (CTDIvol), DLP, SSDE, ED, and organ doses between multiple groups were analyzed and compared between two groups using Kruskal-Wallis test and Wilcoxon rank-sum test using SAS version 9.4 (SAS Institute, Cary, NC, USA). A p value of <0.05 was considered to be statistically significant.

3. RESULTS
3.1. Patients demographics
A total of 164,073 patients were examined for radiation dose metrics (adults: n = 153,149; adult men: n = 86,791). The median age of all patients was 52.18 (37.85-62.73) years.

3.2. CT image distribution and radiation doses in all patients
Overall, the most common areas imaged were the chest (38.60%), head (31.04%), abdomen (23.43%), spine (4.24%), neck (0.78%), and pelvis (0.50%). Apart from these, only 1.42% of the examinations were of other anatomic areas (Figure 1A). The median radiation doses and IQRs are detailed in Table 1. The median CTDIvol values were highest in the head at 51.7 mGy (IQR, 33.2-51.7 mGy) and lowest in the chest at 7.9 mGy (IQR, 7.9-10.3 mGy). Similarly, the median DLPs were 906.5 mGy-cm (IQR, 582.4-1068.2 mGy-cm) in the head and 284.8 mGy-cm (IQR, 249.0-412.6 mGy/cm) in the chest. The median SSDE values were lowest in the chest at 12.1 mGy (IQR, 10.8-14.1 mGy) and highest in the pelvis at 36.3 mGy (IQR, 34.0-38.9 mGy). The median EDs were highest in the abdomen at 16.7 mSv (IQR, 12.7-22.4 mSv) and lowest in the head at 2.3 mSv (IQR, 1.5-2.7 mSv).

3.3. CT image distribution and radiation doses in adults and children
There were slight differences between adults and children in the most commonly imaged areas (Figure 2). In adults, the most common areas were the head (37.1%), hand (26.8%), abdomen (23.0%), spine (4.2%), neck (0.7%), and pelvis (0.5%), and 1.2% of the examinations were of other anatomic areas (Figure 1B). In children, the most common areas were the head (4.2%), chest (1.3%), abdomen (0.5%), spine (0.6%), neck (0.5%), and pelvis (0.01%), and 0.07% of the examinations were of other anatomic areas (Figure 1B).

There were significant differences in radiation dose metrics between adults and children in all the areas, except CTDIvol and DLP of the pelvis and EDs of the abdomen, spine, and neck (Table 2). The EDs were significantly high in children compared with adults with 1.5- and 1.7-fold in the head and pelvis, respectively (p < 0.001 for all).

SSDE dose is used for body CT to account for differences in patient size, especially when comparing dose levels from different organizations that may have significant differences in patient demographics (affecting size or weight).

ED is calculated based on the organs exposed by the applied radiation multiplied by tissue-weighting factors. In Radimetrics, the organ doses are first calculated using Monte Carlo probabilistic simulations that account for scattered radiation using a library that includes standardized male and female anthropomorphic mathematical phantoms, then the ED is estimated according to the published ICRP103 tissue-weighting factors.20

Patient sex, age, and date of the examination, scan region (head, chest, abdomen, spine, neck, pelvis, and other anatomical areas), study description, protocol name, scanner manufacturer, and model were extracted from Radimetrics and PACS.

3.4. CT image distribution and radiation doses in different groups
Different CT group were dispersed based on patients’ triage to examine different anatomical areas (Figure 1C). A total of

www.ejcms.org
103,149 CT examinations were collected from group A and 14,798 examinations were collected from group C. For group B, these two facilities were mostly used for routine head (18,149, 11.1%) and chest (27,871, 17.0%) examinations, and only 9 (<0.1%) and 91 (0.1%) patients had their abdomen or spine scanned. There were 1574 (1.0%), 6 (<0.1%), and 289 (0.2%) examinees in groups A, B, and C for other anatomic areas, respectively.

The median radiation doses and IQRs in each group are reported in Table 3. Among the three teams, CTDIvol and DLP of the chest ([9.8 versus 7.9 versus 8.8 mGy] and [387.8 versus 262.1 versus 334.5 mGy·cm], respectively) and the spine ([19.9 versus 21.3 versus 16.6 mGy] and [564.6 versus 1023.6 versus 417.6 mGy·cm], respectively) were significantly different (p < 0.0001 for all). Abdominal and pelvic CTDIvol (18.2 versus 13.8 mGy) and (26.7 versus 15.4 mGy) and DLP (894.4 versus 709.2 mGy·cm) and (502.1 versus 338.3 mGy·cm) differed significantly only between groups A and C (p < 0.0001, for both regions). CTDIvol of the head in group B were significantly lower only compared with team A (33.2 versus 51.7 mGy; p < 0.0001).

Overall, it was apparent that radiation dose tended to increase as slice number increased from group B to A, and doses tended to reduce with the use of exposure reduction techniques in group C.

3.5. Radiation doses in different organs

The median organ doses were listed in Figure 2. During the ED calculation, the Monte Carlo simulations were used by Radimetrics for different scanning protocols with various examination parameters. Using the Monte Carlo simulations, the median highest dose received by the head was 24.8 mGy in the eye lenses and 18 mGy in the brain. The lowest doses were received by the pelvis and the ovaries at 4.2 mGy, bladder at 3.2 mGy, and uterus at 2.8 mGy.

4. DISCUSSION

The disproportionate increase in radiation-induced cancer risk compared with the benefits of CT has been a challenge for its use, especially in children worldwide. A number of CT dose surveys have been published worldwide based on this. However, Asian surveys have focused on only protocols or phantoms. To the best of our knowledge, this is the first large-sample patient survey that could be the basis for developing radiation dose standards in China. As there are no specific national reference levels in China, we compared the DRLs with DRLs from European guidelines. Our results showed similar or lower results on CTDIvol and a higher DLP, the latter probably occurring due to the longer scan length, as DLP is dependent on scan length, whereas CTDI is almost independent. Also, we tried to compare the dose metric parameters of this study with that of the study by Zhou et al, who surveyed adult patients from the Jiangsu province of China for CT radiation doses for more ethnic generalizability of results. Compared with the Zhou et al. findings, our study had high CTDIvol values for head (51.7 mGy versus 44.54 mGy) and low for chest (7.9 mGy versus 17.31 mGy) anatomical segments. Similarly, the DLP of head (906.5 mGy·cm versus 493.16 mGy·cm) was high and low for chest (284.8 mGy·cm versus 408.96 mGy·cm) in our study compared with the findings of Zhou et al. Compared with CTDIvol and DLP, ED is widely used, as it is the only measure of dose that can be easily compared with radiation dose measurements from other imaging tests and environmental exposures.

When the EDs were compared with Zhou et al. findings, and the US and UK DRLs, the EDs observed in this study were slightly lower than that of doses from the UK and US population and were higher than the EDs of those from the study of Zhou et al. This discrepancy may be due to the smaller population surveyed in the study by Zhou et al. (n = 243) from a...
single province in China. Moreover, individual body or organ surface area may have played a crucial role on the outcome. A study by Li et al. reported that the organ dose and ED decreased with increased organ (chest) diameter.\textsuperscript{32} Given that the Zhou et al. study involved only adult patients who tend to have larger organ diameter than pediatric patients. It is sensible that the high EDs and CTDIs obtained in this study may be due to the enrollment of both adult and pediatric patients who receive increased

Fig. 2 Median radiation doses in different organs. The figure shows median radiation doses in each organ.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Radiation dose metrics in children and adult patients</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anatomical region</strong></td>
<td><strong>Median CTDIvol, mGy(^2) (IQR)</strong></td>
</tr>
<tr>
<td>Head</td>
<td>Children</td>
</tr>
<tr>
<td>Adults</td>
<td>91.7 (33.2-51.7)</td>
</tr>
<tr>
<td>Chest</td>
<td>Children</td>
</tr>
<tr>
<td>Adults</td>
<td>07.9 (7.3-10.4)</td>
</tr>
<tr>
<td>Abdomen</td>
<td>Children</td>
</tr>
<tr>
<td>Adults</td>
<td>18.2 (14.7-18.6)</td>
</tr>
<tr>
<td>Spine</td>
<td>Children</td>
</tr>
<tr>
<td>Adults</td>
<td>19.9 (18.3-19.9)</td>
</tr>
<tr>
<td>Neck</td>
<td>Children</td>
</tr>
<tr>
<td>Adults</td>
<td>12.9 (11.1-15.0)</td>
</tr>
<tr>
<td>Pelvis</td>
<td>Children</td>
</tr>
<tr>
<td>Adults</td>
<td>26.7 (26.7-26.8)</td>
</tr>
</tbody>
</table>

\(p < 0.0001\) among different anatomic areas compared with chest.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Radiation dose metrics of patients in different CT scanner group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scanner teams</strong></td>
<td><strong>Anatomical region</strong></td>
</tr>
<tr>
<td>Team A</td>
<td>Head</td>
</tr>
<tr>
<td></td>
<td>Chest</td>
</tr>
<tr>
<td></td>
<td>Abdomen</td>
</tr>
<tr>
<td></td>
<td>Spine</td>
</tr>
<tr>
<td></td>
<td>Neck</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
</tr>
<tr>
<td>Team B</td>
<td>Head</td>
</tr>
<tr>
<td></td>
<td>Chest</td>
</tr>
<tr>
<td></td>
<td>Abdomen</td>
</tr>
<tr>
<td></td>
<td>Spine</td>
</tr>
<tr>
<td></td>
<td>Neck</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
</tr>
<tr>
<td>Team C</td>
<td>Head</td>
</tr>
<tr>
<td></td>
<td>Chest</td>
</tr>
<tr>
<td></td>
<td>Abdomen</td>
</tr>
<tr>
<td></td>
<td>Spine</td>
</tr>
<tr>
<td></td>
<td>Neck</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
</tr>
</tbody>
</table>

\(p < 0.0001\) among three groups in the same anatomic area.

\(p < 0.0001\) between groups A and C in the same anatomic area.
radiation doses. Moreover, the findings of this survey show that EDs for children were similar to those for adults in the abdomen, neck, and spine, but increased approximately 1.5-fold in the head and 1.7-fold in the pelvis. This is in line with the study by Thomas and Wang, who reported higher ED estimates for younger age groups than older age groups for head, abdomen, and pelvis MSCT scans.23 Further, the relationship between ED and stochastic risk is assumed to be linear24 and the risk of carcinogenesis is estimated to increase proportionally with organ dose.25,26 Furthermore, we should also notice that the number of abdominal scans was small, especially in children (732 cases [0.45%]), as many children would have opted for other imaging techniques such as magnetic resonance (MR) and ultrasound. In addition, MR reports were also preferred for complicated cases in adult patients who underwent CT for cancer staging before surgery. In contrast, we report similar or lower doses to previous values reported for the head, chest, neck, and pelvis.27–30 Due to their lower body weight and sizes, children often receive higher ED than adults when adult-size imaging techniques and protocols are used.30 Usage of age- and child-specific protocols,30 optimizing scan parameters based on patient anatomy, and reducing the number of multiphase scans can go a long way in reducing ED in children.31 Radiation doses showed an obvious tendency to increase with slice number and decrease with the use of exposure reduction techniques such as ASIR and iDose.32 Furthermore, there was an increasing trend toward radiation dose with increasing number of slices, especially in the head and chest, which is in contrast with a study in which dose reduction was achieved for all types of CT examinations with the 236-slice scanner.33 However, the results were similar to those associated with 4-, 8-, 16-, and 64-slice CT scanners.34 Hence, small slice CT scanners and large-sliced scanners with exposure reduction techniques such as ASIR and iDose may be used efficiently to scan anatomical areas with low radiation doses.

It should be noted that although CTDIvol and DLP were higher in the head compared with the chest in our study, the latter was higher in terms of ED. CTDIvol measures the radiation output of a CT scanner, which is useful to compare devices. However, CTDIvol depends on tube current, which changes as per the type of scan being performed. Since the penetrating power required to visualize the brain is higher compared with the chest due to its anatomy, the tube current used is higher, causing the CTDIvol of head scans to rise. On the other hand, ED is a measure of the dose received by the patient, with tissue-weighting factors coming into play. This factor is smaller for the head compared with the chest (0.021 versus 0.014 mGy-cm),35 causing the ED received during head scans to be much lower as compared with chest scans. Hence, the patients who had chest scans received more radiation than patients who had head scans. Furthermore, since the incidence of cancer has been reported to be larger after chest scans,36 it is possible that such patients in our study could also be at risk.

There are several limitations to our study. It was a retrospective, single-center study, similar to many other dose surveys, resulting in an inherent bias in patient selection. The number of examinations included in the evaluation was small compared with the total examinations in our hospital. The time of observation was only 6 months, given the recent introduction of Radimetrics in China. Because of the large number of patients (about 1000 examinations per day) undergoing CT, we had to distribute them into different CT groups: physical examinations and clinical examinations using 16 slices, and coronary CT angiography or cardiac imaging. There was a scarcity of patients in the group using 16-slice scanners for physical examinations and clinical patients, leading to a smaller number of patients in the abdomen and spine CT group and none in the neck and pelvis group. Furthermore, although pediatric-specific CT protocols were used in this study, they were not well optimized as also seen in previous studies.12,13 However, adult CT protocols were not used in pediatric patients. Lastly, the CT equipment used in our analysis were from different manufacturers and had different use situations; for example, CT4 was used for lung scanning because of the larger number of patients, whereas CT5 was used mostly for head and few lungs scans. This led to difficulties in analyzing the scans from the two scanners. In the future studies, we also plan to add more equipment for analysis in case of increase in the patient sample size. Nevertheless, this first survey in China to estimate the radiation doses may be of significant importance for future studies and also clinicians to set DRLs for patients.

In conclusion, the findings of this study reveal the radiation doses in China for a large number of observations using automated data collection. These data provide a basis for evaluation of CT radiation doses in China and allow institutions to understand doses by anatomical area to develop DRLs and allow for cross-country comparisons.

ACKNOWLEDGMENTS

This study was supported by The First Hospital of Jilin University (grant no. JDYY2016055), National Science and Technology project (grant no. 2015DFA11180), and Jilin Province Development and Reform Commission (grant no. 2015Y034-5).

APPENDIX. SUPPLEMENTARY DATA

Supplementary data related to this article can be found at http://links.lww.com/JCMA/A13.

REFERENCES

35. Einstein AJ. Effects of radiation exposure from cardiac imaging; how good are the data? J Am Coll Cardiol 2012;59:553–65.