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ORIGINAL ARTICLE

An Analysis of Computed Tomography-Related Radiation Exposure in Pediatric Trauma Patients

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Objective: To compare radiation doses used for pediatric computed tomography (CT) scans at community-based referring facilities (RF) to those at a designated pediatric trauma center (PTC) to assess the consistency of radiation exposure.

Methods: In this retrospective study, patients 0 to 18 years of age with CT imaging performed either at a RF or at a PTC from January 1, 2015, to January 5, 2016, were identified. Data about patients, CT radiation dose, and characteristics of the RFs were compared.

Results: We identified 502 patients (156 RF, 346 PTC) with 281 head CTs (79 RF, 202 PTC) and 86 abdominal/pelvis CTs (28 RF, 58 PTC). The radiation dose (measured in mean dose-length product [DLP] ± 1 standard deviation) was significantly higher for RF scans compared with PTC scans (head, RF DLP = 545 ± 334 vs PTC DLP = 438 ± 186 ($P < 0.001$); abdomen/pelvis, RF DLP = 279 ± 160 vs PTC DLP = 181 ± 201 [$P = 0.027$]). There was a nonsignificant trend toward lower head CT radiation dosages at RFs with a dedicated pediatric emergency department compared with RFs without a pediatric emergency department.

Conclusions: Our data suggest that CT scans performed at RFs expose pediatric patients to significantly higher doses of radiation when compared with a PTC. These data support further study to identify factors associated with increased radiation and educational outreach to RFs.

Key Words: pediatric trauma, radiology, radiation reduction

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There is a growing appreciation in the medical literature that computed tomography (CT) scans expose pediatric patients to doses of radiation that may increase their lifetime risk of developing cancer.[1] Previous evidence estimated a risk of 1 additional diagnosis of brain cancer for every 4000 pediatric patients who underwent head CT scans.[2] Due to concerns about the risk of radiation exposure, there have been efforts to reduce the number of CT scans pediatric patients are exposed to, such as the well-known Pediatric Emergency Care Applied Research Network head imaging rules, which established evidence-based parameters to limit the use of head CT in pediatric trauma.[3] Beyond decreasing the number of CT scans performed, there have also been efforts to decrease the amount of radiation being administered in each scan through modification of the instructions sent to the CT scanner.[4] Such efforts have been led in large part by the "Image Gently" campaign, organized by an international multidisciplinary committee dedicated to education and outreach about reducing pediatric radiation exposure.[5]

As such, many academic pediatric centers have developed pediatric imaging protocols designed to reduce radiation exposure. These protocols require modification to the parameters of the CT scanner according to clinical characteristics, such as patient size, anatomic region being scanned, and indication for the scan.[4] Despite the availability of these modifications, a recently published study suggests that they may not be consistently implemented by referring facilities (RFs), which may result pediatric patients being exposed to unnecessary additional radiation.[6] However, there has not been an investigation into whether there are identifiable characteristics of patients or RFs that may be associated with a disproportionately higher radiation dose. Thus, the objective of this study is to perform a regional analysis of CT scan radiation exposure for children with traumatic injuries who are imaged at a pediatric trauma center (PTC) compared with those imaged at community-based RFs. We hypothesized that patients imaged at a RF are exposed to a higher radiation dose than those imaged at a PTC. Additionally, we hypothesized that there are characteristics of the patients and/or RFs, including whether the facility has a dedicated pediatric emergency department (ED), that are associated with differences in radiation exposure.

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METHODS

Study Design and Population

An electronic trauma database associated with a tertiary care, academic, American College of Surgeons certified Level 1 Pediatric Trauma Center was utilized to retrospectively identify patients ages 0 to 18 years who presented or were transferred to the ED of the PTC with traumatic injuries from January 1, 2015, to January 5, 2016, and who had at least 1 CT included in their electronic medical record. Only radiation doses for CT scans of the head and abdomen/pelvis were included in this analysis because these are the most common CT scans obtained in pediatric trauma patients.[7] Demographic information (age, sex, and race), Injury Severity Score (ISS), and facility of origin were obtained from the trauma registry. Patient weight (in kilograms), type of CT scan (head or abdomen/pelvis) and CT scan radiation dosage as measured in dose-length product (DLP, mGy-cm) were obtained from the electronic medical record. The CT dosage information from patients imaged at a facility other than the PTC was obtained by viewing CT scan records that were uploaded into the PTC's radiology archive at the time of the patient's ED visit. The PTC institutional review board approved the study and waived patient consent.

Measurement and Analysis of Data

The CT dosages were compared based on where the scan occurred (ie, PTC vs RF), rather than on facility of initial presentation. The CT scans without identifiable DLP information were excluded from further analysis.

TABLE 1. Study Population Demographics

	RF	PTC	*P*
No. patients	105	230	n/a
No. scans	107	260	n/a
Age (mean ± SD)	7.27 (± 5.71)	6.5 (± 4.95)	0.21
Proportion male (%)	57%	68%	0.058
Race	30% African American, 58% white	44% African American, 43% white	0.03
Weight (mean ± SD)	30 kg (± 21)	28 kg (±21)	0.39
ISS (mean ± SD)	7 (± 5.6)	6 (±6.4)	0.13
Distance from RF to PTC (mean per patient ± SD)	37.5 miles (±39.7)	n/a	n/a

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Patient groups were compared based on age (years), weight (kg), and ISS. The RFs were characterized by distance from the PTC (miles) and whether or not there is a dedicated pediatric ED at the RF. Distance between individual RFs and the PTC was calculated using an online mapping tool measuring the route distance with the shortest travel time.

Characteristics of the patients, as well as the RFs, were compared with determine if those characteristics were associated with differences in radiation exposure, either between RF and PTC or between RFs, as applicable. Data were analyzed by Student *t* test or χ^2 as appropriate. A *P* value of 0.05 was considered to be statistically significant for differences in radiation dose.

RESULTS

Patient and CT Scan Characteristics

From the institutional electronic database, a total of 502 patients were eligible for inclusion in the study (156 RF, 346 PTC). Patient demographics between the RF and PTC groups did not differ significantly in age, weight, sex, or ISS. There was a statistically significant difference in racial distribution between the 2 groups (Table 1). T1

From the 502 patients, 589 CT scans were screened. Of these, 367 scans were of either the head or of the abdomen/pelvis and were included in the analysis. After removing CT scans with incomplete DLP information, 281 head CT scans (79 RF, 202 PTC) and 86 CT abdomen/pelvis scans (28 RF, 58 PTC) were analyzed (Fig. 1). F1

Radiation Dosage Administered at RFs Compared With the PTC

There was a statistically significant difference in the amount of radiation administered between the RFs and the PTC, with higher radiation dosages being administered at the RFs for both head and abdomen/pelvis CT scans. Mean radiation doses at RFs were 23% higher for head CT scans

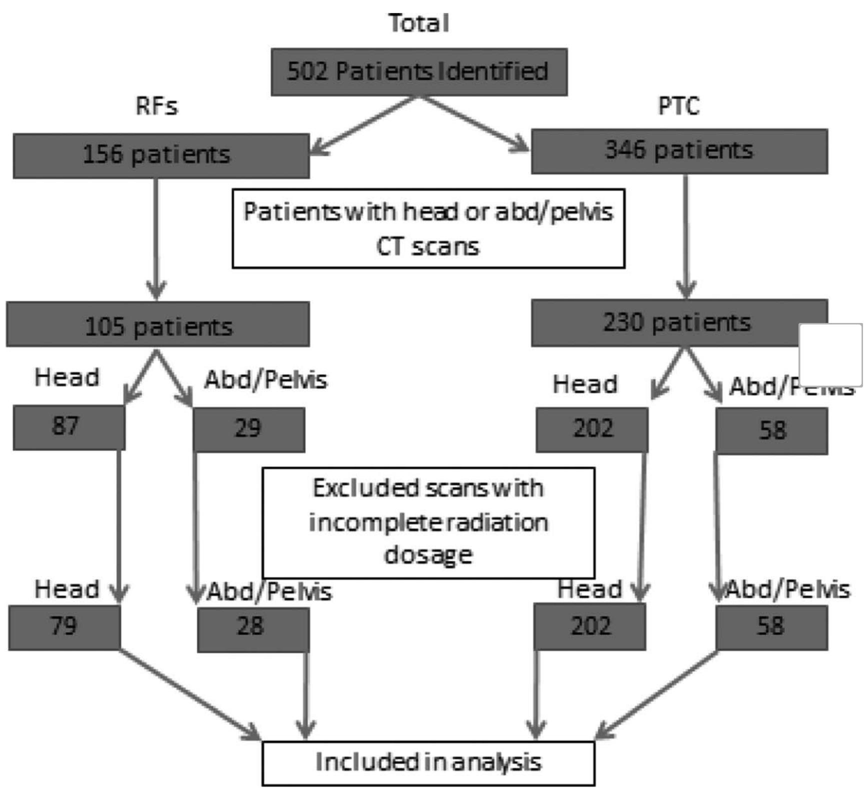


FIGURE 1. Determination of study population.

TABLE 2. CT Head/Brain Dosages

CT Head/Brain	No. Scans	Mean DLP ± SD	*P*
RF	79	545 ± 334	
Trauma Center	203	444 ± 205	<0.01

TABLE 3. CT Abdomen/Pelvis Dosages

CT Abdomen/Pelvis	No. Scans	Mean DLP ± SD	*P*
RF	28	279.2 ± 160	
Trauma center	58	181.4 ± 201	<0.05

and 54% higher for abdomen/pelvic CT scans, compared with the PTC (Table 2 and Table 3).

Analysis of Patient Characteristics

There were no significant differences in the distribution of radiation doses as measured by DLP between patients imaged at a RF versus a PTC based on patient age, weight, or ISS (Figs. 2–7).

Analysis of RF Characteristics

There was no significant relationship between radiation dosage as measured by DLP and distance between an RF and PTC (Figs. 8–9). There was a trend, though not statistically significant ($P = 0.15$), toward lower mean head CT radiation dosages at RFs with a dedicated pediatric ED compared with facilities that did not have a dedicated pediatric ED (Table 4).

DISCUSSION

In general, nearly 90% of pediatric ED visits do not occur at pediatric specialized facilities.[8] Pediatric patients with traumatic injuries may also frequently be evaluated at community-based facilities for initial stabilization and management if transported by private vehicle or if they do not meet criteria for emergency medical services transport to a PTC. In these cases, CT scans may be performed to evaluate the severity of the injuries and determine the need for transfer to a PTC for subspecialty care and definitive management. The decision whether or not to perform a CT scan must be balanced by the knowledge that radiation exposure, particularly for pediatric patients, carries an increased lifetime cancer risk.[2,9] It is, therefore, imperative that when a CT scan is deemed clinically appropriate that the radiation exposure to the patient is kept to the "as low as reasonably achievable" (ALARA) standard.[10] To this end, the "Image Gently" campaign was started in 2006 to provide resources and outreach to help institutions and individual physicians reach the ALARA standard.[11]

Previous studies have shown that patients imaged at community-based RFs are exposed to higher CT scan radiation dosages when compared with patients imaged at PTCs.[6,12] These studies analyzed patients imaged in the early 2010s, shortly after the "Image Gently" campaign to reduce pediatric CT radiation dose. Our study sought to determine whether such differences in CT scan-related radiation dosages have persisted as well as to see if there are any identifiable characteristics of either patients or RFs that may be associated with increased radiation exposure.

Reducing CT scan-related radiation dosage is a continual process of quality improvement requiring intermittent updates to CT scanner protocols.[4] As such, there is a possibility for heterogeneity in radiation dosage between institutions due to differences in CT scanners, frequency of protocol updates, technician training, and adherence to implementing pediatric protocols.

Our findings remain consistent with the earlier work of Brinkman et al[6] and Puckett et al[12] Specifically, there was a higher radiation dosage as measured by DLP for both CT scans of the head and of the abdomen/pelvis when performed at RFs compared at a PTC. Thus, that this differential in radiation exposure persists nearly a decade later suggests that additional strategies are needed to reduce and to eliminate this difference.

There were no significant differences in mean radiation doses between groups based on patient age, weight, or ISS for either CT scans of the head or of the abdomen/pelvis. Thus, we were not able to identify a discrete subpopulation (eg, the youngest, the heaviest, or the least severely injured) as being associated with the additional radiation exposure recorded. Similarly, characteristics of the RFs themselves were not significantly associated with increased radiation exposure when compared with other RFs. However, there was a trend that did not reach statistical significance, suggesting that RFs with a dedicated pediatric ED may be associated with the use of lower head CT radiation dosage in comparison to those RFs without a pediatric ED. The presence of a dedicated pediatric ED may be an indication of greater institutional dedication toward pediatric patients that may result in improved care if coupled with analytic and strategic focus on reliable implementation of best practices. This possibility is supported by 1 study in which the admission rate for bronchiolitis, controlling for case

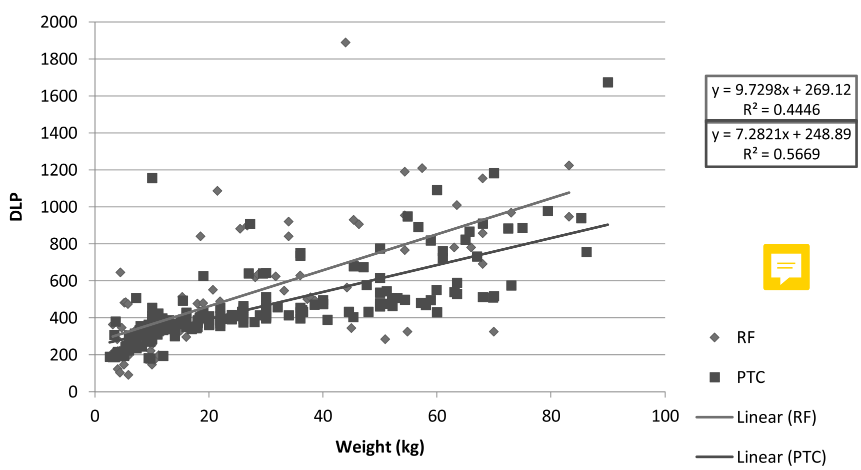
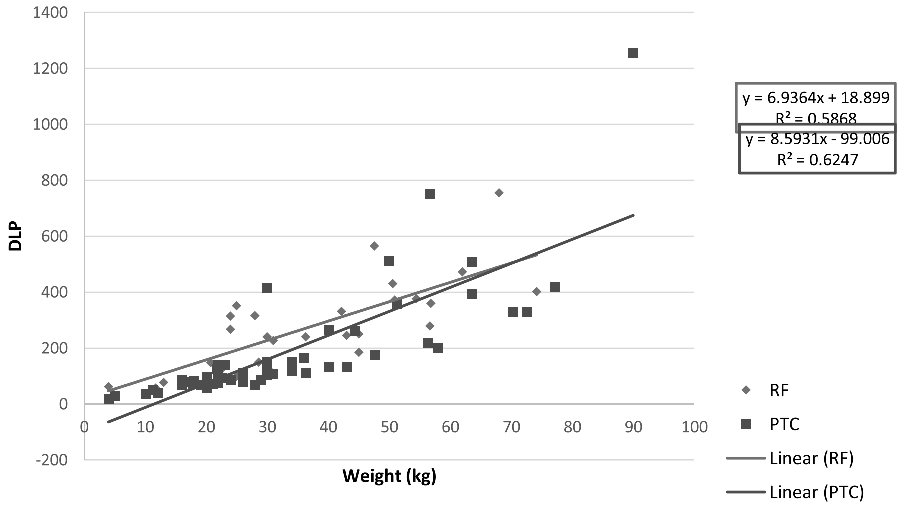


FIGURE 2. Head CT radiation dose as a function of patient weight.



AQ4 **FIGURE 3.** Abdomen/pelvis CT radiation dose as a function of patient weight.

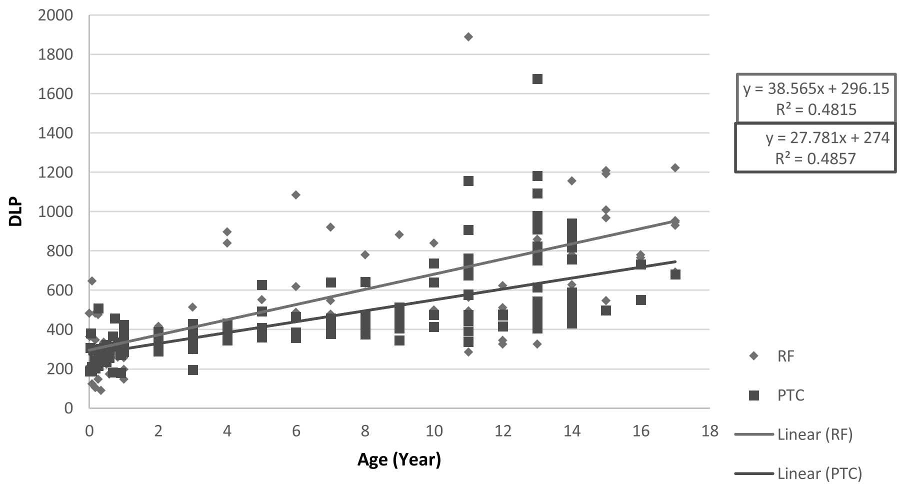


FIGURE 4. Head CT radiation dose as a function of patient age.

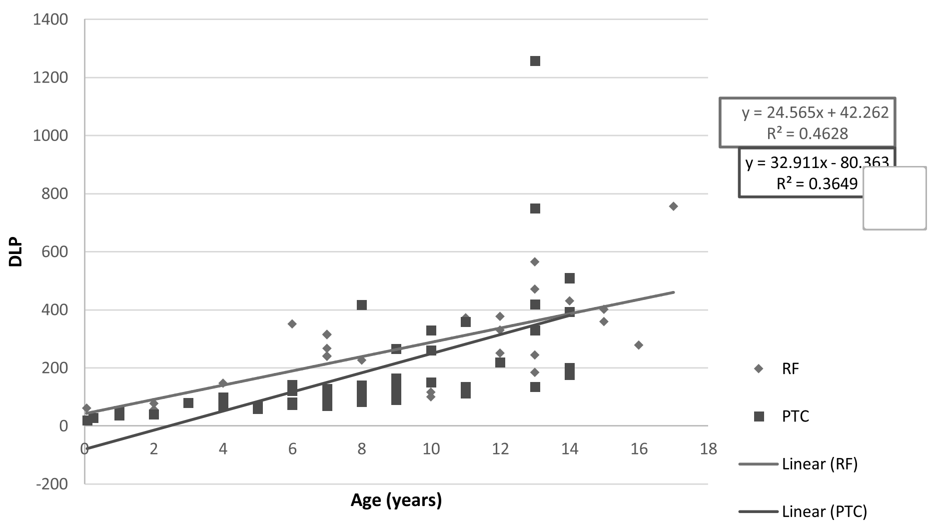


FIGURE 5. Abdomen/pelvis CT radiation dose as a function of patient age.

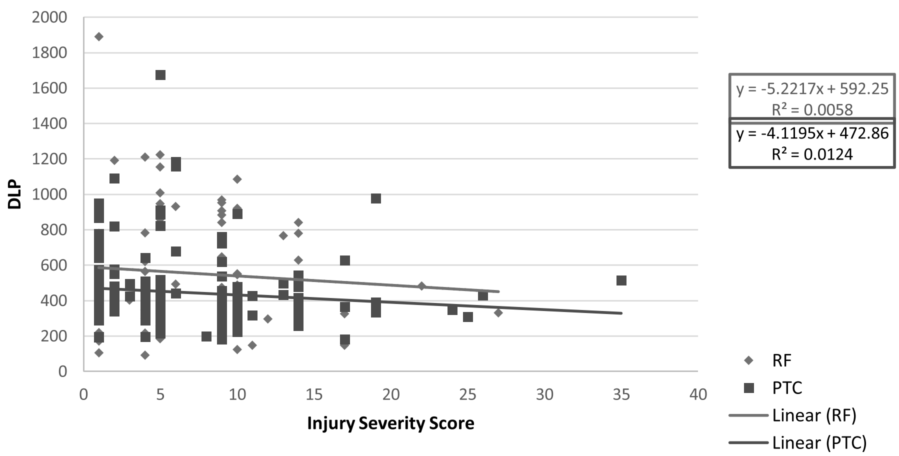


FIGURE 6. Head CT radiation dose as a function of patient ISS.

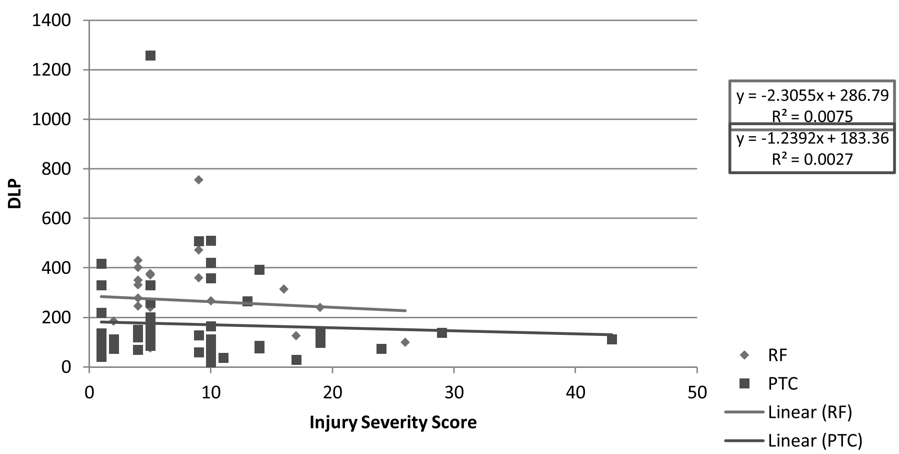


FIGURE 7. Abdomen/pelvis CT radiation dose as function of patient ISS.

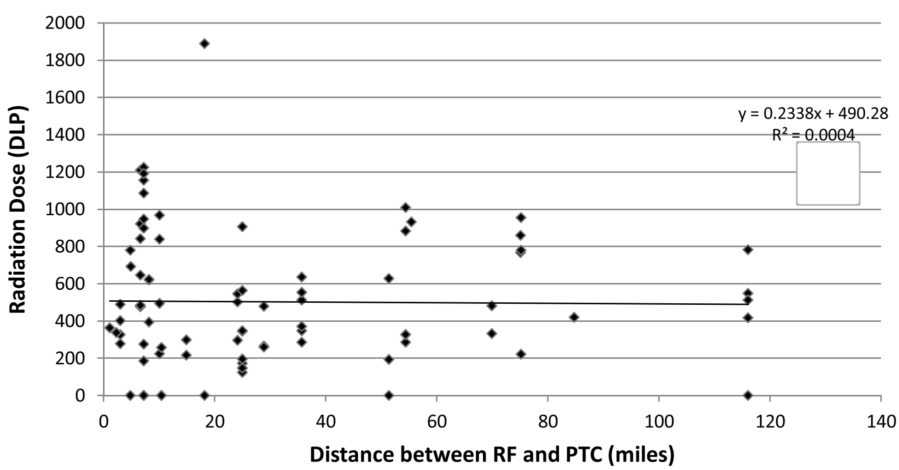


FIGURE 8. Head CT radiation dose as a function of distance from PTC.

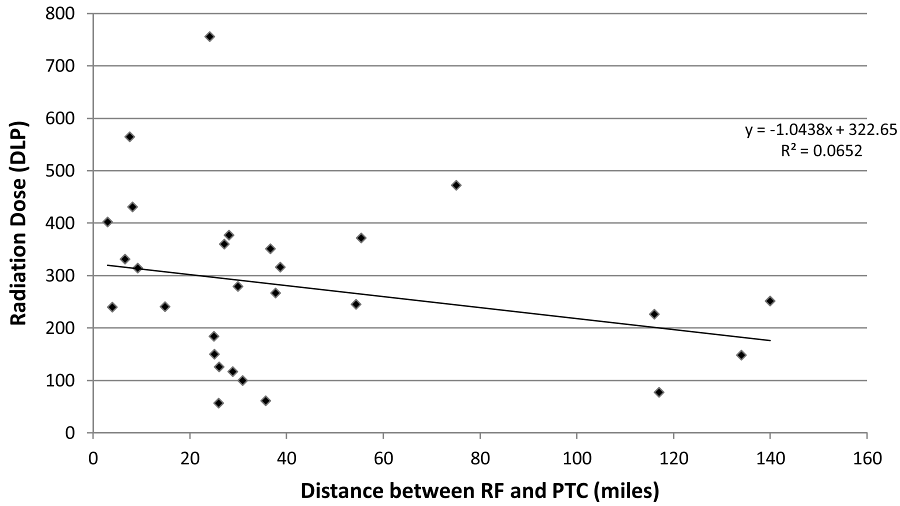


FIGURE 9. Abdomen/pelvis CT dose as a function of distance from RTC.

severity, was higher in a general ED at a community hospital compared with a pediatric ED at a children's hospital.[13] The sample for patients imaged at RFs with a dedicated pediatric ED was small, and further investigation into this trend is warranted.

This study has several limitations, including a limit to its generalizability because the analysis focused on only 1 PTC, although data were included from 34 RFs in our geographic region. Despite the single-site PTC and regional focus, our findings are similar to those reported in prior studies of other regions.[6,12] Additionally, the retrospective nature of the study design required a delay in analyzing patient records that, therefore, will not reflect any recent changes to radiation dosages at the RFs, if such has occurred. Only those patients who were transferred to the PTC and had their CT scans uploaded into the PTC radiology system were included in this analysis, and those patients may not be a representative sample of all pediatric patients imaged at the RFs. Finally, although DLP has been shown to be a surrogate for effective dose, there was no measurement of organ-specific effective dose in this study.[14]

In summary, although CT scanning may be a necessary part of the evaluation of the pediatric trauma patient, care must be taken to ensure that the radiation dose administered is compliant with ALARA standards. Furthermore, despite the "Image Gently" campaign having started 8 years before the period analyzed in this study, there continues to be differences in CT-related radiation dosages between centers. As the dose associated with ALARA standards changes frequently in response to advances in research and new technologies, efforts should be made to ensure that CT scanners at each facility that images pediatric patients are exposing patients to similar, ALARA-compliant radiation dosages. In this study, we show that there are significantly higher radiation dosages being administered at RFs when compared to a PTC. These differences are not associated with patient age, weight, or ISS. Furthermore, distance from a RF to the PTC was not associated with differences in radiation dosage; however, there was a trend toward lower head CT dosage at RFs with a dedicated pediatric ED. These findings have led to the initiation of a quality improvement initiative that aims to standardize radiologic care radiologic care of pediatric patients regionally through interinstitutional outreach and education. Furthermore, our data show that this is an ongoing and persistent issue within pediatric trauma care. These findings highlight the need for all pediatric trauma systems across the U.S. to determine whether similar differential radiation exposures are present within their regions and to initiate quality improvement efforts to address this disparity in care.

TABLE 4. Presence of Pediatric ED

CT Head/Brain	No. Scans	Mean DLP ± SD	*P*
No pediatric ED	30	619 ± 354	
Pediatric ED	48	502 ± 320	0.13
CT Abdomen/pelvis			
No pediatric ED	6	257 ± 145	
Pediatric ED	22	285 ± 166	0.71

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