Just One Drop: The Significance of a Single Hypotensive Blood Pressure Reading During Trauma Resuscitations

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Background: Single, isolated hypotensive blood pressure (BP) measurements frequently are ignored or considered "erroneous." Although their clinical significance remains unknown, we hypothesized that single, isolated hypotensive BP readings during trauma resuscitations signify the presence of severe injuries that often warrant immediate intervention.

Methods: A prospective observational study was performed on all trauma patients admitted from June 2008 to January 2009. Patients with a single systolic blood pressure (SBP) reading <110 mm Hg during their trauma resuscitation were evaluated, and demographics, hemodynamics, resuscitation (fluids, blood products, and duration), injuries, and operative or endovascular management were analyzed. Single and multiple variable logistic regression analyses were performed. Cutpoint analysis of the entire range of lowest single SBP measurements determined which SBP value best predicted the need for immediate therapeutic intervention.

Results: Patients (n = 145) were predominantly male (77.2%) but age (mean, 35.1 ± 15.3 years) and injury mechanisms varied (penetrating, 46.2%; blunt, 53.8%). Cutpoint analysis determined that a single SBP reading <105 mm Hg best predicted the need for immediate therapeutic intervention. Although 38.1% patients with isolated SBP <105 mm Hg measurements underwent immediate therapeutic operative or endovascular procedures, only 10.4% ($p < 0.001$) with isolated SBP ≥105 mm Hg required these procedures. Patients were 12.4 times (confidence interval: 2.6–59.2; $p = 0.002$) more likely to undergo immediate therapeutic intervention than those with a single SBP ≥105 mm Hg.

Conclusions: Single, isolated hypotensive BP measurements during trauma resuscitations should not be ignored or dismissed. Instead, our results suggest that a single SBP reading <105 mm Hg is associated with severe injuries that often require immediate operative or endovascular treatment and surgical intensive care unit admission.

Key Words: Brief hypotension, Isolated hypotensive measurements, Blood pressure, Trauma resuscitation.

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Advanced Trauma Life Support teaches that hemorrhagic shock is not clinically evident until tachycardia and narrowed pulse pressure develops during a 15% to 30% blood volume, class II hemorrhage.[1] Hypotension becomes clinically apparent during class III hemorrhage when >1,500 mL of blood, or 30% of circulating blood volume, is lost.[1] Despite this well-established classification scheme, tachycardia in trauma patients may be an unreliable indicator of injury,[2–9] and persistent hypotension is often a late manifestation of shock that becomes evident once end-organ damage has already begun in the decompensated shock state.[10–13]

However, brief episodes of hypotension may be an early indication of impending shock. Transient hypotension during prehospital care or in the surgical intensive care unit (ICU) has been reported and determined to be predictive of both severe injury and poor outcome.[14–21] Despite these reports, single, isolated hypotensive blood pressure (BP) measurements during trauma resuscitations are often ignored or considered "erroneous."

Although their significance remains unknown, we hypothesized that a single, isolated hypotensive BP reading during trauma resuscitations indicates the presence of severe injuries that warrant immediate operation. Our primary study objective was to prove that these single, isolated hypotensive BP measurements should not be dismissed but instead should alert the clinician to the presence of injuries that require immediate operative or endovascular treatment. To this end, we also sought to determine a single hypotensive BP "cutpoint" value; measurements below which indicate the greatest likelihood of immediate therapeutic intervention.

METHODS

After Institutional Review Board approval, a prospective observational study was performed on all trauma patients admitted from June 2008 through January 2009 at Temple University Hospital. All patients with a single systolic BP (SBP) reading <110 mm Hg during their initial trauma resuscitation were evaluated. Patients between 18 years and 88 years, regardless of injury mechanism, were eligible. Patients who were transferred from outside hospitals, injured >2 hours before emergency department (ED) arrival, managed initially by ED staff, or who had only isolated prehospital hypotension were excluded. Also excluded were the patients with two or greater SBP measurements <90 mm Hg during their initial trauma resuscitation. Patients with a single SBP reading <90 mm Hg but with other measurements

between 90 mm Hg and 110 mm Hg were included in the study to allow a cutpoint analysis to determine which single SBP cutpoint value was most associated with the need for urgent operation. The final study population comprised 145 patients.

All patients with a single SBP measurement <105 mm Hg during their initial trauma resuscitation were categorized as "<105 mm Hg," regardless of other 105 mm Hg to 110 mm Hg measurements. Furthermore, all patients with at least one SBP measurement within the 105 mm Hg to 110 mm Hg range but no measurement <105 mm Hg during their initial trauma resuscitation were categorized as "≥105 mm Hg," regardless of the number of SBP readings within these limits.

Admission data analyzed included demographics, antihypertensive medications, intoxication, injury mechanism, prehospital hemodynamics and resuscitation, Injury Severity Score (ISS), Glasgow Coma Scale score, and serum lactate. Alcohol intoxication was defined by a blood alcohol level >80 mg/dL. On admission, trauma resuscitation parameters including lowest SBP, total number of BP measurements, and total initial trauma resuscitation time were analyzed. Resuscitation time was defined as the elapsed time beginning with the trauma team activation and ending with the completion of computed tomography studies after the initial trauma resuscitation. The initial BP was manually obtained within 10 minutes of arrival to the ED. The remainder of recorded BPs were automatically measured (Duracheck blood pressure cuffs [Zefon International, Ocala, FL] with Datascope Passport 2 bedside monitors [Datascope, Mahwah, NJ]) for a minimum of every 5 minutes for the first 15 minutes, then every 15 minutes for the first hour, and then hourly thereafter. All BPs were documented on the trauma flow sheet by the trauma nurse. On a daily basis, data from trauma flow sheets were then transferred to the study database.

Hemodynamics and resuscitation with blood products or intravenous fluids during this time period were recorded and analyzed. All SBP measurements <90, 100, and 110 mm Hg and all heart rates >100, 110, and 120 bpm were categorized and assessed. Outcomes including immediate operative or endovascular procedures, operative resuscitation, ICU admission, hospital length of stay (LOS), and survival were analyzed. "Immediate" procedures were defined as any operating room procedure, excluding operative repair of soft tissue lacerations, performed immediately after the initial trauma resuscitation period. Procedures performed in the operating theater later, after the "immediate" period, were defined as additional operative procedures. Operative procedures were considered nontherapeutic if no intervention or repair was required during the surgical procedure (e.g., small and nonbleeding liver laceration). Endovascular procedures were defined as nontherapeutic when contrast angiography without angiographic embolization was performed.

The primary study endpoint was a need for immediate therapeutic intervention. Means are accompanied by standard deviations. Categorical and continuous variables were analyzed using Fisher's Exact Test and Student's *t* test, respectively. Single and multiple variable logistic regression analyses were used to determine predictors of the primary study endpoint. Significant univariate predictors were included in a multiple logistic regression model to determine independent/adjusted predictors. A cutpoint analysis of the entire range of lowest single SBP measurements was then performed to determine which SBP best predicted the need for immediate operation. Locally weighted regression was used to determine inflection points in the relationship of lowest SBP measurement to immediate operative intervention based on the Pearson residuals. Based on observed inflection points, several cutpoints for the lowest SBP measurement were chosen. These were substituted into the multivariate model and tested for the best fit based on −2 log likelihood values. A p value ≤0.05 was considered statistically significant. Data were analyzed using SAS V9.1.3 (SAS Institute, Cary, NC).

RESULTS

Although 4.8% of study patients (n = 145) were hypotensive during prehospital care, 30.3% had isolated SBP measurements <90 mm Hg during the initial trauma resuscitation. The mean lowest SBP was 97.0 mm Hg ± 12.0 mm Hg (mean ± standard deviation) during a mean of 6.8 ± 2.4 BP measurements per patient. Overall, patients commonly underwent immediate operative or endovascular intervention (33.8%) and required ICU admission (44.8%) although hospital survival was favorable (97.9%).

To determine which isolated SBP value best predicted the need for immediate operation, a cutpoint analysis of the entire range of lowest single SBP measurements was performed (Fig. 1, A and B). When several lowest single SBP cutpoints were tested, an isolated SBP <105 mm Hg proved to be the cutpoint SBP with best model fit and thus most predictive of immediate operative intervention.

After this cutpoint value was established, patients were compared on the basis of the lowest isolated SBP measurement (<105 mm Hg vs. ≥105 mm Hg) in Table 1. Patients with a single SBP <105 mm Hg reading during their initial trauma resuscitation more often suffered penetrating injuries ($p = 0.025$) with greater mean ISSs ($p = 0.002$) and had lower mean admission and "lowest" BPs ($p < 0.001$) despite more aggressive administration of intravenous fluids ($p = 0.004$) in the ED than those with isolated SBP ≥105 mm Hg measurements. Furthermore, patients with isolated SBP readings <105 mm Hg were more likely to undergo immediate therapeutic operative or endovascular procedures (Fig. 2; $p < 0.001$), more likely to require admission to the surgical ICU ($p = 0.001$), and had a prolonged hospital LOS ($p = 0.009$) when compared with patients with single SBP measurements ≥105 mm Hg.

Predictors of the primary study endpoint, need for immediate therapeutic intervention, were assessed with single and multiple variable logistic regression analyses (Table 2). Parameters that independently influenced the need for immediate therapeutic intervention included gunshot wound injury mechanism, ISS, isolated SBP <105 mm Hg, and initial resuscitation duration. Patients with an isolated SBP <105 mm Hg measurements were >12 times as likely to undergo

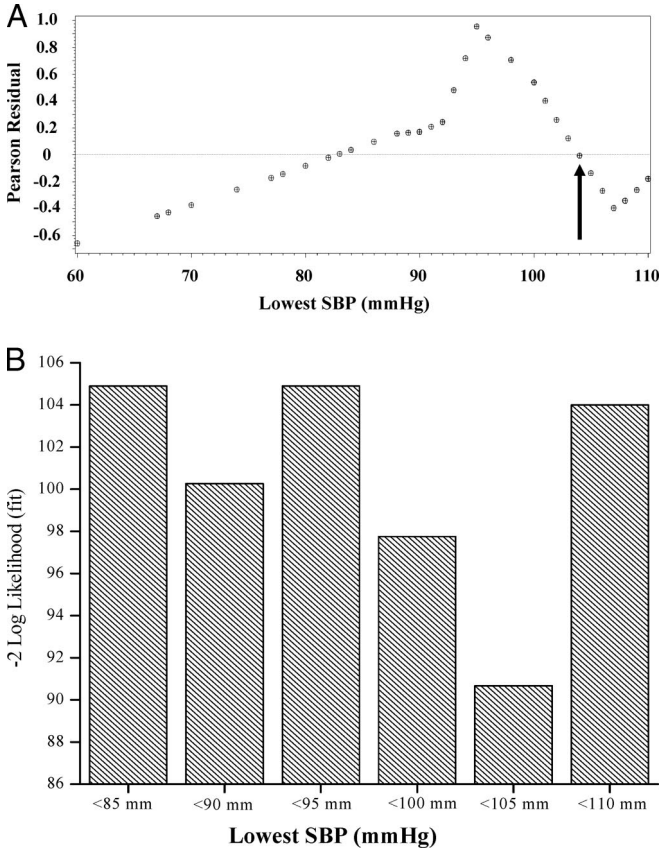

Figure 1. Cutpoint analysis of the range of lowest isolated SBP established the SBP value most predictive of the need for immediate operation. Locally weighted regression was used to determine inflection points in the lowest SBP measurement to immediate operative intervention relationship based on the Pearson residuals (*A*). Results of different lowest SBP cutpoint values on fit of regression model; smallest value indicates best fit (*B*).

immediate therapeutic operative or endovascular procedures (odds ratio, 12.4; confidence interval, 2.6–59.2; $p = 0.002$) than those with measurements SBP ≥105 mm Hg.

DISCUSSION

The most important finding of this prospective study of patients with isolated hypotensive SBP measurements was that a single SBP reading <105 mm Hg during trauma resuscitations indicated severe injury. Patients with isolated SBP <105 mm Hg measurements were ~12.4 times more likely to require immediate therapeutic operative or endovascular procedures than those with single SBP readings ≥105 mm Hg. These patients commonly required additional operative procedures (30%), surgical ICU admission (54%), and prolonged hospital LOS (mean, 8.3 ± 10.7 days). Our findings suggest that isolated hypotensive SBP measurements during an initial trauma resuscitation should not be ignored or considered erroneous but should raise suspicion for severe underlying injury.

TABLE 1. Demographics and Clinical Characteristics by Lowest Isolated SBP Measurement

Characteristic	SBP <105 mm Hg (n = 97)	SBP ≥105 mm Hg (n = 48)	*p*
Age (yr)	34.4 ± 15.2	36.6 ± 15.6	0.413
Gender (male)	78 (80.4%)	34 (70.8%)	0.212
Antihypertension medications	6 (6.2%)	3 (6.3%)	1.000
Prehospital hypotension (<90 mm Hg)	7 (7.2%)	0	0.039
Prehospital IVF	21 (21.7%)	11 (22.9%)	1.000
Prehospital IVF (mL)	423 ± 240	518 ± 371	0.389
Injury mechanism			
Gunshot wound	37 (38.1%)	10 (20.8%)	
Stab wound	18 (18.6%)	2 (4.2%)	
Fall	17 (17.5%)	14 (29.2%)	
Motor vehicle collision	9 (9.3%)	10 (20.8%)	0.025
Assault	9 (9.3%)	7 (14.6%)	
Motorcycle collision	2 (2.1%)	2 (4.2%)	
Pedestrian struck by automobile	5 (5.2%)	3 (6.3%)	
Injury severity score	12.4 ± 10.3	7.2 ± 8.7	0.002
Admission HR (bpm)	98.5 ± 23.2	100.3 ± 23.0	0.669
Admission SBP (mm Hg)	100.7 ± 24.2	121.8 ± 17.3	<0.001
Admission DBP (mm Hg)	66.3 ± 15.7	75.2 ± 13.4	0.001
Admission pulse pressure (mm Hg)	43.8 ± 17.4	47.0 ± 15.8	0.294
Admission GCS	14.1 ± 2.5	13.4 ± 3.8	0.247
Admission lactate (mmol/L)	5.7 ± 4.8	4.0 ± 4.2	0.036
Resuscitation HR >110 bpm	36 (37.1%)	15 (31.3%)	0.649
Resuscitation HR >120 bpm	23 (23.7%)	13 (27.1%)	0.662
Lowest resuscitation SBP (mm Hg)	91.1 ± 10.5	108.9 ± 1.4	<0.001
Resuscitation SBP <90 mm Hg	44 (45.4%)	0	<0.001
Number of recorded BP measurements	6.9 ± 2.5	6.8 ± 2.2	0.816
Total initial resuscitation time (min)	52.9 ± 29.5	55.3 ± 23.0	0.584
ED blood transfusion	11 (11.3%)	1 (2.1%)	0.105
ED IVF (mL)	1494 ± 955	1003 ± 868	0.003
Immediate procedure	43 (44.3%)	6 (12.5%)	<0.001
Immediate procedure type			
Abdominal	19 (19.6%)	4 (8.3%)	0.095
Thoracic	10 (10.3%)	1 (2.1%)	0.101
Neck	4 (4.1%)	0	0.302
Vascular	10 (10.3%)	2 (4.2%)	0.338
Orthopedic	3 (3.1%)	1 (2.1%)	1.000
Endovascular	5 (5.2%)	0	0.171
Nontherapeutic operative procedures	4/40 (10.0%)	1/6 (16.7%)	0.520
Nontherapeutic endovascular procedures	3/5 (60.0%)	NA	NA
Operative EBL (mL)	935 ± 1438	560 ± 428	0.217
Operative IVF (mL)	4474 ± 3028	3710 ± 1396	0.352
Operative blood transfusion	16 (16.5%)	3 (6.3%)	0.117
Additional OR during hospitalization	29 (29.9%)	8 (16.7%)	0.106
Surgical intensive care unit admission	52 (53.6%)	12 (25.0%)	0.001
Hospital length of stay (d)	8.3 ± 10.7	4.2 ± 7.5	0.009
Hospital survival	94 (96.9%)	48 (100%)	0.551

SD, standard deviation; mm Hg, millimeters of mercury; IVF, intravenous fluids; HR, heart rate; bpm, beats per minute; DBP, diastolic blood pressure; GCS, Glasgow coma scale score; EBL, estimated blood loss; OR, operating room procedure; NA, not applicable.

Values are represented as n (%) or mean ± SD.

Demographics, clinical characteristics, and outcomes were compared with respect to lowest isolated SBP (<105 vs. ≥105 mm Hg).

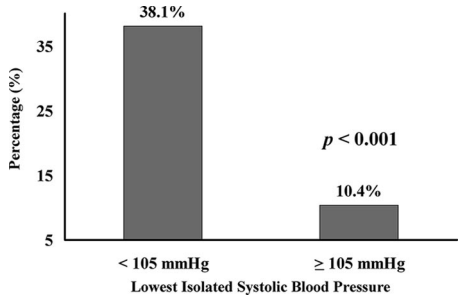

Figure 2. Patients with isolated SBP <105 mm Hg measurements more often underwent immediate therapeutic operative or endovascular procedures than those with single SBP ≥105 mm Hg readings.

TABLE 2. Predictors of Immediate Therapeutic Intervention

	Univariate Analysis			Multivariate Analysis		
Parameter	**OR**	**95% CI**	***p***	**OR**	**95% CI**	***p***
Age (yr)	0.98	0.96, 1.01	0.188			
Gunshot wound	8.84	3.93, 19.92	<0.001	8.00	2.70, 23.69	<0.001
Stab wound	1.39	0.51, 3.76	0.523			
Fall	0.13	0.03, 0.56	0.007			
Motor vehicle collision	0.42	0.16, 1.52	0.185			
Prehospital hypotension (<90 mm Hg)	2.94	0.58, 14.93	0.194			
Injury severity score	1.05	1.01, 1.08	0.013	1.07	1.02, 1.12	0.003
Admission GCS	1.03	0.90, 1.17	0.674			
Admission SBP (mm Hg)	0.98	0.96, 0.99	0.020			
Admission DBP (mm Hg)	0.97	0.94, 0.99	0.020			
Resuscitation HR >120 bpm	0.96	0.76, 1.20	0.701			
Lowest resuscitation SBP (mm Hg)	0.96	0.94, 0.99	0.014			
Resuscitation SBP <105 mm Hg	2.93	1.26, 6.82	0.012	12.36	2.58, 59.23	0.002
Total initial resuscitation time (min)	0.95	0.93, 0.97	<0.001	0.94	0.92, 0.96	<0.001
ED blood transfusion	1.00	1.00, 1.003	0.029			
ED IVF (mL)	1.00	1.00, 1.001	0.234			

OR, odds ratio; CI, confidence interval; mm Hg, millimeters of mercury; GCS, Glasgow coma scale score; DBP, diastolic blood pressure; HR, heart rate; bpm, beats per minute; IVF, intravenous fluids.

Single and multiple variable logistic regression analyses were used to determine predictors of the primary study endpoint, need for immediate therapeutic intervention.

By analyzing the entire range of lowest SBP values, we have determined that an isolated SBP <105 mm Hg measurement was the cutpoint value most predictive of immediate operative intervention. This finding corroborates recent work that has questioned whether hypotension is best defined by a value of 110 mm Hg rather than 90 mm Hg.[10–13] Bruns et al.[10] sought to determine the association between prehospital SBP and death, attempting to refine prehospital triage criteria. When patients were stratified by prehospital BP, inhospital mortality increased dramatically when prehospital SBP was <110 mm Hg. Eastridge et al.[11] analyzed the National Trauma Data Bank to find that with SBP values below 110 mm Hg, nearly a 5% increase in mortality accompanied each 10 mm Hg decrease in admission SBP until a maximum mortality rate was reached at 60 mm Hg. The authors argued that the appearance of admission hypotension does not mark the beginning of circulatory failure but rather the beginning of physiologic decompensation. We have studied the effects that the depth of single, isolated hypotension measurements during initial trauma resuscitations had on clinical outcomes. Although a 105 mm Hg cutpoint value was found to be most predictive, patients with SBP 105 mm Hg to 110 mm Hg readings were also evaluated in this report. Patients with measurements within this SBP range required immediate procedures (13%) and surgical ICU admission (25%) although survival was universal (100%). By comparison, 11.4% of all 1,608 trauma activations at Temple Hospital were transported immediately to the operating room from the trauma resuscitation area during this 7-month study period.

To the best of our knowledge, no previous report has attempted to describe the implications of single, isolated hypotensive SBP measurements during trauma resuscitations. The effects of transient, prehospital hypotension on outcomes have been well documented.[10,11,14–20] Codner et al.[15] found that patients with prehospital hypotension and normal ED BPs were often severely injured, requiring surgery or ICU admission. Shapiro et al.[20] correlated prehospital hypotension in helicopter-transported trauma patients with normal ED BPs to outcomes and reported that patients with prehospital hypotension were 2.9 times more likely to require chest or abdominal surgery and 4.4 times as likely to die as those without hypotension. In a prospective analysis of 1,067 patients, Lipsky et al.[18] determined that patients with prehospital hypotension were more likely to undergo emergent therapeutic operations and also more likely to die than those without prehospital hypotension. Taken together, these studies indicate that reports of prehospital hypotension from Emergency Medical Services should not be ignored or considered erroneous but instead signify severe injury often requiring surgical repair or ICU admission.[10,11,14–20] Although prehospital hypotension was infrequent in our study population, we did find that single, isolated hypotensive BP measurements during trauma resuscitations often indicate the presence of severe injuries that warrant immediate surgery or ICU admission.

Others have compared outcomes in patients with prehospital hypotension to those with either admission or sustained hypotension in the ED.[16,17,22,23] Franklin et al.[16] analyzed 791 patients with prehospital hypotension defined by SBP <90 mm Hg to find a strong correlation between postinjury hypotension and need for operative intervention. Although 52% of patients who were hypotensive during both prehospital and ED care required an urgent operation, those who were either hypotensive in the field or ED still underwent emergent operation 45% and 47% of the time, respectively. In a large retrospective review of

19,409 patients, Arbabi et al.[22] compared prehospital SBP to ED SBP. When the authors stratified SBP by severity, only 60% of field and ED SBP were in the same category. ED BP proved to be a better predictor of outcome compared with field BP. Although these reports have offered convincing evidence that the presence of either prehospital or ED hypotension adversely affects outcomes,[16,17,22,23] we have correlated the depth of isolated hypotensive readings to outcome—need for an immediate operation. Because of a different study focus, single hypotensive measurements during trauma resuscitations, and the infrequency of prehospital hypotension in our study population, we were unable to correlate prehospital and ED values.

One previous report is similar in concept to this report. Although the study focused on a different resuscitation phase, Zenati et al.[21] prospectively reviewed all trauma patients admitted to the surgical ICU for >48 hours and correlated their lowest systolic BP and duration of hypotensive episodes <90 mm Hg to outcomes. Brief hypotension (<10 minutes) in the ICU significantly impacted outcomes. Although outcomes were associated with the depth and duration of ICU hypotension, both ICU LOS and mortality were increased in patients with only brief episodes of hypotension in the ICU.

We have analyzed several other potential outcome predictors in addition to isolated trauma resuscitation hypotension. Although gunshot wound injury was related to the need for immediate therapeutic intervention, presenting physiology, namely single SBP <105 mm Hg readings, proved to be an independent clinical outcome predictor regardless of the causative injury mechanism. The presence of tachycardia was unrelated to outcomes, supporting previous reports which have described tachycardia as an inaccurate injury predictor in trauma patients. Although the need for immediate therapeutic operative or endovascular intervention was the primary study endpoint, hospital survival was also assessed. Ninety-seven percent of patients with single SBP <105 mm Hg measurements survived despite often requiring immediate operative intervention, surgical ICU admission, and prolonged hospital LOS. One explanation for this favorable survival rate is that these isolated hypotensive measurements are early indicators of severe injury. Although further study is warranted, timely, aggressive operative or endovascular intervention and close hemodynamic monitoring in a surgical ICU likely are responsible for the favorable survival in this injured population.

We acknowledge our study limitations. By using patients with 105 mm Hg to 110 mm Hg SBP readings as a comparison group instead of normotensive patients, the significance of isolated hypotensive measurements may be underestimated in this report. Patients with brain and spinal cord injuries were included in this investigation and may potentially confound our analysis. Prehospital data such as resuscitation volumes were incomplete in some cases. BP was automatically measured after the initial manual measurement. As automated measurements become less reliable with more profound hypotension, this method of measurement may have introduced a potential study bias.[24–28] Vital signs were manually recorded by a trauma nurse at 15-minute intervals, a documentation method which may add another potential for bias if vital signs were selectively recorded.

In conclusion, single, isolated hypotensive BP measurements during trauma resuscitations should not be considered erroneous or dismissed. Instead, our results suggest that a single SBP <105 mm Hg measurement indicates the presence of severe injuries that often require immediate operative or endovascular treatment. Given the prevalence of injury in this patient population, our data further implies that early trauma team activation, aggressive utilization of diagnostic adjuncts, and close monitoring in a surgical ICU would benefit all patients with isolated SBP measurements <105 mm Hg.

REFERENCES

1. American College of Surgeons Committee on Trauma. *Advanced Trauma Life Support: Student Manual*. 8th ed. Chicago, IL: American College of Surgeons; 2008.
2. Adams SL, Greene JS. Absence of a tachycardic response to intraperitoneal hemorrhage. *J Emerg Med.* 1986;4:383–389.
3. Barcroft H, Edholm OG, McMichael J, et al. Posthaemorrhagic fainting study by cardiac output and forearm flow. *Lancet.* 1944;1:489–491.
4. Demetriades D, Chan LS, Bhasin P, et al. Relative bradycardia in patients with traumatic hypotension. *J Trauma.* 1998;45:534–539.
5. Luna GK, Eddy AC, Copass MK. The sensitivity of vital signs in identifying major thoracoabdominal hemorrhage. *Am J Surg.* 1989;157:512–515.
6. Sander-Jensen K, Secher NH, Bie P, et al. Vagal slowing of the heart during haemorrhage: observations from 200 consecutive hypotensive patients. *Br Med J.* 1986;292:364–366.
7. Shenkin HA, Cheney RH, Govons SR, Hardy JD, Fletcher AG Jr, Starr I. On the diagnosis of hemorrhage in man study of volunteers bled large amounts. *Am J Med Sci.* 1944;208:421–436.
8. Siegel JH, Rivkind AI, Dalal S, Goodarzi S. Early physiologic predictors of injury severity and death in blunt multiple trauma. *Arch Surg.* 1990;25:498–508.
9. Victorino GP, Battistella FD, Wisner DH. Does tachycardia correlate with hypotension after trauma? *J Am Coll Surg.* 2003;196:679–684.
10. Bruns B, Gentilello L, Elliott A, Shafi S. Prehospital hypotension redefined. *J Trauma.* 2008;65:1217–1221.
11. Eastridge BJ, Salinas J, McManus JG, et al. Hypotension begins at 110 mmHg: redefining "hypotension" with data. *J Trauma.* 2007;63:291–299.
12. Edelman DA, White MT, Tyburski JG, Wilson RF. Post-traumatic hypotension: should systolic blood pressure of 90–109 mmHg be included? *Shock.* 2007;27:134–138.
13. Parks JK, Elliott AC, Gentilello LM, Shafi S. Systemic hypotension is a late marker of shock after trauma: a validation study of Advanced Trauma Life Support principle in a large national sample. *Am J Surg.* 2006;192:727–731.
14. Chan L, Bartfield JM, Reilly KM. The significance of out-of-hospital hypotension in blunt trauma patients. *Acad Emerg Med.* 1997;4:785–788.
15. Codner P, Obaid A, Porral D, Lush S, Cinat M. Is field hypotension a reliable indicator of significant injury in trauma patients who are normotensive on arrival to the emergency department? *Am Surg.* 2005;71:768–771.
16. Franklin GA, Boaz PW, Spain DA, Lukan JK, Carrillo EH, Richardson JD. Prehospital hypotension as a valid indicator of trauma team activation. *J Trauma.* 2000;48:1034–1039.
17. Heckbert SR, Vedder NB, Hoffman W, et al. Outcome after hemorrhagic shock in trauma patients. *J Trauma.* 1998;45:545–549.
18. Lipsky AM, Gausche-Hill M, Henneman PL, et al. Prehospital hypotension is a predictor of the need for an emergent therapeutic operation in trauma patients with normal systolic blood pressure in the emergency department. *J Trauma.* 2006;61:1228–1233.
19. Schenarts PJ, Phade SV, Agle SC, et al. Field hypotension in patients who arrive at the hospital normotensive: a marker of severe injury of crying wolf? *N C Med J.* 2008;69:265–269.

20. Shapiro NI, Kociszewski C, Harrison T, Chang Y, Wedel SK, Thomas SH. Isolated prehospital hypotension after traumatic injuries: a predictor of mortality? *J Emerg Med.* 2003;25:175–179.
21. Zenati MS, Billiar TR, Townsend RN, Peitzman AB, Harbrecht BG. A brief episode of hypotension increases mortality in critically ill trauma patients. *J Trauma.* 2002;53:232–237.
22. Arbabi S, Jurkovich GJ, Wahl WL, et al. A comparison of prehospital and hospital data in trauma patients. *J Trauma.* 2004;56:1029–1032.
23. Knudson MM, Lieberman J, Morris JA Jr, Cushing BM, Stubbs HA. Mortality factors in geriatric blunt trauma patients. *Arch Surg.* 1994; 129:448–453.
24. Davis RF. Clinical comparison of automated auscultatory and oscillometric and catheter-transducer measurements of arterial pressure. *J Clin Monit.* 1985;1:114–119.
25. Davis JW, Davis IC, Bennink LD, Bilello JF, Kaups KL, Parks SN. Are automated blood pressure measurements accurate in trauma patients? *J Trauma.* 2003;55:860–863.
26. Gourdeau M, Martin R, Lamarche Y, Tétreault L. Oscillometry and direct blood pressure: a comparative clinical study during deliberate hypotension. *Can Anaesth Soc J.* 1986;33:300–307.
27. Hunt RC, Allison EJ Jr, Whitley TW, Robinson MJ, Smart TL. Comparison of EMT blood pressure measurements with an automated blood pressure monitor on scene, during transport, and in the Emergency Department. *Ann Emerg Med.* 1985;14:871–875.
28. Pessenhofer H. Single cuff comparison of two methods for indirect measurement of arterial blood pressure: standard auscultatory method versus automatic oscillometric method. *Basic Res Cardiol.* 1986;81: 101–109.

DISCUSSION

Dr. Tammy R. Kopelman (Phoenix, Arizona): I would like to thank the association for the privilege of discussing this well written and well presented article by Doctor Seamon and his colleagues.

The authors present a prospective observational study of 145 patients presenting to their trauma center with a systolic blood pressure less than 110, of which 34 percent had a single isolated systolic blood pressure measurement of less than 90.

This subgroup of patients were notably more often the victim of penetrating injury as well as more likely to undergo a larger resuscitation of both blood products and crystalloids when compared to their normal tensive counterparts.

The focus of the article revolved around this group of patients being more likely to undergo immediate operative or endovascular intervention, leading the authors to conclude that a single hypotensive measurement should not be ignored or though of as erroneous but rather should raise suspicion for severe underlying injury.

Regarding the methodology of data generation the authors stated in their protocol that blood pressure measurements were obtained within ten minutes of arrival then every five, then every fifteen and then hourly thereafter.

These measurements were automated using a commercially available product and recorded by the nurse into the medical record.

In my experience it's not uncommon for an isolated, unexpected systolic reading that is low to be immediately repeated, especially in the face of a palpable distal pulse and lack of tachycardia.

You note in your manuscript that the trauma nurses were blinded to their role in this study so how can you be certain that all BP readings were included even if immediate repeats were normal tensive? Do you not believe it would have been better to have un-blinded the nurses to the study going on?

In addition, the authors defined immediate operative intervention as any operative procedure performed immediately following the initial resuscitation and did not distinguish between therapeutic versus unnecessary.

Overall, while 51 patients went to the OR or endovascular suite 16 percent of these cases were non-therapeutic.

My question to the authors is, therefore, had you performed your statistics using therapeutic intervention rather than simply immediate intervention would your results have differed in regards to penetrating injuries?

And, finally, it appears from your data that the longer one stayed in the ED the more likely they were to go to the OR.

I did find it surprising that the initial resuscitative time averaged almost an hour in the sub-group with an isolated hypotensive episode despite the fact that 53 percent of the patients went to the OR immediately. I wonder if the authors can explain these findings.

In conclusion, I'd like to congratulate the authors and again thank the association for the privilege of discussing this article.

Dr. Mark J. Seamon (Philadelphia, Pennsylvania): The first question regarding should we have un-blinded the nurses, and repeated the blood pressure measurements, I think what we were trying to do from this study from the get-go was really to avoid that in the future.

I think what we want is to actually believe those pressures. What we did do, we did realize that nurses may in fact be selectively recording pressures and we mentioned that as a study limitation. But in our opinion there was no way, really, around that.

In terms of the therapeutic/non-therapeutic interventions, the overall non-therapeutic operative rate was about 10 percent and the overall non-therapeutic OR and IR rate was about 15 percent.

So if we only looked at patients undergoing immediate operative procedures there was no difference in the therapeutic or non-therapeutic rates. If we looked at patients only undergoing endovascular procedures, once again, there was no difference in the non-therapeutic or therapeutic rates.

And if we combined both of those modalities, again, there is no difference in the non-therapeutic rates of both combined IR and operative.

But, as I've shown in the presentation, patients in the less than 90 group did undergo more therapeutic procedures, statistically more therapeutic procedures, than the greater than or equal to 90 group. And that is statistically significant.

Explain the time of resuscitation. So we defined the initial resuscitation time probably a little differently.

This was defined as the moment the patient arrives into the emergency department until either the patient is up into the operating room after the initial resuscitation or until the completion of all imaging, so that includes CT scan, x-rays, etc cetera. So in that way I don't think an average time of 50 minutes is that out of the ordinary.

Dr. C. William Schwab (Philadelphia, Pennsylvania): Mark, thanks very much for a nice paper and I want you to know that I agree with this but, having said that, this reminds me of the article that came out with John Holcomb in the Army actually asking the question if a blood pressure under 110 systolic predicted the need for immediate operation and transfusion. Perhaps it reflects on the deconditioning of the urban warrior.

But let me also ask just a few questions. In the penetrating group did you try to analyze, though your numbers were small, as to whether the pattern of injury and a lower blood pressure just once predicted therapeutic laparotomy or thoracotomy?

And then the second thing is because we practice in the same town with the same kind of clientele I would ask you why you didn't do a little bit more sophisticated of a retrospective search and look at substance abuse and the presence of substance and/or alcohol abuse as to whether that invalidated your findings. Thank you.

Dr. John R. Hall (Kingsport, Tennessee): I found it a very interesting paper but I do have a question. Your data is totally opposite from what the pediatric data shows: that the initial pressure or low pressure means nothing as long as the child is stable after resuscitation.

We have also found this with adults with liver and spleen injuries. How many of your "interventions" in the abdomen were liver or spleen injuries that probably could have been watched and not needed an intervention at all? And how many of your data were in children?

Dr. Thomas M. Scalea (Baltimore, Maryland): You described this as a prospective observational study. I assume that means that you had somebody in the Emergency Department 24-hours a day to collect this data as the clinicians certainly could not be doing it. If the nurses were really blinded, who did they think that person was?

Dr. Mark J. Seamon (Philadelphia, Pennsylvania): Yes, to answer Doctor Schwab's question first, were the patterns of injury and blood pressures correlating, we did stratify by different injury types. We did not, however, go back and look at individual pressures, blood pressures for those injury patterns, however.

In terms of substance abuse, yes, we actually, we did look at that along with anti-hypertensives. Each group had about a 30 to 40 percent abuse rate of either alcohol or elicit drugs. And very few patients actually came in anti-hypertensive, at least by their report.

How many had liver and spleen injuries, I don't have that exact data here. This was an adult-only study, though, from Ages 18 to 88 years of age.

And how did we collect the data. We had someone available about 16 hours a day. The other 8 hours were collected after that, after that shift. And I believe that was it.