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An evidence-based algorithm decreases computed tomography use in hemodynamically stable pediatric blunt abdominal trauma patients☆,☆☆,☆☆☆

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ABSTRACT

Background: There are concerns about overuse of abdominopelvic-computed tomography (CTAP) in pediatric blunt abdominal trauma (BAT) given malignancy risks. This study evaluates how an evidence-based algorithm affected CTAP and hospital resource use for hemodynamically stable children with BAT.
Materials and methods: This is a retrospective cohort study of hemodynamically stable pediatric BAT patients one year before and after algorithm implementation. We included children less than or equal to 14 years of age treated in a Level I pediatric trauma center. We compared CTAP rates before and after algorithm implementation.
Results: There were 65 in the pre- and 50 in the post-algorithm implementation group, and CTAPs decreased by 27% ($p = 0.02$). The unadjusted and adjusted odds ratio of receiving a CTAP after algorithm implementation were 0.3 (95% CI 0.1–0.6) and 0.2 (95% CI 0.1–0.7), respectively. There were no significant missed injuries in the post cohort. ED length of stay (LOS) decreased by 53 min ($p = 0.03$).
Conclusions: An evidence-based algorithm safely decreased CTAPs for pediatric BAT with no increase in hospital resource utilization.

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Introduction

Trauma is the leading cause of mortality in children after infancy, resulting in an estimated 20,000 annual deaths.[1,2] Additionally, there are approximately 500,000 annual hospital admissions for pediatric trauma.[2] The majority (approximately 85%) of pediatric trauma cases are due to blunt force trauma, with blunt abdominal trauma (BAT) a major contributor to morbidity and mortality.[2]

Evaluation of BAT in pediatric patients is challenging. While computed tomography (CT) is common practice for a pediatric BAT patient with strong evidence of intra-abdominal injury (IAI), (such as free fluid on a focused assessment using sonography in trauma (FAST) exam) or hemodynamic instability,[3] there is variation in the management of hemodynamically stable pediatric BAT patients without those signs of IAI.[4–8] Although abdominopelvic CT scan (CTAP) is considered the gold standard imaging modality for evaluating for IAI,[2] a minority (estimated 10%) of pediatric BAT patients have IAI on CTAP,[8] and most of those injuries are managed non-operatively.[7,8]

Additionally, CT-associated radiation exposure carries the risk (albeit small) of developing radiation-associated malignancies. Those risks are higher for CTAP when compared to CT scans of other

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areas, particularly for younger children and females. It is estimated the lifetime attributable risk for cancer following CTAP in children is about 30 per 10,000 scans, with a higher risk of developing solid tumors than any other type of cancer.[9,10] With a growing focus on reducing CT use in pediatric trauma patients given the above listed concerns about future radiation-associated malignancy, methods to identify which pediatric BAT patients require CTAP are needed.

Clinical decision rules have been developed utilizing mechanism of injury, physical signs/symptoms, laboratory testing, and the FAST exam to guide clinicians in deciding whether or not to order a CTAP.[4,6–8] However, there is no consensus approach to BAT such as the Pediatric Emergency Care Applied Research Network (PECARN) guidelines for pediatric head injury.[9] Further to this, previous studies sought to validate components of existing prediction models to identify patients at-risk for significant IAI, rather than examining outcomes after implementation of an evidence-based clinical decision-making algorithm.[4–8] Therefore, this objective of this study was to compare CTAP use, clinical outcomes, and hospital resource utilization before and after implementation of an evidence-based pediatric BAT algorithm.

Materials and Methods

Study Design and development of the algorithm

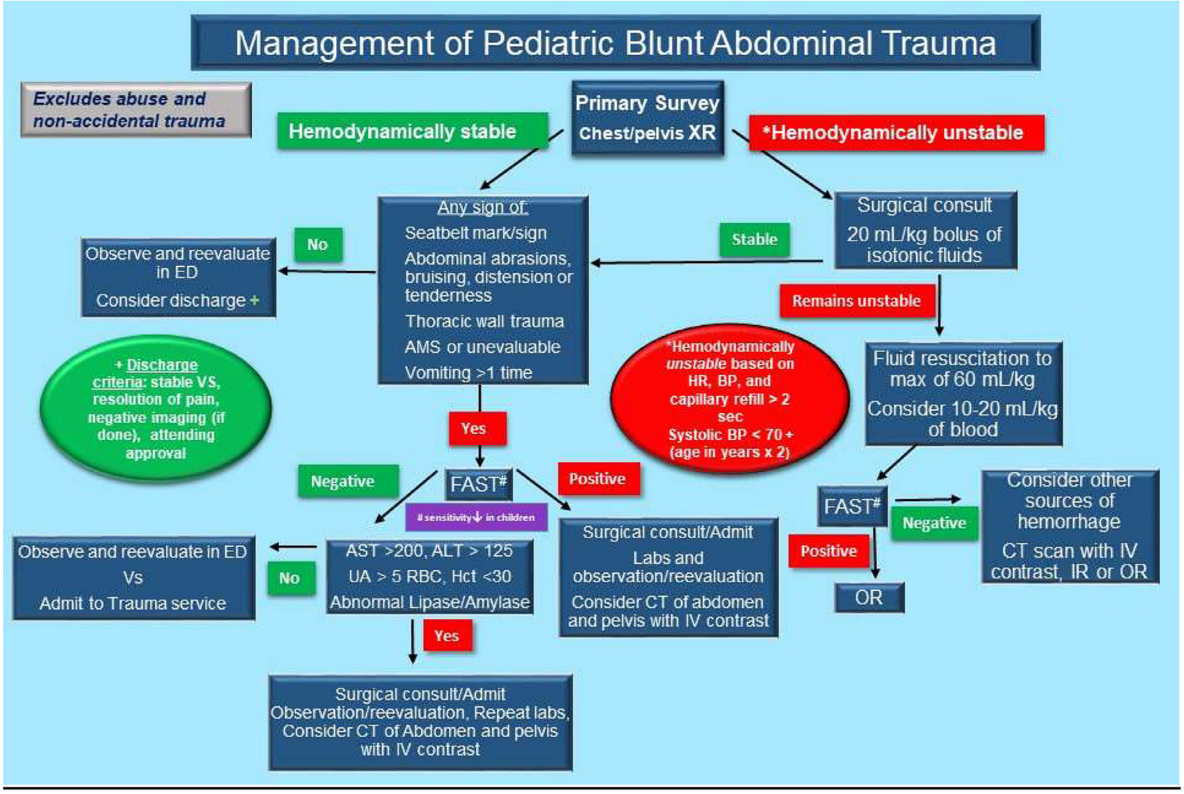
This is a two-year retrospective cohort study evaluating pediatric BAT patients before and after implementation of an evidence-based algorithm. Our Institutional Review Board approved this study. The evidence-based clinical algorithm was informed by imaging prediction rules for BAT,[4–8,11] with input from key stakeholders from the divisions of Pediatric Emergency Medicine and Trauma Surgery. The initial draft of the BAT algorithm was developed in February 2017, and subsequent drafts incorporated faculty feedback. A pilot implementation began in March 2017, during which discrepancies were addressed in multiple multidisciplinary symposiums. The final draft was produced and official implementation started in May 2017, and presented in-person at the Trauma Surgery multidisciplinary meeting and by email to all residents, fellows and faculty in the emergency department (ED). Posters of the algorithm were displayed in the Trauma Center and Pediatric ED (Fig. 1).

Study setting and population

This study was conducted at a Level I adult and pediatric trauma center and its associated emergency department that serves a large geographic area encompassing approximately 15 counties. “Pediatric trauma” patients are defined as less than or equal to 14 years of age, in accordance with state statutes. Subjects were divided into a “pre-algorithm” cohort, which included patients seen from March 2016 through March 2017, and a “post-algorithm” cohort, which included patients seen from April 2017 through April 2018.

Study protocol

Data was obtained from our institutional trauma registry, which contains information about patients who were admitted, discharged, transferred or died, including demographics and clinical information. This study included patients 14 years and younger who were evaluated for BAT. We included hemodynamically stable



CT: computed tomography, BP: blood pressure, ALT: alanine aminotransferase, AST: aspartate aminotransferase, ED: emergency department, FAST: Focused assessment with sonography in trauma, Hct: hematocrit, HR: heart rate, IR: interventional radiology, IV: intravenous, OR: operating room, RBC: red blood cell, UA: urinalysis, XR: radiography

Fig. 1. Evidence-based clinical decision algorithm for blunt abdominal trauma.

BAT patients, and excluded those who were hemodynamically unstable (defined *a priori* as hypotension for age and/or Glasgow Coma Score (GCS) < 10).[12] We also excluded patients who were victims of penetrating trauma or who transferred from an outside institution with a CTAP already performed. To define IAI for this study, we used previously accepted definitions as any injury apparent on abdominal CT scan or identified in surgery to any of the following: spleen, liver, kidney/urinary tract/bladder, adrenal gland, gastrointestinal system (from stomach through colon), mesentery, abdominal vascular structure, gallbladder or abdominal fascial disruption. [8, 13–15]

Key outcome measures

This study's primary outcome was the percentage of patients with a CTAP performed, measured before and after the implementation of the BAT algorithm. Secondary outcomes were ED length-of-stay (LOS), hospital LOS, and return visits within 7 days. We also categorized patients by whether they required an *a-priori*-defined intervention (blood transfusion, operation, and/or interventional radiology procedure), and if intervention patients had a CTAP performed while in the trauma center or ED.

Data analysis

We summarized categorical variables as frequencies and percentages, and continuous variables as standard deviations and means if normally distributed, and medians and interquartile ranges (IQR) if non-normally distributed. We used the Shapiro-Wilk test to determine normality. Differences in characteristics between the pre- and post- BAT algorithm patients were assessed using Chi-square or Fisher Exact tests as appropriate for categorical variables, and Student's t-test or Wilcoxon-rank-sum test as appropriate for continuous variables.

For the primary outcome, we compared CTAP rates before and after algorithm implementation first using univariate analysis. We then performed an adjusted logistic regression controlling for: age, mode of arrival, trauma activation level, severe mechanism of injury (defined as all-terrain vehicle (ATV) crash, MVC with ejection or rollover, unrestrained passenger or death in the same crash, falls >10 feet in height, pedestrian or bicyclist struck by an automobile, motorcycle or dirt bike crashes, and bicycle collision with handlebar striking the abdomen), GCS, complaint of abdominal pain, abdominal tenderness, abdominal guarding, "seatbelt sign", signs of chest trauma, and a positive or indeterminate FAST. We selected those covariates based on clinical experience and prior studies.[4,7,8,13] All analyses were performed using SAS® Version 9.4 (Cary, NC).

Results

A total of 115 patients met inclusion criteria, of which 65 were in the pre- and 50 in the post-algorithm cohorts. The median age was 8 years (IQR 5–12) and 59.1% were male (Table 1). A majority of patients (81.7%, N = 94) were transported by emergency medical services, and MVC was the most frequent mechanism of injury,

Table 1
Demographics and clinical presentation of subjects' pre and post implementation of the BAT algorithm.

	Overall N = 115	Pre-BAT Algorithm N = 65	Post-BAT Algorithm N = 50	p-value[a]
Age (years), Median (IQR)	8 (5–12)	7 (4–10)	9.5 (5-13)	0.062
Male Gender	68 (59.1%)	36 (55.4%)	32 (64.0%)	0.351
Race				0.756
White	61 (53%)	34 (52.3%)	27 (54%)	
African-American	40 (34.8%)	23 (35.4%)	17 (34%)	
Hispanic	12 (10.4%)	6 (9.2%)	6 (12%)	
Other	2 (1.7%)	2 (3.1%)	0 (0%)	
Mode of Arrival				**0.014**[b]
Ground EMS	94 (81.7%)	54 (83.1%)	40 (80%)	
Flight	13 (11.3%)	10 (15.4%)	3 (6%)	
Private Vehicle	8 (7%)	1 (1.5%)	7 (14%)	
Mechanism of Injury				**0.223**
MVC	78 (67.8%)	43 (66.2%)	35 (70%)	
Peds vs Auto	12 (10.4%)	6 (9.2%)	6 (12%)	
Fall	9 (7.8%)	8 (12.3%)	1 (2%)	
ATV	8 (7%)	4 (6.2%)	4 (8%)	
Bicycle	3 (2.6%)	1 (1.5%)	2 (4%)	
Kicked by Horse	2 (1.7%)	2 (3.1%)	0	
MCC	1 (<1%)	1 (1.5%)	0	
Other	2 (1.7%)	0	2 (4%)	
Trauma Level				**0.004**[b]
1[c]	11 (9.6%)	1 (1.5%)	10 (20%)	
2	49 (42.6%)	32 (49.2%)	17 (34%)	
3	48 (41.7%)	31 (47.7%)	17 (34%)	
Seen in PED	7 (6.1%)	1 (1.5%)	6 (12%)	
Abdominal Pain	68 (59.1%)	38 (58.5%)	30 (60%)	0.868
Abdominal Tenderness	54 (50%)	33 (50.8%)	21 (42%)	0.350
Abdominal Guarding	17 (14.8%)	16 (24.6%)	1 (2%)	**0.005**[b]
Seatbelt Sign	37 (32.2%)	12 (18.5%)	25 (50%)	**0.003**[b]
Signs of Chest Trauma	21 (18.3%)	12 (18.5%)	9 (18%)	0.949
Total Glasgow Coma Score	15 (15–15)	15 (15–15)	15 (15–15)	0.218
Injury Severity Score	4 (1–6)	4 (1–5)	2 (1–6)	0.473

ATV: All-terrain vehicle, EMS: Emergency medical services, IQR: Interquartile range, MCC: Motorcycle collision, MVC: Motor vehicle collision, PED: Pediatric emergency department.

[a] p-value for difference between Pre and Post algorithm patients.

[b] Denotes statistical significance at $p < 0.05$.

[c] Denotes highest level of trauma activation.

(67.8%, $N = 78$). Most patients (93.9%, $N = 198$) were evaluated in the trauma center, while seven (6.1%) were seen in the pediatric ED. Overall, most patients (59.1%, $N = 68$) complained of abdominal pain.

As between the pre- and post-cohorts, there were no significant differences in injury severity scores (ISS) ($p = 0.47$). There were no significant differences between the cohorts for subjects who presented with abdominal pain or had tenderness on exam ($p = 0.87$ and $p = 0.35$, respectively). Significantly more patients in pre-cohort had abdominal guarding on exam ($p = 0.005$), while significantly more patients in the post-cohort ($p = 0.003$) had a seatbelt sign on exam.

Overall 69 (60%) subjects received a CTAP scan. Of those 69 subjects with CTAP imaging, 19 (27.2%) had findings indicating IAI. CTAP findings and any subsequent interventions are detailed in Table 2. CTAP utilization significantly decreased after algorithm implementation from 72.3% to 44% ($p = 0.002$), with no significant difference in CTAP findings of IAI. The unadjusted and adjusted odds of a pediatric BAT patient receiving a CTAP post-implementation were 0.3 (95% confidence interval (CI) 0.1–0.6) and 0.2 (95% CI 0.07–0.67), respectively.

ED/trauma center LOS significantly decreased after algorithm implementation from 256 min to 203 min ($p = 0.003$) (Fig. 2). Despite the decrease in CTAP imaging, there was no significant increase in hospitalization rates in the post cohort, however post cohort patients who were admitted did have a significantly longer hospital LOS (2–3 days, $p < 0.001$) (Fig. 3). There were no statistically significant differences in patients who received surgery or other interventions, nor differences in 7-day return visits after the BAT algorithm was implemented. There were no major missed IAIs in the post cohort that did not receive a CTAP during the initial evaluation. However, there was a case in the post cohort of a 12-year old male who was admitted for observation, became more tachycardic after admission, and a subsequent CTAP scan showed a hollow viscus injury. He underwent a laparotomy for bowel resection and repair and recovered uneventfully.

Discussion

This study demonstrates a decrease in CTAP rates in pediatric BAT patients after implementation of an evidenced-based algorithm. The decrease in CTAP rates was accompanied by decreases in ED/trauma center LOS, no increase in hospital admission rates, and no significant missed injuries. This study's 27% decrease in CTAP use is similar to the 33% reduction in CTAP use predicted for a similar clinical decision rule.[13] That study considered hypotension, abdominal tenderness, femur fracture, increased liver enzyme levels, microscopic hematuria, and admission hematocrit level <30% as predictors for IAI, and estimated a 33% reduction in CTAP rates with application of their clinical decision rule.[13]

We saw no significant changes in the numbers of patients who had interventions. While we had no cases of missed diagnosis or change in 7-day return visits, there was a single patient with a hollow viscus injury who did not receive a CTAP on initial evaluation. However, he was admitted per the BAT algorithm for observation, and his injury was subsequently diagnosed and managed operatively. With regard to hollow viscus injuries, initial CTAP scan has a widely variable sensitivity (29–77%),[16–19] reinforcing the importance of clinical evaluation and observation.

The post-BAT algorithm's decrease in CTAP rates of 27% also

Table 2
Diagnostic investigations, including CT scan use pre and post algorithm implementation.

Diagnostic Investigations	Overall	Pre-BAT Algorithm	Post-BAT Algorithm	p-value[a]
AST (IU/L)	45 (31–74.5)	55 (33.5–179.4)	38 (30–57)	0.09
ALT (IU/L)	21 (16.5–40)	26 (18–116.5)	19.5 (15–33.5)	0.04[b]
Amylase (U/L)	60 (51–89)	70.5 (51–91)	60 (51–89)	0.72
Lipase (U/L)	22 (18–31)	22.5 (19–30)	22 (18–36)	0.78
Hemoglobin				0.14
Abnormal[c]	5 (4.4%)	5 (7.7%)	0	
Normal	91 (79.1%)	49 (75.4%)	42 (84%)	
Not Performed	19 (16.5%)	11 (16.9%)	8 (16%)	
Urinalysis				< **0.001**[b]
Positive[d]	5 (4.4%)	2 (3.1%)	3 (6%)	
Normal	33 (28.7%)	8 (12.3%)	25 (50%)	
Not Performed	77 (67%)	55 (84.6%)	22 (44%)	
FAST				**0.004**[b]
Positive	8 (7%)	7 (10.8%)	1 (2%)	
Negative	91 (79%)	45 (69.2%)	46 (92%)	
Indeterminate	1 (<1%)	0	1 (2%)	
Not Performed	15 (13%)	13 (20%)	13 (20%)	
CT Abdomen/Pelvis				**0.002**[b]
Yes	69 (60%)	47 (72.3%)	22 (44%)	
No	46 (40%)	18 (27.7%)	28 (56%)	
CT Abdomen/Pelvis Result (Total N = 69)				0.26
Positive[e]	19 (27.5%)	11 (23.4%)	8 (36.4%)	
Negative	50 (72.5%)	36 (76.6%)	14 (63.6%)	

Post Patients: 1 with an undefined Grade Splenic Laceration, 1 with Grade 2 Liver laceration, 1 with Pelvic Hematoma, 1 with Grade 3 Splenic Laceration, 2 with pelvic free fluid, 1 with perihepatic free fluid and lumbar fracture, 1 with Subcapsular Liver hematoma.

ALT: Alanine aminotransferase, AST: Aspartate aminotransferase, CT: Computed tomography, FAST: Focused assessment with sonography in trauma, IU: International units, L: liter.

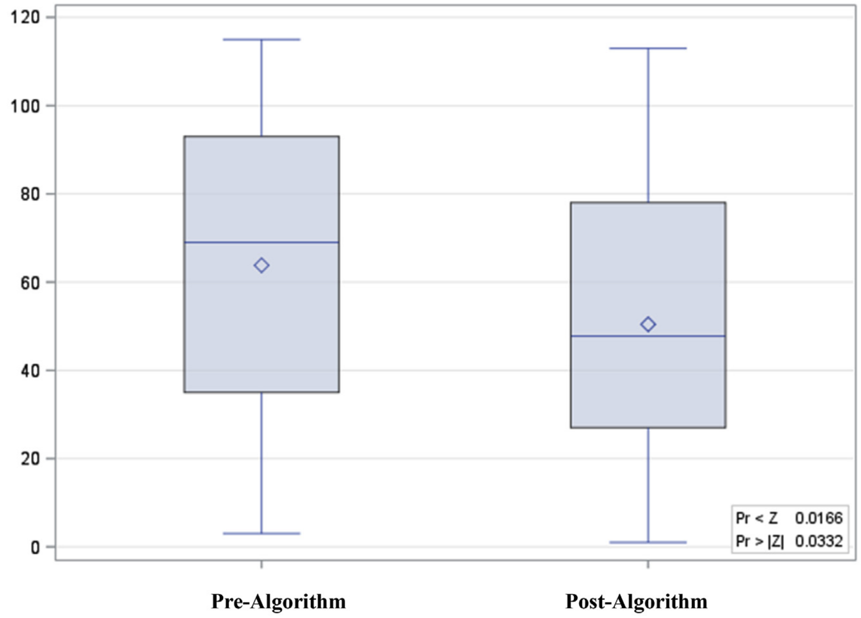
[a] pValue for difference between Pre and Post algorithm patients.

[b] Denotes statistical significance at $p < 0.05$.

[c] Hemoglobin reference value normal: 14.0–18.0 g/dL.

[d] Positive: ≥ 5 red blood cells per ml of urine.

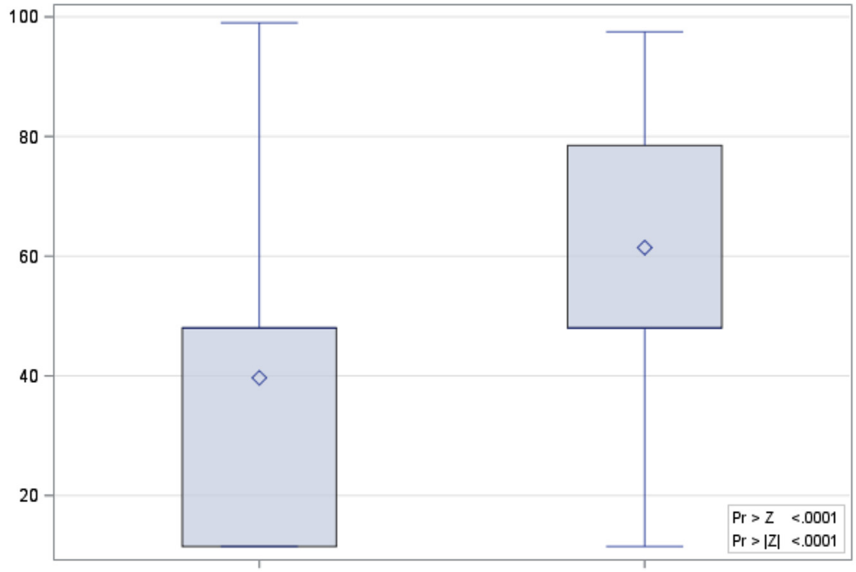
[e] Pre Patients: 4 with pelvic hematomas, 1 with Grade 1 Liver & Splenic Lacerations, 1 with Grade 3 Splenic and Kidney lacerations with Grade 1 Liver laceration, 1 with Grade 5 Liver Laceration and Adrenal Bleed and Grade 2 Splenic Laceration and Grade 3 Renal Laceration, 1 with Pelvic Hematoma and External Iliac Pseudoaneurysm, 1 with Grade 2 Splenic Laceration with perisplenic hematoma, 1 with Grade 3 Splenic Laceration and Grade 2 Liver Laceration and Adrenal Hemorrhage, and 1 with Duodenal Hematoma.



Graph represents Box and Whisker plots with minimum to maximum (“whiskers”), box borders represent the interquartile range, the diamond represents the mean and the line represents the median. LOS in minutes is shown on the y axis. Wilcoxon rank sum scores are shown in the lower left.

ED LOS: Emergency department length-of-stay

Fig. 2. Decrease in Trauma Center/ED LOS in minutes pre and post BAT algorithm implementation.



Graph represents Box and Whisker plots with minimum to maximum (“whiskers”), box borders represent the interquartile range, the diamond represents the mean and the line represents the median. Hospital LOS in hours is shown on the y axis. Wilcoxon rank sum scores are shown in the lower left.

LOS: Length-of-stay

Fig. 3. Hospital LOS in hours pre and post BAT algorithm implementation.

translates to a reduction in the risk of pediatric radiation associated malignancies. A study that looked at estimated pediatric cancer risk from radiation exposure proposed that a 33% decrease in CT scan rates corresponded to a one-third decrease in the rates of all radiation-induced pediatric malignancies.[9] No studies have directly looked at the pediatric cancer risk from CTAP, but since CTAP are the second most commonly ordered CT scans in pediatrics after head CT, [9,10,20] and are associated with a higher risk of developing solid tumors than any other CT scans,[9,10] our results further highlight the potential for decreasing radiation associated malignancies in children through a BAT evidence-based algorithm.[21] Additionally, potentially improved stewardship of CTAP use may have contributed to the increased rates of true positives for IAI in this study (from 12% to 36.4%). Those rates are significantly higher than the rates of positive CTAP scans from other studies of pediatric BAT (10%).[7,8] However, those other studies did include hemodynamically unstable patients.[7,8]

Additionally, the BAT algorithm did not increase hospital resource use, as evidenced by the decrease in average ED/trauma center LOS and no changes in hospital admission rates. However, for admitted patients, average hospital LOS increased from 2 to 3 days. A study done at large-tertiary referral pediatric trauma center showed similar results, with no increases in length of hospital stay after implementation of a protocol for imaging suspected solid organ injury.[22]

Although this study did not specifically examine cost, the reduction in CTAP rates without concomitant increases in LOS or hospitalization rates likely resulted in great cost savings. Extrapolating data from Fair Health Consumer®, the estimate from November 2018 of the cost for a CTAP scan in our hospital's zip code was $6250 for out of network or uninsured patients, and $2284 for in network patients.[23] If applied to our cohort, a reduction of $194,062 and $70,804, respectively, would have resulted during the study period.

Limitations

This study has limitations that merit discussion. It is a retrospective study, and as such did not prospectively evaluate patient factors and provider decision-making in real time. There may be confounding variables related to patient's clinical status as well as the reason providers did or did not order CTAP imaging which this study does not reveal. There were fewer patients in the post-cohort, as our trauma center saw declining volumes of pediatric trauma patients in the year after algorithm implementation, which may bias results due to the smaller sample size. Additionally, our 7-day return visit metric may not capture all patient complications, as some may occur out of a 7-day window, or patients may have presented to other hospitals. Finally, this is a study of a single urban mixed adult and pediatric trauma center, and results may not be generalizable to all health care settings. However, since our institution is not a freestanding children's hospital, our findings may be valuable to similar institutions.

Conclusions

An evidence-based clinical decision algorithm for evaluating hemodynamically stable pediatric BAT patients can safely decrease CTAP use without missing significant injuries, and with no attendant increases in hospital resource utilization. Future multicenter studies should validate such an algorithm, especially including a variety of non-children's hospital settings such as ours. Additionally, prospective and longitudinal studies measuring machine-specific radiation dosing are required to evaluate the true reduction in malignancy risk for pediatric trauma patients.

Author contributions

This original manuscript is being submitted only to *The American Journal of Surgery*, and it will not be submitted elsewhere while under consideration. All authors are responsible for the reported research. Osayi Odia contributed to the study concept and design, acquisition of the data, interpretation of the data, drafting of the text, and critical revision of the manuscript for important intellectual content. Brian Yorkgitis contributed to the study concept and design, acquisition of the data, interpretation of the data, and critical revision of the manuscript for important intellectual content. Phyllis Hendry contributed to the study concept and design, acquisition of the data, interpretation of the data, and critical revision of the manuscript for important intellectual content. Marie Crandall contributed to the study design and concept, and critical revision of the manuscript for important intellectual content. Lori Gurien contributed to the study design and concept, and critical revision of the manuscript for important intellectual content. David Skarupa contributed to the study design and concept, and critical revision of the manuscript for important intellectual content. Jennifer Fishe contributed to the study concept and design, acquisition of the data, analysis and interpretation of the data, drafting of the text, and critical revision of the manuscript for important intellectual content.

Declaration of competing interest

None.

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