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Validation of Rules to Predict Emergent Surgical Intervention in Pediatric Trauma Patients

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Abstract

Background—Trauma centers use guidelines to determine when a trauma surgeon is needed in the emergency department (ED) on patient arrival. A decision rule from Loma Linda University identified patients with penetrating injury and tachycardia as requiring emergent surgical intervention. Our goal was to validate this rule and to compare it to the American College of Surgeons' Major Resuscitation Criteria (MRC).

Study Design—We used data from 1993 through 2010 from two Level 1 trauma centers in Denver, Colorado. Patient demographics, injury severity, times of ED arrival and surgical intervention, and all variables of the Loma Linda Rule and the MRC were obtained. The outcome, emergent intervention (defined as requiring operative intervention by a trauma surgeon within one hour of arrival to the ED or performance of cricothyroidotomy or thoracotomy in the ED) was confirmed using standardized abstraction. Sensitivities, specificities, and 95% confidence intervals (CIs) were calculated.

Results—8,078 patients were included and 47 (0.6%) required emergent intervention. Of the 47 patients, the median age was 11 years (IQR: 7–14), 70% were male, 30% had penetrating mechanisms, and the median ISS was 25 (IQR: 9–41). At the two institutions, the Loma Linda Rule had a sensitivity and specificity of 69% (95% CI: 45%–94%) and 76% (95% CI: 69%–83%), respectively, and the MRC had a sensitivity and specificity of 80% (95% CI: 70%–92%) and 81% (95% CI: 77%–85%), respectively.

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Conclusions—Emergent surgical intervention is rare in the pediatric trauma population. Although precision of predictive accuracies of the Loma Linda Rule and MRC were limited by small numbers of outcomes, neither set of criteria appears to be sufficiently accurate to recommend their routine use.

Keywords

trauma; pediatrics; triage; emergency department; emergency medical services; emergent intervention; validation; clinical prediction instrument

INTRODUCTION

Trauma is the leading cause of death among children greater than one year of age.^{1,2} Pediatric trauma accounts for approximately 10 million emergency department (ED) visits and 300,000 hospitalizations in the United States each year.³ Yet, only approximately 0.4% of all pediatric trauma patients require immediate surgical intervention.^{4,5} Consequently, secondary trauma triage protocols have been developed to help determine which patients might require urgent or emergent operative intervention in order to decrease the burden on surgical staff.⁵

The American College of Surgeons has specified six Major Resuscitation Criteria (MRC) to determine if a trauma surgeon's presence is needed at the bedside when a patient arrives to the ED (Table 1).⁶ However, the MRC were not empirically derived and have not been validated or compared with other criteria for use in a pediatric trauma population.⁷

In 2006, investigators from Loma Linda University derived a clinical decision rule to predict the need for emergent operative or procedural intervention for pediatric trauma patients presenting to the ED.⁵ Their rule included any penetrating mechanism and age-specific tachycardia, as defined by Pediatric Advanced Life Support (PALS), as the only two criteria for which a surgeon should be summoned to the ED in anticipation of requiring emergent intervention. In the original study, the Loma Linda rule was reported to have a sensitivity of 100% and a specificity of 60%.⁵

The goal of this study was to validate the Loma Linda Rule and MRC in a large heterogeneous pediatric trauma population, with the hypothesis that the Loma Linda Rule would be more sensitive for identifying emergent intervention than the MRC.

METHODS

Study Design and Setting

This was a retrospective cohort study performed at Denver Health Medical Center in Denver, Colorado and the Children's Hospital of Colorado in Aurora, Colorado and was approved by the institutional review boards of both institutions. Denver Health Medical Center and the Children's Hospital of Colorado represent the majority of Level 1 pediatric trauma care for the county of Denver and serve as the only two pediatric trauma referral centers for Colorado. Denver Health Medical Center is a 477-bed urban safety-net hospital and the Rocky Mountain Regional Trauma Center.⁸ It has approximately 30,000 annual

pediatric ED visits, of which approximately 150 per year are included in the trauma registry. Among these 150 patients, 13% are classified as major trauma (defined by an Injury Severity Score [ISS] >15). The Children's Hospital of Colorado is an academic pediatric hospital with 318 beds and an approximate annual ED census of 85,000 visits. Approximately 800 per year are included in the trauma registry and, of these 18% are classified as major trauma.

Study Population

All pediatric trauma registry patients (<15 years of age) who presented to Denver Health Medical Center from January 1, 1993 through December 31, 2010 and to Children's Hospital of Colorado from January 1, 2004 through December 31, 2010 were included in this study. Inclusion criteria for the registries are all trauma patients admitted to the hospital, those who remained in the ED for 12 hours, were transferred from another hospital, or died in the ED or hospital. During the study periods, each institution used criteria similar to the MRC to summon a trauma surgeon to the bedside on patient arrival.

Data Collection and Processing

Dedicated trauma registry staff from both institutions are specifically trained in the oversight of each registry. They search the ED patient log daily to identify patients who meet criteria for inclusion in the trauma registry. Subsequently, data from the medical records of such patients are abstracted and entered into an electronic database (TraumaBase, Clinical Data Management, Conifer, CO). For quality assurance, members of the trauma registry staff internally review approximately 20% of the registry records, and the trauma registry committee reviews all discrepancies and makes corrections through a consensus process.

Data included in the trauma registry and extracted for purposes of this study were: demographics (age and sex); trauma mechanism (penetrating or blunt); date and time of presentation to the ED; prehospital and ED vital signs (heart rate [HR], respiratory rate [RR], and systolic blood pressure [SBP]); prehospital and ED Glasgow Coma Scale (GCS) score; prehospital or ED intubation or cricothyroidotomy; Abbreviated Injury Scale (AIS) for head, neck, chest, abdomen, extremities, and skin; ISS; whether the patient was transferred from an outside hospital and whether the patient received blood prior to or during transfer; whether the emergency physician designated the patient as a "Trauma Activation" (the Denver Health designation for requiring an attending trauma surgeon at the patient's bedside on arrival to the ED) or "Trauma Red" (the Children's Hospital designation for requiring an attending trauma surgeon at the patient's bedside on arrival to the ED); and all ED and operating room procedures performed on the patient and their timing relative to when the patient arrived to the ED.

Outcomes

Emergent operative intervention or emergent procedural intervention served as our composite primary outcome. Emergent operative intervention was defined as requiring operative intervention by a trauma (general or pediatric) surgeon within one hour of arrival to the ED, and emergent procedural intervention included performance of cricothyroidotomy or thoracotomy in the ED. Operative or procedural intervention within one hour was chosen

to select the subset of patients most likely to benefit from the early presence of a trauma surgeon and is consistent with the outcome definition used to develop the original Loma Linda Rule.⁵

Secondary outcomes included: emergent operative intervention only, recognizing that emergent procedural intervention is quite rare in the pediatric trauma population and performance of ED thoracotomy is controversial; urgent operative intervention (defined as requiring operative intervention by a trauma surgeon within four hours of arrival to the ED), since use of a one-hour threshold may be considered too stringent and not reflective of the patient's need for emergent operative intervention; and a composite of urgent operative intervention or emergent procedural intervention.

Using data from the trauma registry, we identified all patients who either went to the operating room at any time during their hospitalizations or had cricothyroidotomy or thoracotomy performed in the ED. Two medical student abstractors blinded to the purpose of the study used structured medical record abstraction methodology to confirm (or not) both outcomes for all such patients.⁹ Prior to initiating outcome abstraction, each abstractor was trained using sample datasets until abstraction yielded perfect agreement when compared to a criterion abstraction standard defined by the study team. Abstraction was performed using an electronic closed-response data collection instrument and a standardized workflow for chart abstraction defined *a priori* by the study team.

Data Management and Statistical Analyses

Data were transferred from each trauma registry and outcome data were manually entered into separate electronic spreadsheets (Microsoft Excel, Microsoft Corporation, Redmond, WA). Each was then transferred into native SAS format (dfPower DBMS Copy, DataFlux Corporation, Cary, NC) and analyses performed using SAS Version 9.3 (SAS Institute, Inc., Cary, NC).

Missing values were handled using multiple imputation to minimize bias and preserve power.^{10,11} The validity of multiple imputation for imputing missing out-of-hospital values and trauma data has been previously demonstrated.¹² We used a sequential regression imputation method (IVEware, Survey Methodology Program, Survey Research Center, Institute for Social Research, University of Michigan, MI) to generate 10 multiply-imputed datasets per institution. Both institution-specific imputed datasets were then concatenated, analyses performed, and results combined using Rubin's rules to appropriately account for within- and between-dataset variances.¹³ First available vital signs, whether in the prehospital or ED settings, were retained; vital sign estimates were only imputed when both prehospital and ED values were missing.

Age-specific tachycardia was defined by PALS criteria, although a sensitivity analysis was performed in which tachycardia was separately defined using criteria by Sharieff & Rao.¹⁴ Both sets of criteria differ and the latter set of criteria has been suggested to be more accurate in defining pediatric tachycardia.¹⁴ For purposes of the MRC, age-specific hypotension was defined as $<70 \text{ mmHg} + [(\text{age}) \times 2]$ to represent the 5th percentile for patients <10 years of age and $<90 \text{ mmHg}$ for those ≥ 10 years of age. Prehospital or ED

intubation or cricothyroidotomy were used as a proxy for “respiratory compromise, obstruction, or intubation”. Gunshot wounds to the neck, chest, or abdomen were coded using “gunshot wound” and AIS scores from each region, respectively. Because both institutions use criteria similar to the MRC, patients who met “Trauma Activation” or “Trauma Red” criteria, respectively, but none of the other MRC were classified as having met the “physician discretion” criterion.

Additional sensitivity analyses were performed and included: complete case analyses, analyses where transfers from other facilities were excluded, and analyses restricting the Denver Health dataset to only observations from January 1, 2004 through December 31, 2010 to correspond with the date range from the Children’s Hospital of Colorado, and possibly more current trauma practices. Finally, to improve the predictive accuracy of the Loma Linda Rule, refined rules were planned *a priori* to correspond with previously developed adult rules,¹⁵ and included age-specific hypotension, age-specific tachycardia, and penetrating mechanism to the torso or gunshot wound to the torso (Table 1). We also calculated the positive and negative likelihood ratios for each criterion of the Loma Linda Rule and the MRC to evaluate whether one or more other criteria would logically contribute to the Loma Linda Rule to improve its predictive accuracy beyond inclusion of hypotension.¹⁶ Sensitivities, specificities, and positive and negative likelihood ratios were calculated with their respective 95% confidence intervals (CIs) to evaluate the predictive accuracy of each rule. No sample size calculation was performed prior to initiating this study.

RESULTS

During the cumulative 25-year study period, 8,078 pediatric trauma patients met criteria for inclusion. A description of the study sample is provided in Table 2. Of the 8,078 patients, 47 (0.6%, 95% CI: 0.5%–0.8%) underwent emergent operative or procedural intervention. Of the 47 interventions, 33 (70%) underwent laparotomy with intervention, 14 (30%) underwent ED thoracotomy, and 0 (0%) underwent ED cricothyroidotomy. Additionally, of the 8,078 patients, 577 (7%, 95% CI: 6%–8%) underwent urgent operative intervention. Table 3 shows the proportions of the study sample that met each criterion for the Loma Linda Rule and the MRC as well as proportions of missing data.

Table 4 shows the sensitivities, specificities, and likelihood ratios for the Loma Linda Rule, the MRC, and the two refined Loma Linda Rules relative to the primary outcome, emergent operative or procedural intervention; Table 5 shows their accuracies for emergent operative intervention only; Table 6 shows accuracies for the Loma Linda Rule and MRC relative to urgent operative intervention or emergent procedural intervention; and Table 7 shows their accuracies for urgent operative intervention only. Finally, Table 8 lists the accuracies of each criterion of the Loma Linda Rule and the MRC. Among the criteria, gunshot wound to the torso, transfer from another hospital requiring blood, and respiratory compromise, obstruction, or intubation had positive likelihood ratios >10, whereas hypotension and a GCS score <8 each had positive likelihood ratios >3 but <10.

After restricting the datasets to only those with complete data, sensitivities of the Loma Linda Rules and MRC remained relatively unchanged, whereas their specificities improved (Appendix Table 1, online only). Additionally, the Loma Linda Rule failed to identify 19 (42%) patients who received emergent intervention, whereas the MRC failed to identify 10 (21%) patients who received emergent intervention (Appendix Tables 2 and 3, online only). After restricting the datasets to exclude patients who were transported from other facilities, the sensitivities and specificities of the Loma Linda Rules remained relatively unchanged (Appendix Table 4, online only). After restricting the Denver Health dataset to include only those from January 1, 2004 through December 31, 2010 to correspond with the dates of observations from the Children's Hospital, sensitivities remained relatively unchanged and specificities of the Loma Linda Rules decreased (Appendix Table 5, online only). Replacing the PALS criteria for tachycardia with those by Sharieff & Rao, we found them to have statistically similar sensitivities (Appendix Table 6, online only). Additional rules where GCS score and respiratory compromise were added to hypotension, tachycardia, and penetrating injury to the torso also resulted in sensitivities similar to those for the MRC (Appendix Table 7, online only).

DISCUSSION

The extremely low prevalence of emergent intervention in our large, heterogeneous pediatric trauma population confirms prior low estimates in other regions of the United States;^{5,17} this suggests, in conjunction with relatively poor and variable predictive accuracies of the Loma Linda Rule and the MRC, the need for novel approaches to secondary trauma triage in children. Evaluation of individual components of the two sets of criteria provided us with the opportunity to refine one or both in order to further improve their predictive accuracies; however, this approach did not result in any set of criteria with sufficient predictive accuracy to recommend their routine use.

The American College of Surgeons' Committee on Trauma emphasizes 10% under-triage and 50% over-triage thresholds for secondary trauma triage.⁶ Rationale for this approach stems from attempting to maximize criteria sensitivity (i.e., minimizing under-triage) while maintaining reasonable specificity (i.e., reasonable over-triage). Although nearly all sets of criteria evaluated in this study, including the Loma Linda Rule or the MRC, met the specificity threshold, none met the sensitivity threshold. However, across all analyses, the sensitivity point estimates for the MRC were consistently higher than the sensitivity point estimates for the Loma Linda Rule, although statistical separation was not achieved. These results suggest the MRC may be more sensitive than the Loma Linda Rule, although larger samples will be required to confirm this observation.

Contrasted by prevalence estimates of emergent intervention in adult trauma populations ranging from 3% to 5%,^{5,15,18} during the cumulative 25-year study period, the prevalence of emergent intervention at two large, urban pediatric Level 1 trauma centers was only 0.6%. This difference likely stems from different injury patterns (e.g., lower prevalence of penetrating injuries in pediatric population) and causes of mortality (e.g., head injury as the leading cause of death among pediatric patients). The low prevalence of emergent

intervention in pediatric trauma patients has led some to argue that no rule or set of criteria, other than physician judgment, is feasible for secondary triage.¹⁹

Although application of the Loma Linda Rule would fail to identify emergent operative intervention in only 0.2% of patients, not identifying the small proportion of pediatric patients who require emergent intervention in the ED may not be satisfactory. The Loma Linda Rule failed to identify 19 of 47 patients who underwent emergent intervention over a 25 year period. Of these 19 patients, 11 were hypotensive, and 4 of the hypotensive patients were pulseless in the field or upon presentation to the ED. Additionally, one patient of the 19 false negatives suffered an amputation at the mid-humerus, and two others had absent distal pulses. These cases demonstrate the importance of physician discretion in conjunction with any rule when evaluating pediatric trauma, especially blunt pediatric trauma.

By definition, each of the false negatives from the Loma Linda Rule involved blunt trauma. The performance of laparotomy for pediatric blunt trauma has decreased dramatically over the last two decades.^{20,21} Green *et al.* in 2002 estimated the prevalence of laparotomy for pediatric blunt abdominal trauma at three major pediatric centers and found the combined prevalence to be only 0.3%.⁴ Non-operative management in children is successful in 95% to 97% of splenic injuries, 94% of liver injuries, and 94% of renal injuries.^{20,22} Additionally, Tataria *et al.* in 2007 demonstrated that failed non-operative management or laparotomy occurring greater than three hours after arrival, in pediatric blunt trauma had no impact on mortality, intensive care unit length of stay, or hospital length of stay.²² Considering this coupled with the largely nonoperative approach to pediatric trauma patients, the continued in-hospital medical management may be more important to morbidity and mortality than need for emergent intervention.²³

We recognize the importance of involvement of a trauma surgeon in the resuscitation and decision-making of seriously injured patients, and the added importance of appropriate primary trauma triage (i.e., children being taken to hospitals capable of caring for their injuries). A hallmark of trauma care includes systematic and efficient evaluation and treatment. However, the infrastructure and processes for pediatric trauma is substantially different than for adults – the key may in fact be the experience and wisdom to pursue non-operative resuscitation, rather than emergent operative intervention.²⁴ There is mounting evidence that trauma hospitals with a pediatric commitment have better outcomes than adult trauma centers.²⁵ This is contrasted by the estimated 17.4 million children in the United States in 2009 without access to a pediatric trauma center within 60 minutes, either by ground or air transport.²⁶ We believe that optimal patient care starts with universally-applied, evidence-based standards for secondary trauma triage.²⁷ In the end, the total approach to pediatric trauma care, from presentation to hospital discharge, must also be evaluated to understand how the use of limited resources impact patient outcomes. Additional research will be required to completely understand the clinical and financial implications of using any set of triage criteria, including use of real time specialty consultation or no criteria at all, on institutions and at systems and population levels.

LIMITATIONS

We used a retrospective design and it therefore may be limited by the nature of how data were collected or that they were not specifically collected for research purposes. Several of the variables included in both triage criteria had missing values or may have been misclassified; although we used multiple imputation to estimate missing values, the estimates may not accurately reflect their true values. We performed several sensitivity analyses, including one using complete cases in order to describe any differences between the statistical approaches.

An additional assumption was that each operative intervention occurred within an ideal time frame. It is possible that some interventions that occurred after one hour should have been performed within an hour of arrival. It is also possible that some procedures occurred within an hour because of the availability of resources, and not because the injury actually required emergent intervention. We therefore included additional analyses using a four-hour operative intervention threshold.

Another potential limitation was the impact of transfers on the classification of emergent interventions. Of the patients included in the study, approximately 70% who presented to the Children's Hospital of Colorado and approximately 10% who presented to Denver Health Medical Center were transferred from other facilities. Our study defines emergent intervention strictly based on the time present at the study institutions and did not include time that the patient spent at the prior hospital or during transit. We did, however, perform a sensitivity analysis where the datasets were restricted to only those patients transported from the scene.

Our study included pediatric trauma patients from Denver Health from 1993 through 2010 and from the Children's Hospital of Colorado from 2004 through 2010. We included a shorter timeframe from the latter institution due to concerns over data quality prior to 2004. We, however, conducted a sensitivity analysis in which we restricted data from Denver Health to correspond to the same timeframe from the Children's Hospital. Additionally, this six-year overlap may have resulted in patients being seen initially at Denver Health and subsequently transferred to the Children's Hospital, or vice versa. Consequently, the possibility exists that some patients were counted twice in this study. Moreover, differences in trauma management between physicians and institutions (e.g., whether to manage a spleen laceration operatively within one or by expectant management) may contribute to the lack of generalizability of our results, although an additional sensitivity analysis demonstrated relatively similar results between the two time periods.

Finally, the relatively small number of outcome events resulted in relatively wide precision estimates for sensitivities, which substantially limited our ability to make compare statistically of the different sets of criteria. Additionally, when ED thoracotomy was removed from the composite outcome as part of a sensitivity analysis, the number of events decreased further, thereby further impacting precision estimates. Given the small outcome prevalence, a much larger cohort, likely from multiple institutions, is required to make such comparisons.

CONCLUSIONS

Emergent surgical intervention is rare in the pediatric trauma population. Although precision of predictive accuracies of the Loma Linda Rule and MRC were limited by small numbers of outcomes, neither set of criteria appears to be sufficiently accurate to recommend their routine use.

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Table 1

Individual Criteria Used to Define when a Trauma Surgeon Should Be Present in the Emergency Department when a Pediatric Trauma Patient Arrives

Major resuscitation criteria	
1	Age-specific hypotension *
2	Respiratory compromise, obstruction, or intubation
3	Gunshot wound to the neck, chest, or abdomen
4	GCS score <8 with mechanism attributed to trauma
5	Transfer of patients from other hospitals who receive blood to maintain vital signs
6	Physician discretion
Loma Linda rule	
1	Penetrating injury
2	Age-specific tachycardia †
Refined Loma Linda rule #1	
1	Age-specific hypotension *
2	Age-specific tachycardia †
3	Penetrating injury to torso ‡
Refined Loma Linda rule #2	
1	Age-specific hypotension *
2	Age-specific tachycardia †
3	Gunshot wound to torso ‡

* Age-specific hypotension defined as $(SBP + [2 \times \text{age}]) < 70$ mmHg for those ≤ 10 y of age and $SBP < 90$ mmHg for those > 10 y of age.

† Age-specific tachycardia defined by Pediatric Advanced Life Support.

‡ Defined as penetrating injury to the neck, chest, or abdomen.

GCS, Glasgow Coma Scale; PALS, Pediatric Advanced Life Support.

Table 2
Patient Characteristics Stratified by Emergent Operative or Procedural Intervention

	Emergent operative intervention		Emergent procedural intervention		No emergent intervention		Missing	
	n	(%)	n	(%)	n	(%)	n	(%)
Total	36	(0.5)	11	(0.1)	8,031	(99)		
Median age (IQR)	9	(5–14)	13	(10–14)	6	(3–10)	8	(0.1)
Male gender	26	(72)	7	(64)	5,019	(63)	5	(0.1)
Median ISS (IQR)	18	(9–37)	34	(26–48)	9	(4–10)	81	(1)
Median HR (IQR)	112	(100–135)	40	(0–60)	111	(96–130)	487	(6)
Median SBP (IQR)	101	(91–121)	0	(0–60)	113	(102–124)	1,401	(17)
Median GCS score (IQR)	14	(3–15)	3	(3–3)	15	(15–15)	160	(2)
Penetrating mechanism	11	(31)	3	(27)	345	(4)	0	(0)
Gunshot wound	5	(14)	3	(27)	72	(0.9)		
Stab wound	3	(8)	0	(0)	33	(0.4)		
Other	3	(8)	0	(0)	240	(3)		
Blunt mechanism	25	(69)	8	(73)	7,368	(96)	0	(0)
Motor vehicle crash	8	(22)	1	(9)	651	(8)		
Motorcycle crash	0	(0)	1	(9)	431	(5)		
Fall	1	(3)	2	(18)	2,732	(34)		
Assault	0	(0)	0	(0)	70	(0.9)		
Auto versus pedestrian	6	(17)	1	(18)	398	(5)		
Other	10	(28)	3	(27)	2,986	(37)		
Transfer from another facility	21	(58)	0	(0)	4,108	(51)	0	(0)

Emergent operative intervention is defined as requiring operative intervention by a general or pediatric surgeon within one hour of ED arrival and emergent procedural intervention is defined as performance of cricothyroidotomy or thoracotomy in the ED. IQR, interquartile range; ISS, Injury Severity Score; HR, heart rate; SBP, systolic blood pressure; GCS, Glasgow Coma Scale.

Table 3

Proportions of the Study Sample that Met Criteria for the Loma Linda Rule and the American College of Surgeons' Major Resuscitation Criteria

	Available data		Missing data for all patients		Missing data for patients with EOI/EPI	
	n	(%)	n	(%)	n	(%)
Total	8,078		8,078		47	
Loma Linda Rule						
Penetrating injury	359	(4)	0	(0)	0	(0)
Age-specific tachycardia *	837	(10)	487	(6)	2	(4)
At least one criterion	1,127	(14)	487	(6)	2	(4)
Major resuscitation criteria						
Age-specific hypotension †	154	(2)	1,401	(17)	5	(11)
Respiratory compromise, obstruction, or intubation	317	(4)	0	(0)	0	(0)
Gunshot wound to the neck, chest, or abdomen	28	(0.3)	0	(0)	0	(0)
GCS score <8 with mechanism attributed to trauma	516	(6)	160	(2)	1	(2)
Transfer from other hospital and requiring blood	57	(1)	0	(0)	0	(0)
Physician discretion	95	(1)	0	(0)	0	(0)
At least one criterion	719	(9)	1,487	(18)	6	(13)

* Age-specific tachycardia defined by Pediatric Advanced Life Support.

† Age-specific hypotension defined as (SBP + [2 × age] <70 mmHg for those <10 years of age and SBP <90 mmHg for those >10 years of age.

GCS, Glasgow Coma Scale score; EOI, emergent operative intervention; EPI, emergent procedural intervention.

Table 4

Accuracy of the Loma Linda Rule, the American College of Surgeons' Major Resuscitation Criteria, and Refined Loma Linda Rules for the Prediction of Emergent Operative Intervention or Emergent Procedural Intervention

	EOI/EPI*		Sensitivity		Specificity		LR +	(95% CI)	LR -	(95% CI)
	Yes	No	(%)	(95% CI)	(%)	(95% CI)				
Loma Linda Rule										
Met criteria	33	2,008	69	(45–94)	76	(69–83)	2.8	(2.2–3.7)	0.4	(0.2–0.8)
Did not meet criteria	14	6,023								
Major Resuscitation Criteria										
Met criteria	37	1,522	80	(70–92)	81	(77–85)	4.2	(3.2–5.5)	0.2	(0.1–0.5)
Did not meet criteria	10	6,524								
Refined Loma Linda #1										
Met criteria	33	2,283	71	(57–85)	72	(66–78)	2.6	(2.0–3.4)	0.4	(0.2–0.6)
Did not meet criteria	14	5,748								
Refined Loma Linda #2										
Met criteria	32	1,363	68	(55–82)	83	(80–86)	4.0	(3.1–5.2)	0.4	(0.3–0.6)
Did not meet criteria	15	6,668								

Emergent operative intervention is defined as requiring operative intervention by a trauma surgeon within one hour of ED arrival and emergent procedural intervention is defined as performance of cricothyroidotomy or thoracotomy in the ED.

* The values below represent summary 2x2 tables where median values for each cell across the 10 multiply-imputed datasets are reported. Predictive accuracy estimates were combined across the 10 multiply-imputed datasets using Rubin's rules; as such, predictive accuracies are not directly calculable from the summary 2x2 tables.

CI, confidence interval; EOI, emergent operative intervention; EPI, emergent procedural intervention; LR +, positive likelihood ratio; LR -, negative likelihood ratio.

Table 5

Accuracy of the Loma Linda Rule, the American College of Surgeons' Major Resuscitation Criteria, and Refined Loma Linda Rules for the Prediction of Emergent Operative Intervention

	EOI*		Sensitivity		Specificity		LR +	(95% CI)	LR –	(95% CI)
	Yes	No	%	(95% CI)	%	(95% CI)				
Loma Linda Rule										
Met criteria	26	2,016	72	(53–91)	74	(64–85)	2.8	(1.9–4.3)	0.4	(0.2–0.7)
Did not meet criteria	10	6,026								
Major Resuscitation Criteria										
Met criteria	26	1,533	74	(59–89)	81	(76–85)	3.8	(2.8–5.2)	0.3	(0.2–0.6)
Did not meet criteria	10	6509								
Refined Loma Linda #1										
Met criteria	22	2,294	63	(47–80)	72	(66–78)	2.3	(1.7–3.1)	0.5	(0.3–0.8)
Did not meet criteria	14	5,748								
Refined Loma Linda #2										
Met criteria	22	1,373	61	(45–77)	83	(80–86)	3.6	(2.6–4.9)	0.5	(0.3–0.7)
Did not meet criteria	14	6,679								

Emergent operative intervention is defined as requiring operative intervention by a trauma surgeon within one hour of ED arrival.

*The values below represent summary 2×2 tables where median values for each cell across the 10 multiply-imputed datasets are reported.

Predictive accuracy estimates were combined across the 10 multiply-imputed datasets using Rubin's rules; as such, predictive accuracies are not directly calculable from the summary 2×2 tables. CI, confidence interval; EOI, emergent operative intervention; EPI, emergent procedural intervention; LR +, positive likelihood ratio; LR -, negative likelihood ratio.

Accuracy of the Loma Linda Rule, the American College of Surgeons' Major Resuscitation Criteria for the prediction of urgent operative intervention or emergent procedural intervention

Table 6

	UOI*		Sensitivity		Specificity		LR +	LR -	
	Yes	No	%	(95% CI)	%	(95% CI)		(95% CI)	(95% CI)
Loma Linda Rule									
Met criteria	472	6,050	82	(77-86)	20	(17-22)	1.0	(1.0-1.1)	0.9 (0.7-1.2)
Did not meet criteria	105	1,452							
Major Resuscitation Criteria									
Met criteria	147	1,413	25	(20-30)	81	(77-85)	1.3	(1.1-1.6)	0.9 (0.9-1.0)
Did not meet criteria	430	6,090							

Urgent operative intervention is defined as requiring operative intervention by a trauma surgeon within four hours of ED arrival and emergent procedural intervention is defined as performance of cricothyroidotomy or thoracotomy in the ED.

* The values below represent summary 2x2 tables where median values for each cell across the 10 multiply-imputed datasets are reported. Predictive accuracy estimates were combined across the 10 multiply-imputed datasets using Rubin's rules; as such, predictive accuracies are not directly calculable from the summary 2x2 tables.

CI, confidence interval; LR +, positive likelihood ratio; LR -, negative likelihood ratio; UOI, urgent operative intervention.

Accuracy of the Loma Linda Rule, the American College of Surgeons' Major Resuscitation Criteria, and Refined Loma Linda Rules for the Prediction of Urgent Operative Intervention

Table 7

	UOI*		Sensitivity		Specificity		LR +	(95% CI)	LR -	(95% CI)
	Yes	No	%	(95% CI)	%	(95% CI)				
Loma Linda Rule										
Met criteria	461	6,061	81	(77-86)	20	(17-21)	1.0	(1.0-1.1)	1.0	(0.8-1.2)
Did not meet criteria	104	1,452								
Major resuscitation criteria										
Met criteria	136	1,424	24	(19-29)	81	(77-85)	1.2	(1.0-1.5)	0.9	(0.9-1.0)
Did not meet criteria	430	6,090								

Urgent operative intervention is defined as requiring operative intervention by a trauma surgeon within four hours of ED arrival.

*The values below represent summary 2x2 tables where median values for each cell across the 10 multiply-imputed datasets are reported.

Predictive accuracy estimates were combined across the 10 multiply-imputed datasets using Rubin's rules; as such, predictive accuracies are not directly calculable from the summary 2x2 tables. CI = confidence interval; LR + = positive likelihood ratio; LR - = negative likelihood ratio; UOI, urgent operative intervention.

Table 8

Accuracy of Each Criterion of the Loma Linda Rule, the American College of Surgeons' Major Resuscitation Criteria for the Prediction of Emergent Operative or Procedural Intervention

	Sensitivity		Specificity		LR +	(95% CI)	LR -	(95% CI)
	(%)	(95% CI)	(%)	(95% CI)				
Original Loma Linda Rule criteria								
Penetrating mechanism	45	(3-81)	86	(77-94)	2.8	(1.2-6.1)	0.6	(0.4-1.2)
Age-specific tachycardia	40	(26-54)	88	(87-88)	3.2	(2.3-4.6)	0.7	(0.5-0.9)
Major resuscitation criteria								
Age-specific hypotension	36	(22-50)	95	(91-98)	7.0	(3.3-15.0)	0.7	(0.5-0.8)
Respiratory compromise, obstruction, or intubation	40	(26-55)	96	(96-97)	10.9	(7.6-15.7)	0.6	(0.5-0.8)
Gunshot wound to the torso *	15	(5-25)	100	(100-100)	57.0	(25.4-127.5)	0.9	(0.8-1.0)
GCS <8 with mechanism attributed to trauma	57	(43-71)	92	(91-92)	6.8	(5.2-8.8)	0.5	(0.3-0.7)
Transfer from other hospital and requiring blood	13	(3-22)	99	(99-100)	20.1	(9.1-44.6)	0.9	(0.8-1.0)
Physician discretion	1	(0-5)	95	(91-98)	Undefined		1.0	(1.0-1.1)
Other criteria								
Penetrating wound to torso	27	(0-54)	87	(79-94)	1.8	(0.7-5.0)	0.8	(0.6-1.2)

Emergent operative intervention is defined as requiring operative intervention by a trauma surgeon within one hour of ED arrival and emergent procedural intervention is defined as performance of cricothyroidotomy or thoracotomy in the ED. Predictive accuracy estimates were combined across the 10 multiply-imputed datasets using Rubin's rules.

* Defined as to the neck, chest, or abdomen.

CI, confidence interval; LR +, positive likelihood ratio; LR -, negative likelihood ratio; GCS, Glasgow Coma Scale score.