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Application of a Thoracic CT Decision Rule in the Evaluation of Injured Children: A Quality Improvement Initiative

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BACKGROUND: Differences in injury patterns in children suggest that life-threatening chest injuries are rare. Radiation exposure from computed tomography increases cancer risk in children. Two large retrospective pediatric studies have demonstrated that thoracic computed tomography can be reserved for patients based on mechanism of injury and abnormal findings on chest radiography.

OBJECTIVE: Implement a decision rule to guide utilization of thoracic computed tomography in the evaluation of pediatric blunt trauma, limiting risk of unnecessary radiation exposure and clinically significant missed injuries.

METHODS: A protocol for thoracic computed tomography utilization in pediatric blunt trauma was implemented using a Plan-Do-Study-Act cycle at our Level I pediatric trauma center, reserving thoracic computed tomography for patients with (1) mediastinal widening on chest radiography or (2) vehicle-related mechanism and abnormal chest radiography. We modified our resuscitation order set to limit default imaging bundles. The medical record and trauma registry data were reviewed for all pediatric blunt trauma patients (younger than 18 years) over a 30-month study period before and after protocol implementation (May 2017 to July 2018 and February 2019 to April 2020), allowing for a 6-month implementation period (August 2018 to January 2019).

RESULTS: During the study period, 1,056 blunt trauma patients were evaluated with a median (range) Injury Severity Score of 5 (0–58). There were no significant demographic differences between patients before and after protocol implementation. Thoracic computed tomography utilization significantly decreased after implementation of the protocol (26.4% [129/488] to 12.7% [72/568; $p < .05$]), with no increase in clinically significant missed injuries. Protocol compliance was 88%.

CONCLUSIONS: Application of decision rules can safely limit ionizing radiation in injured children. Further limitations to thoracic computed tomography utilization may be safe and warrant continued study due to the rarity of significant injuries.

KEY WORDS: Blunt chest trauma, Computed tomography, CT, Imaging guidelines, Pediatric trauma, TCT, Thoracic computed tomography

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The leading cause of mortality in children older than 1 year is unintentional injury (Centers for Disease Control and Prevention [CDC], 2019), with thoracic trauma occurring in 5%–12% of pediatric trauma patients (Pearson et al., 2017; Peclet et al., 1990). The use of thoracic computed tomography (TCT) in adult blunt trauma patients following deceleration injuries has become the gold standard screening test because of the risk of aortic injury in adults and the increased sensitivity of TCT for these injuries, regardless of chest radiography findings (Fox et al., 2015). However, there are no established guidelines for the use of TCT in pediatric blunt trauma patients.

Differences in injury patterns due to mediastinal, vascular, and chest wall anatomy in children suggest that life-threatening blunt thoracic injuries are rare compared with adults (Golden et al., 2016). The pediatric chest wall is more compliant due to flexible ligamentous attachments and musculature that has not fully developed, which allows for transmission of high-energy forces to internal organs and compression of the thorax without fractures (Bliss & Silen, 2002; Skinner et al., 2015; Snyder et al., 1990; Tovar & Vazquez, 2013). Increased mobility of the pediatric mediastinum allows a greater degree of visceral shift and changes in cardiac function, while the arterial structures are more

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KEY POINTS

- Traumatic injuries of the chest are rare in children.
- Application of decision rules can safely limit ionizing radiation and cancer risk in injured children.
- Pediatric imaging protocols are recommended as best practice.
- Electronic medical records functionality standardizes and supports clinical workflows.

elastic, allowing for increased ability to compensate for hypovolemia (Bliss & Silen, 2002). Although the incidence of blunt thoracic injuries in pediatric traumas is very low, the mortality rate associated with significant blunt thoracic injuries in children is high (Pearson et al., 2017; Peclet et al., 1990).

Radiation exposure from computed tomography (CT) is also a concern in the evaluation of pediatric blunt trauma patients. Children may receive higher doses of radiation during CT, are more radiosensitive, and due to exposure at an earlier age, have more years to develop cancers than adults (Meulepas et al., 2019). Overall, cancer incidence rates are higher in children with a history of CT than in unexposed children (Krille et al., 2015; Mathews et al., 2013; Meulepas et al., 2019). Regarding TCT, the lifetime risk of developing a solid cancer has been reported as 20.9–30.5 cases per 10,000 TCT for females and 6.1–9.2 cases per 10,000 TCT for males, and the lifetime risk of developing leukemia has been reported as 0.4–0.6 cases per 10,000 TCT, depending on age less than 15 years (Miglioretti et al., 2013). Despite an increased risk of cancer, TCT rates for children with no or minimal injuries to the chest are significant and have been reported to be 3% in children without a chest injury and 13% in children with mild chest injuries (Strait et al., 2020), and an average of 3.9 body regions may be scanned during initial CT evaluation (Holscher et al., 2013). The estimated risk of cancer associated with TCT is greater than the likelihood of identifying an aortic injury on TCT in children (Arbuthnot et al., 2019).

Clinical predictors of thoracic injury (abnormal thoracic signs/symptoms, abnormal chest auscultation, oxygen saturation <95%, blood pressure less than the fifth percentile for age, and femur fracture) when used without chest radiography have been shown to miss important thoracic injury (Weerdenburg et al., 2019). When compared with TCT alone, chest radiography with selective use of TCT can reliably detect blunt thoracic trauma (Yalçın-Ş̧afak & Akça, 2018). Recent studies suggest that TCT often serves as a confirmatory diagnostic tool and can be avoided in many pediatric blunt trauma patients without affecting care (Azari et al., 2020; Holl et al., 2020; Holscher et al., 2013).

Two large retrospective pediatric studies have recently demonstrated that TCT can be reserved for pediatric trauma patients based on mechanism of injury and abnormal mediastinal findings on chest radiography (Golden et al., 2016; Stephens et al., 2017). Reserving TCT for these patients would have decreased TCT rates by 80% (Golden et al., 2016; Stephens et al., 2017). Another recent study found that when both chest radiography and TCT were obtained to screen for thoracic injury, more than 91% of the children did not significantly change their management (Ugalde et al., 2021).

Given these recent findings and concerns for increased lifetime risk of cancers associated with CT, a protocol was implemented at our Level I pediatric trauma center to reduce utilization rates of TCT in the primary evaluation of pediatric trauma patients. We hypothesized that implementing decision rules would decrease use of ionizing radiation in pediatric trauma patients while not missing significant blunt thoracic injuries.

OBJECTIVE

Implement a decision rule to guide utilization of TCT in the evaluation of pediatric blunt trauma, limiting risk of unnecessary radiation exposure and clinically significant missed injuries.

METHODS

Prior to protocol implementation, there were no clinical guidelines at our pediatric Level I trauma center for the evaluation of blunt thoracic injuries in children. Despite evidence supporting the limited use of TCT, our review demonstrated continued and nonstandardized use of TCT evaluation for injured children. Within our Performance Improvement and Patient Safety Committee (PIPS), we received unanimous support for modification of our pediatric trauma imaging and evaluation protocol by adding specific criteria for when TCT is indicated. This quality improvement initiative followed the Plan-Do-Study-Act (PDSA) Model for Improvement framework (see Figure 1). The decision rule was created jointly with the adult surgeons who perform the initial evaluation and stabilization of pediatric trauma patients and the pediatric surgeons who assume care and lead the pediatric trauma program performance improvement efforts. This decision rule resulted in a new protocol for TCT utilization in pediatric blunt trauma that reserves TCT for patients with (1) mediastinal widening on chest radiography or (2) vehicle-related mechanism combined with positive chest radiography findings. A positive chest radiography finding was defined as any abnormal finding representing an injury or concern for an injury, including pulmonary contusion, pneumothorax, pneumomediastinum, effusions, rib

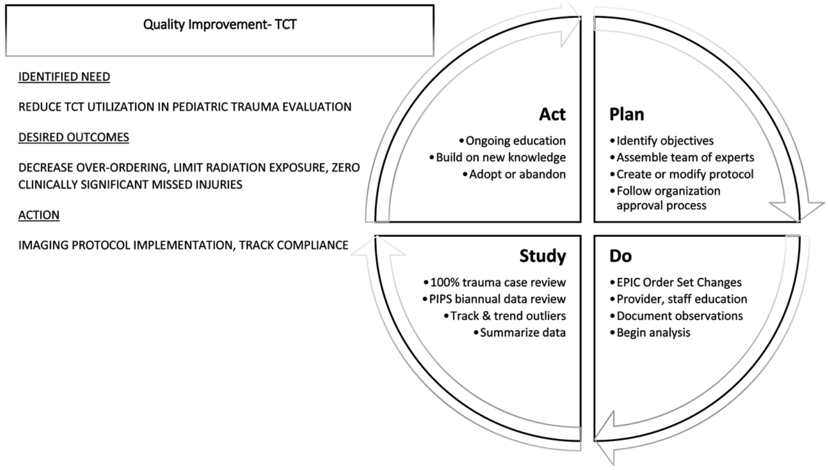

Figure 1. Plan-Do-Study-Act (PDSA) Model for Improvement. PIPS = Performance Improvement and Patient Safety Committee; TCT = thoracic computed tomography.

fractures, or other bony fractures. Noninjury findings such as scoliosis, endotracheal tube in right mainstem, or lung findings suggestive of reactive airway disease or viral process were excluded.

The first phase of protocol implementation focused on modifying the existing organizational policy for pediatric imaging practices in trauma. A reference box was added to the abdominal and thoracic evaluation section of the imaging policy, noting valid criteria for obtaining a TCT. This protocol was developed using evidence-based publications and was reviewed by our PIPS subspecialty liaisons, including trauma surgery and radiology. The proposed changes were sent through the required organizational approval channels and ultimately published for reference in August 2018.

Another important component of protocol implementation was ensuring that provider workflows and functions of the electronic medical record (EMR) reflected the modified policy. The order set used for trauma resuscitation has the functionality to differentiate by age and weight, allowing for specialized standardization across the various trauma cohorts we serve. We elected to remove the preselected CT Chest-Abdomen-Pelvis bundle from the standard imaging orders so that inadvertent autoselection could not occur. With that change, an order for TCT must be entered separately from other CT imaging orders, cuing the providers to first consider clinical indication according to the new protocol before proceeding.

Using Trauma One (Lancet Technology, 2019), our state trauma registry reporting system, we first identified all patients younger than 18 years who had undergone CT of the thorax during the emergency department phase of their trauma care over a 30-month study period before and after protocol implementation (May 2017 to July 2018 and February 2019 to April 2020), allowing for a 6-month implementation period (August 2018 to January 2019). Patients with mechanisms of hanging, drowning, or penetrating trauma were excluded. Each patient was reviewed in the EMR (Epic, version 2012) to identify (a) vehicle-related mechanism, (b) chest radiography completed prior to TCT, (c) positive chest radiography findings, and (d) documented mediastinal widening. All patients who had undergone chest radiography without subsequent TCT evaluation during the postprotocol study period were also identified and used in determining overall protocol compliance. We used the following definitions to review and categorize the data:

Blunt trauma: Motor vehicle–related accident, pedestrian struck, fall, crush injury, sports injury, nonpenetrating animal injury, nonpenetrating assault, nonaccidental trauma

Vehicle-related mechanism: Motor vehicle crash (MVC) or pedestrian versus automobile with vehicle conceived as broadly as possible (any motorized vehicle including all terrain vehicles [ATVs] and motorbikes)

Positive chest radiography: Any abnormality (e.g., pneumothorax, effusion, fracture, mediastinal widening)

Protocol compliance: Defined as a patient encounter involving appropriate use of the imaging protocol by one of the following pathways: (1) chest radiography only or deferred imaging of chest (2) chest radiography with mediastinal widening and subsequent CT chest, or (3) vehicle-related mechanism with positive chest radiography and subsequent CT chest. To estimate compliance, the sum of compliant encounters was divided by the total number of patient encounters during the study period.

Nonparametric data were reported as medians with ranges and compared using the Mann–Whitney *U* test. Categorical variables were compared using the

χ^2 test and Fisher exact test. Statistical significance was defined at p value of less than .05. All analyses were performed using SPSS, version 25 (IBM, Armonk, New York). The Legacy Research Institute Institutional Review Board granted a quality improvement exemption #5-15-21.

RESULTS

A total of 1,056 blunt trauma patients with a median (range) Injury Severity Score (ISS) of 5 (0–58) were evaluated for TCT utilization and protocol compliance by comparing pre- and postprotocol 15-month periods, allowing for an interval of 6-month protocol implementation period. The most common mechanism of injury was motor vehicle–related accidents. The preprotocol period reviewed 488 pediatric blunt trauma patients, 312 males (63.9%) and 176 females (36.1%), with a median (range) ISS of 8 (0–59) and median (range) age of 8 years (7 days to 17 years). The postprotocol period reviewed 568 patients, 366 males (64.3%) and 202 females (35.7%), with a median (range) ISS of 5 (0–48) and median (range) age of 8 (1 day to 17 years; see Table 1).

Regarding TCT utilization, there were 129 patients who underwent TCT evaluations and 359 patients who did not have TCT evaluation in the preprotocol period. In the postprotocol period, there were 72 patients who underwent TCT evaluation and 496 patients who did not undergo TCT evaluations. The TCT utilization significantly decreased after implementation of the protocol (26.4% [129/488] to 12.7% [72/568; $p < .05$]; see Table 2). Regarding protocol compliance, 501 of the 568 patients in the postprotocol period were evaluated according to the TCT protocol, with a compliance rate of 88%. Importantly, none of the patients without any chest imaging performed or those who underwent chest radiography without TCT had clinically significant missed injuries (subsequent hemodynamic instability or finding requiring pharmacologic or procedural intervention).

DISCUSSION

This study demonstrates a decrease in TCT utilization overall, down from 26.4% to 12.7% of all pediatric trauma patients, and an 88% compliance rate in the postprotocol period. This metric includes all patients who did not undergo any imaging of the chest, those who had only chest radiography, and those who underwent TCT evaluation after a positive chest radiography and appropriate mechanism of injury.

There are differences in utilization rates of TCT in stand-alone pediatric trauma centers, adult trauma centers, and combined adult/pediatric trauma centers, with Level I stand-alone pediatric trauma centers being less likely to perform TCT (Strait et al., 2020). Our institution is a verified ACS Level I pediatric trauma center in a children's hospital within an adult hospital, which results in the initial evaluation of injured children being done by adult trauma surgeons who have pediatric expertise. This model is common for many trauma centers but poses challenges in creating different protocols for adults and children. Providers who treat pediatric and adult patients for similar or identical injury patterns have the challenge of adhering to the unique differences in the evidence-based care practices for each cohort. Azari et al. (2020) describe how implementing a guideline effectively reduced inappropriate TCT rates. More specifically, implementing evidence-based imaging guidelines has been shown to reduce CT in pediatric trauma patients (Wu et al., 2021), and our experience has helped providers stay informed of the unique differences in pediatric clinical practice. Our pediatric trauma imaging guidelines now include pathways for CT scanning of the head, cervical spine, abdomen/pelvis, and thorax.

These pediatric-specific imaging guidelines could be provided to outlying hospitals, along with the findings from our protocol implementation, in an educational format to guide appropriate imaging of patients prior to transfer and avoid unnecessary CT scanning. The new protocol narrows the criteria for TCT eligibility to vehicle-related mechanisms with positive

Table 1. Pre- and Postprotocol Demographics for Sex, Age, and ISS

	Preprotocol *N* = 488	Postprotocol *N* = 568	*p*
Male	312 (63.9%)	366 (64.3%)	.898
Female	176 (36.1%)	202 (35.7%)	
Median (range) age	8 (7 days to 17 years)	8 (1 day to 17 years)	.692
Median (range) ISS	8 (0–59)	5 (0–48)	.001

Note. ISS = Injury Severity Score.

Table 2. Pre- and Postprotocol Chest Radiography and Thoracic Computed Tomography Utilization

	Preprotocol *N* = 488	Postprotocol *N* = 568	*p*
No imaging of chest	240 (49.2%)	340 (59.9%)	
Chest radiography only	119 (24.4%)	156 (27.5%)	
TCT only	74 (15.2%)	55 (9.7%)	
Chest radiography and TCT	55 (11.3%)	17 (3.0%)	
Total TCT	129 (26.4%)	72 (12.7%)	<.05
Compliance		501 (88%)	

Note. TCT = thoracic computed tomography.

chest radiography findings or the presence of mediastinal widening on chest radiography. It is unlikely that all of these patients need TCT, and rarely would it change clinical management, but we felt that the risk of missing a single aortic injury was too great. Compared with other centers that use mediastinal widening as their single criteria, they may order fewer TCTs but may miss a clinically significant injury (Stephens et al., 2017).

Prior to the TCT protocol, we were already using EMR functionality to differentiate adult and pediatric clinical workflows, using technology to guide providers by embedding guidelines into standardized order sets. Our institution's adult trauma order sets default with all-inclusive imaging bundles. Henry et al. (2021) demonstrated that liberal use of CT imaging in hemodynamically stable pediatric blunt trauma patients led to significantly higher radiation exposure, longer hospital length of stay, and increased follow-up imaging than selective CT imaging without an improvement in mortality or difference in additional long-term interventions. We recommend against using a "pan scan" method for evaluating pediatric blunt trauma patients and supporting clinical guidelines with EMR workflows when possible.

Although these initial data are promising and are trending in the right direction, there are still a number of injured children getting TCT evaluation who do not meet criteria or who do not first undergo chest radiography evaluation per the protocol pathway. Continued protocol reinforcement and review of results are necessary to make the changes lasting. Our trauma PIPS committee has identified the need for another PDSA cycle, where each case of TCT evaluation is reviewed for appropriateness and compliance. This process will include, at minimum direct provider feedback in real time, as well as trending and reviewing all outliers with the committee members. Resuscitation audits and advanced EMR enhancements are two proposed action items for the next cycle. As protocol compliance continues to increase with time and following our quality improvement PDSA model, we expect continued reduction in TCT utilization.

LIMITATIONS

There are limitations to this study, which may be factored into future iterations of this quality work. Differences in median ISS scores of the two groups were statistically significant, which could be attributed to some of the overall decrease in chest imaging; however, ISS is not known at the time of patient presentation, so it cannot be used as a decision rule within clinical resuscitation guidelines. In addition, provider discretion and clinical picture are not captured in the discrete data fields of the trauma registry. This study does not reflect the entirety of a patient's clinical presentation, which in some cases may have warranted or supported TCT evaluation or deviations from the protocol's imaging pathway. An example of this might be concern for injury to the thoracic spine, where TCT may be practically the most appropriate diagnostic test, even with evidence of normal chest radiography. In our institution, we see this in practice as adding the TCT to the CT abdomen/pelvis with thoracic/lumbar reconstructions rather than ordering a CT abdomen with lumbar reconstruction only and a separate thoracic spine CT. Our current protocol does not have a specific pathway for thoracic spine imaging. Vehicle-related mechanism definitions could also be interpreted differently, either broadly or more narrowly defined, and are often based on accuracy and availability of event details.

In addition, in some cases, radiographic studies done at referring facilities are not readily available for provider review upon patient arrival, which could mean that radiography of the chest was done prior to transfer but may not factor into real-time clinical decision making in the trauma bay. Generally, this would be rare with the presence of a statewide virtual private network system allowing for electronic imaging sharing. Similarly, TCT evaluation may have already occurred at referring facility without regard to pediatric imaging protocols. We generally recommend that our transfer facilities defer CT scanning in stable patients to avoid any delay in transfer to a pediatric facility.

There is limited visibility to statewide data within the state trauma registry that would allow us to track and target gaps in imaging practices across the state more efficiently. At this time, this is done by request or when specific cases are reviewed through our outreach program. Similarly, pediatric imaging practices at the national level have not been identified as a metric for benchmarking through the American College of Surgeons Trauma Quality Improvement Program (ACS TQIP). These are areas for further investigation and development of best practice imaging protocols currently underway by the Emergency Medical Services for Children Innovation and Improvement Center.

CONCLUSIONS

Application of decision rules can safely limit ionizing radiation in injured children. Implementing a pediatric imaging clinical guideline can guide providers to safely and systematically identify injuries during the resuscitation phase of care and is especially true in centers where providers care for both injured adults and children. Embedding these clinical pathways into the EMR saves time during the trauma resuscitation and prevents unintentional "pan scan" defaults that may be standard practice in adult trauma surgery. Limiting the use of TCT in pediatric trauma limits ionizing radiation, decreases unnecessary hospital costs to families, and decreases cancer risk. Further limitations to TCT utilization may be safe and warrant continued study due to the rarity of significant injuries.

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This activity is also provider approved by the California Board of Registered Nursing, Provider Number CEP 11749 for 2.0 contact hours. Lippincott Professional Development is also an approved provider of continuing nursing education by the District of Columbia, Georgia, West Virginia, New Mexico, South Carolina, and Florida, CE Broker #50-1223. Your certificate is valid in all states.

Payment: The registration fee for this test is FREE for STN members and $21.95 for nonmembers.

STN members can take JTN CE for free using the discount code available in the members-only section of the STN website. Use the discount code when payment is requested during the check-out process.

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