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ABSTRACT

BACKGROUND AND PURPOSE: Radiologists should manage the radiation dose for pediatric patients to maintain reasonable diagnostic confidence. We assessed the variation in estimated radiation dose indices for pediatric noncontrast head CT in the United States.

MATERIALS AND METHODS: Radiation dose indices for single-phase noncontrast head CT examinations in patients 18 years of age and younger were retrospectively reviewed between July 2011 and June 2016 using the American College of Radiology CT Dose Index Registry. We used the reported volume CT dose index stratified by patient demographics and imaging facility characteristics.

RESULTS: The registry included 295,296 single-phase pediatric noncontrast head CT studies from 1571 facilities (56% in male patients and 53% in children older than 10 years of age). The median volume CT dose index was 33 mGy (interquartile range = 22–47 mGy). The volume CT dose index increased as age increased. The volume CT dose index was lower in children's hospitals (median, 26 mGy) versus academic hospitals (median, 32 mGy) and community hospitals (median, 40 mGy). There was a lower volume CT dose index in level I and II trauma centers (median, 27 and 32 mGy, respectively) versus nontrauma centers (median, 40 mGy) and facilities in metropolitan locations (median, 30 mGy) versus those in suburban and rural locations (median, 41 mGy).

CONCLUSIONS: Considerable variation in the radiation dose index for pediatric head CT exists. Median dose indices and practice variations at pediatric facilities were both lower compared with other practice settings. Decreasing dose variability through proper management of CT parameters in pediatric populations using benchmarks generated by data from registries can potentially decrease population exposure to ionizing radiation.

ABBREVIATIONS: $CTDI_{vol}$ = CT dose index volume; DIR = Dose Index Registry; DLP = dose-length product; IQR = interquartile range

In 2011, eighty-five million CT scans were performed in the United States; approximately 5%–11% of these scans were performed on children.[1,2] A more recent study using the American College of Radiology Dose Index Registry (DIR) reported that approximately 6% of CT scans performed in participating facilities the United States were performed on children.[3] CT scans alone accounted for about 50% and 75% of the radiation doses in adults and in children, respectively.[4] The most frequently imaged pediatric body part was the head.[3] The most common indication was trauma, followed by headache, convulsions, and syncope.[5,6] In the past 2 decades, there has been an increase in the use of CT scans in pediatric patients in emergency departments, which includes both first-time and repeat head CT scans.[6-8]

Many attempts have been made to quantify risks associated with ionizing radiation use in medical imaging. Some studies have suggested that the radiation dose from pediatric head CT scans may increase the risk of developing leukemia or other solid tumors.[9-12] Another study has suggested that the radiation dose to the lens of the eye from head and neck CT scans may increase the risk of cataracts.[13] A recent cohort study of nuclear medicine technologists suggested a higher risk of cataracts from their occupational radiation exposures.[14] Children are more radiosensitive than adults and, therefore, have a higher risk of developing cataracts.[15] They are also more likely to be affected by cancers such as leukemia, brain, breast, skin, and thyroid cancer as well as cardiovascular diseases after high doses of

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Indicates article with supplemental on-line table.

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radiation from therapies. Interpretation of some of the literature is controversial as they associate cancer risks with ionizing radiation on the basis of myriad assumptions.[16-18] Nevertheless, pediatric patients do have a longer expected lifetime during which diseases and radiation-related complications might occur, which may or may not be linked to ionizing radiation.

The As Low As Reasonably Achievable principle guides radiologists to use the lowest radiation dose on any given imaging examination that will answer the clinical question, yet preserve the radiologist's ability to make a diagnosis. This diagnostic capability can be influenced by many practical issues, including patient factors such as motion or the degree of medical illness/complexity, technical factors, and the level of training and experience of the interpreting radiologist. Therefore, there is an expected wide variability of imaging practices within a framework of best practice. The radiation dose from head CT and its variation in the pediatric population has had a limited focus, with small institutional studies or surveys[19-22] each demonstrating substantial variation in radiation dose. However, the optimal current practices and the magnitude of variation in the radiation dose delivered by pediatric noncontrast head CT have not been assessed at the national level. Participation in dose registries allows those providers who care for children the opportunity to compare their performance against published national benchmarks.[23]

The purpose of this study was to assess variations in estimated radiation dose indices for pediatric noncontrast head CT in the United States using the American College of Radiology DIR.

MATERIALS AND METHODS

Study Design

This was a retrospective analysis of pediatric noncontrast head CT examinations in the American College of Radiology DIR from July 1, 2011, through June 30, 2016. Because this study qualified as "nonhuman subject" research, institutional review board oversight was not required by our institution.

Dose Index Registry

The DIR launched in mid-2011 by the American College of Radiology is a national data base of dose indices associated with CT scans, which allows facilities to compare their dose indices with those at other facilities as well as other population and geographic denominations and to improve their practices when appropriate.[24,25] Given that different facilities may use different examination names for the same imaging test, when a facility submits data to the DIR, every CT examination name used at that facility is mapped to a standardized list of examination names used by the DIR, using the RadLex Playbook identifiers (https://www.rsna.org/RadLex_Playbook.aspx).[24] All of the data presented in this study came from facilities that submit their data to the DIR data base.

Study Setting and Population

We included noncontrast head CT examinations performed in patients 18 years of age or younger during the study period. Multiphase examinations (ie, with and without contrast examinations) were excluded to avoid overestimating the radiation dose index. Furthermore, these examinations are not routine in pediatric head CT.

Study Protocol

We used the following examination names submitted by participating facilities mapped in the DIR to define noncontrast head CT examinations: "CT BRN WO IVCON," "CT HEAD BRN WO IVCON," "CT HEAD BRN DUAL ENG CT WO IVCON," "CT HEAD MLTPL AREA SM BDY REG WO IVCON," "CT PEDS HEAD WO IVCON," "CT HEAD TRAUMA WO IVCON," "CT PEDS HEAD BRN WO IVCON," "CT HEAD WO IVCON." These examinations included noncontrast head CT using routine or low-dose protocols. Of note, institutions may name CT examinations differently, and the name under which an examination was listed in the DIR may not reflect whether a low-dose protocol was actually used.

The 2 primary CT dose indices, which can be used to calculate estimates of the radiation dose to the patient during head scans, were analyzed in this study. The first, CT dose index volume ($CTDI_{vol}$) is an indication of the average absorbed radiation within the scan volume for a standardized cylindric CTDI phantom.[26] In children, this is made of Plexiglas (https://www.plexiglas-shop.com/shopselect.htm) with a diameter of 16 cm. The second, dose-length product (DLP), is the product of $CTDI_{vol}$ and scan length along the z-axis of the patient, which estimates the total energy delivered to the CTDI phantom during the examination. The scan length can be estimated by dividing the DLP by the $CTDI_{vol}$.[26]

We obtained additional information including patient demographics (age, sex), characteristics of the imaging facility, and the year the examination was performed using the DIR data base. Age groups were defined on the basis of previous work[5] and were as follows: 0–2, 3–6, 7–10, 11–14, and 15–18 years of age. Imaging facility characteristics included hospital type (academic, community hospital, multispecialty clinic, freestanding center, children's hospital, and other), trauma designation (I, II, III, IV, and not applicable), facility location (metropolitan, suburban, and rural), and census regions (Northeast, Midwest, South, and West) based on the US Census Bureau categorization.[27] Because facilities can designate only a single hospital type, facilities designated as academic and community were further assigned as pediatric if they used "children" in the name or if they performed at least 75% of the total examinations on children 18 years of age or younger[5] as defined by the DIR.

Data Analysis

We used summary statistics to describe the patient and hospital characteristics, including number and frequency. The $CTDI_{vol}$ and DLPs were reported as median and interquartile range (IQR). The median $CTDI_{vol}$ was compared among the categories for each variable using the Kruskal-Wallis test. We further compared the median $CTDI_{vol}$ among facility types adjusting on the basis of patient age and sex using the ANOVA test. The data analysis for this article was generated using SAS software (SAS Institute, Cary, North Carolina). P values $\leq .05$ were considered statistically significant. The results were displayed graphically using 5 pediatric age categories (0–2, 3–6, 7–10, 11–14, and 15–18 years of age) that the American College of Radiology DIR provides to all enrolled facilities.

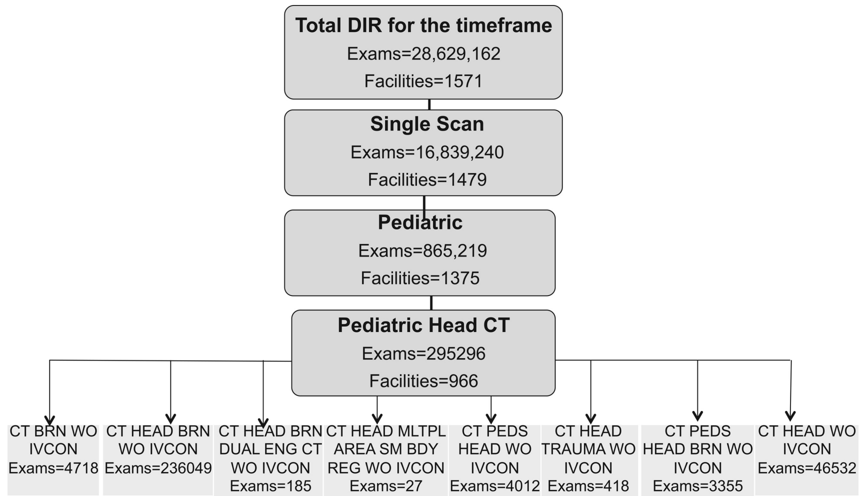

FIG. Head CT examinations included in the study cohort from the DIR.

RESULTS

Patient Population

Of the 28,629,162 CT examinations within the DIR data base, 59% (n = 16,839,240) were performed as a single scan, and 5% of these single scans (n = 865,219) were obtained in patients 18 years of age or younger. Of these pediatric single scans, 34% (n = 295,296) were noncontrast head CT scans (Figure).

Examinations in male patients represented 56% (n = 165,482) of examinations (On-line Table). The distribution of head CTs across patients in pediatric age groups was as follows: 21% (n = 62,933) in 0–2 years, 13% (n = 38,144) in 3–6 years, 13% (n = 38,847) in 7–10 years, 20% (n = 58,091) in 11–14 years, and 33% (n = 97,281) in 15–18 years.

Hospitals

There were a total of 1571 facilities in the DIR during the study period, and 966 facilities (61%) performed pediatric single noncontrast head CT scans (Figure). Most of these facilities (55%; 533/966) were community hospitals and 24% (226/966) were designated as trauma levels I and II.

While only 42% (404/966) of facilities performing pediatric single noncontrast head CT scans were in metropolitan areas, 65.7% (n = 194,155) of these examinations were performed in these facilities. Furthermore, 32% of the facilities (304/966) were in the Southern regions and 43% (n = 126,874) of examinations were performed in this area. More detailed information on patient demographics and characteristics of the imaging facilities are listed in the On-line Table.

Radiation Dose Indices

Across all pediatric single noncontrast head CT examinations, the median $CTDI_{vol}$ was 33 mGy (IQR = 22–47 mGy), with approximately 107% difference between the 25th and 75th percentiles. The median $CTDI_{vol}$ was higher for older age groups, as expected (On-line Table). The variations in the median $CTDI_{vol}$ for examinations were statistically significant among facility types ($P < .0001$). The pediatric facilities had a lower median $CTDI_{vol}$ (26 mGy, IQR = 19–33 mGy) compared with other facility types. Even though statistical tests showed that when controlling for age group, sex, and other facility characteristics, the mean $CTDI_{vol}$ was statistically significantly different among facility types ($P < .0001$), lower age groups of 0–2 and 3–6 years did not have any clinically significant variations in their mean $CTDI_{vol}$ among facility types (On-line Figure). Community hospitals, which had the largest proportion of examinations, had a median $CTDI_{vol}$ of 40 mGy (IQR= 27–52 mGy). The variations in the median $CTDI_{vol}$ for examinations were also statistically significant among facility trauma designations ($P < .0001$). Trauma levels I and II had the lowest median $CTDI_{vol}$ (27 mGy for level I and 32 mGy for level II) compared with other hospitals. The facilities with average monthly examinations of ≤100 had higher median $CTDI_{vol}$ compared with facilities with >100 examinations (On-line Table).

For all pediatric single noncontrast head CT examinations, the median DLP was 543 mGy × cm (IQR = 357–758 mGy × cm), with an approximately 112% difference between the 25th and 75th percentiles. This finding corresponds to a median scan length of 16.5 cm along the z-axis of the patient for a pediatric head examination regardless of age. Accordingly, the median scan length for the 0–2 years of age group was 14.7 cm compared with a range of 16.2–16.7 cm for all patients older than 2 years of age.

DISCUSSION

The results of the current national study of radiation dose indices for pediatric single-phase noncontrast head CT showed variations in radiation dose estimates as measured by $CTDI_{vol}$ and DLP, with approximately 107% and 112% difference between the 25th and 75th percentiles, respectively. As expected, the $CTDI_{vol}$ increased with patient age. The median dose indices were lower at pediatric facilities compared with other facility types and lower in metropolitan areas compared with suburban and rural facilities.

Our results are similar to findings from prior studies (Table 1) showing practice variations among imaging facilities. Prior studies have reported that the dose indices of pediatric hospitals were less than those in general hospitals[21] or trauma centers.[19] A national survey of US hospitals using the American Hospital Association 2010 annual survey data base showed that 82% of hospitals reported doses of <40 mGy.[21] Practice variations were found in a survey of trauma centers in the state of Washington, which showed a large proportion of level III–V trauma facilities tended to have higher milliampere-second values due to late adoption of dose-reduction strategies, resulting in larger median $CTDI_{vol}$ values.[20] Our results showed that facilities in metropolitan areas had lower median $CTDI_{vol}$ compared with urban and rural locations ($P < .0001$) possibly due to the poorer quality imaging equipment (eg, low-resolution equipment) in the smaller, rural facilities,[28] which requires a greater patient dose to produce acceptable images. Imaging facilities in the metropolitan areas may also be academic centers, which continually try to follow benchmarks

Table 1: Studies of radiation dose indices for pediatric noncontrast head CT

Study	Publication Year	Type	Findings
Kanal et al[21]	2015	National survey	Pediatric hospitals had lower dose indices compared with general hospitals
Kanal et al[20]	2011	Washington State survey	Level I–II trauma centers had lower dose indices compared with Levels III–V
King et al[19]	2009	Bi-institutional studies	Regional pediatric hospitals had lower dose indices compared with trauma centers
Current study	2018	National study of ACR DIR	Pediatric hospitals had lower dose indices compared with other facility types Level I–II trauma centers had lower dose indices compared with level III–IV trauma centers or nontrauma hospitals Facilities in metropolitan areas had lower dose indices compared with urban and rural locations

Note:—ACR indicates American College of Radiology.

Table 2: Suggested dose-reduction strategies

Roles of radiologists and imaging center staff
Imaging pediatric patients in a dedicated pediatric imaging department with dedicated pediatric team including
Pediatric radiologists
Certified CT technologists with experience in pediatric populations
Qualified medical physicists to help manage complex equipment
Child life specialists to work with families of patients
Frequent use of information created by the Image Gently Alliance regarding radiation dose reduction
Referring clinician role
Careful consideration of evidence-based clinical algorithms that can help assess the risk versus benefit of not obtaining a CT scan and choosing an imaging modality that provides necessary diagnostic information and does not use ionizing radiation
Considering referring children to pediatric facilities when available

and compete with other centers. This effort can be facilitated by national, educational, or institutional campaigns.[22]

As expected, our results show that both $CTDI_{vol}$ and DLP increase with age. However, younger patients are expected to experience increases in DLP due to both an increase in $CTDI_{vol}$ and scan length, given increasing head sizes. The scan lengths were 14.7 and 16.4 cm for the 0- to 2-year and 3- to 6-year age groups, respectively. The scan length in patients younger than 6 years of age being only slightly shorter than that in adult-sized heads, suggests that the total energy deposited in the small pediatric patients' heads could possibly be reduced further by more careful control of the beginning and end of the chosen scan length by the operator. In addition, the smaller the child, the more likely that radiosensitive organs are included within the imaging area of interest.[29]

Multiple causes result in a wide range of patient radiation doses, including variability of equipment makes and models,[30,31] patient positioning,[32] and anatomic coverage (eg, scan length versus length of patient anatomy of interest).[33] All factors controlled by the technologist (eg, voltage, tube current, rotation time, pitch, scan length, bow-tie filter, and so forth) can affect the range of patient doses when not set properly.[34]

Imaging pediatric patients with a dedicated pediatric team that includes pediatric radiologists, certified CT technologists with experience in the pediatric population, qualified medical physicists to help manage complex equipment, and child life specialists to work with families of patients in a dedicated pediatric imaging department may result in improved pediatric CT protocols that reduce the patient dose while maintaining image quality (Table 2).[35] The Image Gently Alliance has created information to help facilities achieve these types of goals.[36-38]

While radiologists, medical physicists, and CT technologists directly manage CT imaging techniques, clinicians can influence the patients' radiation doses by careful consideration of evidence-based clinical algorithms, which can help assess the risk versus benefit of not obtaining a CT examination and choosing an imaging technique that provides the necessary diagnostic information and does not use ionizing radiation. Clinicians may also consider referring children to pediatric facilities when available (Table 2).[5,39]

Our study has several limitations. First, both CT dose indices for the head and $CTDI_{vol}$ and DLP stored by the DIR are estimates of the dose to a standard plastic phantom as opposed to the patient. However, these are the only 2 CT dose indices available until the American Association for Physicists in Medicine finishes its development of a size-specific dose estimate to serve the same purpose for the head as the size-specific dose estimate currently serves for the trunk.[26] When the head-size-specific dose estimate is available, it will be expressed as a function of the size of the head, which correlates better to patient dose than the age of the patient.[40] Second, because participation in the DIR is voluntary, there may be a selection bias in our study population.[5] Facilities involved in the DIR may be more likely to audit their practices and follow dose-reduction protocols and dose-modification techniques; therefore, our dose-estimate results may be an underestimate of both CT doses and the variation in current CT practices.[5] Third, data collected in the early years of the DIR (2011 launch) may contain some systematic errors that were reduced or eliminated with more experience. Fourth, institutions may name CT examinations differently, which can be associated with inconsistent or incorrect mapping to the standardized list of examinations used by the DIR.[41] Furthermore, the name under which an examination was listed in the DIR may not reflect whether a low-dose protocol was used. It is possible that pediatric facilities perform low-dose head CT examinations more commonly for evaluation of ventricular shunt catheters; therefore, their median $CTDI_{vol}$ is lower compared with nonpediatric facilities. Finally, facilities continually change their protocols with time, especially as more attention is given to the importance of checking doses and having appropriate protocols.

CONCLUSIONS

Practice variations in the radiation dose index for pediatric head CT exist. Less variation occurred in pediatric compared with adult facilities and in metropolitan areas compared with suburban/rural facilities. Decreasing dose variability through proper management of CT parameters in pediatric populations using benchmarks generated by data from registries may help decrease population exposure to ionizing radiation.

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