Variation in radiation dosing among pediatric trauma patients undergoing head computed tomography scan

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BACKGROUND: When head injured children undergo head computed tomography (CT), radiation dosing can vary considerably between institutions, potentially exposing children to excess radiation, increasing risk for malignancies later in life. We compared radiation delivery from head CTs at a level 1 pediatric trauma center (PTC) versus scans performed at referring adult general hospitals (AGHs). We hypothesized that children at our PTC receive a significantly lower radiation dose than children who underwent CT at AGHs for similar injury profiles.

METHODS: We retrospectively reviewed the charts of all patients younger than 18 years who underwent CT for head injury at our PTC or at an AGH before transfer between January 1 and December 31, 2019. We analyzed demographic and clinical data. Our primary outcome was head CT radiation dose, as calculated by volumetric CT dose index ($CTDI_{vol}$) and dose-length product (DLP; the product of $CTDI_{vol}$ and scan length). We used unadjusted bivariate and multivariable linear regression (adjusting for age, weight, sex) to compare doses between Children's Hospital Los Angeles and AGHs.

RESULTS: Of 429 scans reviewed, 193 were performed at our PTC, while 236 were performed at AGHs. Mean radiation dose administered was significantly lower at our PTC compared with AGHs ($CTDI_{vol}$ 20.3/DLP 408.7 vs. $CTDI_{vol}$ 30.6/DLP 533, $p < 0.0001$). This was true whether the AGH was a trauma center or not. After adjusting for covariates, findings were similar for both $CTDI_{vol}$ and DLP. Patients who underwent initial CT at an AGH and then underwent a second CT at our PTC received less radiation for the second CT ($CTDI_{vol}$ 25.6 vs. 36.5, $p < 0.0001$).

CONCLUSIONS: Head-injured children consistently receive a lower radiation dose when undergoing initial head CT at a PTC compared with AGHs. This provides a basis for programs aimed at establishing protocols to deliver only as much radiation as necessary to children undergoing head CT. (*J Trauma Acute Care Surg.* 2021;91: 566–570. Copyright © 2021 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Care Management/Therapeutic, level IV.

KEY WORDS: Head injury; pediatric; trauma; CT; radiation.

In children, traumatic brain injury accounts for more than 1,400 deaths, 600,000 emergency department visits, and nearly 18,000 hospitalizations annually.[1,2] Head computed tomography (CT) scans are used to detect intracranial injury and remains the standard initial imaging modality for patients with closed head trauma.[3] Nearly 1 in 10 pediatric trauma-related emergency department patient evaluations include performance of a head CT scan.[4] Therefore, head CT scans are an important source of ionizing radiation exposure.[3] Although a definitive association has yet to be established between CT scans and subsequent development of malignancies or other complications, epidemiologic studies suggest that such a link is plausible, particularly in children, who may be expected to live for decades before such issues are manifest.[5–7] Thus, clinicians who care for children must seek methods to mitigate ionizing radiation exposure without sacrificing diagnostic accuracy and time to definitive care.

Because of these concerns, efforts have been made to decrease both the unnecessary utilization of CT scanning and the per-event radiation dosing.[8] The "Image Gently" campaign promotes a qualitative standard balancing diagnostic accuracy and radiation dosing using the "as low as reasonably achievable" (ALARA) principle. Quantitative standards have also been outlined by the American College of Radiology for pediatric CT accreditation.[9,10] Despite these standards, as well as published guidelines for determination of CT radiation dosing by patient age, weight, and body size, adult hospitals, including trauma centers, are likely to have their CT machines configured for adult dosage.[11] In contrast, pediatric trauma centers (PTCs) are anticipated to be more likely to use radiation reduction protocols.

In this study, we aimed to compare radiation delivery from head CT scans performed for pediatric head trauma at an American College of Surgeons (ACS) verified, level I, freestanding PTC versus scans performed at referring adult general hospitals (AGHs) (including adult trauma centers) before transfer. We hypothesized that pediatric head trauma patients who undergo

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a head CT scan at the level I PTC receive a significantly lower dose of radiation than patients who initially undergo a head CT scan at adult centers (AGHs) for similar injury profiles.

PATIENTS AND METHODS

Study Population and Definitions

We captured all children younger than 18 years evaluated at Children's Hospital Los Angeles (CHLA) and who received a head CT scan for head trauma at either CHLA or referring AGHs or adult trauma centers from January 1, 2019, to December 31, 2019. Eligible children were identified within our electronic medical record by using the Los Angeles County Trauma and Emergency Medicine Information System (TEMIS) trauma database. The TEMIS includes all pediatric trauma patients from the dozens of hospitals, including the 15 trauma centers, in Los Angeles County, an area that includes 2.1 million children across the county. Of these 15 hospitals, CHLA is the sole ACS-verified level 1 PTC, and the remaining 14 hospitals are ACS-verified level 1 or level 2 adult trauma facilities. Patients were included if they underwent an initial head CT scan at CHLA or at an AGH before transfer to CHLA. We excluded patients if head CT scan radiation dose data were not available.

Patient and clinical characteristics included sex, age, weight (kilograms), race/ethnicity, insurance status, mechanism of injury, Injury Severity Score, Glasgow Coma Scale (GCS) categories, and type of neurosurgical intervention. We further categorized standard mechanism of injury codes recorded in TEMIS into four groups: (1) all fall-related injuries, including falls greater than 15 ft for adults, greater than 10 ft for children, and less than 10 ft; (2) bicycle crashes, including those involving an automobile moving greater than 20 mph, those involving an automobile moving less than 20 mph, those where the patient was run over by an automobile, and those where the patient was hit by an automobile while on a moped; (3) motor vehicle–related injuries where the patient was not on a bicycle or moped; and (4) all other injuries. We categorized GCS as mild (14–15), moderate (9–13), and severe (3–8). With Institutional Review Board approval, data were abstracted from the TEMIS database and the electronic medical record at CHLA.

Outcome Measures

The primary outcome was head CT scan radiation dose based on a 16-cm diameter CT dosimetry phantom, as calculated by volumetric CT dose index ($\mathrm{CTDI_{vol}}$) and dose-length product (DLP), which are recorded on all CT scans. These metrics were selected rather than the effective radiation dose because they are standardized values that are readily available from any hospital and can be measured and compared without the help of a physicist. The first, $\mathrm{CTDI_{vol}}$, is an indication of the average absorbed radiation within the scan volume for a standardized cylindric CTDI phantom. The second, DLP, is the product of $\mathrm{CTDI_{vol}}$ and scan length along the z axis of the patient, which estimates the total energy delivered to the CTDI phantom during the examination.[12] The maximum acceptable phantom $\mathrm{CTDI_{vol}}$ dose for a pediatric head CT scan is 40 milligray for a 1-year-old child, and the national diagnostic reference level is 35 milligray.[10] The diagnostic reference level is set at the upper third or quartile of doses sampled from clinical practice data and serves to initiate investigation of dose appropriateness if routinely exceeded.[13]

Statistical Analysis

Statistical analyses were conducted with a two-tailed α equal to 0.05 (5%) level of significance. The assumptions underlying all statistical analyses were checked using graphical and numerical methods. The Shapiro-Wilk test was used to assess normality for continuous variables, whenever applicable. Unadjusted bivariate analyses were used to investigate differences in initial radiation dose between CHLA and AGHs that performed a head CT scan. Similar analyses were used when AGHs were stratified into trauma centers and non–trauma centers. Categorical variables were analyzed using the χ^2 or Fisher's exact test, if the expected cell frequencies were below 5. For continuous variables, the Student's t test or Wilcoxon-Mann-Whitney test was used when appropriate.

To investigate differences in radiation dose at the patient level, we next performed a subanalysis among patients who received a head CT scan at an AGH and who subsequently received a repeat head CT scan at our facility. Overall mean radiation dose between initial and repeat CT scan was compared, as well as a stratified comparison of dose by age group. Differences in $\mathrm{CTDI_{vol}}$ and DLP data were normally distributed in this subgroup, and a paired t test was used to test differences in dose between AGHs and CHLA.[14]

Finally, we conducted a multivariable hierarchical linear regression analysis for the primary continuous outcomes of interest. Hospitals were treated as a random effect to control for variation across institutions and account for the potentially correlated nature of such data. Covariates, including referring AGH, age, patient weight, sex, mechanism of injury, and GCS category, were selected a priori and additionally adjusted for relevant patient characteristics. Interaction between categorical age and hospital type was evaluated but found to be insignificant and was dropped from the final models. Our final model was selected by using a stepwise process comparing fit metrics, including R^2 value, to evaluate and select the best fitting and most parsimonious stepwise model.[15] Radiation dose was also evaluated as a natural log-transformed outcome because of its skewed nature; results from linear and log-linear outcomes were compared for consistency in trend. Results between continuous and log-transformed radiation doses for $\mathrm{CTDI_{vol}}$ and DLP were consistent at $p < 0.001$. All data were analyzed using SAS software 9.4 (Copyright© 2016, SAS Institute Inc., Cary, NC).

RESULTS

Demographic, clinical, and injury characteristics are detailed in Table 1. We reviewed 429 head CT scans performed between January 1 and December 31, 2019. Of these, 193 patients (45%) had their initial scan at CHLA, while 236 (55%) were obtained at an AGH before transfer. The distribution of mechanism of injury was similar between the two groups, with a majority of injuries resulting from falls (64.8% at CHLA vs. 60.6% at AGHs) followed by motor vehicle–related injuries (5.7%at CHLA vs. 9.8% at AGHs). There was no significant difference in age between the groups (mean age, CHLA 6 years vs. 6.1 at AGHs; $p = 0.768$).

TABLE 1. Demographic, Clinical, and Injury Characteristics of Children Younger than 18 Years of Age Evaluated at CHLA and Who Received a Head CT Scan for Head Trauma Either at CHLA or at a Referring AGH

Characteristics	Imaged at CHLA (n = 193)	Imaged at AGH (n = 236)	*p*
Age, mean (SD), y	6 (5.7)	6.1 (6)	0.768
Age categories, n (%)			0.116
<1 y	44 (22.8)	73 (30.9)	
≥1–2 y	19 (9.8)	11 (4.7)	
≥2–6 y	43 (22.3)	51 (21.6)	
≥6–16 y	72 (37.3)	79 (33.5)	
≥16 y	15 (7.8)	22 (9.3)	
Female, n (%)	69 (35.8)	95 (40.3)	0.340
Weight, mean (SD), kg	28.8 (24.5)	30.2 (27.5)	0.710
Mechanism of injury, n (%)			0.145
All fall related	125 (64.8)	143 (60.6)	
Bicycle involving an auto	9 (4.7)	20 (8.5)	
Motor vehicle related	11 (5.7)	23 (9.8)	
Other	48 (24.9)	50 (21.2)	
GCS categories, n (%)			0.089
Mild (14–15)	181 (93.8)	209 (88.6)	
Moderate (9–13)	5 (2.6)	6 (2.5)	
Severe (3–8)	7 (3.6)	21 (8.9)	

Head CT scan radiation dosing is presented in Table 2. Among all patients, the mean radiation dose administered for initial head CT scan was significantly lower at CHLA than at AGHs ($\mathrm{CTDI_{vol}}$ 20.3/DLP 408.7 vs. $\mathrm{CTDI_{vol}}$ 30.6/DLP 533, $p < 0.0001$ for both $\mathrm{CTDI_{vol}}$ and DLP). When patients were stratified by age group, the dose administered to patients was significantly lower at CHLA than at AGHs for all age groups except 1 to 2 years old. Of the 236 patients who underwent their initial head CT at an AGH, 76 patients (32.2%) had a repeat scan done at CHLA. In these cases, the scan was repeated to monitor the progression of an injury. The timing of the repeat scan was at the discretion of the consulting neurosurgery team and would range from 6 hours to 24 hours after the initial scan. In our patient-level subanalysis of radiation dose among these patients (Supplementary Table 1, http://links.lww.com/TA/C36), we found similar results, with children receiving significantly lower doses at CHLA compared with AGHs ($\mathrm{CTDI_{vol}}$ 25.6 vs. 36.5, $p < 0.0001$; DLP 513.1 vs. 652.7, $p = 0.0003$).

In our multivariable mixed-effects regression analysis (Table 3), after adjusting for demographic and clinical characteristics, we found significant variation in differences in hospital $\mathrm{CTDI_{vol}}$ and DLP. Hospitals differed in $\mathrm{CTDI_{vol}}$ (64.12, $p < 0.001$) with considerable variation among patients within hospital (114.44, $p < 0.001$); interclass correlation demonstrated that approximately 35.9% of total variance in $\mathrm{CTDI_{vol}}$ occurred between institutions. Similar significant variation was seen in regard to DLP among hospitals and patients within a hospital with an interclass correlation of approximately 22%. However, while children received lower radiation doses at CHLA compared with AGHs ($\mathrm{CTDI_{vol}}$ and DLP), the findings were not statistically significant when accounting hospitals as a random effect. When we split AGHs into trauma centers and non–trauma centers (Table 4), we found that CHLA delivered significantly lower mean radiation doses than both, by similar margins ($\mathrm{CTDI_{vol}}$ 20.3 for CHLA vs. 31.8 for trauma centers and 29.4 for non–trauma centers, $p < 0.0001$ for both).

DISCUSSION

We examined differences in radiation dose exposure for children undergoing head CT scans between AGHs and a level I freestanding PTC. Consistent with our hypothesis, we found that the majority of head-injured children in this cohort were subject to significantly higher head CT scan radiation doses at AGHs. These differences were similar in a patient-level subanalysis, indicating that variation in the pediatric patient population between hospitals was not a significant contributing factor. Opportunities exist to standardize radiation dosing across hospitals that care for injured children.

We found that the greatest difference in radiation dose between our institution and AGHs was seen in the older age groups (≥6–16 and ≥16 years), while infants and young children had less of a disparity. We hypothesize that this differential observation may be in part due to AGHs practicing a more stringent adherence to ALARA principles in the youngest patients but reverting to adult dosing in older age groups. In comparison, our institution practices standardized application of ALARA principles across all age groups. In addition, it is routine practice at our institution to extend the scans for trauma patients younger than 9 years to include the first two cervical vertebrae, because of the increased incidence of upper cervical spine injury in this age group.[16] This increases the DLP, even though we adhere to a reduced dose. The American Association of

TABLE 2. Mean Radiation Dosing Between CHLA and AGH, Stratified by Age

	Radiation Dose, Mean (SD) $\mathrm{CTDI_{vol}}$				Radiation Dose, Mean (SD) DLP			
Age Categories	Overall	CHLA	AGH	*p*	Overall	CHLA	AGH	*p*
<1 y (n = 117)	18.4 (7.5)	14.3 (0.7)	20.8 (8.7)	<0.0001	284.6 (114.1)	234.1 (28.9)	315.1 (134.1)	0.0009
≥1–2 y (n = 30)	17.1 (6.1)	14.9 (1.3)	20.8 (9.1)	0.1538	288.8 (80.3)	265.9 (30.5)	328.5 (119.5)	0.1822
≥2–6 y (n = 94)	22.2 (7.2)	17 (1.8)	26.6 (7.2)	<0.0001	395.6 (132.5)	331 (67.6)	450.1 (149.1)	<0.0001
≥6–16 y (n = 151)	32.2 (13.4)	24.8 (7.7)	39 (14)	<0.0001	643.4 (307.4)	547.7 (305.8)	730.5 (283.8)	<0.0001
≥16 y (n = 37)	41.4 (14.2)	32.9 (10.9)	47.2 (13.5)	0.0027	766.5 (231.1)	656.4 (96.8)	841.6 (266)	0.0068
All	26 (13.0)	20.3 (8.0)	30.6 (14.3)	<0.0001	477.1 (276.5)	408.7 (242.7)	533 (290.1)	<0.0001

TABLE 3. Multivariable Mixed-Effects Linear Regression for Radiation Dose Among Trauma Patients Seen at Referring AGHs and CHLA

	Radiation Dose							
	Initial CTDI_{vol}*				Initial DLP Dose*			
	Estimate	95% CI		p	Estimate	95% CI		p
Intercept	10.91	−1.20	21.02	0.08	161.93	−46.34	370.21	0.12
AGH	10.84	−1.30	22.98	0.08	135.33	−72.48	343.15	0.19
Age categories								
<1 y	Ref	Ref	Ref		Ref	Ref	Ref	
≥1–2 y	0.08	−3.19	3.35	0.96	20.56	−56.34	97.47	0.59
≥2–6 y	2.93	0.60	5.26	0.01	84.25	29.90	138.59	0.00
≥6–16 y	7.49	4.59	10.40	<0.0001	195.38	127.36	263.41	<0.0001
≥16 y	10.07	5.28	14.86	<0.0001	178.17	66.46	289.89	0.00
Weight, kg	0.18	0.13	0.24	<0.0001	4.36	3.10	5.64	<0.0001
Male	0.30	−1.35	1.95	0.92	14.82	−23.78	53.41	0.44

*Final models additionally adjusted for mechanism of injury and GCS categories.
CI, confidence interval; Ref, reference level.

Physicists in Medicine has published head CT scan protocol suggestions that use age-stratified dosing recommendations that result in lower doses for younger and smaller patients.[17] These standards are used at our institution as a dose reduction strategy, and implementation of a similar standardized approach at AGHs may limit unnecessary radiation exposure to children.

Notably, some children who undergo head CT scans for trauma may not need the study. Consequently, children may not only be exposed to marginal increases in radiation dosing from head CT scans at AGHs, but also the increased exposure may be unnecessary in toto. In an effort to identify patients who could safely forgo a CT scan following blunt head trauma, the Pediatric Emergency Care Applied Research Network described a list of prediction rules, which, if not fulfilled, would indicate that a patient is at very low risk for a clinically significant traumatic brain injury.[8]

Importantly, it has been demonstrated that quality improvement initiatives can achieve better awareness of, and adherence to, Pediatric Emergency Care Applied Research Network guidelines in AGHs, thereby reducing unnecessary exposure to radiation from head CT scans.[18] Similarly, quality improvement initiatives that improve adherence to the Image Gently Think A-Head campaign, which outlines appropriate radiation dosing and delivery specifications for various age groups, would likely decrease the differential radiation exposure that was observed in our study.[17,19–21] Other techniques that have been successful in dose reduction include specific training for CT technologists. This ensures that they are familiar and comfortable with age-appropriate dose protocols. An important counterpart to this is the design and implementation of CT scanners that have an easy usability when adjusting for a lower dose protocol. Finally, the use of electronic feedback tools to identify barriers to adhering to age-appropriate protocols, as well as any concerns regarding the image quality from a reduced-dose scan, has proven to be helpful.[22]

TABLE 4. Mean Radiation Dosing at CHLA Compared With Outside Trauma Centers and Non–Trauma Centers

	CHLA (n = 193)	Trauma Centers (n = 107)		Non–Trauma Centers (n = 141)	
	Mean (SD)	Mean (SD)	p	Mean (SD)	p
CTDI_{vol}	20.3 (8)	31.8 (14.8)	<0.0001	29.4 (13.9)	<0.0001
DLP	408.7 (242.7)	575.2 (294.7)	<0.0001	498.3 (279.1)	0.0011

Efforts to reduce radiation exposure from CT scans extend beyond the trauma population. Similar concerns have been raised for children who undergo multiple head CTs for ventriculoperitoneal shunt placement, for instance, and a number of institutions have adjusted their protocols accordingly.[23,24] Furthermore, while the dose of radiation necessary to cause harm has not been clearly identified, there is evidence that cumulative radiation dose can theoretically increase the lifetime risk of cancer.[6,7,24] It is worthwhile, therefore, to strive for the lowest effective dose of radiation in children.[25] A survey of hospitals across the United States found that, in the broader cohort of all pediatric patients, dedicated children's hospitals consistently used significantly lower radiation doses when obtaining a head CT scan when compared with hospitals that did not exclusively treat children.[10] These results are supported by data obtained by the American College of Radiology from reported CT dose indices.[12] In addition, there have been studies from several institutions around the country demonstrating that dedicated children's hospitals have been more successful in implementing lower CT radiation dosing in pediatric patients when compared with AGHs for a broad range of clinical indications, including trauma.[26–31] This remains true even if the referring institution is a trauma center.[32] Indeed, when we split our AGHs into trauma centers and non–trauma centers, we found a similarly significant dose reduction for both. Our study adds to this growing body of literature, with a detailed description of radiation dose delivery for head CT scans in the pediatric trauma population.[33]

There are several limitations to our study. First, our data set did not include those patients who were evaluated for head injury at an AGH and were not subsequently transferred to our hospital. Therefore, our findings do not take into account the total patient population who underwent head CT for trauma at an

AGH. Since we obtained the majority of our data through a chart review of our own electronic medical record, our access to data for patients not transferred to our institution was extremely limited. Another limitation is that we did not abstract data beyond the first 24 hours. Therefore, we do not have information regarding short- or long-term outcomes. We are also unable to determine the actual dose of radiation delivered to each patient and must rely instead on the CTDI_{vol} and DLP, which are standardized surrogates for the actual dose delivered. This is a standard limitation for most studies reporting on CT radiation dosing.

Viewed in aggregate, the findings of this current study and the available published data suggest that there are opportunities to educate and implement radiation dose-reduction strategies for injured children evaluated at AGHs.

AUTHORSHIP

M.J.L., M.A., C.J.G., and M.B.-D. contributed in the study design, data collection, data analysis, drafting, and editing of the article. R.S., S.O., L. L., P.S., P.P.C., and D.B. contributed in the study design, data analysis, drafting, and editing of the article.

DISCLOSURE

The authors declare no conflicts of interest.

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