Association Between a Geriatric Trauma Resuscitation Protocol Using Venous Lactate Measurements and Early Trauma Surgeon Involvement and Mortality Risk

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OBJECTIVES: To investigate whether implementing a geriatric resuscitation protocol that uses lactate-guided therapy with early trauma surgeon involvement is associated with lower mortality through the early recognition of occult hypoperfusion (OH).

DESIGN: Prospective cohort study.

SETTING: Level I trauma center.

PARTICIPANTS: All hemodynamically stable individuals with blunt trauma aged 65 and older admitted to the Level I trauma center from October 1, 2008, through December 31, 2011 (n = 1,998).

MEASUREMENTS: Mortality over time (according to quarter) was analyzed using an adjusted logarithmic regression model stratified according to the presence of OH. OH was defined as lactate of 2.5 mM or greater.

RESULTS: Overall mortality was 3.9% (n = 78). Admission venous lactate was collected in 73.5% of participants, of whom 20.5% had OH (n = 301). In participants with OH, a significant decrease in mortality was observed over time (adjusted coefficient of determination (R^2) = 0.66, P = .002). A smaller yet significant decrease in mortality rates in participants with normal perfusion status was also observed (adjusted R^2 = 0.55, P = .01).

CONCLUSION: Early identification and treatment of OH in elderly adults with trauma using venous lactate-guided therapy coupled with early trauma surgeon involvement was associated with significantly lower mortality. A protocol that uses lactate-guided therapy with early trauma surgeon involvement should be followed to improve the care of elderly adults with trauma. **J Am Geriatr Soc 61:1358–1364, 2013.**

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Trauma is the fifth leading cause of death in individuals aged 65 and older.[1] Optimal triage and care of elderly adults presenting with trauma is difficult, with frequent failure to appreciate injury severity and its physiological consequences. Poor physiological reserve reduces the ability to respond to injury or tolerate aggressive resuscitation,[2] whereas polypharmacy can alter the hemodynamic response and complicate the individual's clinical picture.[3] As a result, the severity of injury and the response to resuscitative efforts are often underestimated.[4,5]

Hemodynamically stable, severely injured individuals have high rates of occult hypoperfusion (OH), ranging from 16% to 70%.[6–8] OH that lasts longer than 12 hours in elderly adults with trauma increases mortality from 12% to 35%.[1] An initial venous lactate measurement has been shown to be strongly predictive of in-hospital mortality,[9–15] particularly in older adults.[1,16,17] Measuring admission venous lactate may facilitate recognition and early treatment of OH in elderly adults with trauma.

Few triage and resuscitation guidelines include measures of hemodynamic instability other than systolic blood pressure, heart rate, cardiac output, and urine output. Recently the International Consensus Conference and Eastern Association for the Surgery of Trauma published guidelines regarding the utility of venous lactate and base deficit in the diagnosis of shock and intensive care unit (ICU) admission.[18–20] Although guidelines have been developed suggesting the utility of lactate measurements, few studies have shown the long-term effects of such a protocol,[6,7,21,22] and none have examined the utility of lactate-guided therapy in older adults with trauma. Because of the high risk of OH and mortality after traumatic injury in older adults, triage and resuscitation guidelines should be customized to identify inadequate and underrecognized hypoperfusion.

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A novel geriatric trauma resuscitation protocol at a Level I trauma center that uses venous lactate measurement on admission and trauma surgeon involvement in all elderly adults with trauma was recently reported.[23] This study demonstrated lower mortality and a trend toward significantly fewer preventable deaths in the short term after the geriatric protocol was implemented than in the preimplementation period. The current study objective was to determine whether the geriatric resuscitation protocol has decreased mortality since it was implemented. It was hypothesized that lactate-guided therapy with early trauma surgeon involvement would be associated with lower mortality, particularly for individuals with recognized OH.

METHODS

Study Location, Selection Criteria, and Design

St. Anthony Hospital is an urban Level I Trauma Center in Lakewood, Colorado. More than 20% of the 2,400 individuals admitted for trauma annually are aged 65 and older. This prospective observational cohort study evaluated the medical records of all individuals consecutively admitted for trauma aged 65 and older from October 1, 2008, through December 31, 2011. Individuals were excluded if they were not hemodynamically stable, defined as systolic blood pressure less than 90 mmHg or heart rate greater than 120 beats per minute in the emergency department (ED); had experienced a penetrating or thermal mechanism of injury; were dead on arrival; died in the ED; were discharged from the ED; or were transferred out of the ED (n = 145 exclusions). Dedicated trauma registrars prospectively abstracted data on all trauma admissions into a trauma registry (TraumaBase, Denver, CO), including venous lactate measurements. The St. Anthony Hospital institutional review board approved the study.

Treatment Protocol

A geriatric trauma resuscitation guideline was first developed in January 2008 to use venous lactate in the ED for resuscitation and early trauma surgeon involvement for all elderly adults with trauma. The protocol was phased in during the last quarter of 2008 and was later revised in January 2011 to include serial lactate measurements and early trauma surgeon involvement for all elderly adults with trauma (Figure 1). The details of protocol development, as well as adherence and outcomes before and after implementation, have been previously published.[23] Briefly, individuals are triaged according to the American College of Surgeons Committee on Trauma and Centers for Disease Control and Prevention trauma triage criteria.[24,25] All individuals with trauma aged 65 and older have an admission venous lactate measurement in the ED; that measurement (normal (<2.5 mM) or high (≥2.5 mM), as described below) guides care. Vital signs (systolic blood pressure, heart rate) and occasionally base deficit are also used to measure tissue perfusion. The lactate value of 2.5 mM was used for the geriatric resuscitation protocol based on previous studies that identified a greater risk of mortality with a lactate measurement of 2.5 mM or higher.[11,13,16]

For individuals who are hemodynamically stable with a normal venous lactate (<2.5 mM), trauma surgeons consult within 6 hours of arrival to ensure that all resuscitative and diagnostic strategies are completed, there are no missed injuries, and any additional questions are addressed related to age, comorbidity, and polypharmacy. Serial lactate measurements are taken in individuals with a normal admission venous lactate every 6 hours for the first 24 hours, and pre- and postoperatively, to ensure that all incidences of OH are recognized, including cases in which the older adult's response to trauma is delayed or manifests after surgery.

Elderly adults with trauma with lactate levels of 2.5 mM or greater are admitted to the trauma service, and Advanced Trauma Life Support (ATLS) protocols are used, including control of active bleeding and fluid resuscitation with 2 L of crystalloids. Serial lactate measurements and central venous pressure guide volume resuscitation, and nonemergent surgical procedures are delayed until lactate is improving (~ <1.9 mM). Diagnostic procedures are performed as indicated according to the individual's condition (to identify alternative explanations for high lactate levels). Serial lactate measurements are taken in individuals with a high admission venous lactate level to guide resuscitation or identify an alternative condition that needs to be treated and repeated as needed until lactate is improving (~ <1.9 mM).

Outcome and Covariates

The primary outcome was in-hospital mortality, which was examined in hemodynamically stable individuals with trauma with high lactate levels (≥2.5 mM) and in those with normal perfusion status (lactate <2.5 mM). Covariates were age (65–84 vs ≥85), sex, trauma team activation (TTA, prehospital activation of the trauma team, defined as yes vs no), fall cause of injury (fall vs all other types), injury severity score (ISS, ≥16 vs <16), Glasgow Coma Scale (GCS, ≤12 vs 13–15), presence of a comorbidity (yes vs no), and presence of liver disease (yes vs no).

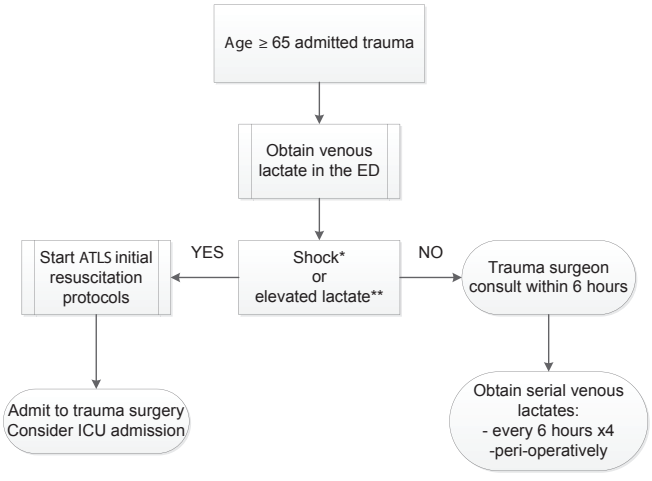

Figure 1. Geriatric trauma resuscitation protocol, revised January 1, 2011, to include serial venous lactate measurements in participants with normal perfusion status.
* Shock, systolic blood pressure <90 mm Hg or heart rate >120 beats/min.
** Elevated lactate, ≥2.5 mM.

Statistical Analysis

Statistical analyses were performed using SAS, version 9.2 (SAS Institute, Inc, Cary, NC). Categorical data are reported as proportions with 95% confidence intervals (CIs) and tested for significant differences using chi-square tests and Cochran-Armitage trend tests where appropriate. For continuous variables, multiple groups were compared using analysis of variance with Tukey-Kramer post hoc adjustment.

There were three distinct phases of development during the study period: training staff for Version 1 of the protocol (training, October 1, 2008–March 31, 2009), implementation of Version 1 (initial protocol, April 1, 2009–December 31, 2010), and implementation of the revised protocol that incorporates serial lactate measurements (revised protocol, January 1, 2011–December 31, 2011). Demographic and clinical characteristics were examined according to stage of protocol development (Table 1) to present differences in demographic characteristics during the study period, which would not otherwise be easily presentable over time (according to quarter).

Demographic and clinical characteristics were examined over time (according to quarter), stratified according to the presence or absence of OH, to identify variables with $P < .20$ to be adjusted for in multivariate analysis. TTA ($P = .16$) and GCS ($P = .05$) were significant at $P < .20$ in univariate analyses in the OH population; TTA ($P = .04$), GCS ($P = .15$), fall injury ($P = .06$), comorbidity ($P = .09$), and liver disease ($P = .04$) were significant in the normal perfusion status population (data not shown). The association between the geriatric protocol and mortality over time was analyzed using an adjusted logarithmic regression model, stratified according to the presence or absence of OH. Mortality would not be expected to reach or cross 0.0%, so a linear model was not chosen; a log-based transformation was used, because this produced the best fit according to coefficient of determination (r^2). Significance was set at $P < .05$ for all analyses.

RESULTS

Participant Demographics

There were 1,998 elderly adults with trauma who met inclusion criteria. The majority of the study population were women (55.5%) aged 65 to 84 (69.4%) with comorbidities (85.5%) with minor injuries from a fall (79.6%) and with no or minor neurological deficit (GCS 13–15: 95.0%). Demographic and clinical data are presented for the three implementation periods in Table 1. As expected, admission lactate measurements, serial lactate measurements, and trauma surgeon consultations increased over the study period ($P < .001$). There was also a significant increase in individuals with liver disease ($P = .04$), but there were no differences in terms of age, proportion of women, comorbidity, fall cause of injury, severe injury (ISS $\geq$ 16), moderate to severe neurological deficit (GCS $\leq$ 12), or trauma team activation between the three implementation periods.

Adherence to taking lactate measurements and providing trauma surgeon consultations is shown in Figure 2. Admission venous lactate measurements were performed in 73.5% of participants. Median time to the first lactate measurement within 24 hours of hospital arrival was 148 minutes; 44.8% of participants had a lactate measurement within 60 minutes. There were significantly more participants who had a lactate measurement over time ($r^2 = 0.36$, $P = .03$, Figure 2A), with adherence of 52.2% during the training period, 73.1% during the initial protocol period, and 82.8% during the revised protocol period. Half of participants (50.3%) had serial lactate measured, which signifi-

Table 1. Demographic and Clinical Characteristics According to Protocol Revision

Characteristic	Training Period,[a] n = 276	Initial Protocol,[b] n = 1,047	Revised Protocol,[c] n = 675	*P*-Value[d,e]
Aged ≥85, n (%)	93 (33.7)	313 (29.9)	206 (30.5)	.50
Female, n (%)	156 (56.5)	577 (55.1)	375 (55.6)	.88
Comorbid condition, n (%)	236 (85.5)	884 (84.6)	584 (86.8)	.40
Liver disease, n (%)	1 (0.4)	12 (1.1)	13 (1.9)	.04
Trauma team activation, n (%)	66 (23.9)	241 (23.0)	134 (19.9)	.10
Fall cause of injury, n (%)	218 (79.0)	831 (79.4)	541 (80.2)	.65
Injury severity score ≥16, n (%)	31 (11.2)	135 (13.0)	84 (12.5)	.75
Glasgow Coma Scale score ≤12, n (%)	19 (7.4)	48 (4.6)	31 (4.6)	.17
Trauma service admission, n (%)	125 (45.3)	583 (55.7)	363 (53.8)	.10
Trauma service consultation, n (%)	185 (67.0)	819 (78.2)	558 (82.7)	< .001
Lactate measured, n (%)	144 (52.2)	765 (73.1)	559 (82.8)	< .001
Serial lactate measured, n (%)	43 (29.9)	318 (41.6)	378 (67.6)	< .001
Initial lactate level >2.5 mM, n (%)	23 (16.0)	167 (21.8)	111 (19.9)	.77
Initial lactate level, mean ± SD	1.9 ± 1.4	1.9 ± 1.0	1.9 ± 1.3	.99
TRISS pS, mean ± sd	0.95 ± 0.12	0.96 ± 0.09	0.96 ± 0.10	.53
In-hospital mortality, n (%)	20 (7.2)	34 (3.2)	24 (3.6)	.04

[a]October 1, 2008–March 30, 2009 (one quarter before and after implementation on January 1, 2009).
[b]April 1, 2009–December 31, 2010 (admission lactate measurements only).
[c]January 1, 2011–December 31, 2011 (admission and serial lactate measurements).
[d]Analysis of variance with Tukey-Kramer adjustment was used for continuous variables.
[e]Cochran-Armitage trend tests were used for categorical variables.
SD = standard deviation; TRISS pS = Trauma Injury Severity Score Probability of Survival.

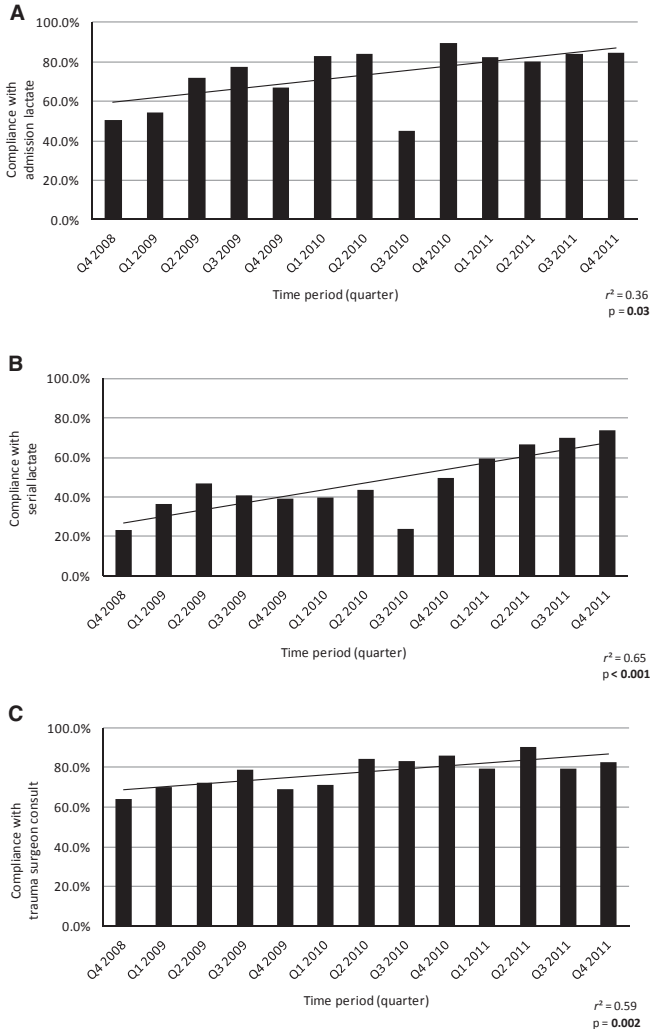

Figure 2. Geriatric trauma resuscitation protocol compliance over time: (A) admission venous lactate, (B) serial venous lactate, (C) trauma surgeon consultation.

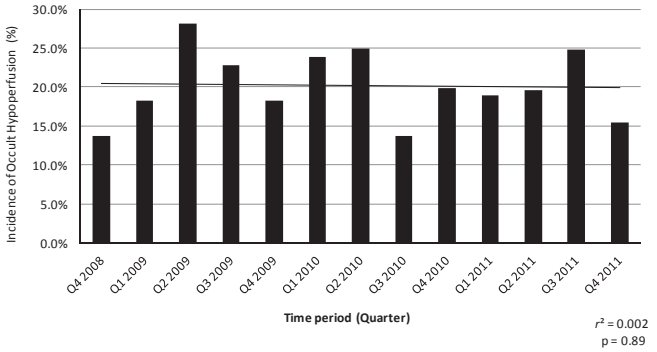

Figure 3. Incidence of occult hypoperfusion (venous lactate ≥2.5 mM in hemodynamically stable participants (systolic blood pressure >90 mmHg and heart rate <120 beats/min)) over time. R^2 = coefficient of determination.

cantly increased over time (r^2 = 0.65, P < .001, Figure 2B). Over two-thirds (78.2%) of participants had a trauma surgeon consultation, which increased significantly over time (r^2 = 0.59, P = .002, Figure 2C).

Three hundred one of 1,468 participants with lactate recorded (20.5%) had OH. The incidence of OH did not

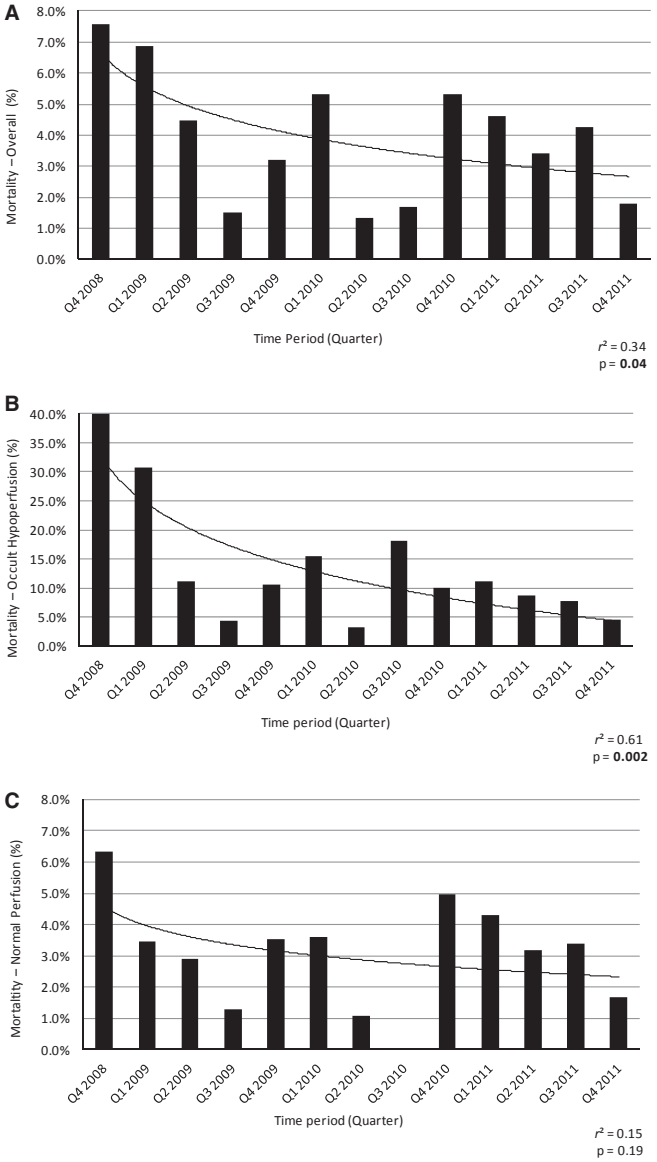

Figure 4. Percentage mortality over time: (A) overall mortality, (B) mortality in participants with occult hypoperfusion (venous lactate ≥ 2.5 mM), (C) mortality in participants with normal perfusion status (venous lactate < 2.5 mM). R^2 = coefficient of determination.

increase significantly over time (r^2 = 0.002, P = .89, Figure 3), with an incidence of OH of 16.0% during the training period, 21.8% during the initial protocol period, and 19.9% during the revised protocol period.

Mortality

Overall mortality during the study period was 3.9% (n = 78). Mortality fell significantly by quarter (Figure 4A; R^2 = 0.34, P = .04) and by implementation period (Table 1; 7.2%, 3.2%, 3.6%, P = .04). Compared to participants who were discharged, participants who died were more often male (44.0% vs 57.7%; P = 0.02), had worse overall injuries (ISS ≥ 16: 11.1% vs 47.4%, P < .001) and worse GCS (≤12: 3.6% vs 40.3%, P < .001), were more often TTA (21.2% vs 43.6%, P < .001), and had lactate levels of 2.5 mM or higher (19.1% vs 47.8%, P < .001)

than participants who were discharged. There were no significant differences in mortality according to age ($P = .13$), comorbidity ($P = .08$), liver disease ($P > .99$), and fall cause of injury ($P = .76$).

In participants with OH, a significant decrease in mortality was observed over time after the protocol was implemented ($r^2 = 0.61$, $P = .002$, Figure 4B). After adjustment for GCS and TTA, there continued to be a significant decrease in mortality ($R^2 = 0.66$, $P = .002$).

In participants with normal perfusion status, mortality did not fall significantly over time before adjustment ($r^2 = 0.15$, $P = .19$, Figure 4C), although after adjustment for GCS, TTA, fall cause of injury, comorbidity, and liver disease, mortality fell significantly over time ($r^2 = 0.55$, $P = .01$).

DISCUSSION

Older adults respond to trauma differently than their younger counterparts because of comorbid conditions, polypharmacy, and inadequate cardiovascular response to trauma. This study demonstrates that using a geriatric-specific initial resuscitation protocol that includes an admission lactate measurement and resuscitation under the supervision of a trauma surgeon using objective markers of perfusion decreases mortality. These findings were observed in a low-risk population of older adults with trauma that excluded individuals with criteria that normally necessitate aggressive triage and resuscitation. ATLS protocols were used before the study but only in individuals with symptoms and signs of shock; ATLS protocols were not used in individuals with OH because this would not have been routinely recognized before the protocol. Elderly adults with trauma should be closely monitored because the observed hemodynamic parameters may not fully elucidate tissue perfusion status. More-aggressive and timely resuscitation and trauma care should be given to individuals with hyperlactemia because a high initial lactate level has consistently been shown to be a useful marker of injury severity and mortality, and several studies have shown that failure of an initially high lactate to return to normal is associated with higher infection rates[6,7] and mortality.[6,26]

A recent systematic review reported that an initial lactate measurement is useful for risk assessment and, if high, requires close monitoring for signs of deterioration, but additional studies are needed to support the usefulness of lactate-guided therapy.[27] Four studies have examined lactate-guided therapy, including three observational studies[6,7,21,22] and one randomized clinical trial.[21] These studies all showed that lactate-guided therapy is associated with improved outcomes. One study reported that participants required additional therapy after initial resuscitation and stabilization according to heart rate and mean arterial pressure and that resuscitation using central venous oxyhemoglobin saturation and arterial lactate can be used to guide additional therapy.[22] Another examined hemodynamically stable individuals with severe blunt trauma injury (ISS $\geq$ 20) and demonstrated that aggressive resuscitation aimed at correcting lactate improves survival and decreases complications.[6] Another study examined individuals with trauma admitted to the ICU to determine the relationship between OH and infectious episodes and found that lactic acid levels that did not correct within 12 hours were independently predictive of infections.[7] A randomized clinical trial demonstrated that, in individuals with hyperlactatemia on ICU admission, lactate-guided therapy significantly reduced hospital mortality when adjusting for predefined risk factors.[21] Like these studies, the current one also demonstrated, in a population of older adults with trauma, that using lactate-guided protocol may be important in improving outcomes such as survival. The results were demonstrated in a population with predominantly minor injuries.

It is recognized that the management of elderly adults with trauma should differ from that of their younger counterparts because older adults often have inadequate cardiovascular response to trauma, despite normal vital signs in the ED.[2] Only four studies have examined outcomes after the implementation of a geriatric-specific triage or resuscitation protocol.[2,28–30] The first published geriatric protocol in 1986 included early invasive monitoring and delayed diagnostic testing in the ED; these changes led to a decrease in mortality and multiple organ failure by recognizing occult shock early.[2] A "high-risk geriatric protocol" in which individuals are deemed high risk and meet eligibility criteria for the geriatric protocol if they present with a high-risk injury, a medical history indicator, and an assessment indicator such as high lactate was recently published; it was determined that the protocol significantly decreased mortality through prompt recognition of occult shock.[28] Previously developed TTA criteria were revised to include aged 70 and older and to introduce an early, aggressive resuscitation protocol, leading to better survival.[29] Evidence-based geriatric-specific trauma triage criteria developed in Ohio are used statewide and will be used to examine over- and undertriage and mortality.[30] The authors of the current protocol believe that is easy to understand, and continuing education with the ED physicians, trauma physician assistants, and inpatient hospitalists increased adherence to lactate measurements and trauma surgeon consultations. Before institution of the geriatric resuscitation protocol, management of the elderly population did not differ from that of their younger counterparts. The protocol heightens the awareness that the geriatric population requires vigilance of all clinicians in the trauma continuum, including ED physicians, consulting surgeons, anesthesiologists, and trauma surgeons.

Based on these findings in nearly 2,000 elderly adults with trauma, the use of an admission venous lactate measurement to identify elderly adults with trauma with poor or incomplete resuscitation is advocated, particularly because there is a surprisingly high percentage with OH even in a population with minor injuries. These results demonstrate that, in individuals identified in the ED with hyperlactemia, a lactate-guided resuscitation protocol was associated with significantly lower mortality over the study period.

Furthermore, early trauma surgeon involvement in individuals with normal perfusion status in the ED and lactate monitoring in the first 24 hours and perioperatively may identify individuals with delayed inadequate perfusion, decreasing mortality; slightly but significantly lower mortality was observed in individuals with normal perfusion status in the ED over the study period. Consultation by trauma surgeons was mandatory after the geriatric

trauma resuscitation protocol was implemented, unlike during the preprotocol period, when emergency medicine physicians and in-patient hospitalists cared for older adults not presenting with overt shock or severe trauma. Consultations usually require minimal time (~20 minutes), yet they ensure that extra care is taken in the management of elderly adults. It was previously reported that trauma surgeon involvement and commitment to trauma care decreased mortality.[31] Early trauma surgeon involvement was associated with better outcomes in the current study as well.

The effect of the geriatric protocol 1 year after implementation was previously reported on. Because it was decided to focus this study on the long-term effects and consequences of instituting a geriatric-specific resuscitation protocol after traumatic injury, there is no true control group. A decrease in mortality was observed concurrently with greater protocol adherence over time. It may be that commitment and adherence to a protocol based on objective markers of perfusion resulted in lower mortality, although the act of standardizing practice protocols may have improved outcomes independent of whether the protocols were evidence-based or effective; as such, the "Hawthorne effect" cannot be excluded.

Only 73.5% of participants had an admission lactate measurement. Participants who did not have lactate measured were less severely injured and more likely to have a fall cause and had lower mortality than those with lactate measured in the ED. Lactate measurement adherence increased over the study period, but there were no differences in the incidence of OH or in any covariates except liver disease over the study period (Table 1). There was no association between probability of survival over time in participants with a lactate measurement, so it is unlikely that the increase in lactate adherence over time biased the findings by increasing the number of individuals studied with a survival benefit in later years.

This study has limitations. First, it was a single-center study; the geriatric resuscitation protocol is expanding to additional trauma centers in the Centura Health Trauma System, and there are plans to repeat the study in a multiinstitutional setting once it has been implemented throughout the system. Second, this was an observational study that has inherent limitations of a study using registry data. This limitation is minimized because lactate measurements were added to the trauma registry at the beginning of the study period, and all data were entered prospectively. Additional prospective studies in a large subset of elderly adults with trauma are warranted to confirm the findings. Third, the population of elderly adults with trauma admitted to the trauma center is skewed away from very minor traumatic injury. Information was not available on individuals who were not admitted, and thus whether the risk of deterioration after discharge from the ED was similar before and after the protocol was implemented cannot be determined. Finally, there are other causes of high lactate levels than tissue hypoxia and hypoperfusion, including seizures, severe respiratory distress, certain medications, thiamine deficiency, carbon monoxide or cyanide toxicity, and diabetic ketoacidosis.[32] The current study did not determine the etiology of hyperlactemia in the individuals with OH; it was assumed that high lactate levels were a result of tissue hypoxia after traumatic injury.

CONCLUSION

A geriatric trauma resuscitation protocol that uses admission venous lactate measurement for risk assessment and guidance of care was significantly associated with lower mortality. These findings were observed in a low-risk population of older adults with trauma that excluded individuals with criteria that normally necessitate aggressive triage and resuscitation. Admission venous lactate and serial lactate measurements should be used to quickly identify OH and guide early resuscitation and early trauma surgeon involvement to improve the care and outcomes of elderly adults with trauma.

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Conflict of Interest: The authors have no conflict of interest disclosures to report.

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Author Contributions: Salottolo and Bar-Or conceived the study idea. Salottolo and Bourg were involved in data selection and data collection. Salottolo, Orlando, and Bar-Or are responsible for the integrity of the data in this study and the accuracy of the data analysis. Salottolo, Orlando, and Bar-Or were involved in writing the manuscript. Mains, Offner, and Bourg reviewed and revised the manuscript for accuracy.

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