

Variation in Utilization of Computed Tomography Imaging at Tertiary Pediatric Hospitals

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abstract

BACKGROUND: Recent efforts have focused on reducing computed tomography (CT) imaging in children. Although published reports show variability in CT scanning for specific indications, an assessment of the effects of institutional factors (case-mix or hospital volume) on the rate of CT scanning for any indication is necessary to better understand variability across pediatric hospitals.

METHODS: Data from 2009 to 2013 on inpatient, observation, and emergency department (ED) encounters were extracted from the Pediatric Health Information System. Chronological trends and institutional variability in CT scan rates were examined by using negative binomial regression models. Case-mix was adjusted by using All Patient Refined Diagnosis Related Groups and severity level.

RESULTS: Thirty hospitals were included. There were 12 531 184 patient encounters and 701 644 CT scans resulting in a mean of 56 scans per 1000 encounters (range: 26–108). The most common scan types were head (60.1%) and abdomen/pelvis (19.9%). There was an inverse relationship between the CT scan rate and hospital volume ($P = .002$) and a direct relationship between the CT scan rates for inpatient/observation and ED encounters ($P < .001$). The rate of CT imaging decreased from 69.2 to 49.6 scans per 1000 encounters during the study period ($P < .001$).

CONCLUSIONS: The overall use of CT imaging is decreasing, and significant variability remains in CT use across tertiary pediatric hospitals. Hospital volume and institutional-level practices account for a significant portion of the variability. This finding suggests an opportunity for standardization through multi-institutional quality improvement projects to reduce CT imaging.

WHAT'S KNOWN ON THIS SUBJECT: Given the efforts to decrease the use of ionizing radiation in pediatric patients, there is significant variability in head computed tomography (CT) scan use in pediatric emergency departments for minor head trauma.

WHAT THIS STUDY ADDS: This study characterized variability in CT scan rates for all body regions in emergency department, observation, and inpatient encounters across 30 tertiary pediatric hospitals. Two-fold variation remained after case-mix adjustment, with higher volume hospitals having lower rates of CT scanning.

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The number of computed tomography (CT) scans performed in pediatric patients more than doubled in the last 2 decades.¹ Although CT comprises only 15% of the imaging that uses radiation, it accounts for more than one-half of the radiation dose to patients. Every year in the United States, >4 million CT scans are performed in children. Reducing variation in pediatric CT utilization is an important target for improving pediatric health care for several reasons. First, pediatric patients are inherently more radiosensitive and have longer life spans; therefore, CT scans in children may carry a higher biological risk of radiation-induced malignancy.^{1,2} Second, CT overutilization can lead to increased costs related to the test³ and prolonged length of stay related to additional evaluation of incidental findings.^{4,5} Finally, false-positive results from CT scanning can lead to increased patient morbidity.^{6,7}

Several reports examining pediatric CT scanning for particular indications, including head trauma and appendicitis, suggest that variability across hospitals exists and is in part due to differences in institutional practice, availability of CT, and lack of protocol-driven decision-making on when to image.⁸⁻¹² An assessment of the variability in the rate of CT scanning inclusive of all body regions and indications is useful to evaluate if differences in CT imaging rates are due to institutional factors, such as case-mix or hospital volume. Furthermore, identifying the contribution of patient disposition (emergency department [ED] treat-and-release, inpatient, or outpatient) may help identify specific patient cohorts undergoing higher rates of CT scanning or groups of prescribers that may be overusing CT scans. A better understanding of the potential causes of variability in the rate of CT scanning may also allow for the development of multi-institutional

quality improvement projects to reduce CT imaging in the future.

The primary objective of the present study was to evaluate variability in the use of CT scanning across all body regions among pediatric hospitals in the United States from 2009 to 2013. Our goal was to evaluate the extent of variability explained by case-mix, hospital volume, and patient disposition (ED treat-and-release, inpatient, and observation) as well as evaluate trends in CT use over this time period.

METHODS

Study Population

This study used data from the Pediatric Health Information System (PHIS), which includes comprehensive administrative data on demographic characteristics and diagnoses and procedures using *International Classification of Diseases, Ninth Edition, Clinical Modification*, codes from 47 children's hospitals in the United States. Clinical transaction codes (CTCs) for a CT scan in the PHIS were used to identify patients who underwent a CT scan and to determine which type of scan was performed. The PHIS was queried for patients aged <18 years who had a CTC for a CT scan at an inpatient, observation, or ED encounter from 2009 to 2013 at 1 of the 30 PHIS hospitals that submitted billing data on these types of encounters throughout the study period.

Statistical Analysis

Each hospital's rate of CT scanning (number of scans per 1000 encounters) was calculated for inpatients, observation status patients, and treated and released ED patients. The type of encounter was based on the patient's status at discharge, such that ED encounters comprised treated and released patients only. Patients who were evaluated in the ED and then subsequently admitted were included as inpatient encounters. CT scans were categorized according to

body region. The variability in the rate of "pan scanning" (ie, head, chest, and abdomen/pelvis scans on the same day) was also evaluated as an exploratory analysis. When overdispersion in the data existed, negative binomial regression models were used.

The variability in scanning rates across hospitals was assessed by using negative binomial regression models with random hospital effects. Subsequently, All Patient Refined Diagnosis Related Group (APR-DRG) and severity level were added to the models to adjust for differences in case-mix across hospitals (APR-DRG, version 30; 3M, Minneapolis, MN).¹³ The proportion of interhospital variability in CT scan rates explained by case-mix was calculated as 1 minus the ratio of the variance of the random hospital effect in these 2 models. The APR-DRG and accompanying severity level are assigned at the time a patient is discharged from the hospital and incorporate information on diagnoses and procedures (surgical and nonsurgical), age, gender, birth weight (for neonates), and discharge status. There are 314 unique APR-DRG classes and 4 severity level subclasses (minor, moderate, major, and extreme). The APR-DRG algorithm defines the severity level as "the extent of physiologic decompensation or organ system loss of function" within each APR-DRG class. Because there are specific APR-DRGs for trauma and nontrauma-related encounters, the APR-DRG and severity groupings will account for some of the case-mix variation across hospitals due to different volumes of trauma patients. If the data recorded did not allow for the assignment of APR-DRG, the encounter was sorted into an "ungroupable" APR-DRG class and assumed to be of "minor" severity.

The association between hospital volume and rate of CT scanning was

evaluated by using a negative binomial regression model. The proportion of interhospital variability in CT scanning explained by hospital volume, after accounting for case-mix differences, was calculated as 1 minus the ratio of the variance of the random hospital effect in the models with and without hospital volume data. Volume was defined as the average annual hospital volume from 2009 to 2013.

The association between hospitals' CT scan rates for treat-and-release ED patients and inpatient/observation patients was assessed by using a Spearman correlation coefficient. The correlation between the rates of CT scanning in the ED and in the inpatient setting was also examined by assuming that CT scans performed on the day of admission for inpatient encounters with ED charges were performed in the ED.

As an exploratory analysis, the rate of change in CT scanning over time for the 5 hospitals with the highest rates of CT use in 2009 was compared with that of all other hospitals. In addition, a *t* test was used to compare the absolute change in CT scan rate from 2009 to 2013 between the highest utilizers in 2009 and the other hospitals. Because the decision to define the highest utilizers as the top 5 hospitals was arbitrary, we performed a sensitivity analysis redefining the highest utilizers as the top 10 hospitals.

For the descriptive analyses of the numbers of CT scans according to body region, every CTC for a CT scan was considered a unique scan. For the analyses of hospital variability and time trends in CT use, scans of the same body region on the same day were assumed to involve reconstruction from a single imaging event and were counted as a single scan. If >1 scan of identical type (eg, multiple head CT scans) was performed on the same day, these were counted as multiple scans. If the body region of the scan was unspecified, it was considered to be a unique scan rather than

TABLE 1 Characteristics of Hospitals and Number of CT Scans Performed

Hospital	Total No. of CT Scans	Hospital Volume (All Encounters 2009–2013)	Rate of Scans per 1000 Encounters (95% CI)
1	26 643	1 037 629	25.7 (25.4–26.0)
2	23 623	665 150	35.5 (35.1–36.0)
3	17 144	459 961	37.3 (36.7–37.8)
4	31 553	806 286	39.1 (38.7–39.6)
5	8789	220 850	39.8 (39.0–40.6)
6	19 569	484 194	40.4 (39.8–41.0)
7	10 334	254 977	40.5 (39.7–41.3)
8	33 089	799 244	41.4 (41.0–41.8)
9	8531	202 103	42.2 (41.3–43.1)
10	10 705	241 239	44.4 (43.5–45.2)
11	24 213	488 129	49.6 (49.0–50.2)
12	14 039	278 543	50.4 (49.6–51.2)
13	33 953	629 740	53.9 (53.3–54.5)
14	14 106	261 399	54.0 (53.1–54.9)
15	18 067	328 152	55.1 (54.3–55.9)
16	16 919	302 777	55.9 (55.0–56.7)
17	20 103	355 139	56.6 (55.8–57.4)
18	18 374	313 209	58.7 (57.8–59.5)
19	19 317	311 667	62.0 (61.1–62.9)
20	50 308	785 827	64.0 (63.5–64.6)
21	26 861	388 768	69.1 (68.3–69.9)
22	28 767	395 349	72.8 (71.9–73.6)
23	41 297	542 126	76.2 (75.4–76.9)
24	16 639	211 270	78.8 (77.6–80.0)
25	23 704	282 394	83.9 (82.9–85.0)
26	32 584	373 269	87.3 (86.3–88.2)
27	23 219	238 441	97.4 (96.1–98.6)
28	31 119	311 443	99.9 (98.8–101.0)
29	31 882	318 305	100.2 (99.1–101.3)
30	26 193	243 604	107.5 (106.2–108.8)

a reconstruction. Lastly, because some hospitals submit their urgent care patients as ED patients in PHIS, we evaluated whether this factor was associated with the overall rate of CT scanning by using a negative binomial regression model with a random hospital effect and a fixed effect for whether the hospital submitted urgent care data as ED data. All analyses were performed by using SAS version 9.4 (SAS Institute, Inc,

Cary, NC). All tests were 2-tailed, and *P* < .05 was considered statistically significant. The Nationwide Children's Hospital institutional review board approved this study.

RESULTS

The cohort encompassed 12 531 184 patient encounters and 701 644 CT scans performed at 30 children's hospitals from 2009 to 2013. There

TABLE 2 Types of CT Scans and Percentage of Total Number of CT Scans

Body Region	All Encounters	Treat-and-Release ED Encounters	Inpatient and Observation Encounters	<i>P</i>
Head	436 991 (60.1)	200 913 (73.7)	236 078 (51.9)	<.001
Abdomen/pelvis	145 084 (19.9)	42 760 (15.7)	102 324 (22.5)	<.001
Neck	61 064 (8.4)	18 544 (6.8)	42 520 (9.3)	<.001
Chest	56 271 (7.7)	2661 (1.0)	53 610 (11.8)	<.001
Spine	9420 (1.3)	2074 (0.8)	7346 (1.6)	<.001
Extremity	6503 (0.9)	2155 (0.8)	4348 (1.0)	<.001
Other or unspecified	12 104 (1.7)	3504 (1.3)	8600 (1.9)	<.001

Data are presented as *n* (%). Upper and lower abdomen CT scans performed on the same day were counted as a single abdomen/pelvis scan; every other charge for a CT scan was counted as a distinct scan in this table. *P* values are from the χ^2 test.

was an overall mean of 56 scans per 1000 encounters (95% confidence interval [CI]: 55.9–56.1), with hospital-specific rates ranging from 26 to 108 scans per 1000 encounters (Table 1). The most common body regions imaged were head (60.1%), abdomen/pelvis (19.9%), neck (8.4%), and chest (7.7%) (Table 2). Higher proportions of abdomen/pelvis, neck, and chest imaging were obtained in inpatient/observation encounters, whereas a higher proportion of head scans were performed in ED treat-and-release encounters.

The rate of CT scanning varied significantly across hospitals. There was an ~4-fold range in scan rates between the hospitals with the lowest and highest rates before case-mix adjustment, which was reduced to 2-fold variation after adjustment (Fig 1A). When analyses were stratified according to the type of encounter, significant variability was also found for treat-and-release ED encounters (Fig 1B) and inpatient/observation encounters (Fig 1C). Of note, 48% of all inpatient/observation encounters with a CT scan involved initial evaluation and a CT scan in the ED. For treat-and-release ED visits, hospitals had a 6-fold variation between the lowest and highest utilizers before case-mix adjustment and a 2-fold variation after adjustment. For inpatient/observation encounters, hospitals had a 5-fold variation between the highest and lowest utilizers before adjustment and a 2-fold variation after adjustment. Variability remained significant ($P < .001$ for all) after adjustment for case-mix (APR-DRG and severity level). Of note, APR-DRG and severity level were missing in only 0.2% of all encounters; these encounters were classified as a distinct APR-DRG category and were assumed to be of minor severity. When comparing the statistical models with and without case-mix adjustment, patients' APR-DRGs and severity levels explained a large proportion (49%) of the

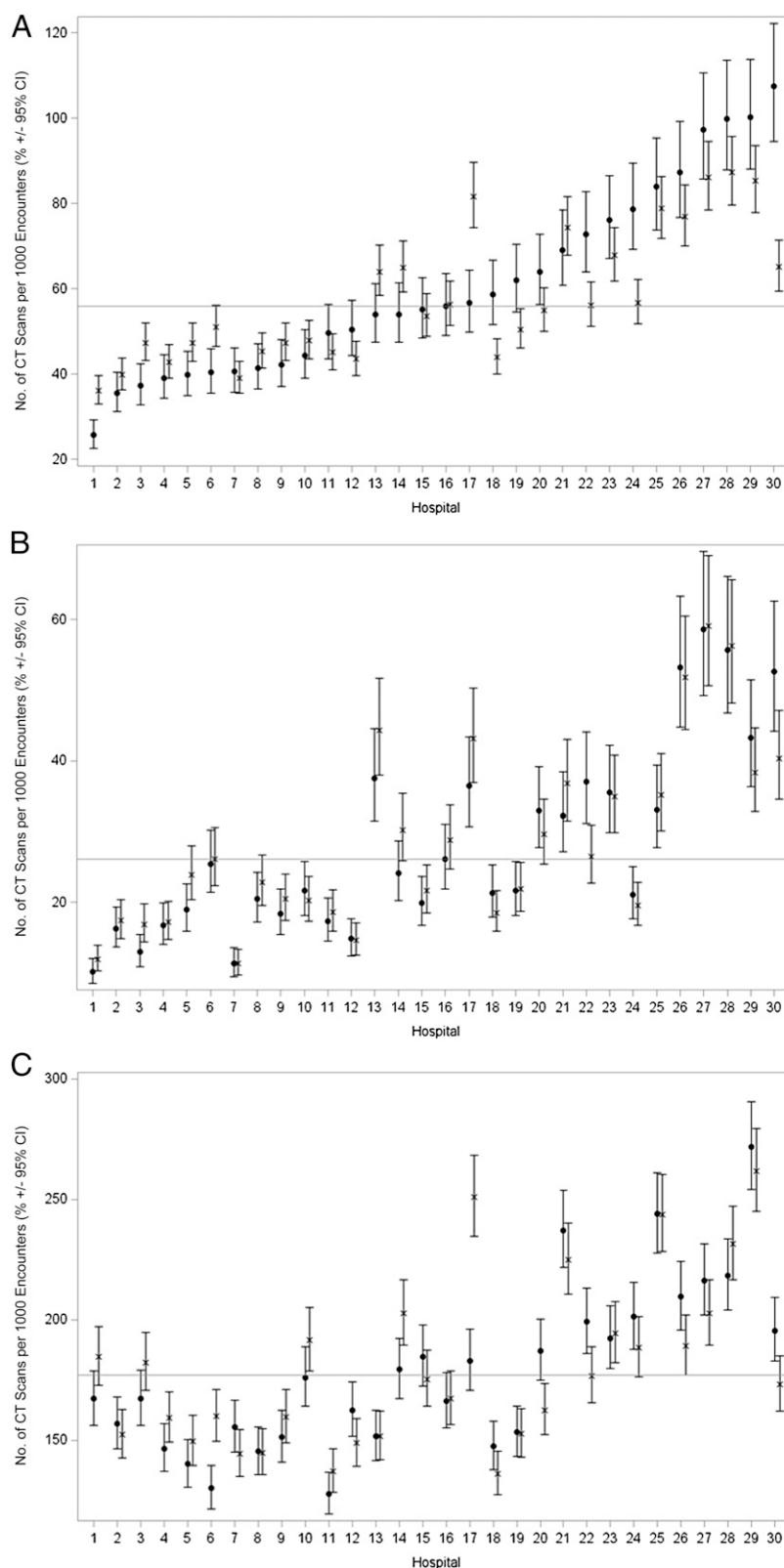


FIGURE 1 Hospital variability in CT scan rates in: (A) all patients; (B) treat-and-release ED patients; and (C) inpatient/observation patients. Hospital estimates and 95% CIs are shown; solid circles represent unadjusted estimates and "X" represent adjusted estimates. Numbers along the x-axis represent the same hospitals in all 3 panels. $P < .001$ for all.

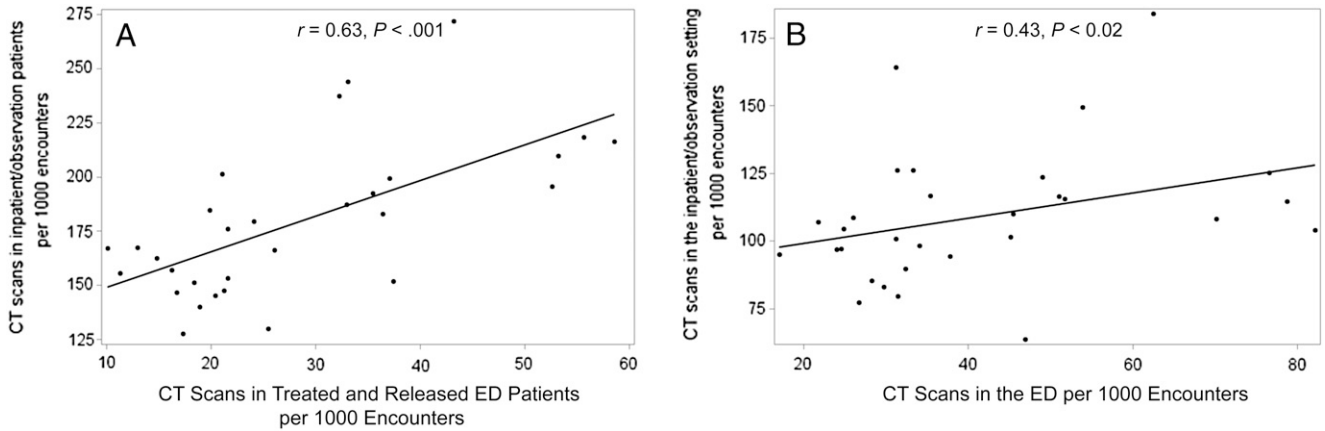


FIGURE 2

Correlation between hospitals' rates of CT scanning of: (A) treat-and-release ED patients versus inpatient/observation status patients; and (B) all patients in the ED setting (both patients treated and released and those who were evaluated in the ED and subsequently admitted) versus in the inpatient/observation setting.

interhospital variability in the CT scan rate when considering all 3 types of encounters. Results were similar when head CT scans and abdomen/pelvis CT scans specifically were evaluated. Hospital-specific rates of head CT imaging varied from 12.9 to 63.3 per 1000 encounters before case-mix adjustment ($P < .001$) and from 16.7 to 47.5 per 1000 encounters after adjustment ($P < .001$). Hospital-specific rates of abdomen/pelvis CT scanning varied from 2.5 to 25.7 per 1000 encounters before case-mix adjustment ($P < .001$) and from 2.9 to 21.1 per 1000 encounters after adjustment ($P < .001$). Pan scans were performed in 7 of every 10 000 encounters across all hospitals, with significant interhospital variability: hospital-specific rates ranged from 0.13 to 4.17 per 1000 encounters before case-mix adjustment ($P < .001$) and from 0.24 to 3.54 per 1000 encounters after adjustment ($P < .001$).

A significant correlation was found between the rate of CT scanning for inpatient/observation patients and the rate of CT scanning for treat-and-release ED patients ($r = 0.63$, $P < .001$) (Fig 2A). A similar correlation was found when all ED scans (including both patients treated and released and those who were evaluated in the ED and subsequently admitted) were compared with

inpatient/observation scans (all ED versus inpatient: $r = 0.43$, $P = .02$) (Fig 2B). When the association between the overall rate of CT imaging and average annual hospital volume during the study period was evaluated, a significant inverse relationship was found (incidence rate ratio: 0.96 per 10 000 encounters [$P = .002$]), and this inverse relationship remained statistically significant after adjustment for case-mix (APR-DRG and severity level) (incidence rate ratio: 0.98 per 10 000 encounters [$P < .001$]) (Fig 3). After accounting for differences in case-mix, comparison of statistical models found that hospital volume explained

15% of the remaining variability in CT scan rates among hospitals. Whether a hospital submitted their urgent care patients as ED patients to PHIS was not associated with the overall rate of CT scanning in inpatient, observation, and ED patients either before (rate ratio: 0.82 [95% CI: 0.62–1.09]; $P = .17$) or after (rate ratio: 1.00 [95% CI: 0.81–1.24]; $P = .98$) adjustment for case-mix.

The overall rate of CT imaging across all hospitals decreased from 2009 to 2013 (Fig 4). The rate of CT use declined from 69.2 scans per 1000 encounters to 49.6 scans per 1000 encounters from 2009 to 2013

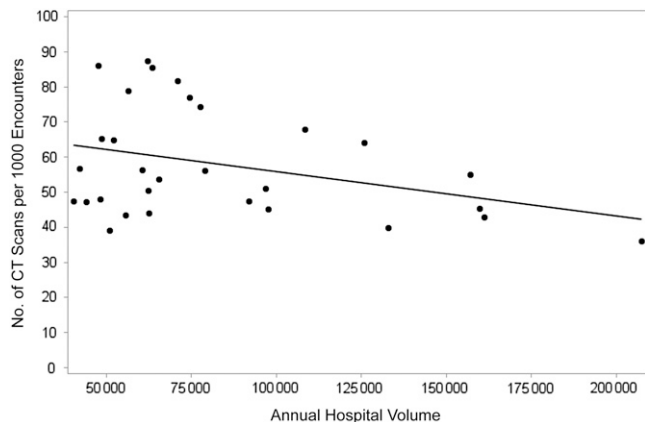


FIGURE 3

Association between hospitals' rates of CT scanning and total annual hospital volume (including ED, inpatient, and observation patients) after adjustment for APR-DRGs and severity level. $P < .001$ for the association between CT scan rate and hospital volume in the adjusted mixed effects negative binomial regression model.

(average annual percent reduction: 5.6%; $P < .001$). Both head imaging and abdomen/pelvis imaging rates also showed significant decreases over the study period ($P < .001$ for both). The average rate of decline was 6.7% per year for head scans and 5.8% per year for abdomen/pelvis scans. No statistically significant difference was found when the relative reduction in CT scan rate from 2009 to 2013 of the 5 highest utilizing hospitals was compared with that of all other hospitals (average annual percent reductions of 7.0% and 4.4% respectively; $P = .40$). However, there was a significant difference between these groups in the mean absolute rate reduction in CT use, with the top 5 utilizers decreasing by an average of 27.4 scans per 1000 encounters and the other 25 hospitals decreasing by an average of 7.9 scans per 1000 encounters ($P = .009$). Similar results were found when the group of high utilizers was redefined as the hospitals with the 10 highest CT scan rates in 2009 (reductions of 20.9 scans per 1000 encounters vs 6.3 scans per 1000 encounters from 2009 to 2013; $P = .01$).

DISCUSSION

This study illustrates the marked variability in the use of CT imaging

across tertiary pediatric institutions. Overall, the use of CT imaging decreased from 2009 to 2013, but unadjusted rates of CT scanning varied nearly 4-fold between the hospitals with the lowest and highest scanning rates. Case-mix (APR-DRGs and severity levels) accounted for 49% of the variability across institutions, and hospital volume accounted for an additional 15% of the remaining variability, with higher volume hospitals scanning at lower rates. Therefore, 36% of the variability in the use of CT imaging across hospitals remains unexplained. This finding suggests that 36% of the variability in CT scan rates may be due to differences in institutional or clinician practices, and it represents a potential opportunity to reduce CT imaging through multi-institutional quality improvement projects.

Each of the included institutions in this study is a large children's hospital in a metropolitan area that sees a diverse patient population; however, the wide variability in the rate of CT imaging was consistent across encounter type, suggesting that differences in scan rates are due to institutional differences in clinical practice. There was also a significant and positive correlation between inpatient/observation scan rates and treat-and-release ED scan rates,

which suggests that institutions with higher CT utilization will have higher scan rates across encounter types. Moreover, the rate of CT use decreased with increasing hospital volume, suggesting that higher volume hospitals may be more likely to use other diagnostic methods or institute alternative practices.

Our data reveal an overall average decrease in the rate of CT scanning of 5.6% per year. Hospitals with the highest rates of CT imaging in 2009 exhibited the largest absolute decreases during the study period. Head and abdomen/pelvis imaging decreased roughly the same amount across the study period (6.7% and 5.8% per year, respectively), suggesting that the decrease in CT use is due to a global reduction in scans. Some hypothesized reasons for this decline include increased media attention, the national educational campaign of Image Gently,¹⁴⁻¹⁶ and clinical decision guidelines^{17,18} that raised awareness for minimizing ionizing radiation exposure in children. Efforts to implement multi-institutional standards and protocols to reduce variation in the prescribing of CT scans may decrease variability and improve overall care. Previous collaborative efforts across pediatric institutions in critical care and surgery have been shown to be both feasible and successful.¹⁹

Our study characterizes the variability in CT scan rates across tertiary pediatric hospitals for ED, inpatient, and observation encounters and is inclusive of all body regions. Previous multi-institutional pediatric studies on CT utilization focused on ED encounters. One study using PHIS reported an overall decrease in CT imaging and a 3-fold interhospital variability in the use of CT scans for head trauma in pediatric EDs from 2005 to 2009,¹² which was similar to the extent of variability found in the present study. Another study reported no change in overall CT scan rates for all indications in 2 tertiary

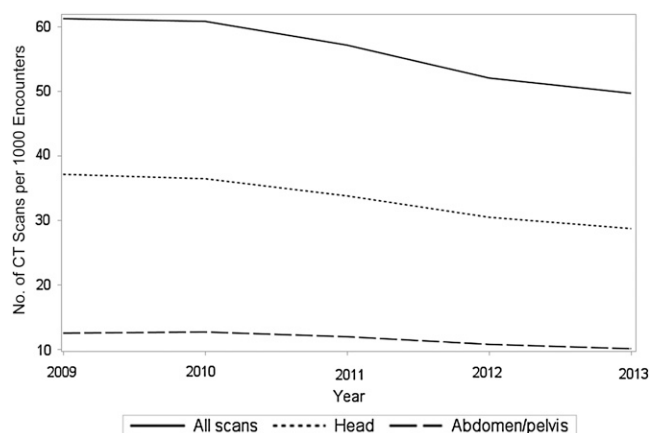


FIGURE 4

Rate of CT scans performed annually across all patient encounters (inpatient, observation, and ED combined). Rates are shown for all types of scans combined, head scans, and abdomen/pelvis scans. From negative binomial regression models, P values were $< .001$ for all trends over time.

pediatric hospital EDs from 2003 to 2010.²⁰ In this latter study, CT scan rates decreased between 2008 and 2010, although the significance of this trend was not statistically tested. Lastly, a study that examined national trends in CT scan rates in the ED from 1995 to 2008 found a steady increase in scan rates over this period, with no difference in rates between pediatric and nonpediatric EDs.²¹ In contrast, our findings demonstrate that pediatric CT scan rates have decreased in recent years but vary widely across institutions.

The present study has several limitations. First, this analysis includes data from only 30 tertiary care children's hospitals that submitted complete ED, inpatient, and observation data to PHIS during the study period. It is unclear whether these findings would be generalizable; however, our results likely represent a best-case scenario because the included centers are focused on pediatric care and were more likely to have clinical care protocols and 24-hour availability of alternative evaluation methods such as pediatric ultrasound or MRI. Second, because PHIS is an administrative database, there is inevitably some misclassification of data that could potentially affect these results. In

particular, it was not always clear whether multiple CTCs for CT scans on the same day represented distinct radiation exposure events. To produce conservative estimates of scanning rates, we assumed that scans of the same body region performed on the same day represented a single exposure event unless the exact same scan was billed multiple times (eg, multiple head scans on the same day were counted as distinct scans). Third, it is possible that some PHIS hospitals would have had more transfers in which imaging had already been performed at a referring hospital. The impact of transfer status cannot be assessed due to the unreliability of the source of admission data element in PHIS. However, given that all PHIS hospitals are tertiary children's hospitals, we would expect all of them to have relatively high incoming transfer rates. Fourth, data were missing on some of the variables that were included in our analyses, but this omission is expected to have had minimal effect on our findings because <2% of scans had any missing data. Finally, additional differences in case-mix, beyond those accounted for by using APR-DRGs and severity levels, may exist that could explain some of the remaining variability in scan rates.

CONCLUSIONS

Although there has been an overall decrease in the use of CT scans in tertiary pediatric hospitals since 2009, the rate of CT scan use in ED, inpatient, and observation patients exhibited 4-fold variation across tertiary pediatric hospitals; this outcome can, in part, be explained by differences in case-mix and hospital volume. Large variations in care across institutions may represent areas for health care quality improvement. Further studies examining practice differences between low and high outlier institutions may be useful for identifying areas in which standardization of imaging protocols could further decrease prescribing of CT scans.

ABBREVIATIONS

APR-DRG: All Patient Refined
Diagnosis Related
Group
CI: confidence interval
CT: computed tomography
CTC: clinical transaction code
ED: emergency department
PHIS: pediatric health information
system

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Daniel L. Lodwick, Jennifer N. Cooper, Kelly J. Kelleher, Richard Brill, Peter C. Minneci and Katherine J. Deans

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