Identifying Children at Very Low Risk of Clinically Important Blunt Abdominal Injuries

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Study objective: We derive a prediction rule to identify children at very low risk for intra-abdominal injuries undergoing acute intervention and for whom computed tomography (CT) could be obviated.

Methods: We prospectively enrolled children with blunt torso trauma in 20 emergency departments. We used binary recursive partitioning to create a prediction rule to identify children at very low risk of intra-abdominal injuries undergoing acute intervention (therapeutic laparotomy, angiographic embolization, blood transfusion for abdominal hemorrhage, or intravenous fluid for ≥2 nights for pancreatic/gastrointestinal injuries). We considered only historical and physical examination variables with acceptable interrater reliability.

Results: We enrolled 12,044 children with a median age of 11.1 years (interquartile range 5.8, 15.1 years). Of the 761 (6.3%) children with intra-abdominal injuries, 203 (26.7%) received acute interventions. The prediction rule consisted of (in descending order of importance) no evidence of abdominal wall trauma or seat belt sign, Glasgow Coma Scale score greater than 13, no abdominal tenderness, no evidence of thoracic wall trauma, no complaints of abdominal pain, no decreased breath sounds, and no vomiting. The rule had a negative predictive value of 5,028 of 5,034 (99.9%; 95% confidence interval [CI] 99.7% to 100%), sensitivity of 197 of 203 (97%; 95% CI 94% to 99%), specificity of 5,028 of 11,841 (42.5%; 95% CI 41.6% to 43.4%), and negative likelihood ratio of 0.07 (95% CI 0.03 to 0.15).

Conclusion: A prediction rule consisting of 7 patient history and physical examination findings, and without laboratory or ultrasonographic information, identifies children with blunt torso trauma who are at very low risk for intra-abdominal injury undergoing acute intervention. These findings require external validation before implementation. [Ann Emerg Med. 2013;62:107-116.]

Please see page 108 for the Editor's Capsule Summary of this article.

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*Participating centers and site investigators are listed in the Appendix.

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INTRODUCTION

Background

Intra-abdominal injury is a leading cause of morbidity in children,[1] and early identification is imperative to minimize morbidity and mortality from delayed or missed diagnosis. In the last 2 decades, computed tomography (CT) has become the reference standard for diagnosing many traumatic injuries,[2-5] including intra-abdominal ones.[6-10] CT use in trauma and emergency care, however, has expanded much faster than the evidence for its appropriate application.[2,3,11]

Importance

Although CT provides detailed and useful information about injuries and helps clinicians to make informed management decisions, it has important drawbacks, primarily that it exposes

Editor's Capsule Summary

What is already known on this topic

The radiation risks of computed tomography (CT) scanning in children are well recognized.

What question this study addressed

Are there history and physical examination criteria that might identify which children with blunt torso trauma do not require abdominal CT scans?

What this study adds to our knowledge

A 7-point decision rule derived in this multicenter study of 12,044 children was 97% sensitive in identifying children with intra-abdominal injury requiring acute intervention. Actual CT ordering characteristics were 99% sensitive. The rule, however, had a 99.9% negative predictive value in identifying a population of children at very low risk for intra-abdominal injury warranting acute intervention.

How this is relevant to clinical practice

If externally validated, this rule could aid clinicians in lowering abdominal CT use in children by identifying a low risk population based on simple history and examination variables.

patients to relatively large radiation dosages, placing them at increased risk of radiation-induced malignancy. Unfortunately, children's inherent radiosensitivity makes them disproportionately at risk compared with adults.[12-14] Several small, single-center studies suggest that children with blunt torso trauma can be risk stratified for intra-abdominal injury through a combination of readily accessible clinical variables.[10,15-18] These studies are limited, however, by their retrospective or single-center study designs but indicate that a large, multicenter study may create a robust and precise prediction rule.

Goals of This Investigation

The objective of the current investigation was to derive a prediction rule to identify children with blunt torso trauma who are at very low risk for intra-abdominal injury undergoing acute intervention. We hypothesized that a reliable prediction rule could be created to identify a cohort of these children for whom CT would generally not be indicated.

MATERIALS AND METHODS

Study Design

We conducted a prospective, observational cohort study of children with blunt torso trauma in the Pediatric Emergency Care Applied Research Network (PECARN).[19] The study was approved by the institutional review board at each participating site.

Decreased level of consciousness (GCS score <15 or neurologic/behavioral status not age-appropriate) in association with blunt torso trauma (but not isolated head trauma).

Blunt traumatic event with either of the following (regardless of the injury mechanism):
- Paralysis
- Multiple nonadjacent long bone fractures (eg, tibia fracture, ulna fracture)

Blunt torso trauma due to any of the following mechanisms of injury:
- Motor vehicle crash: high speed (≥40 mph), ejection, or rollover
- Automobile versus pedestrian/bicycle: automobile moderate to high speed (≥5 mph)
- Falls ≥20 ft in height
- Crush injury to the torso
- Physical assault involving the abdomen

Physician concern for abdominal trauma resulting in any of the following diagnostic or screening tests:
- Abdominal CT or ultrasound (FAST)
- Laboratory testing to screen for intra-abdominal injury
- Chest or pelvic radiography

Figure 1. Patient inclusion criteria. *FAST,* Focused assessment sonography for trauma; *GSC,* Glasgow Coma Scale.

Patient history variables
- Mechanism of injury
- Complaints of abdominal pain: including location and severity
- History of vomiting at any time after injury

Physical examination variables
- Initial ED heart rate
- Initial ED systolic blood pressure: categorized as hypotensive if the initial systolic blood pressure was low after age adjustment.[32]
- Initial ED respiratory rate (categorized as age-adjusted tachypnea)
- Initial GCS score in children ≥2 years of age[33]
- Initial Pediatric GCS score in children <2 years of age[34]
- Evidence of thoracic wall trauma: erythema, abrasion, ecchymosis, subcutaneous air, or laceration to the anterior or posterior chest wall
- Chest auscultation for absent or decreased breath sounds
- Thoracic tenderness
- Costal margin tenderness: tenderness to any of ribs 7–12
- Evidence of abdominal wall trauma: erythema, abrasion, ecchymosis, laceration, "seat belt sign" to the abdominal wall
- Abdominal tenderness, including severity (mild, moderate, or severe)
- Abdominal distention
- Abdominal auscultation for bowel sounds
- Peritoneal irritation: rebound tenderness on palpation or abdominal pain with cough tenderness
- Flank tenderness
- Pelvic bone tenderness or instability on palpation
- Femur fracture
- Clinical evidence of alcohol intoxication
- Presence of a distracting painful injury as determined by the treating physician (not further defined)

Figure 2. Patient history and physical examination variables collected.

Selection of Participants

Children with blunt torso (thorax and abdomen) trauma evaluated in the emergency department (ED) at any of 20 participating PECARN centers from May 2007 to January 2010 were eligible. Inclusion criteria are summarized in Figure 1. Patients were excluded if they met any of the following criteria: injury occurring greater than 24 hours before presentation, penetrating trauma, preexisting neurologic disorders impeding reliable examination, known pregnancy, or transfer from another hospital with previous abdominal CT or diagnostic peritoneal lavage.

Study Protocol

The ED faculty or fellow physician providing care documented patient history and physical examination findings before CT scanning (if performed), using a standardized data collection form. Data collected are listed in Figure 2.

Abdominal CT scans were performed at the discretion of the treating physicians and according to the CT protocols at each institution. For study purposes of intra-abdominal injury identification, abdominal CT results were those from the final interpretation by the site's faculty or board-certified radiologists. Those CT scans considered inconclusive for the determination of intra-abdominal injury were initially reviewed at the study site for definitive interpretation. Final interpretations of CT scans still considered inconclusive were adjudicated by a study radiologist (S.W.-G.).

Hospitalization of study patients was at the discretion of the treating physicians. Medical records of hospitalized study patients were reviewed to identify those with intra-abdominal injuries, particularly those undergoing acute intervention. We conducted telephone follow-up at least 7 days after the original ED visit to identify any patients subsequently receiving a diagnosis of an intra-abdominal injury. If telephone follow-up was unsuccessful, we mailed the guardians the same follow-up survey. For those not returning their mail surveys, we reviewed the medical records, ED and trauma continuous quality improvement records, and local morgue records to identify any patient who subsequently received a diagnosis of intra-abdominal injury or died.

Outcome Measures

The outcome of interest was intra-abdominal injury undergoing acute intervention. Intra-abdominal injury was defined as any radiographically or surgically apparent injury to the following structures: spleen, liver, urinary tract (from the kidney to the urinary bladder), gastrointestinal tract (including the bowel or associated mesentery from the stomach to the sigmoid colon), pancreas, gallbladder, adrenal gland, intra-abdominal vascular structure, or traumatic fascial defect (traumatic abdominal wall hernia). Acute intervention was defined by an intra-abdominal injury associated with any of the following: death caused by the intra-abdominal injury, a therapeutic intervention at laparotomy, angiographic embolization to treat bleeding from the intra-abdominal injury, blood transfusion for anemia as a result of hemorrhage from the intra-abdominal injury, or administration of intravenous fluids for 2 or more nights in patients with pancreatic or gastrointestinal injuries. Therapeutic laparotomy was defined as any surgical intervention to treat an intra-abdominal injury. Blood transfusion for anemia as a result of hemorrhage from the intra-abdominal injury was based on predefined criteria and determined by the site investigator at each site after review of the medical records. Any case in which the site investigator could not make a definitive determination was adjudicated by a 5-member study panel for final determination.

Each site identified eligible patients not enrolled and collected data from each about patient age, mechanism of injury, and intra-abdominal injury status for comparison to the enrolled population. We compared the characteristics of the enrolled patients with those eligible but not enrolled to evaluate for enrollment bias.

Primary Data Analysis

We calculated simple descriptive statistics on the study sample with 95% confidence intervals (CIs) around point estimates. Bivariable comparisons are presented with rate differences and 95% CIs to demonstrate associations between possible predictor variables and the outcomes of intra-abdominal injury undergoing acute intervention and any intra-abdominal injury.

We derived the prediction rule for patients with intra-abdominal injury undergoing acute intervention by using binary recursive partitioning (CART software, version 6.0, San Diego, CA), an analytic technique used to develop clinical decision rules when rule sensitivity is most important.[20] This technique divides the population into subpopulations ("nodes") according to the risk of the outcome of interest. Each subpopulation is subsequently divided to minimize misclassification of patients until the final population meets predefined stopping criteria.[21] The results are displayed in a treelike format, easy for the clinician to interpret. We used the Gini splitting technique and 10-fold cross-validation to generate a conservative tree. To minimize the risk for misclassifying a subject with intra-abdominal injury undergoing acute intervention, we set the misclassification costs of a type II error at 500:1 (misclassifying 500 subjects without the outcome of interest to identify 1 with the outcome of interest).

Variables were considered for inclusion into the prediction rule according to previous literature and biological or physiologic plausibility. In addition, we excluded any variable that was missing on more than 5% of the data collection forms. This cutoff was chosen to ensure that we included only variables that are readily available in the ED and to limit bias from excessive missing data.[22] Finally, all variables considered for entry into the final model had at least moderate interrater agreement, with the lower bound of the 95% confidence interval (CI) of the κ measurements at least 0.4.[23-27] Variables considered for inclusion into the prediction rule included age younger than 2 years, severe mechanism of injury (as defined below), vomiting, hypotension, Glasgow Coma Scale (GCS) score, thoracic tenderness, evidence of thoracic wall trauma, costal margin tenderness, decreased breath sounds, abdominal distention, complaints of abdominal pain, abdominal tenderness (stratified by degree of tenderness as mild, moderate, or severe), evidence of abdominal wall trauma or seat belt sign, distracting painful injury, and femur fracture. We defined severe mechanism of injury a priori, according to previous literature and physiologic plausibility and included any of the following: motor vehicle crashes with ejection, rollover, or death in the same crash; motor vehicle crashes with speed greater than 20 miles per hour and patient unrestrained; falls greater than 10 feet; pedestrians or bicyclists struck by vehicles moving greater than 20 miles per hour; and bicycle collision with handlebars striking the abdomen.

Finally, we calculated the sensitivity, specificity, positive predictive value, negative predictive value, and negative likelihood ratios for the derived prediction rule. All statistical analyses were performed by the study statisticians (L.J.C. and

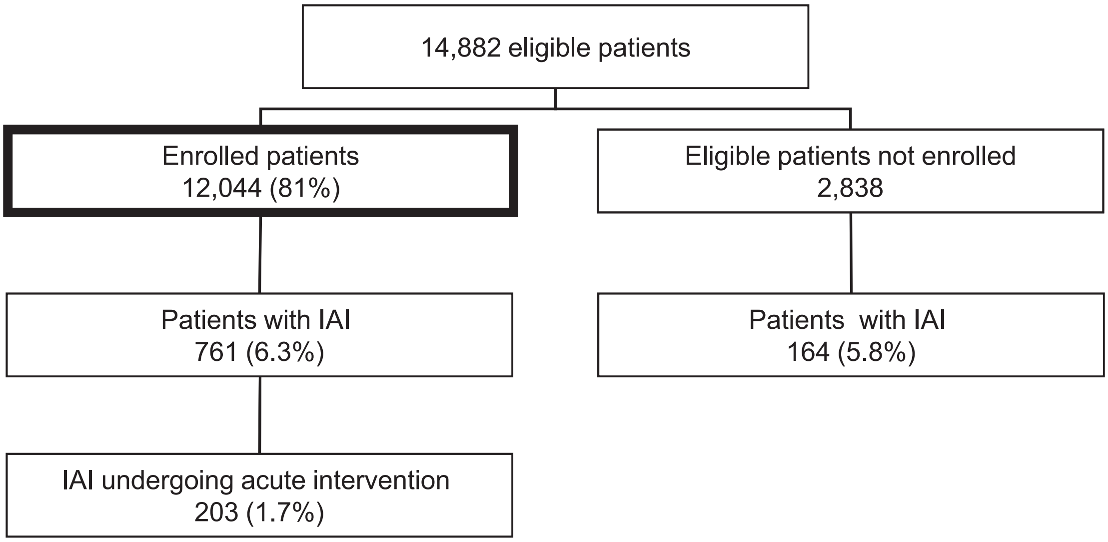


Figure 3. Patient enrollment.

another) at the data coordinating center in conjunction with the principal investigators (J.H. and N.K.).

RESULTS

Characteristics of Study Subjects

Of the 14,882 eligible patients, we enrolled 12,044 (81%) (Figure 3). The median age was 11.1 years (interquartile range 5.8, 15.1 years). Baseline characteristics of enrolled patients are described in Table 1; 5,991 children (50%) were hospitalized and 6,053 (50%) were discharged from the ED. Telephone follow-up was successful for 4,459 (74%) patients discharged from the ED, and the remainder had follow-up performed by mail (n=136) or by review of medical records, continuous quality improvement records, trauma registry records, and local morgue records. A total of 2,838 patients were eligible but not enrolled. The median age (enrolled 11.1 years versus not enrolled 11.7 years), rate of abdominal CT in the ED (enrolled 44.7% versus not enrolled 43.5%), and rate of intra-abdominal injury (enrolled 6.3% versus not enrolled 5.8%) were similar between those enrolled and those eligible but not enrolled.

Main Results

Abdominal CT scans were obtained for 5,514 (46%) patients, including 5,380 in the ED, 232 during hospitalization, and 55 after discharge from the ED (some patients with multiple CT scans performed). In total, 761 patients (6.3%; 95% CI 5.9% to 6.8%) were diagnosed with intra-abdominal injuries, including 204 with injuries to more than 1 organ. Specific organ injuries included the spleen 299 (39%), liver 282 (37%), kidney 147 (19%), gastrointestinal tract 115 (15%), adrenal gland 89 (12%), pancreas 51 (7%), intra-abdominal vascular structure 16 (2%), urinary bladder 18 (2%), ureter 4 (0.5%), and gallbladder 4 (0.5%), and a traumatic fascial defect was identified in 4 patients (0.5%). Intraperitoneal fluid

Table 1. Baseline characteristics of study population.

Characteristic	IAI Undergoing Intervention (n=203)	No IAI Undergoing Intervention (n=11,841)	Total (n=12,044)
Age (SD), y	9.9 (5.3)	10.3 (5.4)	10.3 (5.4)
Age <2 y (%)	10 (5)	1,157 (10)	1,167 (10)
Sex (% male)	125 (62)	7,259 (61)	7,384 (61)
Ethnicity (%)			
Hispanic	18 (9)	1,273 (11)	1,291 (11)
Non-Hispanic	119 (59)	7,537 (64)	7,656 (64)
Unknown	66 (33)	3,031 (26)	3,097 (26)
Race (%)			
American Indian or Alaska Native	0	85 (1)	85 (1)
Asian	4 (2)	218 (2)	222 (2)
Black	45 (22)	3,699 (31)	3,744 (31)
Native Hawaiian or other Pacific Islander	0	38 (0)	38 (0)
White	123 (61)	6,366 (54)	6,489 (54)
Unknown	30 (15)	976 (8)	1,006 (8)
Other	1 (0)	459 (4)	460 (4)
Mechanism of injury (%)			
Motor vehicle crash	91 (45)	3,739 (32)	3,830 (32)
Fall from an elevation	11 (5)	1,612 (14)	1,623 (13)
Fall down stairs	4 (2)	277 (2)	281 (2)
Pedestrian or bicyclist struck by moving vehicle	34 (17)	2,238 (19)	2,272 (19)
Bicycle collision or fall from bicycle while riding	19 (9)	739 (6)	758 (6)
Motorcycle/ATV/ motorized scooter collision	9 (4)	593 (5)	602 (5)
Object struck abdomen	10 (5)	783 (7)	793 (7)
Other	18 (9)	1,673 (14)	1,691 (14)
Unknown	7 (3)	187 (2)	194 (2)
High-risk mechanism of injury (%)	72 (35)	2,646 (22)	2,718 (23)

IAI, Intra-abdominal injury; *ATV*, all-terrain vehicle.

(hemoperitoneum) was identified in 568 patients (75%; 95% CI 71.4% to 77.7%) with intra-abdominal injuries.

The primary outcome of interest (intra-abdominal injury undergoing acute intervention) was identified in 203 of the patients (26.7%; 95% CI 23.6% to 30.0%) with intra-abdominal injuries, including 103 who had more than 1 of these defining events. Events defining the outcomes in these 203 patients included death as a result of the intra-abdominal injury 9 (4.4%), therapeutic laparotomy 114 (56.6%), angiographic embolization of a bleeding abdominal organ 11 (5.4%), blood transfusion for abdominal hemorrhage 122 (60.1%), and administration of intravenous fluids for greater than or equal to 2 nights for patients with pancreatic or gastrointestinal injuries 79 (38.9%). Information about missing data for the enrolled patients is presented in Table E1 (available online at http://www.annemergmed.com). Bivariable associations between the clinical variables collected and both intra-abdominal injury and intra-abdominal injury undergoing acute intervention are presented in Tables E2 and E3 (available online at http://www.annemergmed.com).

Sixteen of the 6,053 patients (0.3%; 95% CI 0.1% to 0.4 %) initially discharged from the ED were subsequently identified with an intra-abdominal injury, including 2 (0.03%; 95% CI 0% to 0.12%) with intra-abdominal injury in need of acute intervention (gastrointestinal tract and spleen injuries). One of these 2 patients with intra-abdominal injury undergoing acute intervention (laparotomy for gastrointestinal tract injury) had an abdominal CT during the initial ED visit, and it was interpreted as normal. Abdominal CT scans were obtained from the ED for 191 of 203 patients (94%; 95% CI 90% to 97%) with intra-abdominal injury undergoing acute intervention. Eleven of the 12 patients who did not undergo abdominal CT scanning in the ED received laparotomy without imaging. One patient with intra-abdominal injury undergoing acute intervention was discharged from the ED without imaging but returned 1 day later and received a diagnosis of a splenic laceration and underwent splenic artery embolization. Abdominal CT scans were obtained in the ED for 542 of 558 patients (97%; 95% CI 95% to 98%) with intra-abdominal injury never undergoing acute intervention and 4,647 of 11,283 patients (41%; 95% CI 40% to 42%) without any intra-abdominal injury. Thus, test characteristics of actual abdominal CT ordering for intra-abdominal injury undergoing acute intervention were sensitivity 191 of 192 (99%; 95% CI 97% to 100%) and specificity 6,652 of 11,841 (56%; 95% CI 55% to 57%).

The derived prediction rule consisted of the following 7 variables, in descending order of importance (Figure 4): evidence of abdominal wall trauma or seat belt sign, GCS score less than 14, abdominal tenderness, evidence of thoracic wall trauma, complaints of abdominal pain, decreased breath sounds, and vomiting. All 7 variables in the derived rule had substantial interrater agreement, with κ values all greater than 0.6 and lower bounds of the 95% CI above 0.4.[26,27]

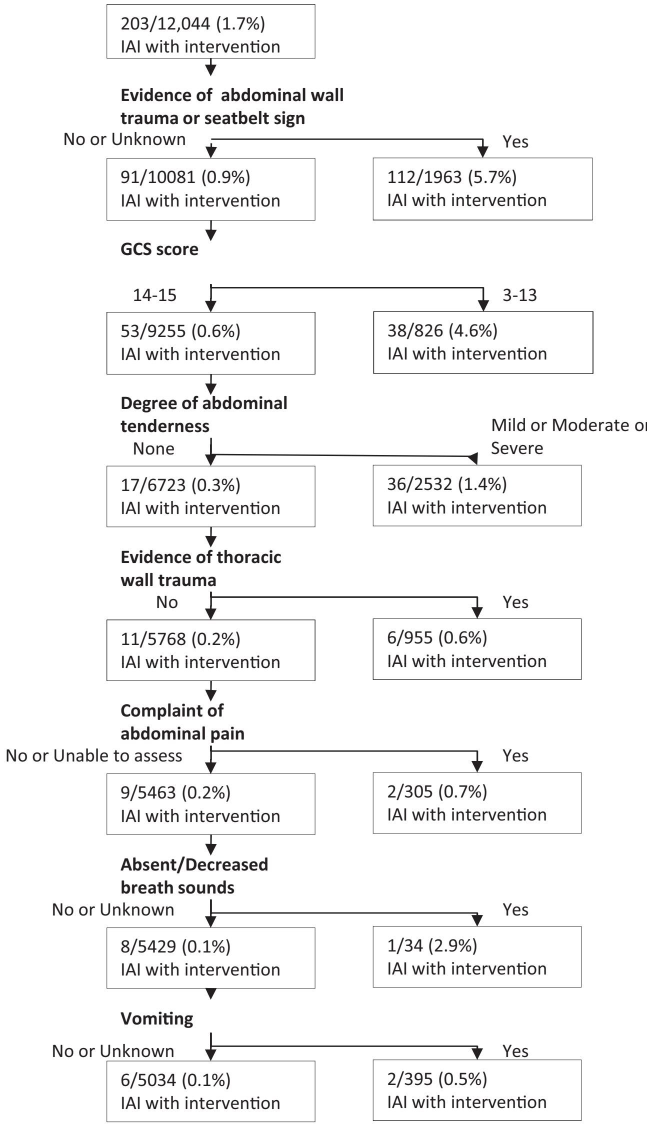
The test characteristics (sensitivity, specificity, positive and negative predictive values, and positive and negative likelihood ratios) of the prediction rule are demonstrated in Figure 4. Five thousand thirty-four patients (42%) were at very low risk for intra-abdominal injury undergoing acute intervention as identified by the absence of any prediction rule variables, and 1,254 of these patients (25%) nevertheless underwent abdominal CT scanning during their ED evaluation. This represents 23% of all the CTs performed on the study patients. If all patients positive for 1 or more of the prediction rule variables underwent abdominal CT and patients negative for the prediction rule did not, a total of 7,010 patients (58%) would undergo abdominal CT scanning. This type of strict application would result in a substantial increase in abdominal CT scanning. However, the intent of the rule is to identify patients at very low risk of important injuries who do not need CT imaging and is not meant to suggest that all patients with 1 or more variables undergo CT imaging.

Figure 5 provides the risk of intra-abdominal injury undergoing acute intervention, stratified by specific rule criteria. Table 2 details the number of patients with intra-abdominal injury undergoing acute intervention stratified by the number of variables present. The frequency of intra-abdominal injury undergoing acute intervention increases as the number of rule variables increases. Clinical characteristics of the 6 patients with intra-abdominal injury undergoing acute intervention who were considered very low risk (no rule variables present) by the prediction rule are presented in Table 3. Five of the 6 patients with intra-abdominal injury undergoing acute intervention who were categorized as very low risk by the prediction rule had laboratory abnormalities (hematuria or elevated liver transaminase levels) suggestive of the presence of intra-abdominal injury, and all 6 had hemoperitoneum.

Although the rule was derived to identify patients at low risk for intra-abdominal injury undergoing acute intervention, we also assessed the performance of the rule for identifying children with any intra-abdominal injury (undergoing intervention or not), which yielded the following test characteristics: sensitivity 704 of 761 (92.5%; 95% CI 90.4% to 94.3%), specificity 4,977 of 11,283 (44.1%; 95% CI 43.2% to 45.0%), positive predictive value 704 of 7,010 (10.0%; 95% CI 9.3% to 10.8%), and negative predictive value 4,977 of 5,034 (98.9%; 95% CI 98.5% to 99.1%).

LIMITATIONS

This study has some limitations. We did not include laboratory testing or abdominal ultrasonography (focused assessment sonography for trauma [FAST]) as possible predictor variables because of variability in the use of these tests among centers and our inability to establish uniformity around laboratory and FAST use in all participating sites for purposes of this study. Previous studies, however, suggest that laboratory testing and the FAST examination may play an important role in risk stratifying children with blunt torso trauma for intra-abdominal injury.[10,15-18] In fact, 5 of the 6 patients with intra-



	IAI with intervention	No IAI with intervention	Total
Any Predictors present	197	6813	7010
No Predictors present	6	5028	5034
Total	203	11841	

	Percent (95% CI)
Prediction rule sensitivity	97.0% (93.7, 98.9)
Prediction rule specificity	42.5% (41.6, 43.4)
Negative predictive value	99.9% (99.7, 1.00)
Positive predictive value	2.8% (2.4, 3.2)
Negative likelihood ratio	0.07 (0.03, 0.15)

Figure 4. Prediction tree for children with IAI undergoing acute intervention. The final box identifies the very-low-risk population.

abdominal injury undergoing acute intervention who were categorized as low risk by the current prediction rule had laboratory abnormalities that would suggest the possibility of an intra-abdominal injury and likely would not be missed in practice. Furthermore, laboratory resources and particularly FAST expertise are not immediately available to all clinicians evaluating injured children, and therefore creating a prediction rule with these variables would not be universally applicable. As such, the prediction rule is based totally on history and physical examination variables and is thus widely generalizable, which is one of its strengths. All children with intra-abdominal injury undergoing acute intervention missed by the decision rule, however, had hemoperitoneum, highlighting the potential utility of the FAST examination, and all also had distracting painful injuries, alcohol intoxication, hematuria, or elevated liver enzyme levels (Table 3), suggesting that the "miss rate" would actually be much lower in practice. Screening those children who are negative for the rule but whom the clinician

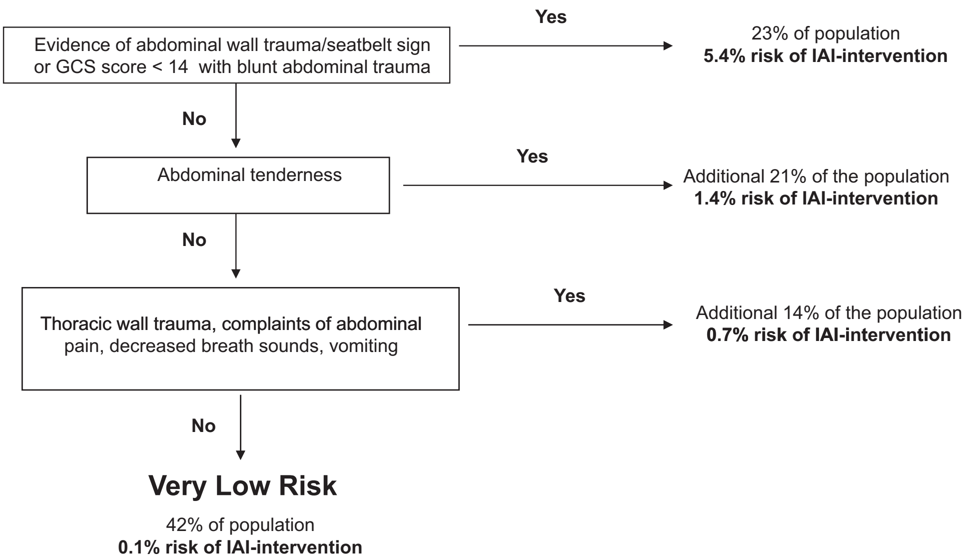


Figure 5. Clinical risk stratification of children with blunt torso trauma.

Table 2. Risk of IAI undergoing acute intervention according to the number of prediction rule variables present.

Number of Variables Present	Patients (%)	IAI Acute Intervention	% (95% CI)
0	5,040 (41.9)	6	0.1 (0.04–0.3)
1	2,679 (22.2)	37	1.4 (1.0–1.9)
2	2,576 (21.4)	47	1.8 (1.3–2.4)
3	1,280 (10.6)	57	4.5 (3.4–5.7)
4 or more	469 (3.9)	56	11.9 (9.2–15.2)

nevertheless considers at risk for intra-abdominal injury with the FAST or laboratory testing would further limit missed injuries. It is likely that a prediction rule with better test characteristics could be derived if laboratory screening or the FAST examination were included.[16,17,28,29]

We could not mandate uniform CT use in this study for ethical reasons. As a result, some minor, clinically silent intra-abdominal injuries may have been missed. However, because we had a clinical, patient-oriented outcome (intra-abdominal injury undergoing acute intervention), missed minor intra-abdominal injuries did not affect our primary endpoint. The importance of these "missed" intra-abdominal injuries is unclear, and many clinicians would be willing to miss minor intra-abdominal injuries that do not require specific therapy. In fact, a particular strength of the study was that we derived the prediction rule with a patient-oriented outcome (intra-abdominal injury undergoing acute intervention) and not a disease-oriented outcome (any intra-abdominal injury regardless of need for intervention). Using the patient-oriented outcome minimizes bias occurring with false-positive abdominal CT scan results.

Finally, the prediction rule was derived in highly specialized trauma referral centers with pediatric trauma expertise and designation, and by general and pediatric emergency physicians accustomed to pediatric trauma patients. It is likely that the prediction rule would be of greater use in centers with less pediatric trauma experience.

DISCUSSION

We derived a clinical prediction rule that risk stratifies children for intra-abdominal injury undergoing acute intervention after blunt torso trauma. Those children without any of the historical or physical examination findings in the prediction rule are at very low risk (6/5,028, or 0.1%) for intra-abdominal injury undergoing acute intervention, and therefore abdominal CT is generally not warranted for them. Twenty-three percent of the abdominal CT scans performed were obtained in the very-low-risk patients. This suggests that there is substantial potential for reducing unnecessary abdominal CT scanning in children after blunt torso trauma because the purpose of the current prediction rule was to identify low-risk children in whom CT could generally be obviated. For children not at low risk, the rule is meant to be assistive for the clinician by providing evidence to aid clinical decisionmaking. The rule is not intended to suggest that all those who screen positive for 1 or more rule variables must undergo abdominal CT scanning. Such a practice would increase the rate of abdominal CT scanning and is not recommended. Ultimately, the rule helps match the risk of radiation with the risk of intra-abdominal injury in that CT scan use should be minimized in patients who are at very low risk by the prediction rule.

Previous research suggests that risk stratifying children with blunt abdominal trauma is possible.[10,15-18] These studies, however, are limited by small sample sizes, being performed at single centers, or retrospective designs. In addition, they use a combination of patient history, physical examination variables, and laboratory screening tests. In the current study, we relied solely on clinical variables available during initial ED evaluation

Table 3. Characteristics of the children with IAI undergoing acute intervention not identified by the prediction rule.

Age, Years	Mechanism	Additional Clinical Findings	Abdominal Injury	Therapy Provided
2	Pedestrian/bicyclist struck by vehicle traveling 5–20 mph	Gross hematuria	Kidney, hemoperitoneum	Blood transfusion
2	Fell down ≤5 stairs (nonaccidental trauma)	Distracting painful injury, AST=255, ALT=368	Liver, gastrointestinal, hemoperitoneum	Intravenous fluids ≥2 nights
16	Motorcycle/ATV/motorized scooter collision	Distracting painful injury (femur fracture), required nonabdominal surgery, hematuria (5 RBC/hpf)	Spleen, gastrointestinal, hemoperitoneum	Angiographic embolization, blood transfusion, intravenous fluids ≥2 nights
17	Rollover MVC, patient wearing seat belt	Alcohol intoxication, hematuria (RBCs too numerous to count/hpf)	Spleen, hemoperitoneum	Angiographic embolization
17	MVC	Distracting painful injury (rib fracture), required nonabdominal surgery, hematuria (10 RBC/hpf)	Spleen, kidney, hemoperitoneum	Angiographic embolization
17	Ejected in a MVC	Alcohol intoxication, thoracic tenderness, required nonabdominal surgery	Spleen, hemoperitoneum	Angiographic embolization

ALT, Alanine aminotransferase; *AST,* aspartate aminotransferase; *hpf,* high-powered field; *MVC,* motor vehicle crash; *mph,* miles per hour.

and did not include laboratory or radiography results. Patient history and physical examination variables in the prediction rule are available to all clinicians evaluating injured children, regardless of location and resources, which enhances the generalizability of the results and the applicability to numerous clinical settings.

Clinicians identified almost all children with intra-abdominal injury undergoing acute intervention because only 1 patient was discharged home and returned with a missed intra-abdominal injury undergoing acute intervention. The remaining patients were all identified during ED evaluation or at laparotomy. Clinicians, however, frequently obtained abdominal CT scan for children at low risks of intra-abdominal injury undergoing acute intervention, exposing children with very low risk of important injuries to unnecessary radiation risk. Those children who have none of the variables in the prediction rule are at very low risk for intra-abdominal injury undergoing acute intervention and therefore abdominal CT is generally unwarranted. In the cohort of children with no variables in the prediction rule, the risk of intra-abdominal injury undergoing acute intervention was just 0.1%, which is less than the risk of radiation-induced malignancy from a single, current-generation abdominal CT scan.[12-14] However, because the risk for intra-abdominal injury undergoing acute intervention is not zero in the low-risk group, clinicians should carefully consider which of these children may benefit from screening laboratory tests or FAST evaluation and provide all patients being discharged from the ED with proper instructions about indications to return for medical care. Patients admitted for other injuries should also be carefully assessed for intra-abdominal injury to avoid complications associated with missed or delayed diagnosis of intra-abdominal injury.

Furthermore, the data provide the evidence for further risk stratification of those children who may have 1 or more variables in the prediction rule. However, patients who screen positive for the clinical prediction rule do not necessarily require abdominal CT scanning. Management of these children, and specifically decisionmaking around CT use, can be based on the specific risks of intra-abdominal injury identified in this large study, as well as on clinician judgment and risk tolerance and guardian preference. That is, the rule is meant to be assistive rather than directive in the management of these patients. This can lead to more appropriate, evidence-based, patient-centered ED evaluations and resource use. Depending on the number and type of variables present, clinician and patient or parent preferences, and other factors, these patients may be observed without CT, further risk stratified with laboratory screening tests or the FAST examination, or undergo abdominal CT. We believe that prediction rules aid and empower clinicians by providing evidence with regard to risk but must be used in conjunction with sound clinical judgment to provide optimal care (ie, prediction rules are not meant to be blindly followed, but rather are assistive decision tools).

Both Figure 5 and Table 2 provide levels of risk for combinations of criteria. As is apparent, risk of intra-abdominal injury undergoing acute intervention increases as the number of variables increases. Patients with blunt abdominal trauma and decreased mental status or physical findings of abdominal wall trauma (abdominal ecchymosis, abrasion, seat belt sign, etc) are at highest risk of intra-abdominal injury, according to the rule. Further abdominal evaluation for these patients is indicated and abdominal CT is warranted in many. However, children with GCS scores greater than or equal to 14 and without evidence of abdominal wall trauma but with evidence of other variables in the prediction rule are at lower risk and ED evaluation should be appropriately modified. Within this cohort, patients with abdominal tenderness (especially moderate to severe) are at highest risk, and additional evaluation (with laboratory tests or the FAST examination) is warranted, along with consideration of abdominal CT. In the remaining patients with lower-risk variables in the prediction rule present, the risk of intra-abdominal injury undergoing acute intervention is less than 1%. In this group of patients, clinicians should individualize evaluation strategies, which may include laboratory screening tests, the FAST examination, or a period of observation.

Screening strategies in low-risk patients depends on many issues, including but not limited to available local resources, physician comfort with caring for children with trauma, follow-up availability, clinician and patient or guardian preferences about tradeoffs between risk of missing injuries and radiation risk, and clinician and parent or guardian willingness to tolerate missing some intra-abdominal injuries that do not require any acute intervention. Certain laboratory tests that can be useful to further risk stratify patients include the hematocrit, urinalysis for hematuria, and liver transaminases.[10,15-18] The FAST examination serves as a screening test to risk stratify patients for intra-abdominal injury and had a negative likelihood ratio of 0.2 in a large meta-analysis of children with blunt abdominal trauma.[30] Such a negative likelihood ratio suggests that a normal FAST examination in patients with a pre-FAST risk for intra-abdominal injury of approximately 1% may indicate such a low risk for intra-abdominal injury that CT is unlikely to be necessary.[30] Some clinicians may wish to use a strategy of observation (instead of abdominal CT) for patients who have 1 or more variables in the rule but nevertheless remain at low risk. A period of ED observation has been shown to decrease cranial CT use in children with minor blunt head trauma without increasing the risk of missing injuries,[31] although it is unclear whether this can be generalized to abdominal CT in the setting of blunt abdominal trauma.

In summary, a prediction rule consisting of 7 patient history and physical examination variables and without laboratory or ultrasonographic information identifies a population of children with blunt torso trauma at very low risk for intra-abdominal injury undergoing acute intervention. These findings require external validation before implementation.

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APPENDIX

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Table E1. Splitting variables used by the CART software and the number of times the variable of interest was missing.

Node	Surrogate	Missing (%)
Abdominal trauma/seat belt sign	Abdominal trauma or seat belt sign	376 (3.1)
GCS 14–15	None	4 (0.03)
Abdominal tenderness degree	Abdominal tenderness, abdominal pain, costal tenderness, left costal tenderness	205 (1.4)
Thoracic trauma	None	76 (0.6)
Abdomen pain	None	148 (1.2)
Decreased breath sounds	None	199 (1.7)
Vomit/retch	None	84 (0.7)

Table E2. Significant associations on bivariable analysis of variables for the presence of any IAI (regardless for the need of intervention).

	Any IAI (n=761)*	No IAI (n=11,283)*	Difference, %
Complaint of abdominal pain	468/752, 62.2 (58.7 to 65.7)	3,152/11,144, 28.3 (27.4 to 29.1)	33.9 (30.4 to 37.5)
Evidence of seat belt sign or abdominal wall trauma	294/731, 40.2 (36.6 to 43.9)	1,669/10,937, 15.3 (14.6 to 15.9)	25.0 (21.3 to 28.6)
GCS 3–13	149/761, 19.6 (16.8 to 22.6)	846/11,279, 7.5 (7.0 to 8.0)	12.1 (9.2 to 14.9)
Degree of abdominal tenderness			
No abdominal tenderness	270/752, 35.9 (32.5 to 39.4)	8,001/11,087, 72.2 (71.3 to 73.0)	−36.3 (−39.8 to −32.7)
Mild	88/752, 11.7 (9.5 to 14.2)	1,525/11,087, 13.8 (13.1 to 14.4)	−2.1 (−4.4 to 0.3)
Moderate	250/752, 33.2 (29.9 to 36.7)	1,286/11,087, 11.6 (11.0 to 12.2)	21.6 (18.2 to 25.1)
Severe	144/752, 19.1 (16.4 to 22.1)	275/11,087, 2.5 (2.2 to 2.8)	16.7 (13.8 to 19.5)
Evidence of thoracic trauma	246/758, 32.5 (29.1 to 35.9)	1,796/11,210, 16.0 (15.3 to 16.7)	16.4 (13.0 to 19.8)
Absent/decreased breath sounds	62/749, 8.3 (6.4 to 10.5)	194/11,096, 1.7 (1.5 to 2.0)	6.5 (4.5 to 8.5)
Vomiting/retching	129/752, 17.2 (14.5 to 20.0)	1,024/11,208, 9.1 (8.6 to 9.7)	8.0 (5.3 to 10.8)
Age <2 y	40/761, 5.3 (3.8 to 7.1)	1,127/11,283, 10.0 (9.4 to 10.6)	−4.7 (−6.4 to −3.1)
High-risk mechanism of injury	231/747, 30.9 (27.6 to 34.4)	2,487/11,090, 22.4 (21.7 to 23.2)	8.5 (5.1 to 11.9)
Low initial systolic blood pressure (age adjusted)	40/755, 5.3 (3.8 to 7.1)	167/11,027, 1.5 (1.3 to 1.8)	3.8 (2.2 to 5.4)
Thoracic tenderness	184/746, 24.7 (21.6 to 27.9)	1,738/11,046, 15.7 (15.1 to 16.4)	8.9 (5.8 to 12.1)
Left or right costal tenderness	206/742, 27.8 (24.6 to 31.1)	1,159/11,041, 10.5 (9.9 to 11.1)	17.3 (14.0 to 20.5)
Abdominal distention	85/750, 11.3 (9.2 to 13.8)	192/11,001, 1.7 (1.5 to 2.0)	9.6 (7.3 to 11.9)
Distracting painful injury	200/755, 26.5 (23.4 to 29.8)	2,605/11,206, 23.2 (22.5 to 24.0)	3.2 (0 to 6.5)
Femur fracture	53/757, 7.0 (5.3 to 9.1)	509/11,031, 4.6 (4.2 to 5.0)	2.4 (0.5 to 4.2)

*Data are presented as n/N, percentage (95% CI).

Table E3. Significant associations on bivariable analysis of variables for IAI undergoing acute intervention.

	IAI Undergoing Intervention (n=203)*	No IAI Undergoing Intervention (n=11,841)*	Difference, %
Complaint of abdominal pain	105/201, 52 (45 to 59)	3,515/11,695, 30 (29 to 31)	22 (15 to 29)
Evidence of seat belt sign or abdominal wall trauma	112/195, 57 (50 to 64)	1,851/11,473, 16 (15 to 17)	41 (34 to 48)
GCS 3–13	67/203, 33 (27 to 40)	928/11,837, 8 (7 to 8)	25 (19 to 32)
Degree of abdominal tenderness			
No abdominal tenderness	87/200, 44 (37 to 51)	8,184/11,639, 70 (69 to 71)	−27 (−34 to −20)
Mild	12/200, 6 (3 to 10)	1,601/11,639, 14 (13 to 14)	−8 (−11 to −4)
Moderate	42/200, 21 (16 to 27)	1,494/11,639, 13 (12 to 13)	8 (2 to 14)
Severe	59/200, 30 (23 to 36)	360/11,639, 3 (3 to 3)	26 (20 to 33)
Evidence of thoracic trauma	66/201, 33 (26 to 40)	1,976/11,767, 17 (16 to 17)	16 (10 to 23)
Absent/decreased breath sounds	25/200, 13 (8 to 18)	231/11,645, 2 (2 to 2)	11 (6 to 15)
Vomiting/retching	49/198, 25 (19 to 31)	1,104/11,762, 9 (9 to 10)	15 (9 to 21)
Age <2 y	10/203, 5 (2 to 9)	1,157/11,841, 10 (9 to 10)	−5 (−8 to −2)
High-risk mechanism of injury	72/196, 37 (30 to 44)	2,646/11,641, 23 (22 to 24)	14 (7 to 21)
Low initial systolic blood pressure (age adjusted)	24/200, 12 (8 to 17)	183/11,582, 2 (1 to 2)	10 (6 to 15)
Thoracic tenderness	36/198, 18 (13 to 24)	1,886/11,594, 16 (16 to 17)	2 (−3 to 7)
Left or right costal tenderness	41/199, 21 (15 to 27)	1,324/11,584, 11 (11 to 12)	9 (4 to 15)
Abdominal distention	49/201, 24 (19 to 31)	228/11,550, 2 (2 to 2)	22 (16 to 28)
Distracting painful injury	61/200, 31 (24 to 37)	2,744/11,761, 23 (23 to 24)	7 (1 to 14)
Femur fracture	17/201, 8 (5 to 13)	545/11,587, 5 (4 to 5)	4 (−0 to 8)

*Data are presented as n/N, percentage (95% CI).