Published in final edited form as:

J Trauma Acute Care Surg. 2016 September ; 81(3): 445–452. doi:10.1097/TA.0000000000001085.

Prehospital Lactate Improves Accuracy of Prehospital Criteria for Designating Trauma Activation Level

Joshua B. Brown, MD, MSc¹, E. Brooke Lerner, PhD², Jason L. Sperry, MD, MPH¹, Timothy R. Billiar, MD¹, Andrew B. Peitzman, MD¹, and Francis X. Guyette, MD, MPH³

Joshua B. Brown: brownjb@upmc.edu; E. Brooke Lerner: eblerner@mcw.edu; Jason L. Sperry: sperryjl@upmc.edu; Timothy R. Billiar: billiartr@upmc.edu; Andrew B. Peitzman: peitzmanab@upmc.edu; Francis X. Guyette: guyefx@upmc.edu

¹Division of General Surgery and Trauma, Department of Surgery, University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania 15213

²Department of Emergency Medicine, Medical College of Wisconsin, Milwaukee, Wisconsin 53226

³Department of Emergency Medicine, University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania 15213

Abstract

Background—Trauma activation level is determined by prehospital criteria. The American College of Surgeons (ACS) recommends trauma activation criteria; however, their accuracy may be limited. Prehospital lactate has shown promise in predicting trauma center resource requirements. Our objective was to investigate the added value of incorporating prehospital lactate in an algorithm to designate trauma activation level.

Methods—Air medical trauma patients undergoing prehospital lactate measurement were included. Algorithms using ACS activation criteria (ACS) and ACS activation criteria plus prehospital lactate (ACS+LAC) to designate trauma activation level were compared. Test characteristics and net reclassification improvement (NRI), which evaluates reclassification of patients among risk categories with additional predictive variables, were calculated. Algorithms were compared to predict trauma center need (TCN) defined as >1 unit of blood in the ED; spinal cord injury; advanced airway; thoracotomy or pericardiocentesis; ICP monitoring; emergent operative or interventional radiology procedure; or death.

Results—There were 6,347 patients included. Twenty-eight percent had TCN. The ACS+LAC algorithm upgraded 256 patients and downgraded 548 patients compared to the ACS algorithm. The ACS+LAC algorithm versus ACS algorithm had a NRI of 0.058 (95% CI 0.044, 0.071;

Correspondence and Reprints: Joshua B. Brown, MD, MSc, Division of Trauma and General Surgery, Department of Surgery, University of Pittsburgh Medical Center, 200 Lothrop Street, Pittsburgh, Pennsylvania 15213, Phone: (716) 400-2471, brownjb@upmc.edu.

Conflicts of Interest

There are no conflicts of interest for the current study

AUTHOR CONTRIBUTIONS: J.B.B. and F.X.G. designed the study, performed the literature search, and data collection. J.B.B. performed the data analysis. J.B.B., F.X.G., and E.B.L. participated in initial manuscript preparation. All authors contributed to data interpretation and critical revision of the manuscript.

$p < 0.01$), with an event NRI of -0.5% and non-event NRI of 6.2% . When weighted to favor changes in under-triage, the ACS+LAC still had a favorable overall reclassification (wNRI 0.041; 95% CI 0.028, 0.054; $p = 0.01$). The ACS+LAC algorithm increased PPV, NPV, and accuracy. Over-triage was reduced 7.2% , while under-triage only increased 0.7% . The area under the curve (AUC) was significantly higher for the ACS+LAC algorithm (0.79 vs. 0.76 , $p < 0.01$).

Conclusions—The ACS+LAC algorithm reclassified patients to more appropriate levels of trauma activation when compared to the ACS algorithm. This overall benefit is achieved by significant reduction in over-triage relative to very small increase in under-triage. In the context of trauma team activation, this trade-off may be acceptable, especially in the current healthcare environment.

Level of Evidence—Diagnostic study, Level IV

Keywords

Triage; prehospital; lactate; reclassification; trauma activation

BACKGROUND

Accurate triage is vital for trauma systems, ensuring resources match the patient's injury severity without overburdening the system. Triage occurs at several levels. The first decision is whether a patient requires transport to a trauma center. The Centers for Disease Control (CDC) and American College of Surgeons (ACS) authored national field triage guidelines based on stepwise identification of physiologic, anatomic, mechanism of injury, and special consideration criteria.¹

For patients brought to a trauma center, information from prehospital providers is used to determine trauma activation level.² Most centers have a tiered trauma activation system which determines the level of resources brought to bear upon an injured patient.^{3–5} The highest level of trauma activation allocates significant multidisciplinary resources for immediate deployment, and should be reserved for the most severely injured patients. Limited trauma activation reduces the resources mobilized for less injured patients. The ACS has defined a minimum set of criteria for the highest level of activation; however these are frequently modified at the hospital level and accuracy may be limited.⁶ The ACS recommends the highest level of activation be based on physiologic and anatomic criteria, while lower levels of activation include high-risk mechanism of injury criteria, substantially overlapping with field triage criteria.⁷

The level of trauma activation is an important step in accurate triage. Even though a patient is brought to a trauma center, limited or no trauma activation for seriously injured patients risks delaying critical interventions. Conversely, trauma activation that overmatches resources to minimally injured patients may divert needed resources away from other patients, overwhelm providers, degrade system efficiency, and increase costs.^{8–10}

Many authors report limitations of current triage criteria.^{6, 11–16} Some suggest biomarkers such as lactate may augment standard triage criteria for predicting severe injury.¹⁷ Lactate is a biomarker indicative of hypoperfusion, and may identify patients requiring trauma center

resources. Prehospital lactate measurement is available through handheld point-of-care devices, and has been shown to predict resuscitation needs and outcomes in trauma patients.^{18, 19} It remains unclear, however, whether using prehospital lactate in designating trauma activation level adds benefit.

Our objective was to evaluate the added diagnostic value of including prehospital lactate in an algorithm to designate trauma activation level at the trauma center. We hypothesize using prehospital lactate with existing prehospital trauma activation criteria will be superior to using these criteria alone to identify patients requiring trauma center resources.

METHODS

Study Population

This was a retrospective cohort study conducted at the University of Pittsburgh Medical Center (UPMC) Presbyterian Hospital, a high-volume urban level I trauma center. All injured patients >15 years undergoing air medical transport by STAT MedEvac between January 2009 and September 2014 with a prehospital lactate measurement were eligible. A separate center within the system is designated as a burn center and has obstetric support, thus outcome and activation criteria related to burns or pregnancy were not considered.

STAT MedEvac is the largest non-profit air medical provider in the US and affiliated with UPMC. During the study period 17% of injured patients were transported by helicopter, while 57% were transported by ground and 26% by private vehicle/other modes. STAT MedEvac was staffed by a paramedic/nurse team and obtained lactate measurement on patients using a hand-held point-of-care serum lactate meter. To our knowledge, prehospital point-of-care lactate measurement in trauma patients is uncommon in the US. The meter requires a single drop of peripheral venous blood (5.0µL) placed on a testing strip. Blood was obtained from peripheral intravenous line start with 5cc waste prior to measurement. The Lactate Pro meter (Arkray, Japan) has a measurement range from 0.5 to 25.0 mmol/L. For patients with more than one prehospital lactate value, the highest value was used for this study. This was done to guard against potential under-triage, using the “worst” lactate to reduce the chance of downgrading activation level based on a lower average, initial, or final value. Prehospital providers and trauma center personnel were not blinded to the lactate values. For prehospital providers, lactate values >4mmol/L prompted a 500cc crystalloid bolus and contact with a medical direction physician. No changes in care were specified for in-hospital providers. Prehospital lactate measurement was not available from ground emergency medical services (EMS) during the study period.

Data Sources

Data sources included emsCharts (Warrendale, PA), a prospectively collected prehospital database, the UPMC trauma registry, and the UPMC electronic health record (Cerner Corporation, Kansas City, MO). Patients meeting inclusion criteria were identified through emsCharts. These patients’ data were linked with the trauma registry and electronic health record to obtain demographics, injury characteristics, vital signs, *International Classification*

of Diseases, ninth revision (ICD-9) diagnosis codes, surgical procedures, complications, and hospital disposition.

Missing Data

For variables missing <25% of observations, multiple imputation was performed. Imputed variables included injury severity score (ISS), admission systolic blood pressure (SBP), respiratory rate (RR), and Glasgow Coma Scale (GCS). Multiple imputation using iterative chained equations with fully conditional specification based on available patient-level data was performed with five imputations. Outcome models were performed by combining model coefficients and standard errors from each imputed dataset while adjusting for the variability between imputed datasets.²⁰ Missing data for imputed variables ranged from 2% (admission GCS) to 9% (admission respiratory rate). Sensitivity analyses were performed using complete cases only, and no significant change in the results was seen.

Trauma Activation Level

The ACS recommends a tiered trauma activation system consisting of full and limited activation levels.⁷ Our institution utilizes a two-tiered trauma activation systems. A level 1 trauma activation denotes full activation which consists of the in-house trauma team, anesthesia personnel, several ancillary personnel including radiology and social work, as well as making resources available in the operating room and blood bank. A level 2 trauma activation denotes limited activation, but includes presence of the in-house trauma team. For the current study we used this model for trauma activation level, with level 1 activation corresponding to a full trauma activation and a level 2 activation corresponding to a limited trauma activation. An emergency physician would evaluate patients receiving no trauma activation with additional resources utilized as necessary. Thus, for purposes of this study, patients could be designated as a level 1, level 2, or no trauma activation.

To evaluate the utility of prehospital lactate to inform trauma activation level for injured patients, two algorithms to assign patients to a trauma activation level were compared. Both algorithms used tiered trauma team activation criteria adapted from the ACS (Table 1).⁷ The first algorithm (ACS algorithm) relied solely on ACS activation criteria (Fig. 1A). Patients with any physiologic or anatomic criteria were designated as a level 1 activation, while patients with only mechanism of injury were designated as a level 2 activation. Patients without any ACS activation criteria were designated as no trauma activation. The second algorithm (ACS+LAC algorithm) incorporated prehospital lactate level categorized as <2.5mmol/L, 2.5–4.0mmol/L, and >4.0mmol/L (Fig 1B). This algorithm allowed both upgrading and downgrading of the trauma activation level based on prehospital lactate.

Prehospital lactate categories were chosen based on prior investigations.¹⁹ To ensure appropriate categorization, the area under the curve (AUC) for continuous prehospital lactate to predict the primary outcome was used to find two optimal cutoffs that maximize sensitivity and specificity.

Statistical Analysis

The primary outcome was trauma center need (TCN). This was defined according to a published consensus-based standard, and included any one of the following criteria: (1) >1 unit of blood in the ED; (2) spinal cord injury; (3) advanced airway placed prehospital or in the ED; (4) thoracotomy within 48hrs of admission; (5) pericardiocentesis within 24hrs of admission; (6) intracranial pressure monitoring; (7) interventional radiology procedure within 4hrs of admission; (8) Abdominal/Thoracic/Vascular/Neurologic surgical procedure within 24hrs of admission; (9) death.²¹ Presence of ACS activation criteria were determined for each patient using prehospital vital signs, ICD-9 diagnosis codes, and mechanism of injury data. We also performed a sensitivity analysis of this definition, using a surgical procedure within 2hrs to capture truly emergent procedures.

To evaluate the incremental predictive value of prehospital lactate, two logistic regression models were developed. The first included only ACS criteria for full or limited trauma team activation, while the second added prehospital lactate to the first model. Discrimination of each model was determined and compared.²² The fit of each model was evaluated using the Akaike Information Criterion (AIC), and compared using the likelihood ratio test. Finally, the net reclassification improvement (NRI) was calculated using quartiles of predicted TCN risk. The NRI assesses the added value of incorporating a new predictive marker for an outcome into an existing model.²³ The NRI is the sum of two components.²⁴ The event NRI measures the net proportion of patients with the outcome correctly classified to a higher risk category. The non-event NRI measures the net proportion of patients without the outcome correctly classified to a lower risk category. Positive values for the NRI and its components indicate the new predictive marker reclassifies patients to a more appropriate risk category.

To compare the two algorithms for classifying patients according to TCN, the NRI was calculated using the trauma activation level as risk categories. Patients were upgraded if the assigned trauma activation level was higher for the ACS+LAC algorithm than for the ACS algorithm. Patients were downgraded if the assigned trauma activation level was lower for the ACS+LAC algorithm than for the ACS algorithm. The NRI assumes equal trade-off between false positives (over-triage) and false negative (under-triage); however under-triage is generally considered more harmful than over-triage.²⁵ Thus, a weighted NRI (wNRI) was performed. This allows differential weighting of the event and non-event NRIs to reflect the relative benefits of reclassifying patients with and without the outcome event.²⁶ To derive weights for the wNRI, the ratio of acceptable over-triage (35%) to acceptable under-triage (5%) was used.²⁵ The event NRI was given a 7-fold higher weight than the non-event NRI, placing more weight on patients with TCN and thereby changes in under-triage were heavily weighted relative to changes in over-triage.

Since both level 1 and 2 trauma activations involve immediate presence of the trauma team with differences concentrated in ancillary resources, we also compared the algorithms for classifying patients to undergo any trauma activation versus no trauma activation. Diagnostic test characteristics including sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for each algorithm. The AUC was compared between the two algorithms. Decision curve analysis was performed to evaluate the most beneficial strategy for trauma activation. Strategies included the ACS and ACS

+LAC algorithms, as well as trauma activation for all patients and for no patients. This method compares the net benefit of trauma activation strategies across TCN risk at which trauma activation would be warranted.²⁷ The net benefit is the difference between expected benefit (patients with TCN undergoing trauma activation) and expected harm (patients without TCN undergoing trauma activation).

For univariate comparisons, Chi-square and Wilcoxon rank-sum tests were used for categorical and continuous variables respectively. A p value 0.05 was considered significant with 2-sided tests. Data analysis was conducted using Stata v13MP (College Station, TX). This study was approved by the Institutional Review Board at the University of Pittsburgh.

RESULTS

A total of 8,729 air medical trauma patients were identified, of which 7,375 (84%) patients had a prehospital lactate level. Of these, 6,347 (86%) patients met inclusion criteria, comprising the study population. Table 2 summarizes the study population, and compares characteristics between patients with and without TCN. Patients with TCN were more severely injured, had higher prehospital lactate, and required more trauma center resources. The optimal cutoffs for lactate to predict TCN were 2.6mmol/L and 3.8mmol/L. Thus, our categorization of lactate coincides with important cutoffs in the data for predicting TCN. To quantify over-triage based on lactate alone, 44% of patients with a lactate >4mmol/L did not have TCN.

The model including ACS activation criteria plus prehospital lactate had a significantly higher AUC (0.852, 95% Confidence Interval [95%CI] 0.841, 0.863) when compared to the model with only ACS activation criteria (0.826, 95%CI 0.815, 0.837) to predict TCN ($p < 0.01$). The AIC for the model including lactate was lower (5066.9 vs. 5190.7) indicating better fit, and the likelihood ratio test indicated adding lactate to the model significantly improved fit ($LR \chi^2 = 127.79$, $p < 0.01$). Across quartiles of predicted TCN, adding prehospital lactate resulted in an event NRI of 0.031 (95%CI 0.009, 0.128) and non-event NRI of 0.074 (95%CI 0.065, 0.082). This gives an overall NRI of 0.105 (95%CI 0.081, 0.128; $p < 0.01$), indicating addition of lactate reclassifies patients to a more appropriate TCN risk quartile.

When evaluating the reclassification based on the algorithms, the ACS+LAC algorithm upgraded 205 patients from no trauma activation to level 1 activation, upgraded 51 patients from level 2 activation to level 1 activation, and downgraded 548 patients from level 2 activation to no trauma activation (Table 3). This resulted in an event NRI of -0.005 (95%CI -0.0013, 0.004) and non-event NRI of 0.062 (95%CI 0.050, 0.074). This gives an overall NRI of 0.058 (95%CI 0.044, 0.071; $p < 0.01$), indicating favorable reclassification using the ACS+LAC algorithm. Weighted reclassification favoring changes in under-triage still results in an overall favorable wNRI of 0.041 (95%CI 0.028, 0.054; $p = 0.01$) for the ACS+LAC algorithm, with an event wNRI of -0.010 (95%CI -0.019, -0.002) and non-event wNRI of 0.051 (95%CI 0.039, 0.063).

Among patients downgraded, there were no deaths in the ED. Ultimately, 4 (0.7%) downgraded patients died. All patients were downgraded from level 2 to no activation. All were older patients (age range 77–91) that fell while on anticoagulation with a lactate <2.5mmol/L. One already had a do-not-resuscitate order. Two patients had a head abbreviated injury scale (AIS) 3, one had a chest AIS 3, while the remaining patient did not have any AIS 3, but suffered a C1 fracture.

Comparing the two algorithms for classifying patients as any trauma activation or no trauma activation, the ACS+LAC demonstrated superior diagnostic characteristics to predict TCN with gains in PPV, NPV, and overall accuracy compared to the ACS algorithm. (Table 4). This resulted in a 7.2% absolute reduction in over-triage with only 0.7% absolute increase in under-triage. The AUC was also significantly higher for the ACS+LAC algorithm ($p<0.01$). Both the NRI (0.065, $p<0.01$) and wNRI (0.042, $p=0.01$) again showed a favorable reclassification of patients using the ACS+LAC algorithm. Decision curve analysis revealed the ACS+LAC algorithm had the greatest net benefit when the threshold for trauma activation was 7% for the risk of TCN (Fig. 2).

Sensitivity analysis using a surgical procedure within 2hrs of admission revealed similar results. The ACS+LAC algorithm resulted in an event NRI of -0.001 and non-event NRI of 0.063 with an overall NRI of 0.062 ($p<0.01$), indicating favorable reclassification. There was also a 7.3% absolute reduction in over-triage with only 0.3% absolute increase in under-triage using the ACS+LAC under this definition.

DISCUSSION

The current study demonstrates the addition of prehospital lactate to the existing ACS trauma team activation criteria improves discrimination and fit for predicting TCN. Adding prehospital lactate to the ACS activation criteria also resulted in reclassification of patients to a more appropriate TCN risk quartile.

Incorporating prehospital lactate into an algorithm for designating trauma activation level led to reclassification of patients to a more appropriate trauma activation level based on TCN. The small negative event NRI indicates slightly more patients with TCN were downgraded than upgraded which may result in under-triage; however, the larger positive non-event NRI indicates many more patients without TCN were downgraded than upgraded, resulting in a larger reduction in over-triage. The weighted NRI, heavily weighted in favor of under-triage, still suggest an overall favorable reclassification of patients using the ACS+LAC algorithm. Moreover, under-triage in the context of trauma activation does not mean patients will not be brought to a trauma center, but that the full spectrum of trauma resources is not immediately mobilized. While still undesirable, some have shown delayed trauma activation does not increase mortality.²⁸ Patients in the current study that were downgraded and died represent a very elderly cohort of anticoagulated falls sustaining head injuries with dismal prognosis regardless of trauma activation level. One may argue that reducing aggressive resource use in these patients may be appropriate depending on goals of the patient and family. The elderly population has unique needs that likely require separate triage strategies,^{29–31} and should be studied independently going forward. Thus an algorithm

that substantially reduces unnecessary resource utilization at the expense of a very small increase in potential under-triage may be a valuable trade-off, particularly in today's evolving healthcare landscape.

When considering any level of trauma activation compared to no trauma activation, the ACS+LAC algorithm again had better discrimination and reclassified patients more appropriately to trauma activation than the ACS algorithm. The ACS+LAC algorithm demonstrated gains in PPV, NPV, and overall accuracy. Decision curve analysis demonstrated the ACS+LAC algorithm provided the greatest benefit when the threshold for trauma activation was for patients with a 7% probability of requiring trauma center care. While there is no standard threshold for the risk of TCN at which trauma activation is warranted, threshold probabilities <7% suggested trauma activation for all injured patients generates the greatest net benefit. Thus the ACS+LAC algorithm is likely superior in the range of clinically relevant probability thresholds for the risk of TCN to warrant trauma activation.

ACS activation criteria rely on prehospital field information. Mechanism of injury criteria are generally low yield for identifying major trauma patients.^{12, 14, 15, 32} Although the physiologic and anatomic criteria have been reported to perform better for triage, several have shown limitations as well.^{13, 33–36} The availability of point-of-care lactate has the potential to enhance the accuracy of traditional triage criteria for predicting trauma center resource requirements.

Lavery and colleagues demonstrated admission lactate levels $\geq 2\text{mmol/L}$ predicted injury severity, ICU resource utilization, and prolonged hospital stay, with superior sensitivity and NPV compared to CDC triage criteria.¹⁷ Our group previously reported prehospital lactate improved prediction of mortality, emergent surgery, and multiple organ dysfunction syndrome (MODS) in air medical trauma patients.¹⁸ The Resuscitation Outcomes Consortium (ROC) extended this work with a prospective evaluation of a prehospital lactate $\geq 2.5\text{mmol/L}$ to predict resuscitative care compared to $\text{SBP} < 90\text{mmHg}$ among trauma patients transported by ground EMS.¹⁹ The ROC investigators found prehospital lactate had higher sensitivity and AUC for resuscitative care compared to $\text{SBP} < 90\text{mmHg}$. The ROC investigators concluded prehospital lactate has potential utility in both field triage and trauma team activation.

Accurate triage of patients to the appropriate level of trauma activation is a critical process for trauma centers.²⁵ Under-triage of patients may delay time-sensitive definitive care, resulting in preventable morbidity or mortality. For example, some have shown trauma team activation to reduce time to head computed tomography (CT) in patients with moderate to severe traumatic brain injury,³⁷ and we also found a slightly lower time to head CT in this population among patients undergoing level 1 activation (20min vs. 28min, $p=0.02$). However, the deleterious effects of over-triage cannot be ignored. The ACS reduced the rate of acceptable over-triage from 50% to 35% in the most recent version of *Resources for Optimal Care of the Injured Patient*, signifying increasing attention to the problem of over-triage.^{25, 38} The evolving healthcare environment has placed emphasis on efficiency and cost containment. Over-triage is a significant threat to efficient use of trauma system resources and results in significant cost.^{9, 10} Trauma system resources are finite and can be

overwhelmed by inappropriate trauma activations for patients with minor injuries. Further, over-triage diverts necessary resources away from other patients. One group found patients with acute coronary syndrome presenting to the ED during trauma activations had a significantly higher rate of 30-day cardiovascular events than patients presenting when there was no trauma activation.⁸ Newgard and colleagues reported that up to 40% of acute injury costs are attributable to care for patients with low risk of severe injury at trauma centers.¹⁰

Several groups have modified trauma activation protocols to significantly reduce over-triage without substantially increasing under-triage.^{39–41} Tominaga and colleagues developed a “trauma resource” designation that avoided trauma team activation, but included expedited evaluation in the ED for patients not meeting ACS activation criteria.⁴² They reported no increase in mortality with a potential cost savings of nearly \$1million.

Prospective study is warranted to evaluate real-world implementation of trauma team activation algorithms using prehospital lactate. These data highlight the need for algorithms to allow both upgrading and downgrading to realize the potential benefit. Studies should focus on resource utilization, costs, and monitoring adverse events. Safety can be maximized by ensuring patients downgraded to no trauma activation are seen by an emergency physician upon arrival to reduce consequences of significant under-triage.

This study has several limitations. First is the retrospective design. Anatomic criteria used to define full trauma team activation were identified in the dataset using ICD-9 codes. Thus, it remains unclear whether these injuries definitely diagnosed in-hospital were recognized in the field by providers, as anatomic triage criteria were not routinely recorded in emsCharts. Our primary outcome has been published to standardize triage research; however, it remains a consensus definition based on expert opinion.²¹ While most patients had lactate measured, some did not which may introduce selection bias. In the majority (52%), this occurred because of inability to obtain intravenous access or no additional access was indicated.⁴³ Other reasons included providers forgot to obtain samples (30%), patient in extremis (9%), equipment issue (3%), sample error (3%), and other/miscellaneous causes (3%).⁴³ Lactate may be elevated for reasons other than hypoperfusion following injury and may confound its value for triage. There may be technical limitations of prehospital lactate based on collection technique; however, our protocol using intravenous catheter blood with discard likely minimizes this. Providers were not blinded to the lactate value and patients with lactate values >4mmol/L received a crystalloid bolus in the field; however, this is unlikely to significantly contribute to differences in TCN. Only a minority of patients had an arterial lactate measured immediately upon arrival to the hospital, thus it is unclear how well prehospital and in-hospital lactate levels correlate in this study. Ongoing resuscitation and time may also contribute to differences between prehospital and in-hospital lactate values. Others have shown the Lactate Pro meter used in this study correlate well with arterial blood gas lactate in a variety of conditions.^{44, 45}

Further, all study participants were air medical patients and thus represent a more severely injured cohort than all injured patients transported by EMS. There is potential selection bias for patients geographically farther from trauma centers. Thus, it is unclear how prehospital lactate may perform in patients not selected for helicopter transport. Our overall injury

severity was comparable to the ROC trial, which evaluated ground EMS prehospital lactate.¹⁹ The tradeoffs of under-triage and over-triage may be different in ground EMS patients compared to air medical patients. It is possible that applying this algorithm across both populations may reduce under-triage in ground patients while reducing over-triage in air patients, resulting in significant improvements to triage overall. The performance of prehospital lactate for trauma team activation requires further evaluation when this technology is routinely available to ground EMS.

Any changes in triage systems that potentially increase under-triage need close monitoring before widespread implementation. Although the wNRI still pointed to a favorable overall reclassification of patients using the ACS+LAC algorithm, weighting of the wNRI was arbitrary. The ACS+LAC algorithm is only one possible permutation of an algorithm incorporating prehospital lactate to designate trauma activation level. The potential benefits of using prehospital lactate in existing trauma activation protocols with modified ACS criteria may be different than reported here, requiring prospective study.

CONCLUSION

This is the first study to evaluate prehospital lactate for designating trauma activation level. Prehospital lactate in combination with ACS trauma team activation criteria reclassified patients to a more appropriate trauma activation level when compared to using ACS criteria alone among air medical trauma patients. This benefit was achieved by a larger reduction in over-triage relative to very small increase in under-triage. These data support consideration of prehospital lactate in designation of trauma activation level, but prospective study is needed to evaluate the added value of prehospital lactate in triage decisions across differing trauma systems.

Acknowledgments

Sources of Funding: No funding or support was directly received to perform the current study. Dr. Brown receives support from an institutional T32 Ruth L. Kirschstein National Research Service Award training grant (5T32GM008516-20) from the National Institutes of Health.

References

1. Sasser SM, Hunt RC, Faul M, Sugerman D, Pearson WS, Dulski T, Wald MM, Jurkovich GJ, Newgard CD, Lerner EB, et al. Guidelines for Field Triage of Injured Patients. *MMWR*. 2012; 61:1–20. [PubMed: 22237112]
2. Phillips JA, Buchman TG. Optimizing prehospital triage criteria for trauma team alerts. *J TraumaAcute Care Surg*. 1993; 34:127–132.
3. Kouzminova N, Shatney C, Palm E, McCullough M, Sherck J. The efficacy of a two-tiered trauma activation system at a level I trauma center. *J Trauma*. 2009; 67:829–833. [PubMed: 19820592]
4. Ochsner MG, Schmidt JA, Rozycki GS, Champion HR. The Evaluation of a Two-Tier Trauma Response System at a Major Trauma Center: Is It Cost Effective and Safe? *J Trauma Acute Care Surg*. 1995; 39:971–977.
5. Tinkoff GH, O'Connor RE, Fulda GJ. Impact of a two-tiered trauma response in the emergency department: promoting efficient resource utilization. *J Trauma*. 1996; 41:735–740. [PubMed: 8858038]
6. Falcone RA Jr, Haas L, King E, Moody S, Crow J, Moss A, Gaines B, McKenna C, Gourlay DM, Werner C, et al. A multicenter prospective analysis of pediatric trauma activation criteria routinely

used in addition to the six criteria of the American College of Surgeons. *J Trauma Acute Care Surg.* 2012; 73:377–384. discussion 384. [PubMed: 22846943]

7. American College of Surgeons Committee on Trauma. Resources for the optimal care of the injured patient. Chicago, IL: American College of Surgeons; 2014. Hospital Organization and the Trauma Program; p. 35-44.
8. Fishman PE, Shofer FS, Robey JL, Zogby KE, Reilly PM, Branas CC, Pines JM, Hollander JE. The impact of trauma activations on the care of emergency department patients with potential acute coronary syndromes. *Ann Emerg Med.* 2006; 48:347–353. Epub ahead of print 2006/09/26. [PubMed: 16997668]
9. Newgard CD, Hsia RY, Mann NC, Schmidt T, Sahni R, Bulger EM, Wang NE, Holmes JF, Fleischman R, Zive D, et al. The trade-offs in field trauma triage: a multiregion assessment of accuracy metrics and volume shifts associated with different triage strategies. *J Trauma Acute Care Surg.* 2013; 74:1298–1306. discussion 1306. [PubMed: 23609282]
10. Newgard CD, Staudenmayer K, Hsia RY, Mann NC, Bulger EM, Holmes JF, Fleischman R, Gorman K, Haukoos J, McConnell KJ. The cost of overtriage: more than one-third of low-risk injured patients were taken to major trauma centers. *Health Aff (Millwood).* 2013; 32:1591–1599. [PubMed: 24019364]
11. Lerner EB, Drendel AL, Falcone RA Jr, Weitze KC, Badawy MK, Cooper A, Cushman JT, Drayna PC, Gourlay DM, Gray MP, et al. A consensus-based criterion standard definition for pediatric patients who needed the highest-level trauma team activation. *J Trauma Acute Care Surg.* 2015; 78:634–638. [PubMed: 25710438]
12. Cook CH, Muscarella P, Praba AC, Melvin WS, Martin LC. Reducing overtriage without compromising outcomes in trauma patients. *Arch Surg.* 2001; 136:752–756. [PubMed: 11448384]
13. Eastridge BJ, Salinas J, McManus JG, Blackburn L, Bugler EM, Cooke WH, Convertino VA, Wade CE, Holcomb JB. Hypotension begins at 110 mm Hg: redefining “hypotension” with data. *J Trauma.* 2007; 63:291–297. discussion 297–299. [PubMed: 17693826]
14. Henry MC, Alicandro JM, Hollander JE, Moldashel JG, Cassara G, Thode HC Jr. Evaluation of American College of Surgeons trauma triage criteria in a suburban and rural setting. *Am J Emerg Med.* 1996; 14:124–129. Epub ahead of print 1996/03/01. [PubMed: 8924131]
15. Henry MC, Hollander JE, Alicandro JM, Cassara G, O’Malley S, Thode HC Jr. Incremental benefit of individual American College of Surgeons trauma triage criteria. *Acad Emerg Med.* 1996; 3:992–1000. [PubMed: 8922003]
16. Newgard CD, Rudser K, Hedges JR, Kerby JD, Stiell IG, Davis DP, Morrison LJ, Bulger E, Terndrup T, Minei JP, et al. A critical assessment of the out-of-hospital trauma triage guidelines for physiologic abnormality. *J Trauma.* 2010; 68:452–462. [PubMed: 20154558]
17. Lavery RF, Livingston DH, Tortella BJ, Sambol JT, Slomovitz BM, Siegel JH. The utility of venous lactate to triage injured patients in the trauma center. *J Am Coll Surg.* 2000; 190:656–664. [PubMed: 10873000]
18. Guyette F, Suffoletto B, Castillo JL, Quintero J, Callaway C, Puyana JC. Prehospital serum lactate as a predictor of outcomes in trauma patients: a retrospective observational study. *J Trauma.* 2011; 70:782–786. [PubMed: 21610386]
19. Guyette FX, Meier EN, Newgard C, McKnight B, Daya M, Bulger EM, Powell JL, Brasel KJ, Kerby JD, Egan D, et al. A comparison of prehospital lactate and systolic blood pressure for predicting the need for resuscitative care in trauma transported by ground. *J Trauma Acute Care Surg.* 2015; 78:600–606. [PubMed: 25710433]
20. Rubin, DB. Multiple Imputation for Nonresponse in Surveys. Hoboken, NJ: John Wiley & Sons; 1987.
21. Lerner EB, Willenbring BD, Pirrallo RG, Brasel KJ, Cady CE, Colella MR, Cooper A, Cushman JT, Gourlay DM, Jurkovich GJ, et al. A consensus-based criterion standard for trauma center need. *J Trauma Acute Care Surg.* 2014; 76:1157–1163. [PubMed: 24662885]
22. Hanley JA, McNeil BJ. A method of comparing the areas under receiver operating characteristic curves derived from the same cases. *Radiology.* 1983; 148:839–843. [PubMed: 6878708]

23. Pencina MJ, D'Agostino RB Sr, D'Agostino RB Jr, Vasan RS. Evaluating the added predictive ability of a new marker: from area under the ROC curve to reclassification and beyond. *Stat Med*. 2008; 27:157–172. discussion 207–112. [PubMed: 17569110]
24. Leening MJG, Vedder MM, Witteman JCM, Pencina MJ, Steyerberg EW. Net Reclassification Improvement: Computation, Interpretations, and Controversies: A literature review and clinician's guide. *Ann Intern Med*. 2014; 160:122–131. [PubMed: 24592497]
25. American College of Surgeons Committee on Trauma. Prehospital Trauma Care. In: Rotondo, MF.; Cribari, C.; Smith, RS., editors. Resources for the optimal care of the injured patient. Chicago, IL: American College of Surgeons; 2014. p. 23-29.
26. Pencina MJ, D'Agostino RB Sr, Steyerberg EW. Extensions of net reclassification improvement calculations to measure usefulness of new biomarkers. *Stat Med*. 2011; 30:11–21. [PubMed: 21204120]
27. Fitzgerald M, Saville BR, RJL. Decision Curve Analysis. *JAMA*. 2015; 313:409–410. [PubMed: 25626037]
28. Ryb GE, Cooper C, Waak SM. Delayed trauma team activation: patient characteristics and outcomes. *J Trauma Acute Care Surg*. 2012; 73:695–698. [PubMed: 23007017]
29. Brown JB, Gestring ML, Forsythe RM, Stassen NA, Billiar TR, Peitzman AB, Sperry JL. Systolic blood pressure criteria in the National Trauma Triage Protocol for geriatric trauma: 110 is the new 90. *J Trauma Acute Care Surg*. 2015; 78:352–359. [PubMed: 25757122]
30. Newgard CD, Richardson D, Holmes JF, Rea TD, Hsia RY, Mann NC, Staudenmayer K, Barton ED, Bulger EM, Haukoos JS, et al. Physiologic Field Triage Criteria for Identifying Seriously Injured Older Adults. *Prehosp Emerg Care*. 2014
31. Werman HA, Erskine T, Caterino J, Riebe JF, Valasek T. Members of the Trauma Committee of the State of Ohio EMSB. Development of statewide geriatric patients trauma triage criteria. *Prehosp Disaster Med*. 2011; 26:170–179. [PubMed: 22107767]
32. Santaniello JM, Esposito TJ, Luchette FA, Atkian DK, Davis KA, Gamelli RL. Mechanism of injury does not predict acuity or level of service need: field triage criteria revisited. *Surgery*. 2003; 134:698–703. discussion 703–694. [PubMed: 14605632]
33. Brasel KJ, Guse C, Gentilello LM, Nirula R. Heart rate: is it truly a vital sign? *J Trauma*. 2007; 62:812–817. [PubMed: 17426534]
34. Bruns B, Gentilello L, Elliott A, Shafi S. Prehospital hypotension redefined. *J Trauma*. 2008; 65:1217–1221. [PubMed: 19077604]
35. Claridge JA, Crabtree TD, Pelletier SJ, Butler K, Sawyer RG, Young JS. Persistent Occult Hypoperfusion Is Associated with a Significant Increase in Infection Rate and Mortality in Major Trauma Patients. *J Trauma Acute Care Surg*. 2000; 48:8.
36. Esposito TJ, Offner PJ, Jurkovich GJ, Griffith J, Maier RV. Do prehospital trauma center triage criteria identify major trauma victims? *Arch Surg*. 1995; 130:171–176. [PubMed: 7848088]
37. Rados A, Tiruta C, Xiao Z, Kortbeek JB, Tourigny P, Ball CG, Kirkpatrick AW. Does trauma team activation associate with the time to CT scan for those suspected of serious head injuries? *World J Emerg Surg*. 2013; 8:48. [PubMed: 24245486]
38. American College of Surgeons Committee on Trauma. Resources for the optimal care of the injured patient. Chicago, IL: American College of Surgeons; 2006. Prehospital Trauma Care; p. 21-26.
39. Lehmann RK, Arthurs ZM, Cuadrado DG, Casey LE, Beekley AC, Martin MJ. Trauma team activation: simplified criteria safely reduces overtriage. *Am J Surg*. 2007; 193:630–634. discussion 634–635. [PubMed: 17434371]
40. Lehmann RK, Brounts L, Lesperance K, Eckert M, Casey L, Beekley AC, Martin M. A simplified set of trauma triage criteria to safely reduce overtriage: A prospective study. *JAMA Surg*. 2009; 144:853–858.
41. Shawhan RR, McVay DP, Casey L, Spears T, Steele SR, Martin MJ. A simplified trauma triage system safely reduces overtriage and improves provider satisfaction: a prospective study. *Am J Surg*. 2015
42. Tominaga, GT.; Danda, IS.; Schaffer, KB.; Wells, C.; Sedwitz, M.; Gawlik, M. Poster 105: Safe and cost effective method of decreasing trauma system overtriage without overburdening the

trauma service. 73rd Annual Meeting of the American Association for the Surgery of Trauma; Philadelphia, PA. 2014;

43. Guyette, FX.; Meier, E.; Kerby, J.; Williams, C.; Schlamp, R.; Want, R.; McMullan, J.; Kannas, D.; May, S.; Daya, M., et al. Prehospital Lactate for Identification of the Need for Resuscitative Care in Trauma Patients Transported by Air. American Heart Association Resuscitation Science Symposium; Nov 15–19 2014; Chicago, IL: American Heart Association; Abstract number 3
44. Pyne DB, Boston T, Martin DT, Logan A. Evaluation of the Lactate Pro blood lactate analyser. Eur J Appl Physiol. 2000; 82:112–116. [PubMed: 10879451]
45. Ridenour RV, Gada RP, Brost BC, Karon BS. Comparison and validation of point of care lactate meters as a replacement for fetal pH measurement. Clin Biochem. 2008; 41:1461–1465. [PubMed: 18824163]

Figure 1.

ACS algorithm, trauma activation algorithm based solely on the American College of Surgeons tiered trauma team activation criteria (A). ACS+LAC algorithm, trauma activation algorithm using both American College of Surgeons tiered trauma team activation criteria and prehospital lactate level (B).

Figure 2.

Decision curve analysis comparing strategies for determining whether patients undergo any level of trauma activation versus no trauma activation. Net benefit represents the difference between expected benefit (patients with trauma center need [TCN] that undergo trauma activation) and expected harm (patients without TCN that undergo trauma activation) multiplied by a weighting factor related to the threshold probability. Threshold probability represents the given risk of a patient requiring trauma center care at which trauma activation is warranted.

Table 1

Adapted American College of Surgeons Tiered Trauma Team Activation Criteria

Full Trauma Team Activation		Limited Trauma Team Activation	
Physiologic Criteria		Mechanism of injury criteria	
1	Unable to adequately ventilate, intubated or assisted ventilation	1	Fall >20 feet
2	Respiratory rate <10 or >29 bpm	2	Fall in anticoagulated older adult
3	Systolic blood pressure <90mmHg	3	Auto crash with ejection or death in same passenger compartment
4	GCS 13 or GCS motor 5	4	Auto versus pedestrian
5	Deterioration of previously stable patient	5	Motorcycle crash
6	Requiring blood transfusion		Ejection from motorcycle or ATV
Anatomic Criteria			
1	Penetrating injury to head, neck, trunk, extremities proximal to elbow/knee		
2	Open or depressed skull fracture		
3	Paralysis or suspected spinal cord injury		
4	Flail chest		
5	Unstable pelvic fracture		
6	Amputation proximal to wrist/ankle		
7	2 proximal long bone fractures		
8	Crushed, degloved, mangled extremity		

Table 2

Study population characteristics and comparison of patients with and without trauma center need

	Study population N=6347	TCN N=1771 (28%)	No TCN N=4576 (72%)	p value*
Age [years, med (IQR)]	44 (27, 61)	45 (28, 64)	44 (27, 61)	<0.01
Gender [n (%) male]	4329 (68.2)	1276 (72.0)	3053 (66.7)	<0.01
Mechanism [n (%) penetrating]	343 (5.5)	162 (9.3)	181 (4.0)	<0.01
Prehospital time [mins, med (IQR)]	57 (46, 71)	65 (53, 82)	54 (44, 67)	<0.01
Prehospital lactate [mmol/L, med (IQR)]	2.1 (1.3, 3.0)	2.6 (1.8, 3.9)	1.9 (1.3, 2.7)	<0.01
Prehospital lactate <2.5mmol/L [n (%)]	4106 (64.7)	842 (47.5)	3264 (71.3)	<0.01
Prehospital lactate 2.5–4.0mmol/L [n (%)]	1501 (23.6)	518 (29.2)	983 (21.5)	<0.01
Prehospital lactate >4.0mmol/L [n (%)]	740 (11.7)	411 (23.2)	329 (7.2)	<0.01
Prehospital SBP [mmHg, med (IQR)]	136 (122, 151)	133 (113, 151)	137 (124, 151)	<0.01
Prehospital GCS [med (IQR)]	15 (14, 15)	11 (3, 15)	15 (15, 15)	<0.01
Prehospital RR [breaths/min, med (IQR)]	18 (16, 20)	18 (15, 20)	18 (16, 20)	0.17
Prehospital HR [beats/min, med (IQR)]	91 (78, 104)	93 (78, 109)	90 (78, 102)	<0.01
ACS physiologic activation criteria [n (%)]	1637 (25.8)	1239 (70.0)	398 (8.7)	<0.01
ACS anatomic activation criteria [n (%)]	1252 (19.7)	613 (34.6)	639 (14.0)	<0.01
ACS mechanism activation criteria [n (%)]	1264 (19.9)	366 (20.7)	898 (19.6)	0.35
Admission SBP [mmHg, med (IQR)]	136 (120, 150)	126 (108, 148)	138 (122, 152)	<0.01
Admission GCS [med (IQR)]	15 (14, 15)	6 (3, 15)	15 (15, 15)	<0.01
Admission RR [breaths/min, med (IQR)]	16 (16, 18)	15 (2, 18)	17 (16, 18)	<0.01
Admission HR [beats/min, med (IQR)]	90 (78, 104)	90 (76, 107)	90 (78, 102)	0.78
ISS [med, (IQR)]	9 (4, 17)	17 (9, 25)	9 (4, 13)	<0.01
ICU admission [n (%)]	2954 (46.5)	1557 (87.9)	1397 (30.5)	<0.01
ICU LOS [days, med (IQR)]	2 (1, 6)	3 (1, 9)	2 (1, 3)	<0.01
Emergent surgery for hemorrhage or craniotomy [n (%)]	360 (5.7)	360 (20.3)	0 (0, 0)	<0.01
LOS [days, med (IQR)]	3 (1, 8)	6 (2, 14)	3 (1, 6)	<0.01
Survival [n (%)]	5993 (94.4)	1417 (80.0)	4576 (100.0)	<0.01

* comparing TCN and No TCN

TCN, trauma center need; med, median; IQR, interquartile range; SBP, systolic blood pressure; GCS, Glasgow Coma Scale; RR, respiratory rate; HR, heart rate; ACS, American College of Surgeons; ISS, injury severity score; ICU, intensive care unit; LOS, length of stay

Table 3

Reclassification table stratified by event status for trauma activation level algorithms

	ACS+LAC algorithm			
ACS algorithm	No trauma activation	Level 2 trauma activation	Level 1 trauma activation	Total
No trauma activation				
Patients with TCN	184	0	20	204
Patients without TCN	2690	0	185	2875
Total	2874	0	205	3079
Level 2 trauma activation				
Patients with TCN	33	11	5	49
Patients without TCN	515	174	46	735
Total	548	185	51	784
Level 1 trauma activation				
Patients with TCN	0	0	1518	1518
Patients without TCN	0	0	966	966
Total	0	0	2484	2484
Totals				
Total with TCN	217	11	1543	1771
Total without TCN	3205	174	1197	4576
Total overall	3422	185	2740	6347

Dark shading indicates upgrade of trauma activation level based on ACS+LAC algorithm; Light shading indicates downgrade of trauma activation level based on ACS+LAC algorithm.

TCN, trauma center need; ACS, American College of Surgeons; LAC, lactate

Table 4

Comparison of diagnostic test and reclassification characteristics for trauma activation level algorithms for trauma center need

Trauma activation vs. No trauma activation	ACS algorithm	ACS+LAC algorithm	p value
Sensitivity (%)	88.4	87.7	-
Specificity (%)	62.8	70.0	-
PPV (%)	47.9	53.1	-
NPV (%)	93.3	93.7	-
Over-triage/False Positive (%)	37.2	30.0	-
Under-triage/False Negative (%)	11.6	12.3	-
Accuracy (%)	70.0	75.0	-
ROC AUC (95%CI)	0.757 (0.746, 0.767)	0.789 (0.779, 0.799)	<0.01
Event NRI [% (95%CI)] *	-	-0.7 (-1.6, 0.1)	-
Non-event NRI [% (95%CI)] *	-	7.2 (6.1, 8.4)	-
NRI (95%CI) *	-	0.065 (0.051, 0.079)	<0.01
Event wNRI (95%CI) *	-	-0.016 (-0.025, -0.008)	-
Non-event wNRI (95%CI) *	-	0.059 (0.048, 0.071)	-
wNRI (95%CI) *	-	0.043 (0.029, 0.057)	0.01

* NRI statistics for reclassification of patients comparing the ACS+LAC algorithm to the ACS algorithm. PPV, positive predictive value; NPV, negative predictive value; ROC AUC, receiver operating characteristic area under the curve; 95%CI, 95% confidence interval; NRI, net reclassification improvement; wNRI, weighted net reclassification improvement; ACS, American College of Surgeons; LAC, lactate