Validation of a Prediction Rule for the Identification of Children With Intra-abdominal Injuries After Blunt Torso Trauma

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Study objective: We validate the accuracy of a previously derived clinical prediction rule for the identification of children with intra-abdominal injuries after blunt torso trauma.

Methods: We conducted a prospective observational study of children with blunt torso trauma who were evaluated for intra-abdominal injury with abdominal computed tomography (CT), diagnostic laparoscopy, or laparotomy at a Level I trauma center during a 3-year period to validate a previously derived prediction rule. The emergency physician providing care documented history and physical examination findings on a standardized data collection form before knowledge of the results of diagnostic imaging. The clinical prediction rule being evaluated included 6 "high-risk" variables, the presence of any of which indicated that the child was not at low risk for intra-abdominal injury: low age-adjusted systolic blood pressure, abdominal tenderness, femur fracture, increased liver enzyme levels (serum aspartate aminotransferase concentration >200 U/L or serum alanine aminotransferase concentration >125 U/L), microscopic hematuria (urinalysis >5 RBCs/high powered field), or an initial hematocrit level less than 30%.

Results: One thousand three hundred twenty-four children with blunt torso trauma were enrolled, and 1,119 (85%) patients had the variables in the decision rule documented by the emergency physician and therefore made up the study sample. The prediction rule had the following test characteristics: sensitivity=149 of 157, 94.9% (95% confidence interval [CI] 90.2% to 97.7%) and specificity=357 of 962, 37.1% (95% CI 34.0 to 40.3%). Three hundred sixty-five patients tested negative for the rule; thus, strict application would have resulted in a 33% reduction in abdominal CT scanning. Of the 8 patients with intra-abdominal injury not identified by the prediction rule, 1 underwent a laparotomy. This patient had a serosal tear and a mesenteric hematoma at laparotomy, neither of which required specific surgical intervention.

Conclusion: A clinical prediction rule consisting of 6 variables, easily available to clinicians in the ED, identifies most but not all children with intra-abdominal injury. Application of the prediction rule to this sample would have reduced the number of unnecessary abdominal CT scans performed but would have failed to identify 1 child undergoing (a nontherapeutic) laparotomy. Thus, further refinement of this prediction rule in a large, multicenter cohort is necessary before widespread implementation. [Ann Emerg Med. 2009;54:528-533.]

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INTRODUCTION

Trauma is a leading cause of morbidity and mortality in children older than 1 year, and abdominal trauma is the third leading cause of death.[1] The identification of intra-abdominal injuries in children who have sustained blunt trauma, however, may be difficult. Abdominal computed tomography (CT) scanning is the reference standard diagnostic test for detecting intra-abdominal injury in children.[2-4] Because of certain risks inherent with abdominal CT scanning (especially radiation-induced malignancy),[5,6] abdominal CT is best used selectively, and only when truly indicated. Although studies have identified high-risk variables associated with the presence of intra-abdominal injury in children who have sustained blunt trauma,[7-11] definitive indications for abdominal CT scanning in injured children remain unclear.

Our group previously demonstrated that a prediction rule that uses simple physical examination findings in combination with readily available laboratory measurements is highly

Editor's Capsule Summary

What is already known on this topic

Though decision rules to guide the performance of computed tomography (CT), laparoscopy, or laparotomy in children with abdominal trauma exist, their performance has not been rigorously evaluated.

What question this study addressed

Are previously created decision rules for evaluation of children with suspected intra-abdominal injury sufficiently accurate for clinical use?

What this study adds to our knowledge

One thousand one hundred nineteen children with blunt torso trauma were evaluated. The decision rules had a sensitivity of 94.9% and specificity of 37.1%. Application of these rules would have reduced abdominal CT use by 33%.

How this might change clinical practice

A decision rule for pediatric abdominal trauma, based on 6 easily obtained variables, is useful in identifying children who require abdominal CT. Additional study of this rule in a larger cohort is necessary before its widespread implementation.

accurate for identifying children at very low and high risk for intra-abdominal injury and therefore is assistive with the decision for abdominal CT scanning after blunt trauma.[9] The derived clinical prediction rule identified those children at very low risk for intra-abdominal injury, as well as those at substantial risk for intra-abdominal injury. The prediction rule consists of the following 6 "high-risk" variables: low age-adjusted systolic blood pressure; abdominal tenderness; femur fracture; aspartate aminotransferase level greater than 200 U/L and alanine aminotransferase level greater than 125 U/L; hematuria level greater than 5 RBCs/high powered field; and an initial hematocrit level less than 30%.[9] In the derivation study, those children without any of these 6 variables were at very low risk of intra-abdominal injury and therefore unlikely to benefit from abdominal CT scanning. Although the clinical prediction rule was internally validated in the derivation study, it has not been externally validated in a separate sample.

The objective of this study was to externally validate the accuracy of this previously derived clinical prediction rule to identify children at very low and high risk for intra-abdominal injuries after blunt torso trauma. We hypothesize that the previously derived prediction rule can identify a sample of injured children in whom abdominal CT imaging for blunt torso injury is of very low utility.

MATERIALS AND METHODS

We conducted a prospective observational cohort study at an urban Level I trauma center. The study was approved by the institutional review board.

Selection of Participants

We enrolled children younger than 18 years who had blunt torso trauma and underwent a definitive diagnostic test to evaluate for the presence of an intra-abdominal injury. For study purposes, a definitive diagnostic test was considered any one of the following: abdominal CT scan, diagnostic peritoneal lavage, diagnostic laparoscopy, or laparotomy. We excluded all patients with penetrating trauma, patients who were pregnant, patients who presented more than 24 hours after their traumatic injury, and patients who did not undergo a definitive diagnostic test because of such low clinical suspicion of intra-abdominal injury.

Data Collection and Processing

Patient historical and physical examination findings were recorded on a standardized data collection form by the treating emergency physician (resident or faculty physician) before knowledge of the results of the diagnostic test. The historical and physical examination findings documented included the 3 physical examination findings from the previously derived prediction rule (systolic blood pressure, abdominal tenderness, and femur fracture). In addition, we collected the results of all laboratory tests, including the 3 laboratory variables in the prediction rule (aspartate aminotransferase and alanine aminotransferase, initial hematocrit, and microscopic hematuria levels). A convenience sample of patients had an additional data collection form (κ form) completed to measure interrater reliability.

Outcome Measures

All abdominal CT scans were interpreted by a board-certified or board-prepared faculty radiologist. The primary outcomes were the presence of intra-abdominal injury and intra-abdominal injury in need of acute specific intervention. Intra-abdominal injury was defined as an injury to any of the following abdominal structures, detected by definitive diagnostic testing: spleen, liver, gallbladder, pancreas, adrenal gland, kidney, ureter, urinary bladder, gastrointestinal tract, or an intra-abdominal vascular structure. Any patient with an intra-abdominal injury was considered to require acute specific intervention for the intra-abdominal injury if he or she underwent any of the following: blood transfusion for anemia as a result of intra-abdominal hemorrhage, angiographic embolization of an injured vascular structure or organ, or a therapeutic intervention at laparotomy.

Primary Data Analysis

Data are described with simple descriptive statistics, including the sensitivity and specificity of the previously derived

Table 1. Characteristics of the 8 patients not identified by the clinical prediction rule.

Age, y	Mechanism	Injury	Physical Examination Findings/Other Injuries	Therapy for Their Intra-abdominal Injury
3	Auto vs Ped	Spleen	Thoracic tenderness; pulmonary contusion	2-day hospital observation
4	MVC	Spleen	Developed abdominal tenderness in ED	6-day hospital observation
8	Auto vs Ped	Spleen	GCS score=12	2-day hospital observation
10	MVC	GI	Abdominal seatbelt sign	Nontherapeutic laparotomy
10	MVC	Spleen	Costal margin tenderness; pneumothorax	16-day hospital observation
14	Skiing accident	Liver/kidney	Rib fx; L1, L2, L4; transverse process fx	7-day hospital observation
14	Auto vs Ped	Kidney	Costal margin tenderness; elbow fx	3-day hospital observation
16	Auto vs Ped.	Spleen	GCS score=9	7-day hospital observation

Ped, Pedestrian; *MVC,* motor vehicle collision; *GCS,* Glasgow Coma Scale; *GI,* gastrointestinal; *fx,* fracture; *L,* lumbar.

prediction rule. We calculated relative risk ratios for intra-abdominal injury for each evaluated predictive variable. Ninety-five percent confidence intervals (CIs) are provided when appropriate. For assessment of the accuracy of the clinical prediction rule, we included only those patients who either had all variables documented as normal ("negative prediction rule") or had at least 1 variable documented as abnormal ("positive prediction rule"). Thus, we excluded those patients who had any of the prediction rule variables missing, assuming they had no high-risk variable documented as abnormal (indeterminate for the prediction rule). Interrater reliability was measured with the κ statistic.

We calculated the study sample size needed to validate the clinical prediction rule according to a requirement of 100 patients with the outcome of interest (any intra-abdominal injury present), which is supported by statistical estimates described previously for external validation of clinical prediction rules.[12] In accordance with our previous work,[9] we estimated the enrolled sample would have a prevalence rate of intra-abdominal injury of 10%, and thus the total needed sample size was calculated at 1,000 patients. Data analysis was performed with Stata statistical software (release 8.0; StataCorp, College Station, TX).

RESULTS

We enrolled 1,324 children with blunt torso trauma. Of these, 1,119 (85%) had the necessary variables in the prediction rule documented for purposes of assessment and made up the validation study sample. These patients had a mean age of 9.7±5.3 years. Of the 1,119 enrolled patients, 157 (14.0%; 95% CI 12.0% to 16.2%) had identified intra-abdominal injuries. The mechanisms of injury for the 1,119 patients were as follows: motor vehicle crashes in 486 (43%), auto versus pedestrian in 222 (20%), falls in 151 (13%), auto versus bicycle in 77 (7%), motorcycle/motocross crashes in 47 (4%), assaults in 38 (3%), falls off bicycle in 24 (2%), crush injury 11 (1%), and other in 63 (6%).

A total of 754 patients tested positive for the clinical prediction rule (ie, positive for any of the 6 components of the rule), including 149 (19.8%; 95% CI 17.0% to 22.8%) with intra-abdominal injury. Three hundred sixty-five patients tested negative for the rule, including 8 (2.2%; 95% CI 1.0% to 4.3%) with intra-abdominal injury. The clinical prediction rule had the following other test characteristics: sensitivity=149 of 157, 94.9% (95% CI 90.2% to 97.8%) and specificity=357 of 962, 37.1% (95% CI 34.0% to 40.3%). Table 1 describes the clinical characteristics of the 8 patients not identified by the clinical prediction rule. One of the 8 patients not identified by the decision rule underwent a diagnostic laparotomy. This patient had a serosal tear and a mesenteric hematoma but did not require therapy during laparotomy. Therefore, this patient did not have the outcome of intra-abdominal injury needing acute intervention, according to our a priori definitions. The relative risk ratios for intra-abdominal injury for the variables in the prediction rule and other selected variables are presented in Table 2. All of the variables in the prediction rule except femur fracture were strongly associated with the presence of intra-abdominal injury. If the clinical decision rule was strictly applied to the study sample such that abdominal CT scans were not performed if the patient had a negative result for the rule, 365 (32.6%; 95% CI 29.9% to 35.5%) of the abdominal CT scans would have been avoided.

A κ form was completed by a second physician on 153 patients. The interrater reliability for abdominal tenderness was κ=0.63 (95% CI 0.50 to 0.76).

Of the 1,324 enrolled children, 205 (15%) patients were excluded from analysis for lack of complete documentation of the prediction rule variables. The mean age of excluded patients (10.2±6.0 years) was similar to that of included patients (9.7±5.3 years). The prevalence of intra-abdominal injury in those patients excluded from analysis (5/205; 2.4%; 95% CI 0.8% to 5.6%) was lower than that of patients included for analysis (157/1,119; 14%; 95% CI 12% to 16.2%). Most (n=177) of the 205 patients were excluded from the analysis

Table 2. Association of intra-abdominal injury with the 6 variables in the clinical prediction rule, in addition to other selected variables (in the entire enrolled study sample [n=1,324]).

	IAI Present, No. (%)	IAI Absent, No. (%)	Relative Risk (95% CI)
Variables in the clinical prediction rule			
Hypotension	13/162 (8.0)	13/1,162 (1.1)	4.4 (2.9–6.6)
Abdominal tenderness	95/160 (59)	426/1,133 (38)	2.2 (1.6–2.9)
Femur fracture	9/162 (6)	84/1,162 (7)	0.78 (0.41–1.5)
Urinalysis >5 RBCs/hpf	68/157 (43)	131/1,138 (12)	4.2 (3.2–5.6)
Initial hematocrit level <30%	14/162 (9)	33/1,160 (3)	2.6 (1.6–4.1)
Increased liver enzyme levels	47/115 (41)	34/782 (4)	7.0 (5.2–9.3)
Additional variables not included in the initial clinical prediction rule			
Left costal margin injury	30/158 (11)	120/1,126 (19)	1.8 (1.2–2.5)
Right costal margin injury	22/156 (14)	91/1,122 (8)	1.7 (1.1–2.5)
GCS score <14	50/162 (26)	142/1,162 (9)	2.6 (2.0–3.5)
Seatbelt sign	25/162 (15)	62/1,162 (5)	2.6 (1.8–3.7)
Pelvic fracture	18/162 (11)	54/1,162 (5)	2.2 (1.4–3.3)

IAI, Intra-abdominal injury.

because of missing aspartate aminotransferase or alanine aminotransferase levels.

LIMITATIONS

This study has certain limitations. Not all patients enrolled were included in the analysis because they lacked one of the 6 variables in the prediction rule. Most variables were specific laboratory measurements (especially aspartate aminotransferase or alanine aminotransferase levels). In many of these instances, the decision to obtain an abdominal CT scan was made before obtaining laboratory testing, and thus "screening" laboratory testing to determine the need for abdominal CT scanning was not performed. In addition, we included only patients who received a reference standard test for intra-abdominal injury (abdominal CT scan, diagnostic peritoneal lavage, diagnostic laparoscopy, or laparotomy) in the study; patients with blunt torso trauma who were simply observed and did not undergo any diagnostic testing were not included. Because these patients are likely at substantially lower risk of intra-abdominal injury than studied patients, inclusion of these patients would be unlikely to add to the study. Because the primary goal of this study was to validate a rule to identify those children who do not require abdominal CT scanning, the exclusion of these patients likely has minimal effect on this aspect of the study.

We did not collect information on Foley catheterization and the possibility of its causing hematuria. However, the degree of hematuria attributable to Foley catheterization is less than 4 RBCs/hpf.[13] Thus, patients were unlikely to screen positive for the rule solely according to Foley catheter–induced hematuria. We defined intra-abdominal injury in need of acute intervention as a cohort of patients who, because of their requirement for intervention, must be identified by any decision rule. We also provided the outcome of any intra-abdominal injury identified (regardless of the severity). We did not create a third outcome that would separate tiny, inconsequential injuries requiring no therapy (eg, grade 1 renal injury) from more significant injuries (eg, grade III splenic injury) that also required no therapy. In addition, to be inclusive, we included patients with all Glasgow Coma Scale (GCS) scores in this study, although decreased mental status was not identified as a significant variable in the prediction rule. Nevertheless, it has been demonstrated previously that patients with GCS scores less than 14 have unreliable abdominal evaluation results.[14] In fact, 2 of the 8 patients with intra-abdominal injuries not identified by the rule had GCS scores less than 14. Finally, because this prediction rule was developed and validated at only 1 institution, the generalizability of our findings to other centers is unknown and therefore the rule merits a multicenter validation study.

DISCUSSION

Before implementation of a prediction rule into clinical practice, the rule must be prospectively validated in a population separate from the one in which it was derived.[15,16] The current study validates the performance of a previously derived clinical prediction rule for identifying children at very low and high risk for intra-abdominal injury after blunt torso trauma by using a separate sample of children undergoing a reference standard diagnostic test. In this sample, the clinical prediction rule demonstrated good sensitivity, and one third of abdominal CT scans could be obviated if the rule were strictly applied.

The primary goal of developing a clinical prediction rule for this population is to assist clinicians in their evaluation and treatment of children with blunt torso trauma. The prediction rule identifies those children who are at very low risk of having intra-abdominal injury (negative results for the prediction rule). In these children who have negative results for the rule, abdominal CT scan may be avoided because the child is unlikely to have an intra-abdominal injury and very unlikely to require specific acute therapeutic intervention if an intra-abdominal injury is present. In the current study, no patient who had negative results for the prediction rule required specific acute intervention for their "missed" intra-abdominal injury. In addition, the clinical prediction rule may rapidly identify those children at substantial risk for intra-abdominal injury (ie, those who test positive for the rule). Identification of children who are at more than negligible risk for intra-abdominal injury allows the clinician to identify those children needing further evaluation for intra-abdominal injury (eg, abdominal CT scan, abdominal ultrasonography, close observation, hospitalization), according to the specific risk of the patient and resources available.

Previous studies of children with blunt torso trauma have attempted to identify variables predictive of intra-abdominal injury.[7,9-11,17] Three of these studies[7,11,17] using multivariate analytic techniques to predict which children have intra-abdominal injuries have found similar results to the prediction rule presented here and suggest that laboratory screening is highly useful.[9] One study, however, suggested that an abnormal abdominal examination and the presence of microscopic hematuria (>5 RBCs/high powered field) were sufficient to screen for intra-abdominal injury in children.[10] That study by Isaacman et al,[10] however, was limited by its retrospective nature and the fact that 85% of children with known intra-abdominal injury were transferred to the study center, potentially leading to bias in the documentation of abdominal examination findings. Our current study did not include patients who were transferred to the study site and had known intra-abdominal injuries.

Despite the prediction rule's excellent sensitivity, it did not identify all patients with intra-abdominal injury. Seven of the 8 patients with intra-abdominal injury not identified by the rule, however, simply required observation for their intra-abdominal injuries. One patient underwent exploratory laparotomy because of the surgeon's concern of possible gastrointestinal injury, which was confirmed at laparotomy. However, no therapeutic intervention for the identified injuries (colonic serosal tear and mesenteric hematoma) was performed, and therefore this patient did not definitively meet our a priori criterion of intra-abdominal injury requiring therapeutic intervention. Nevertheless, many clinicians may be hesitant to use a clinical prediction rule that fails to identify a child who underwent a laparotomy even if no specific intervention was required during laparotomy. Furthermore, some physicians may be somewhat reluctant to apply a prediction rule with a sensitivity of 95% for radiographically diagnosed intra-abdominal injury (regardless of need for specific therapy). However, closer inspection of the patients with intra-abdominal injury who were not identified by the prediction rule (Table 1) suggests that these patients had additional injuries or clinical variables that placed them at increased risk for intra-abdominal injury (although these variables were not identified as important in the derivation of the rule). The patient undergoing exploratory laparotomy did not have abdominal tenderness documented at the initial examination but had a "seatbelt sign" and developed abdominal tenderness during observation, prompting the exploratory laparotomy. The presence of a seatbelt sign is known to significantly increase the risk of intra-abdominal injury.[18,19] An additional patient "missed" by the rule developed abdominal tenderness during emergency department (ED) observation and was found to have a splenic injury. These patients suggest that observation plays an important role in the evaluation and assessment of some children with blunt torso trauma.

Three other patients "missed" by the rule had tenderness or trauma over the costal margins and were found to have either splenic or hepatic injuries. Previous evidence (primarily in adult patients) indicates that costal margin trauma or tenderness is an important predictor of both splenic and hepatic injuries.[20,21] Furthermore, the single patient with a hepatic injury missed by the rule had increased liver transaminase levels but not above the rule's predefined threshold for enzyme increase. Finally, 2 patients missed by the rule had decreased mental status (GCS=9 and 12). Although the derived prediction rule did not explicitly identify a specific GCS cutoff as an indication for abdominal CT scanning, the authors (ie, our group) of this prediction rule previously suggested this as a potential limitation to this rule.[9] Furthermore, previous work performed by our group suggests that patients with a GCS score less than 14 after blunt trauma have unreliable abdominal examinations and should likely be evaluated with both head and abdominal CT.[14]

These findings suggest that further refinement of this clinical prediction rule is necessary before widespread implementation, similar to that needed for other prediction rules that have also required refinement during their validation phases.[22-25] In the current patient sample, femur fracture had the weakest association with the presence of intra-abdominal injury, and it was documented as the sole positive variable in the rule in only 1 patient with intra-abdominal injury. Furthermore, it was the least important variable in the original decision rule.[9] Future refinement should better determine the importance of isolated femur fracture in the prediction of intra-abdominal injury, as well as the importance of other possible variables (costal margin injury and GCS score) not included in the current prediction rule. Refinement of the rule must be conducted in a multicenter environment with a large sample size such that definitive risk assessments for combinations of certain variables with narrow CIs and wide generalizability may be achieved.

In summary, a clinical prediction rule consisting of 6 variables, easily available to clinicians in the ED, identifies most but not all children with intra-abdominal injury. Application of the prediction rule to this sample would have substantially reduced the number of unnecessary abdominal CT scans performed but would have failed to identify some children with intra-abdominal injuries, including 1 child undergoing laparotomy. Thus, further refinement of this prediction rule in a large, multicenter cohort is necessary before widespread implementation.

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