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Evaluation for intra-abdominal injury in children following blunt torso trauma. Can we reduce unnecessary abdominal CT by utilizing a clinical prediction model?

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Background

Injury is the leading cause of morbidity and mortality in children over one year of age and accounts for over 60% of childhood deaths [1–3]. Up to 90% of these injuries are as a result of blunt trauma [1]. Evaluation of the acutely injured pediatric patient is challenging and is often limited by factors which include alteration in mental status and difficulty communicating with young children [4]. CT is readily available and highly sensitive and has, therefore, become the procedure of choice in the evaluation of injured children [5–6]. Although abdominal CT is considered the best imaging test for diagnosing intra-abdominal injury (IAI), fewer than 15% of pediatric patients sustaining blunt trauma are found to have IAI on CT scan, and most of these injuries are managed non-operatively [7]. Limitations of CT

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include time, cost, need of personnel for transport, and potential need for sedation. An additional concern is the potential risk of malignancy secondary to exposure to ionizing radiation from CT [8–10]. Children are thought to be at greatest risk for radiation-induced malignancy because of their relatively small size per radiation dose and increased life expectancy relative to adults [3]. The dramatic increase in the number of CT scans performed nationally coupled with increased awareness of the risks of radiation exposure has led to active efforts to reduce the utilization of CT scans in the work-up of patients following blunt abdominal trauma. Recent retrospective studies have evaluated multiple factors in an effort to generate prediction rules for IAI that could be applied to limit the use of CT scans in patients who have suffered blunt abdominal trauma, are hemodynamically stable, have normal mental status, and have a reliable physical examination [4, 11–13].

The objective of this study was to measure the utility of a clinical prediction rule to identify IAI in a retrospective cohort of patients. We believe that utilization of a prediction rule, based on six previously defined “high risk” clinical factors, including hypotension, abnormal abdominal examination, elevated AST, elevated amylase, low hematocrit, and hematuria would have identified patients most at risk for IAI. Furthermore, we sought to evaluate additional clinical variables commonly cited as indications for CT scan, which might be used to refine the prediction rule prior to future prospective evaluation.

Methods

In 2009, a multidisciplinary group at the Medical University of South Carolina reviewed the available literature and created a clinical prediction tool to identify those patients at low risk of IAI from blunt abdominal trauma to reduce reliance on CT scan. The prediction rule included hypotension for age, abnormal abdominal exam, AST > 200 U/L, hematuria (>5 rbc/hpf), hematocrit <30%, and amylase > 100 U/L (Table 1). The presence of any one of these six variables was considered predictive of IAI.

In order to validate this prediction rule, a retrospective chart review of all “trauma alert” patients less than 16 years of age during an 18 month period (January 2007 through July 2008) was conducted following approval from the institutional review board. Data collected included aspects of the physical exam, vital signs, laboratory evaluation, and imaging results. Abnormal values for vital signs were determined by the patients age and included systolic blood pressure (abnormal < 70+2(age) for 0–10 years old and < 90 for 11–16 years old) and heart rate (abnormal > 180 for 0–1 year old, > 150 for 1–3 years old, > 135 for 4–8 years old, and > 110 for 9–16 years old). Abdominal exam was considered abnormal if physician documentation described distension, tenderness to palpation, peritonitis, or seatbelt or handlebar contusion. Laboratory data reviewed included aspartate aminotransferase (AST), amylase, hematocrit (HCT), and urinalysis (UA). Plain radiographs reviewed included chest x-ray (CXR), pelvis x-ray (PXR), and femur x-rays. CXR findings considered abnormal included pneumothorax, hemothorax, rib fracture, scapular fracture, pulmonary contusion, and clavicle fracture. Any fracture identified on PXR or femur x-ray was considered an abnormal finding. Potential barriers to abdominal exam such as young age (less than 2 years) and altered mental status (GCS less than 9) were also considered. CT scan images were reviewed, and findings were grouped into one of four categories (normal, trace free fluid, pelvic fracture, or evidence of solid/hollow organ injury).

IAI was considered present only if a solid or hollow organ (spleen, liver, pancreas, diaphragm, kidney/urinary tract or gastrointestinal tract) injury was identified by CT or at time of operative abdominal exploration. Sensitivity, specificity, positive, and negative predictive values of the prediction rule were calculated. For each of the six factors that made up the prediction rule and the six additional clinical factors that were thought to be potential predictors of IAI, sensitivity and specificity for each variable were individually determined along with 95% confidence intervals. Logistic regression models were then used to determine whether an abnormal value on a test was related to the presence of IAI. The odds ratios (and 95% confidence intervals) for having an IAI were calculated from the logistic regression models, comparing the odds of an IAI with an abnormal test to the odds of an IAI with a normal test. All clinical factors with p-values less than 0.15 from univariate models were included in a multivariable, logistic regression model to determine which factors were most highly related to having an IAI.

Results

A total of 136 pediatric trauma alert patients were identified during the study period. Of these, 125 patients had blunt mechanisms of injury. The other eleven patients with penetrating mechanism or burn were excluded. The mean age of included patients was 8.51 +/− 4.97 (SD) years. The mean length of hospital stay was 5.8 days, mean injury severity score was 13.6 +/− 10 (SD) and mortality rate was 4.8%. The mechanisms of injury for the 125 patients were as follows: motor vehicle collision in 66 (52.8%), pedestrian struck by auto in 15 (12%), all-terrain vehicle crash in 14 (11.2%), fall from height in 14 (11.2%), fall from bicycle in 7 (5.6%) and other in 5 (4%). Ninety-seven of the 125 patients underwent abdominal/pelvic CT scans. Fifteen of the 97 (15.5%) scanned patients were found to have an IAI. Two additional patients went directly to the operating room (OR) secondary to hemodynamic instability and high clinical suspicion for IAI; their injuries were identified intra-operatively. Therefore, a total of 17 patients had IAI demonstrated radiographically or operatively. In these patients, the following intra-abdominal injuries were identified: Liver (9), Small bowel (4), Spleen (3), Renal (3), Abdominal wall (2), Colon (1), and Diaphragm (1). Five patients had multiple intra-abdominal injuries.

Forty-two patients had an abnormality in at least one of the six “high-risk” variables, thus testing positive for our clinical prediction rule. Of these, 13 had abnormalities in two or more of the variables. The patients with IAI and their clinical prediction rule abnormalities are described in Table 2. Our clinical prediction rule would have identified 16 of the 17 patients with IAI correctly (Se=94.1%). The patient not predicted by the rule sustained a grade I splenic laceration which did not require surgical intervention and caused no major sequelae. The negative predictive value of our rule was 98.8%. Of the 83 patients identified as low-risk for IAI, 54 underwent a negative abdominal/pelvis CT (8 others demonstrated pelvic fractures with no associated IAI and 20 were not CT-scanned). Twenty-two of these 54 patients had a potential limitation to a reliable abdominal exam (GCS<9 (n=19), GCS>8 but age <2 (n=3)). Therefore, our review identified 32 patients who would be identified as “low-risk” by our prediction rule who were evaluated with CT scan of the abdomen/pelvis (33% of scanned patients). Of the 108 patients who had no intra-abdominal injury, 102 were admitted, most commonly for traumatic brain or orthopedic injuries. Of these, only 9 were admitted for overnight serial abdominal examinations, all of whom had a negative abdominal CT scan performed prior to admission. Our trauma registry and process improvement system did not identify any delayed or missed injuries in those who were not scanned (n=28).

After evaluating our clinical prediction rule as described, we sought to describe the relative importance of each of the studied clinical variables in independently predicting IAI. This was done in an effort to gain information which might help refine our clinical prediction model in the future. This analysis included an evaluation of our six “high-risk” variables (from the prediction rule) and six additional clinical variables (age, heart rate, mental status, plain radiograph findings) which might commonly prompt a trauma CT evaluation. The frequency of abnormal findings for these twelve variables in patients with and without IAI is demonstrated in Table 3.

The clinical variables that were independently associated with IAI were elevated AST, low HCT, abnormal abdominal exam, and abnormal CXR. Not all patients had full data, so percentages were calculated out of the available data. Eleven of 16 patients with IAI (68.8%) had an elevated AST whereas only 4 of 89 patients without IAI (4.5%) had an abnormal AST ($p<0.01$). Five of the 17 patients with IAI (29.4%) had a decreased HCT whereas only 8 of 104 patients without IAI (7.7%) had a decreased HCT ($p<0.02$). Thirteen of the 17 patients with IAI (76.5%) had a documented abnormal abdominal exam whereas only 12 of the 108 patients without IAI (11.1%) had an abnormal abdominal exam ($p<0.01$). Ten of the 17 patients with IAI (58.8%) had an abnormality on CXR whereas 24 of 98 patients without IAI (25%) had an abnormal CXR ($p<0.01$). All other variables including amylase, urinalysis, systolic blood pressure, heart rate, pelvic x-ray, femur x-ray, age and GCS were not statistically significant in predicting the presence of an intra-abdominal injury. The number of patients in whom amylase (n=23) and urinalysis (m=22) were measured during the study period was low because these were not routinely followed in our institution prior to the implementation of our clinical prediction rule. Of the 23 patients with amylase measured, only one was abnormal. Of the 22 patients with urinalysis data, four were abnormal, but there was not enough data to obtain stable odds ratios from the logistic regression models.

The sensitivity and specificity of each clinical variable for detection of IAI is demonstrated in Table 4. The most sensitive variables (given that a child has an IAI, the probability that the test is abnormal) included elevated AST Se=0.69 (95% CI=0.46, 0.91); abnormal abdominal exam Se=0.76 (95% CI=0.56, 0.97); and abnormal CXR Se=0.59 (95% CI=0.35, 0.82). Of note, the specificity for all 12 variables ranged from 0.74 to 0.98. All of the "high risk" clinical variables (except amylase which had inadequate numbers to evaluate) had a specificity of 0.85 or greater.

Odds ratios (and 95% CIs) for each of the 12 variables of interest in predicting IAI are demonstrated in Table 5. Of the 12 variables of interest, only AST, hematocrit, abdominal exam, and CXR were related to IAI at the alpha=0.15 level of significance. The odds of having an IAI were 46.8 times higher for patients with an elevated AST than for those having a normal AST ($p < 0.01$). The odds of having an IAI was 5.0 times higher for those patients with decreased HCT compared to those with normal HCT ($p = 0.01$). The odds of having an IAI was 26.0 times higher for patients with an abnormal abdominal exam compared to those with a normal abdominal exam ($p < 0.01$), and the odds of an IAI was 4.29 times higher for patients with an abnormality noted on CXR compared to those with no abnormality ($p < 0.01$). All other factors (amylase, urinalysis, systolic blood pressure, heart rate, PXR, femur x-ray, age, and GCS) were not related to having an IAI.

In the larger, multivariable model that included AST, HCT, abdominal exam, and CXR, only AST and abdominal exam remained statistically significant when attempting to predict IAI. Both of these factors were significantly related to IAI, although the confidence intervals are very large indicating the point estimate may not be exact.

Discussion

In the Pediatric Emergency Department, a significant proportion of radiation exposure occurs from CT scans performed for the evaluation or blunt abdominal trauma [7–8]. Radiation exposure and malignancy risk are related to the age and size of the patient. The average child in our institution receives 10–20 mSv per CT scan with an estimated 1–3 per 1,000 lifetime risk for radiation-induced malignancy[3]. Due to increased awareness of the risks of childhood irradiation, there have been several recent studies looking at alternative strategies to evaluate hemodynamically stable trauma victims based on clinical evaluation and laboratory analysis with only selective imaging [1,7,14]. Holmes et al. developed an algorithm for predicting IAI in children based on six variables: systolic blood pressure, abdominal examination, urinalysis, liver function tests, hematocrit, and the presence of a femur fracture [1]. In this study, the use of one variable as a trigger for CT scan would lead to a scan in 55% of patients with a negative result in 46% of the studies. Validation of their prediction rule based on abnormal values any of these six variables was conducted in a prospective observational fashion over a three year period ending in 2008 [11]. Their prediction rule demonstrated 95% sensitivity and 37% specificity for IAI. Strict application of their prediction rule would have resulted in a 33% reduction in abdominal CT scans in patients at low risk for IAI. Cotton et al. reported a retrospective study assessing the utility of 23 clinical variables potentially associated with IAI in children. In a cohort of 351 patients, 25% underwent CT scan to determine the presence of IAI, and 42 patients (12%) had an identifiable IAI identified. Cotton identified a number of factors that predicted IAI: abdominal ecchymosis (OR of 16), abdominal abrasions (OR of 17), tender abdomen (OR of 41), increase ALT, and decreased HCT. In all recursive partitioning models, elevation in ALT/AST was identified as the most important variable predicting IAI. They advocate for a clinical prediction rule that combines physical exam with risk stratification based on elevated hepatic transaminases.

We created a clinical prediction rule based on our review of the literature that was used to identify those patients that had suffered a blunt abdominal trauma but were at low risk for IAI. We attempted to retrospectively fit the model and refine the prediction tool by reviewing 18 months of pediatric trauma activation patients. We determined that 78% of our patients with blunt abdominal trauma received a CT scan, and that if our prediction rule had been used prospectively, it would have correctly identified 16 of 17 with IAI (sensitivity of 94.1%) and would have missed only one, non-operative injury (negative prediction value of 98.8%).

In this study, four variables were identified as significant individual predictors of intra-abdominal injury: elevated AST, decreased hematocrit, abnormal abdominal exam, and abnormal chest x-ray. Three of these variables were components of our clinical prediction rule. Elevated AST (>200) was seen in 68.8% of patients with IAI and potentially represents a liver injury or ischemia and should increase suspicion for serious IAI [4, 15–19]. A low HCT (<30) was seen in 29.4% of patients with identified IAI and may reflect significant hemorrhage and/or fluid resuscitation requirements [19–20]. Abnormal abdominal exam was seen in 76.5% of patients with IAI and should prompt further evaluation [14, 21–22]. The sensitivity of abdominal examination may be limited in patients with young age, distracting injuries or decreased levels of consciousness [4–5, 23]. A fourth variable which seemed useful in our population was abnormal CXR which was seen in 58.8% of patients with IAI. An abnormality on CXR, particularly a rib, clavicle, or scapular fracture likely represents a high severity of blunt force to the torso as the bony skeleton in children is more compliant. This degree of force coupled with the relative lack of coverage of internal organs by the skeleton (relatively larger liver, more intra-abdominal than pelvic bladder) significantly increases the likelihood of underlying IAI [24–26].

There are a number of limitations to this study. During the study period, there was no uniform approach to the evaluation of blunt abdominal trauma, so the use of laboratory evaluation and imaging was highly variable and reliant on the clinical discretion of the attending physicians. In addition, some laboratory or exam data was not obtainable due to the retrospective nature of the project. Specifically, amylase (18.4%) and urinalysis (17.6%)

were measured for relatively few of the trauma alert patients during the study period. Renal and pancreatic injuries were seen rarely in our study population; therefore, insufficient data was available to fully evaluate the benefit of urinalysis or serum amylase in predicting IAI in patients with these specific injuries. Furthermore, some patients were not CT scanned so the possibility of missing minor intra-abdominal injuries with little clinical significance exists. It is unlikely, however, that any significant injuries were missed because we have an extensive trauma registry and peer review process. As with many studies in the pediatric population, the number of patients in the study was relatively small, and the number of identified injuries was low. A larger study that included more patients with intra-abdominal injuries would be helpful to elucidate the relative value of these factors in a prediction model. This might also allow development of a more sophisticated scoring system with differential relative variable weighting.

"Low risk" patients with no other major injuries and no limitation to reliable physical exam can be safely discharged home in most cases. A potential limitation to an approach that reduces abdominal CT utilization could be a collateral increase in cost from admission and use of other hospital resources. In practice, the majority of pediatric patients which are evaluated as "pediatric trauma alerts" require admission at our institution. Of the 108 patients who had no intra-abdominal injury, 102 were admitted. Of these, only 9 were admitted for overnight serial abdominal examinations. Interestingly, all nine had negative CT scans prior to admission. The vast majority of admissions were related to other injuries, most commonly traumatic brain and orthopedic injuries. Social and transportation issues which are not infrequent in our institution must be taken into account as well. Unfortunately, we continue to see many children that are injured either intentionally or from neglect and these patients often require admission even in the absence of significant physical injury. The high rate of pediatric trauma alert patients requiring admission for non-abdominal injuries and social issues further supports a strategy of selective abdominal CT utilization as there is often ample opportunity for serial abdominal examinations at no additional cost to the patient who is admitted for other organ system injuries. The hospital charge and interpretation fee for abdominal pelvic CT at our institution is $6558, so avoidance of unnecessary CT scan, performed in at least 33% of our trauma alert population in this study, could represent a significant amount of savings to the health care system.

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Another potential limitation to a strategy of selective CT utilization based on a prediction model which includes laboratory values is a delay in imaging while waiting on lab results. Of the 16 patients with IAI which were predicted by the model, only three tested positive from abnormal clinical laboratory variables alone, and all were managed non-operatively (see Table 2). Due to the retrospective nature of our study, we were unable to measure any delay in imaging or return trips to the CT scanner which may have occurred. This will certainly warrant monitoring as the model is tested prospectively. Fortunately, hypotension for age was infrequently seen (2.4%) and operative intervention for abdominal injury was rarely required (3.2%) in our pediatric trauma alert patients. In hemodynamically stable patients with no "high risk" clinical variables from our model and a reliable physical examination, a decision to CT scan can safely wait until the screening labs and plain films are obtained.

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An exponential increase in CT scan utilization has been seen in the past decade. Factors which have contributed to this increase include improved speed and quality of imaging, high rates of pathology detection, ready availability, and potential fear of litigation related to missed injuries. In addition to the diagnostic information obtained, in many pediatric surgical practices, management of solid organ injury is based upon the degree of injury seen on CT as defined in the AAST solid organ grading systems. Knowledge of the risk factors which are associated with IAI helps to guide the selective use of CT scanning for detection

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of intra-abdominal injuries. The sensitivity and specificity of individual diagnostic studies is also improved by using selective criteria to determine which patients should be imaged. Furthermore, selective imaging is an important consideration for time and resource management as well as cost containment. An essential component of this is the identification of clinical factors that, when normal, are correlated with an absence of IAI. In this fashion, if a patient lacks abnormality in these tests, the clinician can safely avoid a CT scan and thus avoid unnecessary radiation exposure. Further, the high rate of pediatric trauma alert patients requiring admission for non-abdominal injuries and social issues further supports a strategy of selective abdominal CT utilization as there is often ample opportunity for serial abdominal examination at no additional cost to the patient or health care system. In this study, we retrospectively demonstrate that utilization of a clinical prediction model based on six “high-risk” variables for IAI in patients with no limitation to abdominal examination may decrease cost and radiation exposure from potentially avoidable abdominal CT scans in children without missing significant injuries.

Based on the findings, we have generated a clinical practice guideline utilizing a prediction rule to avoid unnecessary abdominal CT in our institution and are currently evaluating the rule prospectively (Table 6).

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Table 1

"High-risk" clinical variables for intra-abdominal injury used in the clinical prediction rule.

Hypotension (for age)
Abnormal abdominal exam (distension, tenderness, peritonitis, or contusion)
AST > 200 U/L
Microhematuria (>5 rbc/hpf)
HCT < 30%
Amylase >100 U/L

Table 2

Clinical prediction model score in patients with intra-abdominal injury

Score	Abnormal Variables	Injuries	CT?	OR?
0	None	Spleen	Yes	No
1	AST	Liver	Yes	No
1	AST	Liver	Yes	No
1	Exam	Spleen	Yes	No
1	Exam	Small Bowel	Yes	Yes
1	Exam	Small Bowel, Abdominal Wall	Yes	Yes
2	AST, amylase	Liver, Kidney	Yes	No
2	Exam, Hct	Liver	Yes	No
2	AST, Exam	Liver	Yes	No
2	AST, Exam	Liver	Yes	No
2	AST, Exam	Spleen	Yes	No
2	Exam, Hct	Liver	Yes	No
2	AST, Exam	Diaphragm, Abdominal Wall	No	Yes
3	AST, Hct, Exam	Kidney	Yes	No
3	AST, Hct, Exam	Liver	Yes	No
3	AST, UA, Exam	Liver	Yes	No
4	AST, Hct, BP, Exam	Small Bowel, Colon	No	Yes

Table 3

Frequencies of abnormal tests between those with IAI and those with no IAI

Abnormal values	no IAI (n=108) N	no IAI (n=108) %	IAI (n=17) N	IAI (n=17) %	Fisher's exact p-value
AST	4	4.5	11	68.8	<0.01
Amylase	0	0	1	20	0.2
HCT	8	7.7	5	29.4	0.02
UA	3	15	1	50	0.3
SBP	2	1.9	1	6	0.4
Abd exam	12	11.1	13	76.5	<0.01
HR	28	26.2	5	29.4	0.8
CXR	24	25	10	58.8	<0.01
Pelvic Fx	7	6.5	0	0	0.6
Femur Fx	11	10.2	2	11.8	0.7
Age	11	10.2	1	5.9	>0.9
GCS	27	25.7	2	11.8	0.4

Table 4

Sensitivity and Specificity of each variable for detection of IAI

Abnormal values	Sensitivity	L 95% CI	U 95%CI	Specificity	L 95% CI	U 95%CI
AST	0.69	0.46	0.91	0.96	0.91	1
Amylase	0.2	0	0.55	-	-	-
HCT	0.29	0.08	0.51	0.92	0.87	0.97
UA	0.5	0	1	0.85	0.69	1
SBP	0.06	0	0.17	0.98	0.96	1
Abd exam	0.76	0.56	0.97	0.89	0.83	0.95
HR	0.29	0.08	0.51	0.74	0.66	0.84
CXR	0.59	0.35	0.82	0.75	0.66	0.84
Pelvic Fx	0	-	-	0.94	0.89	0.98
Femur Fx	0.12	0	0.27	0.9	0.84	0.96
Age	0.06	0	0.17	0.9	0.84	0.96
GCS	0.12	0	0.27	0.74	0.66	0.83

Table 5

Univariate results from logistic regression models for prediction of IAI

Abnormal values	OR	Lower 95 % CI	Upper 95% CI	p-value
AST	46.75	10.89	200.72	<0.01
Amylase	-	-	-	-
HCT	5.00	1.41	17.77	0.01
UA	5.67	0.27	117.45	0.3
SBP	3.28	0.28	38.31	0.3
Abd exam	26.00	7.29	92.69	<0.01
HR	1.18	0.38	3.64	0.8
CXR	4.29	1.47	12.50	<0.01
Pelvic Fx	-	-	-	-
Femur Fx	1.18	0.24	5.83	0.8
Age	0.55	0.07	4.57	0.6
GCS	0.39	0.08	1.80	0.2

Table 6

Recommended clinical guidelines to avoid unnecessary abdominal CT utilization in the evaluation for intra-abdominal injury following blunt torso trauma.

Abdominal CT scan is not necessary in the initial evaluation of children with a reliable physical exam (age >2, GCS>8) following blunt torso trauma in the presence of the following clinical findings:
Normal systolic blood pressure for age
Normal abdominal exam
AST < 200 U/L
Hematocrit > 30%
Normal Chest x-ray