Variation in Pediatric Head CT Imaging Protocols in Washington State

Kalpana M. Kanal, PhD[a], Monica S. Vavilala, MD[b,c,d], Colin Raelson, BA[c], Abhishek Mohan, BS[b], Wendy Cohen, MD[a], Jeffrey Jarvik, MD[a], Frederick P. Rivara, MD, MPH[c,d], Brent K. Stewart, PhD[a]

Purpose: To examine variation in pediatric trauma head CT imaging protocols in Washington state.

Methods: A web-based survey was sent to trauma-designated hospitals in Washington state. Respondents were queried about pediatric head trauma volumes, type of CT scanners, and technical information about the CT imaging protocols. Variation in pediatric trauma volumes, CT dose reduction strategies, and effective dose by trauma center levels was examined. Mean head effective dose and organ dose for a female baby were estimated.

Results: We achieved a 76% overall response rate. Of the 2,215 children who received head CT scans, 36.3% (n=805) received head CT imaging at level 4 trauma center facilities, followed by level 1 trauma center (31.4%; n=695), level 3 trauma center (19.7%; n=436), level 2 trauma center (12%; n=267), and Level 5 (0.5%; n=12) facilities. Most responding trauma center facilities (44/47) reported having a pediatric specific imaging head CT protocols. However, compared to levels 1 and 2 trauma centers together, a greater proportion of levels 3, 4 & 5 trauma center facilities collectively lacked dose reduction strategies (0% vs. 25-57%), tended to have higher mAs (169 ± 113 vs. 110 ± 36), and were later adopters of dose reduction strategies on the CT scanners. There was more than a 10-fold variation in estimated median effective dose for a baby within level 4 trauma center facilities (3.5 ± 0.84 mSv, range 0.60 to 9.60 mSv).

Discussion: There is both within and between trauma center level variation in pediatric head CT imaging protocols and radiation dose in Washington state.

Key Words: CT imaging protocols, pediatric head CT, trauma center level, radiation dose, Washington state

J Am Coll Radiol 2011;8:242-250. Copyright © 2011 American College of Radiology

INTRODUCTION

CT scans are extensively used to diagnose and manage traumatic brain injuries in children but are also the single and largest source of medical radiation in the United States. The National Council on Radiation Protection and Measurements estimated that in 2006, 67 million CT scans accounted for 15% of the total medical radiation procedures and about 50% of the collective dose [1-4]. Although there are recommended pediatric-specific protocols that reduce radiation risk to children with traumatic brain injuries who undergo head CT scans, the implementation and use of these protocols are not known [5,6].

CT technology has changed significantly in the last decade with the availability of modern multi-row detector CT scanners, which provide higher quality images, are more technically challenging, and may have an associated increase in radiation dose [7-10]. Effective dose (ED) is a measure of the radiation and organ system-specific damage in humans [11]. The ED estimated for a child is higher than in an average-size adult undergoing the same imaging examination [12]. Brenner et al [13]

[a]Department of Radiology, University of Washington, Seattle, Washington.

[b]Department of Anesthesiology and Pain Medicine, University of Washington, Seattle, Washington.

[c]Harborview Injury Prevention and Research Center, University of Washington, Seattle, Washington.

[d]Department of Pediatrics, University of Washington, Seattle, Washington.

Corresponding author and reprints: Kalpana M. Kanal, PhD, University of Washington, Department of Radiology, 1959 NE Pacific Street, Box 357987, Seattle, WA 98195-7987; e-mail: kkanal@u.washington.edu.

0091-2182/11/$36.00 • DOI 10.1016/j.jacr.2010.11.005

estimated a lifetime pediatric mortality risk of 0.07%, or 10 times that of an adult, from a single pediatric head CT scan in a 1-year-old child.

The potential for medical radiation from CT to increase the risk for cancer in those exposed has become a focus of attention among scientists and physicians [14,15]. Moreover, published studies [13,16] of radiation dose and risk from CT to children and media investigations of radiation dose pediatric patients receive when undergoing CT examinations [17] have transformed this issue from one of scientific inquiry to a global public health concern.

Previously published work shows that there is variation in pediatric head CT imaging, even among institutions in the same city, resulting in variation in ED to pediatric patients [18]; such variations in medical care are associated with poor outcomes [19]. Therefore, we hypothesized that similar variation would exist across Washington state and that pediatric head CT imaging would vary by trauma center (TC) levels. The purpose of this study was to examine variation in head CT protocols for injured children in Washington state to justify the need for protocol standardization to reduce radiation exposure in children.

METHODS

General Methodology

In Washington state, the Department of Health designates 5 levels of acute care trauma services, 3 levels each of pediatric acute care trauma services and trauma rehabilitation services. Of the 77 designated TCs, there are 8 pediatric designated centers: one level 1 center, two level 2 centers, and five level 3 centers [20]. After internal review board approval, a letter or e-mail introducing the study was mailed to each of the 77 TC-designated hospitals (levels 1-5) in Washington (Table 1). Trauma centers vary in their specific capabilities and are identified by level designations, with level 1 being the highest and level

Table 1. Survey administered to trauma centers in Washington state

Question 1	How many total trauma patients did you have in 2007?
Question 2	How many children received head CT scans in your institution for head trauma in 2007?
Question 3	What is the number of CT scanners that are on site at your hospital?
Question 4	Are there one or more scanners dedicated for pediatric imaging?
Question 5	For the CT machine dedicated to pediatric imaging (or the CT machine most often used for pediatric head trauma CT scans), please provide the following information: a. CT Manufacturer b. CT Model c. Single or Multidetector d. If Multi, specify the number of detector rows
Question 6	Do you have a specific protocol for performing head CT scans on pediatric trauma patients?
Question 7	Please provide the following information for your pediatric head CT protocol. If no pediatric protocols are in place, please provide what you use below. a. Kilovolts (kVp) b. Milliamperes (mA) c. Rotation Time (sec) d. Scan Mode (Axial or Helical) e. Pitch f. Beam Collimation (i.e. 5x4i, 0.625x64, etc.) g. Anatomy Scan Range
Question 8	Have you implemented any dose-reduction strategy for pediatric head CT scans? (i.e. Automatic Tube Current Modulation, Patient Size-Specific Protocols, etc.) If yes, what year were they implemented? a. yes or no b. what year were they implemented?
Question 9	Do you use shielding for patients having CT scans? If yes, please indicate which organs you shield for and the type of shielding used for each organ. a. yes or no b. What type of shielding?

5 the lowest. A 9-item online survey inquiring about pediatric head CT examination was developed and administered using the University of Washington's internal Web-based questionnaire software (https://catalysttools-.washington.edu). A follow-up telephone call or e-mail was used to provide a link to the questionnaire (Table 1). Respondents could directly complete the survey online or fax their responses. A second follow-up phone call was made to nonresponders after two failed responses to telephone or e-mail reminders.

To determine which TCs are ACR accredited for pediatric CT imaging, we cross-referenced the list of 77 designated TCs with the list on the ACR's Web site [21].

Data Analysis

Data were retrieved from Web-based questionnaire software and analyzed. The mean ED for a female baby (length, 57 cm; anteroposterior size, 12.2 cm; weight, 4.2 kg) was determined for those facilities who reported all technical data. This age group was selected for our analysis because the youngest children are at greater risk for inflicted injury, undergo CT scans, and are most sensitive to medical radiation, with sensitivity decreasing with increasing age. Additionally, because females are more at risk than males, we selected a female baby for our analysis to demonstrate effect. This does not imply that this age group of children was exposed to radiation at any facility during this study but simulates radiation exposure for this age group if they would have undergone head CT scans at a given facility. The ED and dose to 3 organs, the brain, eye lens, and thyroid, were calculated for the type of CT scanner from the CT-Expo dosimetry spreadsheet version 1.7 (Medizinische Hochschule, Hannover, Germany), which is a tool based on Monte Carlo methods for calculating patient organ and ED from CT scans for all adults and children [22]. We also compared pediatric-designated centers (n = 8) with adult-designated centers (n = 69).

To determine radiation dose savings, we first selected the TC level for which we received sufficient technical data: level 4 TC. We then calculated the average ED values for these level 4 TCs and subtracted from this the average ED values for level 2 TCs that had the lowest dose in the state. The percentage of radiation dose savings was then calculated by dividing this difference by average ED values for level 4 TCs as

$$\frac{\overline{X}(ED_{TC4}) - \overline{X}(ED_{TC2})}{\overline{X}(ED_{TC4})},$$

where $\overline{X}(ED_{TC4})$ is the average of the ED across all level 4 TCs, and $\overline{X}(ED_{TC2})$ is the average of the ED across all level 2 TCs.

Data are presented using descriptive statistics. Differences (with P values $< .05$ indicating significance) be-

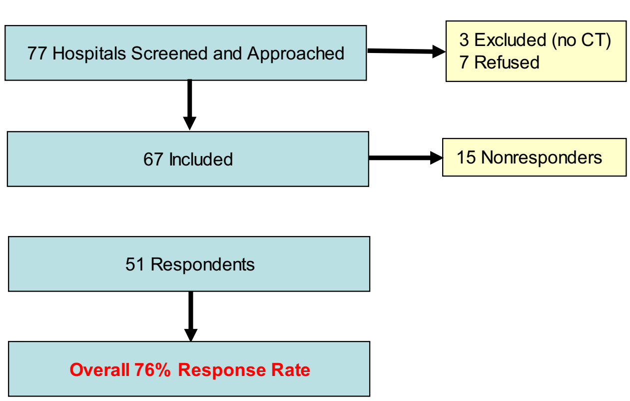

Fig 1. Flow chart of trauma centers surveyed.

Table 2. Response rate by trauma center level across Washington state

Level	Total Number of Hospitals	% of State	Response Rate (n)
1	1	1%	100% (1)
2	4	5%	100% (4)
3	23	30%	70% (16)
4	33	43%	70% (23)
5	16	21%	44% (7)

Table 3. Response rate for survey question by trauma center level across Washington state

Question	Level 1 (%)	Level 2 (%)	Level 3 (%)	Level 4 (%)	Level 5 (%)
1	100	100	100	70	40
2	100	100	100	91	60
3	100	100	100	100	100
4	100	100	100	100	100
5a	100	66.6	100	100	100
5b	100	100	100	100	60
5c	100	100	100	100	100
5d	100	66.6	100	100	100
6	100	100	100	96	80
7a	100	100	100	87	80
7b	100	100	100	74	80
7c	100	100	100	83	80
7d	100	100	100	78	80
7e	100	33.3	100	76	20
7f	100	66.6	100	61	40
7g	100	100	100	74	80
8a	100	100	100	96	100
8b	100	66.6	100	57	40
9a	100	100	100	100	100
9b	100	100	100	65	100

tween and within TCs and between level 1 and 2 (higher) and level 3 to 5 (lower) TCs were examined using Student's *t*-test, analysis of variance, or Fisher's exact test, as appropriate.

RESULTS

Figure 1 shows a 76% response rate. The response rate was highest for level 1 and 2 facilities (100%), lowest for level 5 facilities, and varied by TC (Table 2). Table 3 shows the response rate as a function of the questions asked in the survey; the lowest response rate corresponded to questions about the technical scan parameters of the CT scanner.

In 2007, higher level TCs reported greater average numbers of children imaged per TC: level 1, n = 696; level 2, n = 66.8; level 3, n = 27.3; level 4, n = 35.0; and level 5, n = 1.7 ($P < .001$; Figure 2). However, collectively, level 4 TCs reported the highest total volume of children who received head CT scans in Washington state. Similarly, although the average number of CT scanners was higher at higher level TCs, most CT scanners were at level 3 and 4 TCs compared with those at level 1, 2, and 5 TCs.

Most (71%-100%) TCs reported having pediatric-specific imaging head CT protocols on their CT scanners: levels 1 and 2, 100%; level 3, 88%; level 4, 91%; and level 5, 71%. There was no significant difference between the levels. Most TCs (44 of 47 respondents to this question) reported having multidetector CT scanners, which have some dose reduction capabilities compared with single-slice scanners. Therefore, these centers had some opportunities to reduce dose with dose reduction options readily available on multislice scanners. The 3 facilities with single-detector technology were level 4 and 5 TCs. Tube kilovoltage ranged from 100 to 120 kV and did not vary by TC level. Although the product of tube current (mA) and rotation time (s) did not statistically differ between the 5 TC levels, there was a correlation between higher mAs and lower TC level ($r^2 = 0.57$; Figure 3). Collectively, level 3 to 5 TCs tended to have higher mAs than level 1 and 2 facilities (169 ± 113 vs 110 ± 36 mAs, $P = .08$) but the level 1 TCs had higher mAs than level 2 or 3 TCs, showing that there is variability in radiation dose even among higher level TCs. However, the large standard deviation in mAs for level 3 to 5 TCs clearly illustrates the large variation within lower level TCs. However, when we compared the mAs between the pediatric-designated centers and the adult-designated centers, pediatric-designated centers had statistically significant lower mAs (87.4 vs 182.5 mAs, $P < .00027$) than adult centers.

All level 1 (n = 1) and level 2 (n = 4) facilities reported 100% dose reduction strategies compared with level 3 (75%), level 4 (70%), and level 5 (43%) TCs, but this

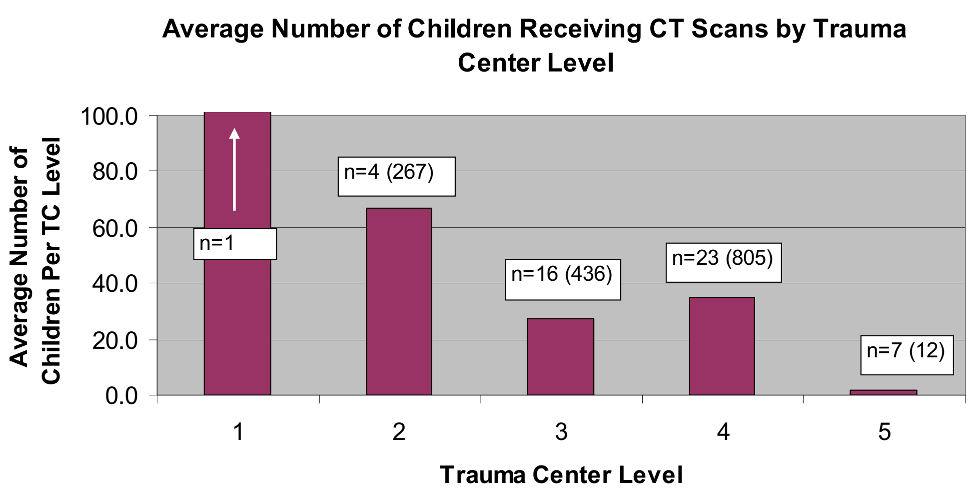

Fig 2. Average number of children undergoing head CT scans by trauma center (TC) level. The total number of facilities per TC is denoted by n, and the total number of children seen per TC level is shown in the boxes. Higher level TC facilities reported greater average numbers of children imaged per TC: level 1, n = 696; level 2, n = 66.8; level 3, n = 27.3; level 4, n = 35.0; level 5, n = 1.7 ($P < .001$). However, collectively, level 4 TCs reported the highest total volume of children who underwent head CT scans in Washington state. Of the 2,215 children, 36.3% (n = 805) underwent head CT imaging at level 4 TCs, followed by level 1 TCs (31.4% [n = 695]), level 3 TCs (19.7% [n = 436]), level 2 TCs (12% [n = 267]), and level 5 TCs (0.5% [n = 12]). Similarly, although the average number of CT scanners was higher at higher level TCs (level 1, n = 3; level 2, n = 2; level 3, n = 2; level 4, n = 1; level 5, n = 1; $P = .001$), most CT scanners were at level 3 (n = 25) and 4 (n = 27) TCs compared with those at level 1 (n = 3), 2 (n = 9), and 5 (n = 9) TCs.

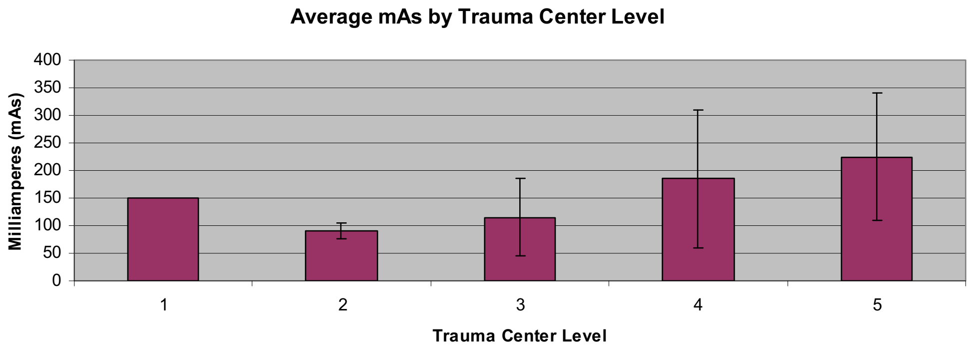

Fig 3. Average tube current-time product (mAs) a function of trauma center level. Bar heights represent mean values, and error bars range over 1 standard deviation.

difference was not significant (Figure 4). The one level 1 TC was the first to adopt dose reduction strategies in 2001. Except for level 2 TCs (2007), lower level facilities adopted dose reduction strategies later: level 3 TCs in 2004, level 4 TCs in 2005, and level 5 TCs in 2007. There was no significant difference in when dose reduction strategies were adopted between pediatric-designated centers and adult-designated centers.

Most (81%-100%) TCs reported using thyroid collars, lead aprons, and bismuth shielding during CT imaging, regardless of TC level: level 1, 100%; level 2, 100%; level 3, 81%; level 4, 83%; and level 5, 86%. There was no difference between higher and lower level TCs.

Mean ED data for a female baby could be estimated only for 19 facilities, including 11 of the level 4 TCs, on the basis of the completeness of reported data (Figure 5). There was a 10-fold variation in ED within level 4 TCs; the median ED was 3.5 ± 0.84 mSv (range, 0.60-9.60 mSv). Collectively, the lowest EDs (1.2 and 1.6 mSv) were reported by level 2 TCs. The average ED for an adult head CT is 2 mSv, also shown in Figure 5 [23,24]. Similarly, the organ doses shown in Figure 6 varied within level 4 TCs. For level 4 TCs, the estimated median brain dose was 37 mGy (range, 7.0-123.8 mGy), the estimated median eye lens dose was 42.4 mGy (range, 8.2-143.3 mGy), and the estimated median thyroid dose was 6.6 mGy (range, 1.1-20.9 mGy). There were insufficient data to statistically compare radiation dose between pediatric-designated centers and adult-designated centers. Only 3 of the pediatric-designated centers provided complete technical information to calculate dose. Figure 5 shows the ED for level 1 and 2 pediatric-designated centers as well as other level adult-designated centers.

Because the level 2 TCs had the lowest EDs, we estimated the dose savings that could be achieved across the level 4 TCs if they used the same CT protocols as level 2 TCs resulting in the same low EDs as level 2 TC. We estimated the dose savings to be 65%, which is significant.

At the time of this study, few (10 of 77 [13%]) TCs in Washington state had successfully achieved ACR accreditation in CT for pediatric imaging, and 2 of the facilities were under review in the process of achieving accreditation [15]. The distribution of accredited facilities across TC level was as follows: level 1, n = 1 (100%); level 2, n = 4 (25%); level 3, n = 16 (38%); level 4, n = 23 (8.7%); and level 5, n = 7 (0%).

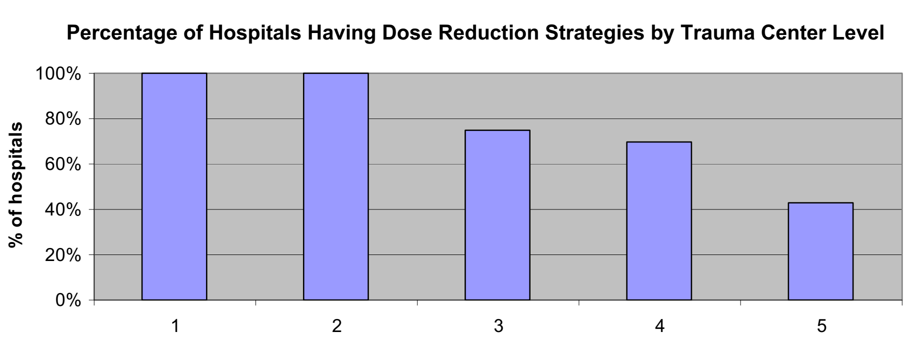

Fig 4. Percentage of trauma centers having dose reduction strategies as a function of trauma center level.

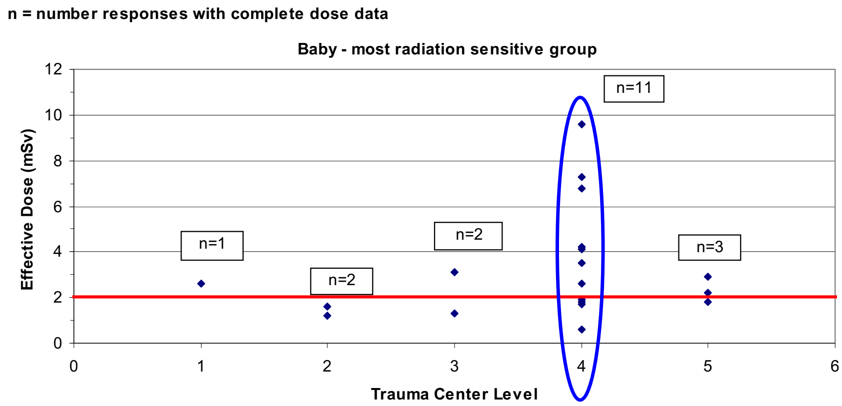

Fig 5. The mean effective dose (ED; millisieverts) as a function of trauma center (TC) level for a female baby. Mean ED data for a female baby could be estimated only for 19 facilities, including 11 of the level 4 TCs, on the basis of the completeness of reported data. There was a 10-fold variation in ED within level 4 TCs; the median ED was 3.5 ± 0.84 mSv (range, 0.60-9.60 mSv). Collectively, the lowest EDs (1.2 and 1.6 mSv) were reported by level 2 TCs. The average ED for an adult head CT is 2 mSv, also indicated by the dark (red online) line.

DISCUSSION

The main finding of this study is that there is variation both within and between TC levels in pediatric head CT imaging protocols and radiation dose in Washington state.

For 2007, (1) level 4 TCs (n = 23) reported the largest total number of children undergoing head CT scans, even though the level 1 TC (n = 1) had the highest number of children scanned; (2) most TCs reported having pediatric-specific imaging head CT protocols on their CT scanners and had multidetector CT scanner technology; (3) collectively, the average mAs tended to be higher for level 3 to 5 TCs, with pediatric-designated centers using lower mAs than adult-designated centers; (4) levels 3 to 5 TCs were later adopters of dose reduction strategies on CT scanners, with no statistically significant difference in the adoption of dose reduction strategies between pediatric-designated centers and adult-designated centers; and (5) there was a large variation in ED and organ dose across level 4 TCs. These data provide new statewide information regarding pediatric head CT care delivery in Washington state. There were insufficient data to statistically compare radiation dose between pediatric-designated centers and adult-designated centers. Only 3 of the pediatric-designated centers provided complete technical information to calculate dose.

Trauma is the leading cause of morbidity and mortality in children aged > 1 year [25], and data show that most injured children are not treated at pediatric TCs, because of the geographically limited distribution of such specialized care and a lack of pediatric surgeons and other specialists [26]. Consistent with these patterns, we found

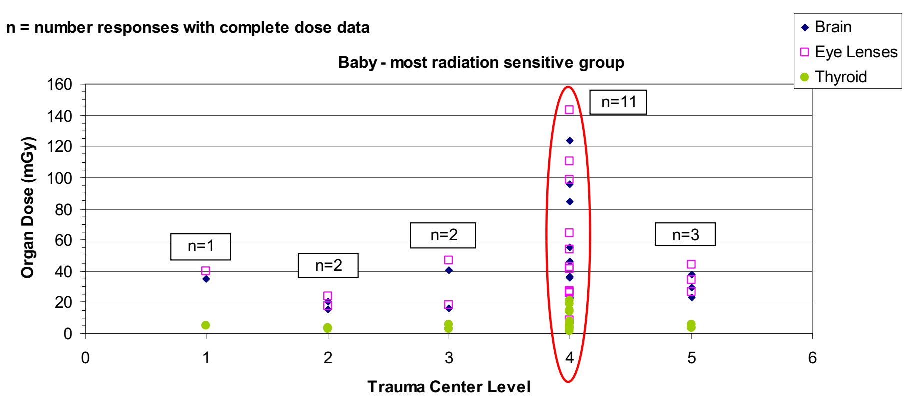

Fig 6. The mean organ dose as a function of trauma center (TC) level for a female baby. The organ doses varied within level 4 TCs. For level 4 TCs, the estimated median brain dose was 37 mGy (range, 7.0-123.8 mGy), the estimated median eye lens dose was 42.4 mGy (range, 8.2-143.3 mGy), and the estimated median thyroid dose was 6.6 mGy (range, 1.1-20.9 mGy).

that although level 4 and 5 TCs had the smallest number of scanners, they reported the highest volume of children being imaged at their facilities, suggesting that lower level TCs play a large role in trauma care delivery to children requiring head CT scans.

Children are more sensitive to radiation than adults [13], and age and body size should be considered [21] when selecting pediatric CT scanning parameters. In 2001, the FDA issued a health notification with guidelines stating that radiologists and health care providers should attempt to minimize radiation to pediatric population and reduce exposure as low as reasonably achievable [27,28]. Most recently, the Alliance for Radiation Safety in Pediatric Imaging promulgated guidelines to encourage improved CT protocols for pediatric patients [29]. The ACR has added relative radiation level designations to its Appropriateness Criteria® for selecting proper imaging procedures for particular medical conditions [30]. Good practice dictates that customized patient-specific protocols and techniques be used that minimize radiation dose without adversely affecting CT diagnostic performance [9,31,32]. In this study, most responding TCs across Washington state used pediatric-specific protocols, suggesting a high level of awareness of the necessity of tailoring CT protocols for pediatric head imaging. We also observed that pediatric-designated centers were more dose conscious and used statistically significant lower mAs compared with adult-designated centers.

Dose reduction options are now available on the CT consoles of modern multidetector CT scanners. Patient radiation dose can be reduced by lowering the mAs (keeping other factors constant). In multidetector CT scanners, automatic tube current modulation is a technique used to reduce overall patient dose by altering the tube current on the basis of anatomic thickness [9,33]. In this study, although not statistically significant, a greater proportion of level 3 to 5 TCs lacked dose reduction strategies and were also later adopters of these strategies; thus, the average mAs tended to be higher for this group of TCs.

In the United States, there are no dose limits for patients undergoing CT examinations [34-36], and it is unknown whether recommended dose reduction techniques available on modern CT scanners are used. We estimated the radiation dose, and although there were insufficient data to describe variation in dose for the other TCs, we observed large variation in dose within level 4 TCs (Figure 5). The linear-no-threshold cancer risk model dictates that the smallest radiation dose has the potential to cause a small increase in cancer risk [37], implying there would also be a large variation in lifetime attributable risk of cancer across the level 4 TCs. This risk could increase if a significant number of pediatric trauma patients who undergo CT scans at referring hospitals before transfer to level 1 pediatric TCs receive additional CT scans after transfer [38] and if patients are female or young children because they are more sensitive to radiation dose effects. In contrast, as our simulated data illustrate, there would be significant radiation dose savings for the whole body if variation in radiation dose were reduced to that of level 2 TC doses.

The lens of the eye is radiosensitive; as little as 50 to 2,000 mGy has been known to cause detectable opacities, with exposures of >4 Gy causing visual impairment secondary to cataracts [39-41]. Because the eyes of children are especially radiosensitive, less than half this exposure would cause cataracts [42]. In this study, although the median eye lens dose was lower (42.4 mGy) than the 50-mGy dose typically quoted for head CT [34], the dose range was similarly large and in some cases more than double the average dose. Angling the gantry or using bismuth shields could decrease dose exposure to the eye lens [39,43]. For level 4 TCs, the brain dose varied between 7.0 and 123.8 mGy, and the median brain dose was 37 mGy, corresponding to median mAs of 160. Brenner and colleagues [1,13,15] reported a median brain dose of 95 mGy at a median mAs of 340 for a child aged 0 years. Data show that although considered to be radioresistant, particularly at low doses, the brain is significantly radiosensitive, with a lifetime attributable risk of cancer decreasing with increasing age [44]. Similar trends were seen in thyroid dose. These data show that the risk to organs is also variable and may result in organ damage with repeat exposure if tissue repair does not occur.

The large amount of missing technical scan data despite follow-up suggests that many TCs might have been unaware of the various CT dose–related factors available on the CT console, or the appropriate person did not respond to the survey, such as the CT technologist. At our pediatric ACR-accredited CT facility, staff members are periodically educated on available dose reduction strategies [45] to ensure optimal imaging of pediatric patients as well to meet the continuing medical education requirements of the ACR CT accreditation program [46]. Becoming accredited by the ACR is one way to ensure that a TC undergoes a peer review, educationally focused evaluation of its imaging protocols, resulting radiation dose and image quality to ensure consistency with the principles of doses as low as reasonably achievable and patient size. At the time of this writing, Washington state did not have regulations pertaining to image quality or radiation dose in CT scanners [47], and very few (13%) TCs in Washington state had successfully achieved accreditation in CT for pediatric imaging [20], suggesting a need for education in this area. Efforts to decrease radiation exposure are also evident by studies examining ways to decrease imaging by identifying children at very low risk for traumatic brain injury for whom CT can routinely be obviated [48]. Radiology efforts to decrease dose are therefore aligned with those of other medical practitioners.

This study had some limitations. First, we did not achieve a 100% response rate, despite follow-up, which introduces bias and may overestimate or underestimate the number of injured children who received head CT scans during 2007. However, our 76% response rate with reasonable distribution among TC levels allowed us to draw some conclusions about protocol variations across the state. Second, we had a small number of level 1 and level 2 TCs, limiting our ability to compare TCs for all parameters. Third, because this was a survey study, we could not objectively verify the responses to our survey. Fourth, the estimated EDs were based on completeness of technical data, which resulted in a very small sample size and prevented us from making any definitive conclusions about radiation dose and cancer risk by TC. Fifth, we did not survey nondesignated centers, which may also provide head CT imaging for injured children in Washington. Finally, we did not ask for clinical images from the TCs to review diagnostic image quality. There is a definite relationship between acceptable diagnostic image quality and radiation dose, with lower perceived image noise with higher dose. We did not investigate this relationship across the TCs in this study.

CONCLUSIONS

This study showed that there is variation in pediatric head CT imaging protocols and dose reduction options across TCs in Washington state, resulting in differences in radiation dose exposure for pediatric head CT scans by TC level. Awareness of variation and associated risks is needed to reduce radiation exposure. Consistent imaging protocols and adjustment of CT settings on the basis of clinical indication and the size of the child may reduce variation and radiation exposure from medical imaging.

ACKNOWLEDGMENTS

We would like to acknowledge the level 1 to 5 TCs in Washington state for participation in this study and the Washington State Department of Health for its support of this work.

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