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Computed tomography rates and estimated radiation-associated cancer risk among injured children treated at different trauma center types

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ABSTRACT

Background: Trauma is a common indication for computed tomography (CT) in children. However, children are particularly vulnerable to CT radiation and its associated cancer risk. Identifying differences in CT usage across trauma centers and among specific populations of injured children is needed to identify where quality improvement initiatives could be implemented in order to reduce excess radiation exposure to children. We evaluated computed tomography (CT) rates among injured children treated at pediatric (PTC), mixed (MTC), or adult trauma centers (ATC) and estimated the resulting differential in potential cancer risk.

Methods: We identified children age ≤18 years with blunt injury AIS ≥2 treated from 2010 to 2013 at 130 U.S trauma centers participating in the Trauma Quality Improvement Program. CT rates were compared across center types using Chi-square analysis. Stratified analyses in children with varying injury severity, mechanism, and age were performed. We estimated the impact of differential rates of CT scans on cancer risk using published attributable risks.

Results: Among 59,010 children identified, CT rates were higher among injured children treated at ATC and MTC versus PTC. Findings were consistent after stratified analyses and were most striking in children with chest and abdomen/pelvis CT, adolescent age, low injury severity and fall injury mechanism. We estimated that for every 100,000 injured children, imaging practices in ATC and MTC would lead to an additional 17 and 16 lifetime cancers, respectively, when compared to PTC.

Conclusion: CT use among injured children is higher at ATC and MTC compared to PTC. Children with low injury severity, fall injury mechanism, and adolescent age are most vulnerable to differential imaging practices across centers. Quality improvement initiatives aimed at reducing heterogeneity in CT usage across trauma centers are required to mitigate pediatric radiation exposure and cancer risk.

Background

Computed tomography (CT) can be an invaluable tool during the evaluation of injured children [1,2]. For this reason, trauma remains one of the commonest indications for CT in children [2,3]. However, children are particularly vulnerable to CT radiation and its associated cancer risk [4,5]. Children are exposed to more radiation during fixed dose CT because of their relatively smaller cross sectional area when compared to adults. Further, they are at

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higher risk due to the increased radiosensitivity of their developing organs and the potential oncogenic effect of radiation is higher in children due to their longer life expectancy [4]. These risks have prompted hospitals to develop strategies limiting the use of CT in children when possible [4]. Pediatric CT protocols, such as the ALARA (as low as reasonably achievable) pediatric CT intelligent dose reduction protocol, have also been developed to minimize radiation exposure [6].

Despite these strategies, significant variability in CT usage and adherence to pediatric radiation dose reduction protocols has been demonstrated among hospitals caring for injured children in the U. S. [5,7]. Part of this variability may be explained by a lack of specific focus in this area at non-pediatric trauma centers caring for injured children. Pediatric trauma centers (PTC) were developed to provide optimal care to injured children by addressing their unique physiological and psychosocial needs [8–10]. In the U.S., limited access to pediatric trauma centers necessitates that most injured children be treated at non-pediatric centers [11], either adult trauma centers (ATC) or adult trauma centers with added pediatric qualifications (MTC-mixed trauma centers). It is plausible that pediatric and non-pediatric trauma centers have different approaches with respect to the importance of limiting radiation exposure in children. Several studies have shown higher rates of CT usage at adult versus pediatric trauma centers [12–15]. These studies have been limited by small sample sizes, state-specific or regional data, lack of stratified analyses in children with varying injury severity and mechanism, and an inability to compare all trauma center types (ATC, MTC, and PTC) in one analysis [13,14].

To fill this knowledge gap, we evaluated how CT rates differ among ATC, MTC, and PTC. We also determined how CT rates across centers vary among children with differing ages, injury severity, and mechanism. To quantify our results in terms of cancer risk, we estimated the impact of differential rates of CT scans on cancer risk using previously reported attributable risks [5]. We hypothesized that treatment at non-pediatric trauma centers would result in higher CT usage, and consequently higher cancer risk for children, than treatment at pediatric trauma centers. Given that outcomes for injured children have been shown to be superior at PTC compared to ATC or MTC, a finding of higher CT use at non-pediatric trauma centers would suggest that a large proportion of the excess CT scans at ATC and MTC are unnecessary [16]. By identifying differences in CT usage across trauma centers and among specific populations of injured children, our goal was to identify where potential quality improvement initiatives could be implemented in order to reduce excess radiation exposure to children.

Methods

Study design

This observational study was designed to evaluate the association between CT and treatment at different trauma center types among children hospitalized for injury in the U.S. We evaluated differences in overall and body-region specific CT scans across different trauma center types. Stratified analyses in children with different injury severities, mechanisms, and age were performed. This work was approved by the Research Ethics Board at Sunnybrook Health Sciences Center, Toronto, Ontario.

Data sources and participating centers

Data were derived from 130 U.S. trauma centers participating in the American College of Surgeons (ACS) Trauma Quality Improvement Program (TQIP) [17,18]. TQIP is a voluntary performance improvement program that was created to provide level I and II trauma centers with feedback on risk-adjusted outcomes for quality-improvement purposes [19]. Data pertaining to TQIP centers is obtained from the National Trauma Databank, which utilizes the National Trauma Data Standard (NTDS) [20] to standardize how abstractors capture data. Inclusion criteria for entry into TQIP require an International Statistical Classification of Diseases, Ninth Revision (ICD-9CM) diagnosis of 800–959 excluding late effects of trauma (905–909), superficial injuries (910–924), or foreign bodies (930–939) [17]. TQIP data quality is evaluated by data checks, external validation, and specialized training of data collection personnel [17].

Study cohort

We identified patients aged 18 or younger who were hospitalized at a TQIP center from January 2010 to December 2013. We included children with blunt trauma who had a minimum Abbreviated Injury Score [21] (AIS) $\geq$2 in any body region. We only included children transported directly from the scene, as we could not ascertain whether or not children transferred from another center had received a CT scan prior to arrival. We excluded patients with superficial injuries, those who were transferred to another hospital or home directly from the emergency department, and those who were dead on arrival. At the center-level, hospitals that had no recorded CT scans during four years were excluded (five centers), suggesting that they were not routinely capturing imaging data as per the NTDS [20]. The NTDS requires that abstractors capture all procedures, including CT, performed in the emergency department, ICU, ward, or radiology department that were essential to the diagnosis, stabilization, or treatment of the patient's specific injuries [20].

Trauma center and outcome classification

Trauma centers were classified as ATC, MTC, or PTC. We defined an ATC as any center having adult ACS verification or adult state designation and no pediatric qualifications [10]. PTC was defined as any center exclusively having either pediatric ACS verification or pediatric state designation. MTC was defined as any center having both adult and pediatric ACS verifications or state designations [10].

Children with CT scans were identified using ICD-9 [20] procedure codes (Appendix 1). CT scans that occurred within 24 h of arrival were included in our analyses. Outcomes were categorized into overall CT (head OR torso OR other), head CT, chest CT, or abdomen/pelvis CT to allow for the evaluation of each type of scan.

Statistical analysis

Baseline characteristics were summarized as counts and compared between those with and without CT scans. Overall and body-region specific CT rates were compared across different trauma center types using Chi-Square analyses. Data were plotted using bar graphs to visually depict differences in CT scan rates across centers types (exact numbers associated with percentages on bar graphs are in Appendix 2). Stratified analyses in children with high injury severity (Injury Severity Score [22] (ISS) $\geq$16) and low injury severity (ISS $<$ 9) were undertaken to determine how differences in CT usage across centers varied in these subsets of injured children. To limit the potential effects of confounding, we performed additional stratified analyses in more homogenous cohorts of injured children - those injured as a result of motor vehicle collision (MVC) or a fall. Additional stratified analyses in different pediatric age groups [23] (young children (0–5 years), children (6–12 years), adolescents (13–18 years)) were performed to evaluate which group may be particularly vulnerable to differential CT rates across trauma centers. All statistical analyses were performed using SAS, version 9.3, Cary, NC. All tests were two-sided with p-values <0.05 considered statistically significant. Lastly, in order to assess the variation of CT rates across individual centers within each trauma center type category we produced a box plot including the mean and median CT rate across each trauma center type, as well as interquartile range, maximum, and minimum.

Attributable Cancer risk from CT

Lifetime cancer risk associated with radiation exposure from CT scans was calculated using previously published attributable risk in children [5]. The risk data that we used from the literature accounted for recently observed variability in CT radiation dosage (pediatric ALARA [6] CT radiation dose reduction protocol versus standard adult CT protocol) across hospitals in the U.S., thereby providing a more realistic estimate of cancer risk [5]. The risk data was quantified as the number of CT scans resulting in one lifetime radiation-induced solid cancer, stratified by body-region specific CT as well. We used these published attributable risks of cancer [5] to determine how many excess lifetime cancers would occur as a result of the differential CT imaging practices at ATC, MTC, and PTC identified in our study for every 100,000 children hospitalized for injury.

Results

We identified 59,010 children, among whom 52.7% received a CT scan of any type, 44.9% had a head CT, 17.3% had a chest CT, and 26.4% had an abdomen/pelvis CT. A total of 130 trauma centers were included in our analyses (77 ATC, 34 MTC, 19 PTC). With respect to triage, 38.5% of children were treated at ATC, 33.5% at MTC, and 28.1% at PTC. Injured children were more likely to undergo a CT scan if they were older, severely injured (higher ISS), had a lower mGCS, MVC injury mechanism, or severe head, chest, or abdominal injuries (Table 1). Children were less likely to get a CT if they were younger, had lower injury severities, or were injured by a fall mechanism (Table 1).

Overall CT rates were 55.8% among children treated at ATC, 56.8% among those treated at MTC, and 43.4% among those treated at PTC (Fig. 1). With respect to head CT, rates were 48.7% at ATC, 48.2% at MTC, and 35.6% at PTC. Rates of chest CT were nearly eight times higher at ATC and MTC compared to PTC (Fig. 1). Rates of abdomen/pelvis CT were over two fold higher at ATC and MTC versus PTC (Fig. 1). Regardless of CT type, rates were significantly higher at ATC and MTC versus PTC ($p < 0.001$ across all comparisons). Differences in CT usage across trauma centers were highest for chest and abdomen/pelvis CT.

Using stratified analyses in children with varying injury severity, those with high injury severity ($ISS \geq 16$) again demonstrated significantly higher rates of chest and abdomen/pelvis CT at ATC and MTC versus PTC (Fig. 1). While differences across centers did exist in overall CT and head CT rates, they were not as evident. However, in children with low injury severity ($ISS < 9$), both overall and body-region specific CT rates were significantly higher at ATC and MTC compared to PTC (Fig. 1).

When evaluating different injury mechanisms, a higher proportion of children with MVC injury mechanism had chest and abdomen/pelvis CT compared to those injured by a fall injury mechanism (Fig. 1). Children injured by a fall injury mechanism had significantly higher rates of overall and body-region specific CT when treated at ATC and MTC versus PTC (Fig. 1). Although children with MVC injury mechanism also had higher rates of head, chest, and abdomen/pelvis CT at ATC and MTC compared to PTC, differences were not as pronounced (Fig. 1).

With respect to age, children aged 0–12 years had higher rates of chest and abdomen/pelvis CT at ATC and MTC versus PTC (Fig. 2), however, differences in overall and head CT rates between trauma center types were not as apparent. In fact, among younger children aged 0–6 years, CT rates were higher at PTC compared to ATC. In contrast, overall and body-region specific CT rates were significantly higher at ATC and MTC versus PTC among injured adolescents (Fig. 2).

Table 1
Baseline Characteristics.

Characteristic	No CT Scan (N = 27,929)	CT Scan (N = 31,081)	p-value
Age Category (%)			
0–5	7965 (28.5)	6319 (20.3)	<0.001
6–12	9109 (32.6)	6250 (20.1)	
13–18	10,804 (38.7)	18,488 (59.5)	
Male Sex (%)	18,152 (65.0)	20,304 (65.3)	0.04
ISS (%)			
4–8	16144 (57.8)	12,996 (41.8)	<0.001
9–15	8600 (30.8)	8578 (27.6)	
16–24	1943 (7.0)	5760 (18.5)	
≥25	1242 (4.5)	3747 (12.1)	
Age Adjusted Hypotension (%)	831 (3.0)	1187 (3.8)	0.02
mGCS (%)			
1–2	871 (3.1)	2165 (7.0)	<0.001
3–4	264 (1.0)	787 (2.5)	
5–6	24,678 (88.4)	27,283 (87.8)	
Severe Injury (AIS ≥ 3) (%)			
Head	3029 (10.9)	8554 (27.5)	<0.001
Chest	1989 (7.1)	5784 (18.6)	<0.001
Abdomen	837 (3.0)	2105 (6.8)	<0.001
Injury Mechanism (%)			
Fall	14696 (52.6)	8080 (26.0)	<0.001
Motorcycle	353 (1.3)	683 (2.2)	
MVC	3908 (14.0)	10,578 (34.0)	
Other	2080 (7.5)	3060 (9.9)	
Pedestrian	6892 (24.7)	8680 (27.9)	

*Chi-square analysis used to test for significant differences. ISS = Injury Severity Score; mGCS = Motor GCS Score; AIS = Abbreviated Injury Scale; MVC = Motor Vehicle Collision.

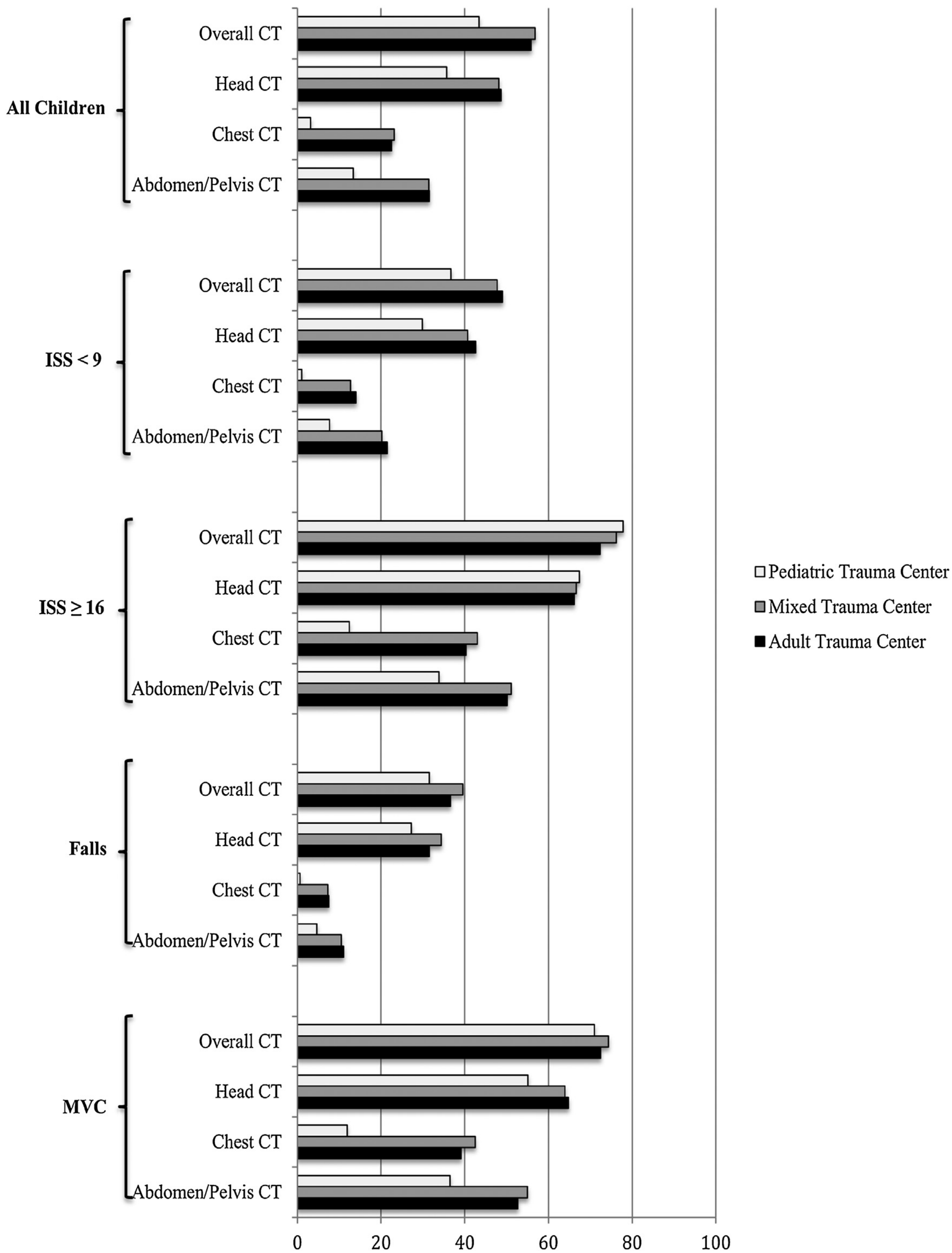

Fig. 1. Bar graph of overall and body-region specific CT rates across trauma center types. X-axis represents percent of patients who received that type of CT scan. All comparisons resulted in significant differences when using Chi-square analysis ($p < 0.001$). Numbers and exact percentages can be found in Appendix 2. CT = Computed Tomography; ISS = Injury Severity Score; MVC = Motor Vehicle Collision.

When assessing variability in CT rates across centers, the mean and median CT rates within each trauma center type were consistent with our overall findings (Fig. 3). However, there was considerable heterogeneity in CT rates between centers within each trauma center category (Fig. 3).

Upon evaluation of cancer risk secondary to differential CT rates, we estimated that treatment at ATC and MTC would lead to an additional 16 and 17 lifetime cancers per 100,000 injured children, respectively, when compared to PTC. With respect to head CT, imaging practices at ATC and MTC would lead to an additional 8 and 7 lifetime cancers, respectively, versus PTC. When evaluating chest and abdomen/pelvis CT in our study, higher radiation doses and more significant differences across centers resulted in a larger number of excess lifetime cancers. In children receiving chest CT, differences in CT use across center types would result in 33 excess lifetime cancers for those treated at ATC and 35

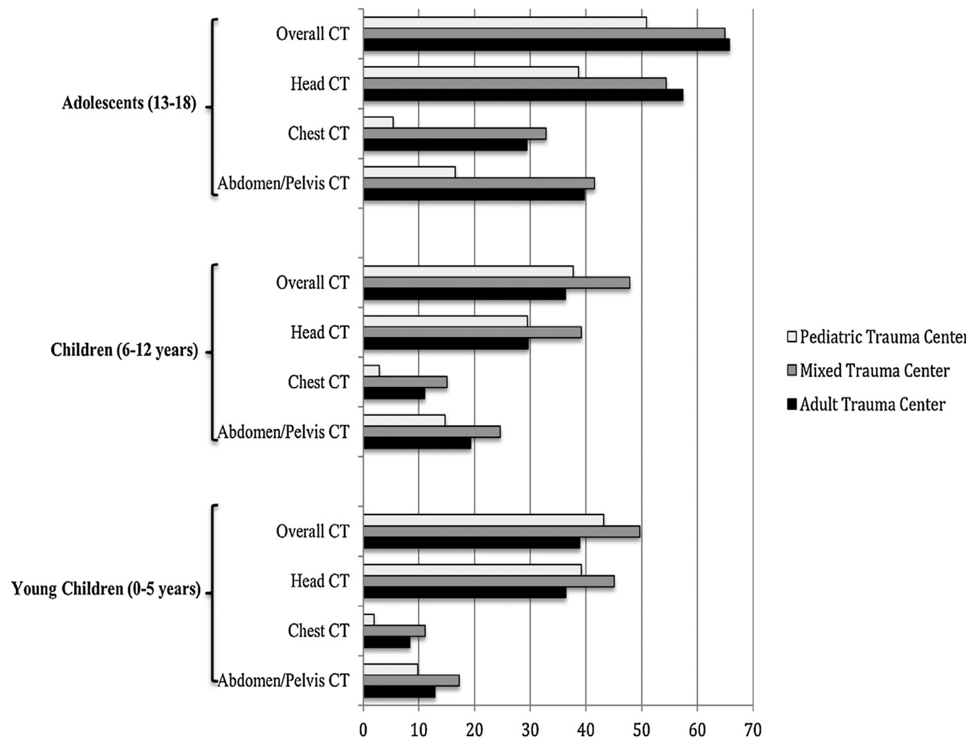

Fig. 2. Bar graph of overall and body-region specific CT rates across trauma center types. X-axis represents percent of patients who received that type of CT scan. All comparisons resulted in significant differences when using Chi-square analysis ($p < 0.001$). Numbers and exact percentages can be found in Appendix 2. CT = Computed Tomography.

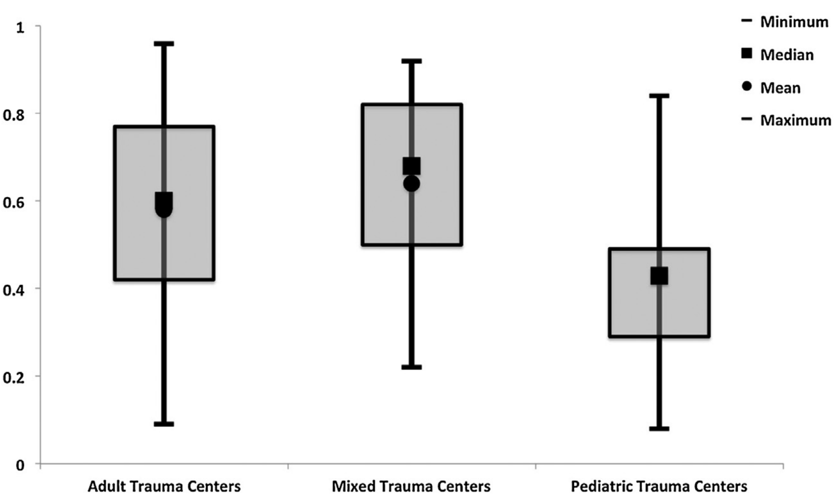

Fig. 3. Box plot displaying the distribution of CT rates across individual centers within each trauma center type category. Y-axis represents overall CT rate (1.0=all trauma patients had at least one CT scan; 0 = no patients had any CT scans). Means (circles), medians (squares), interquartile range (grey boxes), minimums and maximums (horizontal lines) are plotted. CT = Computed Tomography.

for those treated at MTC compared to PTC. Similarly, injured children receiving abdomen/pelvis CT would be prone to 38 excess lifetime cancers if treated at ATC and 38 at MTC compared to PTC.

Discussion

In a large population of injured children admitted to U.S. trauma centers, we demonstrated higher overall and body-region specific CT rates at ATC and MTC versus PTC. Differences in CT rates among trauma center types were the most striking in children receiving chest and abdomen/pelvis CT. Our findings of higher CT usage at ATC and MTC were consistent across stratified analyses in children with varying injury severity and mechanism. We identified a number of pediatric populations that may be more vulnerable to differential imaging practices. Interestingly, differences in CT rates across trauma center types were pronounced among children with lower injury severity, suggesting that ATC and MTC may be excessively scanning non-severely injured children. Furthermore, higher rates of CT at ATC and MTC compared to PTC were more evident in children with falls and older age (adolescents), suggesting that strategies to reduce CT usage should focus on these populations. We estimated that differential imaging practices across trauma center types would result in a significant number of excess lifetime cancers for children treated at ATC and

MTC versus PTC, especially among children receiving chest and abdomen/pelvis CT.

To our knowledge, no other studies have been done comparing CT rates at ATC, MTC, and PTC. A few studies have compared CT rates at ATC and PTC [13–15,24], but results have been conflicting. One study evaluated injured adolescents using the Ohio Trauma Registry [13]. Although imaging was not an *a priori* outcome in this propensity-matched analysis, the authors did make the observation that CT imaging was more common at ATC compared to PTC [13]. Another study evaluating CT among injured adolescents used the Pennsylavnia Trauma Systems Foundation database [14] to compare 4 PTC to 27 ATC in a multivariable analyses. In patients arriving directly from the injury scene, trauma center type was not associated with CT use [14]. These results differ with our findings of higher CT rates at ATC and MTC versus PTC among injured children direct from the scene.

Many of these prior studies have used small sample sizes, state-specific data, and have not compared a large number of PTC and ATC or three center types in a single analysis [13,14]. Although some studies have adjusted for injury severity using ISS, this injury severity scoring system is largely dependant on CT findings [14], making adjustment for ISS when modeling outcomes such as CT a less optimal approach. We addressed these methodological shortcomings in addition to providing a series of stratified analyses.

A major strength of this study was the use of a large nationally representative database [17], allowing us to compare a number of ATC, MTC, and PTC in a single analysis. We also performed stratified analyses, allowing us to evaluate differences in CT use across trauma center types in children of varying injury severity, mechanism and age, thereby identifying populations that are more vulnerable to differential imaging practices and may benefit most from quality improvement interventions. Lastly, we estimated the number of excess lifetime cancers that would result from higher CT usage at ATC and MTC versus PTC, providing readers with a clinically relevant measure of the impact of differential imaging practices across center types.

Our study has several limitations. First, we used a voluntary trauma registry of Level I and II U.S. trauma centers [17]. As a result, selection bias is a concern and our results are only generalizable to centers and patients meeting our inclusion and exclusion criteria. A similar limitation is that we only evaluated non-transfer patients, as we were unable to ascertain whether transfer patients had already received a CT at the transferring center. Residual confounding must be considered as well. To limit this potential, we performed stratified analyses in more homogenous populations of children (single injury mechanism, separate age groups, differing injury severity), thereby reproducing our findings in cohorts where confounding was less of a concern. Children in these homogenous cohorts would also be more likely to have similar clinical outcomes related to mortality and morbidity [10,25,26]. However, since we did not include these outcome data in our analyses, we were unable to determine whether children treated at different center types in this study were indeed comparable with respect to clinical outcomes. Furthermore, case ascertainment of children with CT scans during data abstraction may vary at ATC, MTC and PTC. It is plausible that ATC and MTC may better capture CT scans in our dataset. This would be unlikely given the increased emphasis on avoiding CT scans unless absolutely necessary at PTC. However, studies evaluating ascertainment of CT scans in our dataset our lacking, hence, this is a possible limitation. In addition, we should note that though we chose to only capture CT scans performed within 24 h of presentation, the majority of these scans occurred within 4 h of admission regardless of center type. Lastly, though our study does demonstrate that trauma center type is an important source of heterogeneity in rates of CT imaging among pediatric trauma patients, we also found considerable heterogeneity in CT rates between trauma centers within each trauma center type category. The source of this heterogeneity is unclear and could be due to differences in trauma imaging protocols, inter-physician variation, patient characteristics, and/or differences in structure and processes of care. Future studies should investigate the source of this heterogeneity and devise quality improvement initiatives to minimize adverse consequences of such variability in CT scan usage.

Our findings support the hypothesis that CT use is higher at ATC and MTC compared to PTC. A large proportion of these excess CT scans at ATC and MTC may be unnecessary, since studies have shown that injured children have better outcomes when treated at PTC versus ATC or MTC [16]. Hence, targeted quality improvement interventions at ATC and MTC are required to reduce excess CT use. Although we expected to see a gradient effect whereby CT use at MTC was more similar to that at PTC, we found that imaging practices at MTC were more similar to ATC, suggesting that MTC would similarly benefit from a focused strategy to reduce radiation exposure where possible. Changes to accreditation standards may be required to ensure that trauma centers caring for a large proportion of children limit CT use when possible and adhere to pediatric radiation-dose reduction CT protocols [6]. In addition, we identified populations of children that are particularly affected by higher rates of CT at ATC and MTC compared to PTC. Children with lower injury severity, fall injury mechanism, and older age (adolescents) may derive the most benefit from quality improvement initiatives geared toward avoiding excess CT.

Future study evaluating what processes of care lead to higher CT use at ATC and MTC is required. In addition, studies incorporating clinical outcome data such as time to treatment, mortality, and injuries detected would be helpful in determining the appropriateness of scans and to further assess the comparability of children treated at different center types. Also, evaluation of the use of pediatric protocols to reduce CT associated radiation, such as ALARA [6], at trauma centers caring for injured children would allow for a more accurate assessment of radiation exposure. If indeed ATC and MTC have lower rates of adherence to ALARA [6] compared to PTC, differences in radiation exposure across trauma center types would be even more significant than demonstrated in this study. As such, quality improvement interventions could focus on increasing adherence to pediatric CT protocols, rather than just reducing the number of scans performed.

Conclusion

CT usage, and subsequent radiation associated cancer-risk, is higher among injured children treated at ATC and MTC compared to PTC. Quality improvement initiatives aimed at reducing heterogeneity in CT utilization across trauma centers are required to mitigate pediatric radiation exposure and cancer risk.

Conflict of interest declaration

This work was supported in part by the De Souza Chair In Trauma Research (to A.B.N.) and the Canadian Institutes for Health Research (to C.S). The funding sources had no role in the study design; data collection, analysis, interpretation; or decision for publication. The opinions, results, and conclusions of this study are those of the authors alone. Although the American College of Surgeons oversees the dataset used, the authors of this study are solely responsible for the study design, analysis, and conclusions presented here.

The authors have no conflicts of interest of financial disclosures to declare.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi: https://doi.org/10.1016/j.injury.2018.09.036.

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