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Narrowed pulse pressure predicts massive transfusion and emergent operative intervention following penetrating trauma

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ABSTRACT

Introduction: The early identification of hemorrhagic shock may be challenging. The objective of this study was to examine the utility of a narrowed pulse pressure in identifying the need for emergent interventions following penetrating trauma.
Methods: In this 2.5-year retrospective study of adult patients with a penetrating mechanism, patients with a narrowed pulse pressure (<30 mmHg) were compared to those without. Main outcomes measures were the need for a massive transfusion or emergent operation.
Results: There were 957 patients, of which the majority were male (86%) and 55% presented with gunshot wounds. On multivariate analysis, a narrowed pulse pressure was associated with the need for massive transfusion (OR 3.74, 95% C.I. 1.8–7.7, $p = 0.0003$) and emergent surgery (OR 1.68, 95% C.I. 1.14–2.48, $p = 0.009$).
Conclusions: A narrowed pulse pressure is associated with the presence of hemorrhagic shock and need for emergent interventions among patients with penetrating torso trauma.

Introduction

Hemorrhage remains the leading cause of death following trauma, and early identification of hypovolemic shock is critical during the initial assessment of trauma patients.[1] The diagnosis of life-threatening bleeding, however, may go unrecognized or there may be a delay in recognition, particularly among patients with penetrating torso trauma. Several physiologic variables have been evaluated and used to both identify and estimate the severity of blood loss including heart rate (HR), blood pressure, and level of consciousness.[2] Biomarkers such as lactate and base deficit have also been used both in the prehospital and hospital settings to identify patients at risk for morbidity and mortality following injury.[3]

Pulse pressure (PP), specifically a narrowed PP (defined as systolic arterial pressure minus diastolic arterial pressure <30 mmHg), may also indicate the presence of shock.[4] Previous research has demonstrated that pressure-derived estimates of stroke volume (SV) such as PP may be a better indicator of hypovolemia than more traditional vital signs.[5,6] At present, there are limited data regarding the usefulness of a narrowed PP in identifying trauma patients in hemorrhagic shock and predicting the need for a massive transfusion. Utilizing our institutional experience at a level 1 trauma center with high incidence of penetrating trauma, we focused on studying a population that, based on mechanism, are at increased risk for developing hemorrhagic shock. We hypothesized that a narrowed PP is associated with the need for both a massive transfusion and emergent surgical intervention to control hemorrhage in patients with penetrating trauma.

Materials and methods

Using our institutional trauma registry, we performed a retrospective cohort analysis (November 2014 to April 2017) of adult patients (>17 years old) with penetrating trauma presenting to our urban, university-affiliated level I trauma center. Patients with an initial emergency department (ED) PP less than 30 mmHg were compared to patients with a normal PP. Exclusion criterion included patients presenting in traumatic arrest (presentation

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without pulses or spontaneous respiratory activity), those who arrived via transport other than local emergency medical services (EMS), and patients who were transferred from another ED. Thirteen patients who had incomplete vital signs, missing disposition, or unclear transfusion requirements within the trauma registry were excluded from the study.

Variables analyzed included demographics, mechanism of injury, Injury Severity Score (ISS), ED vital signs including the shock index (SI [defined as HR divided by systolic blood pressure]) and hypotension (defined as systolic blood pressure $\leq$ 90 mmHg), transfusion requirements (including massive transfusion [defined as a transfusion of >10 units of packed red blood cells within the first 24 h of admission]), and need for emergent surgery (defined as thoracotomy, laparotomy, or vascular repair immediately upon disposition from the ED). An elevated SI was defined as >0.7. Individual patient charts were reviewed to confirm registry data and assess EMS fluid-resuscitation volumes, field vitals, and laboratory results.

Data are reported as mean $\pm$ SD for continuous variables and as percentages for categorical variables. Continuous variables were compared using Student's *t*-test or the Mann-Whitney *U* test for ordinal variables, and dichotomous variables were compared using Chi-square or Fisher's exact test, where appropriate. Bivariate analyses were performed to identify statistically significant differences between patients with a narrowed versus normal PP. Variables associated with massive transfusion and emergent operative intervention were also examined using bivariate analysis. Variables with p-value less than 0.1 (narrowed PP, SI, hypotension, sex, GSW, GCS) were entered into multivariate logistic regression to determine the risk factors independently associated with massive transfusion and emergent operation. Sensitivity and specificity of narrowed PP was calculated also for the above two outcome measures. A Hosmer-Lemeshow Test to ensure goodness of fit was conducted. Epi Info™ V.7.2.2.1 (Centers for Disease Control and Prevention) was used for statistical analysis and analysis conducted and reviewed by a statistician. Any p value less than 0.05 was considered statistically significant.

Results

Of 1440 patients identified, 957 patients were included in the study (Fig. 1). Males comprised 86% of the study population and the mean age was 33 $\pm$ 13 years. Gunshot wounds (GSWs) accounted for 55% of injuries. The median ISS was 5 (range 1–75) and the overall mortality rate was 2.2%. A total of 178 patients (18.7%) presented with a narrowed PP. Compared to those with a normal PP, patients with a narrowed PP were younger (31 vs. 34 years old, $p = 0.029$), more likely to present following a GSW (63% vs. 53%, $p = 0.02$).

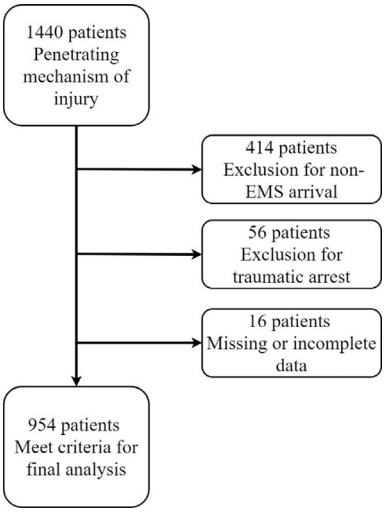

Fig. 1. Patient selection flowchart.

Patients presenting with narrowed PP were more likely to require an emergent procedure (48% vs. 28%, $p < 0.001$) and receive a massive transfusion (11%, vs. 2%, $p < 0.001$) (Table 1). The ISS was higher among patients with narrowed PP (9 vs. 4, $p < 0.001$). These patients also received more crystalloids in the ED (915 $\pm$ 1172 vs. 650 $\pm$ 725 cc, $p < 0.001$). Mortality was increased in patients with a narrowed PP (4% vs. 2%, $p = 0.04$).

Compared to patients who did not receive a massive transfusion, those who did were more likely to be male (100% vs. 86%, $p < 0.014$) and present following a GSW (87% vs. 54%, $p < 0.001$). These patients were also more likely to have admission hypotension (11% vs. 1%, $p < 0.001$), an elevated shock index (70% vs. 46%, $p = 0.004$), and narrowed PP (53% vs. 17%, $p < 0.001$). Patients who underwent an emergent operative intervention were more likely to present with ED hypotension (4% vs. 2%, $p < 0.01$), an elevated SI (55% vs. 44%, $p < 0.001$), and narrowed PP (29% vs. 14%, $p < 0.001$) with no significant difference in age, gender, or mechanism.

On multivariate analysis (Table 2), after controlling for variables with a $p < 0.1$ on bivariate analysis, narrowed PP (OR = 3.7, 95% CI: 1.82–7.68], GSW [OR = 4.6, 95% CI: 1.71–12.08], elevated SI [OR = 2.4, 95% CI: 1.07–5.20], and GCS [OR = 0.9, 95% CI: 0.75–0.97] were independently associated with massive blood transfusion. Variables associated with the need for an emergent operation included narrowed PP (OR = 1.7; 95% CI, 1.14–2.48), hypotension (OR = 3.5, 95% CI:1.23–10.13], and elevated SI (OR: 1.5; 95% CI: 1.06–1.97). Hosmer-Lemeshow Test goodness of fit test demonstrated $p = 0.412$ for massive transfusion and $p = 0.175$ for emergent operative intervention exceeding the 0.05 limit.

Narrowed PP was found to be highly specific for both massive transfusion protocol and need for emergency surgery (Specificity of 82.7% and 85.8% respectively). However, it was associated with low sensitivities (52.8% and 28.5%).

Discussion

Early identification of patients with hemorrhagic shock is critical as this would allow for more rapid triage and activation of trauma team personnel, as well as blood bank and operating room resources. Several methods have been developed to identify shock based on vital signs alone: shock index, modified shock index (heart rate over mean arterial pressure), and age shock index (shock index multiplied by age). Each method has been demonstrated to be superior to blood pressure alone for the prediction of massive transfusion, though admittedly have low sensitivity.[7] PP/HR ratio has also been described to be indicative of the need for massive transfusion in prior studies.[6,8] However, there is a paucity of studies evaluating PP alone in patients with penetrating trauma.

One study has identified the utility of PP < 45 mmHg in conjunction with the shock index may indicate the need for massive transfusion. However, this was completed in a population consisting of primarily blunt trauma patients.[9] Other studies that have utilized PP as a predictor for massive transfusion were completed with arterial line blood pressure measurements.[6] Most recently, another study also identified narrowed PP may be an independent early predictor of blood product transfusion (of any amount) in normotensive patients.[10]

In the current study, we found that a narrowed PP upon arrival to the ED was associated with the administration of a massive transfusion, as well as the need for an emergent operative

Table 1
Baseline demographics and outcomes of patients with and without a narrowed pulse pressure.

Variable	Narrowed Pulse Pressure <30 mmHg (n = 178)	Normal Pulse Pressure >30 mmHg (n = 776)	P-value
Age, mean ± SD	31 ± 13	34 ± 13	0.029
Male Gender, n (%)	152 (85.4)	674 (86.3)	0.892
GSW, n (%)	112 (62.9)	413 (53.4)	0.02
SBP, mean ± SD	118 ± 37	133 ± 39	<0.001
DBP, mean ± SD	104 ± 25	86 ± 20	<0.001
GCS, mean ± SD	14.2 ± 2.4	14.7 ± 1.5	<0.001
Shock Index > 0.7, n (%)	124 (69.7)	326 (42)	<0.001
Median ISS, (range)	9 (1–66)	4 (1–75)	<0.001
> 1u pRBC transfusion, n (%)	55 (30.9)	79 (10.2)	<0.001
Massive Transfusion, n (%)	19 (10.7)	17 (2.2)	<0.001
Emergent Operation, n (%)	85 (47.8)	213 (27.5)	<0.001
Mortality, n (%)	8 (4.5)	13 (1.7)	0.04

MOI-GSW: Mechanism of Injury Gunshot Wound; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; GCS: Glasgow Coma Scale; ISS: Injury Severity Score.

Table 2
Multivariate analysis for emergent procedures and massive transfusion.

Variables	Procedure			Massive Transfusion		
	Odds Ratio	95% CI	p-Value	Odds Ratio	95% CI	p-Value
Narrowed Pulse Pressure	1.68	1.14–2.48	0.009	3.74	1.82–7.68	0.0003
Shock Index >0.7	1.44	1.06–1.97	0.018	2.36	1.07–5.20	0.033
Hypotension	3.54	1.23–10.13	0.019	2.80	0.68–11.54	0.15
GCS	0.84	0.77–0.91	0.0001	0.85	0.75–0.97	0.032
EDDBP	1.01	1.00–1.02	0.034	–	–	–
GSW	–	–	–	4.56	1.72–12.07	0.0023

GCS: Glasgow Coma Scale; EDDBP: Emergency department diastolic blood pressure; GSW: Gunshot Wound.

intervention. When compared to admission hypotension and an elevated shock index, narrowed PP demonstrated a lower sensitivity but higher specificity for the need for both a massive transfusion and emergent operation. Specificity was maintained when injuries were stratified based on location of the chest, abdomen, or extremities. However, narrowed PP was less specific for those injuries occurring to the face or head. Therefore, although a narrowed PP may not be an ideal screening tool to determine which trauma patients may require an intervention, among patients at-risk, the high specificity of this finding suggests that there would be very few false positives and a high probability of the need for an emergent intervention in patients with a positive finding.

While not directly compared to other markers of hemorrhagic shock, it should be noted that within our study population, narrowed PP was able to identify several patients requiring massive transfusion or emergent operation that would have not have otherwise been identified by shock index <0.7 or hypotension (<90 mmHg) alone.

One major advantage of using PP compared to other scoring systems is that it requires limited data without the need for calculations and does not rely upon laboratory values which may result in unnecessary delays. Narrowed PP may provide a new measure to help triage patients' level of care upon their admission with a simple blood pressure measurement. Furthermore, the use of PP as a surrogate for SV is attractive as availability of sophisticated invasive hemodynamic monitoring in the trauma bay is often limited.[11] A previous study in 13 healthy males demonstrated that PP decreased linearly with the degree of central hypovolemia and that PP is positively correlated with stroke volume ($r^2 = 0.9$).[12] Controlled experimental hemorrhage studies have also demonstrated an association between hemorrhage and decreases in PP.[13]

Our study has several limitations in addition to its retrospective study design. First, we did not perform a comparative analysis to other established triggers for activating the MTP such as the ABC score.[14] Although 3 of the 4 variables were readily available, at our center, FAST is not routinely performed in patients with penetrating trauma with the exception of patients at-risk or with concern for cardiac injury. Furthermore, studies evaluating the utility of the FAST exam in penetrating trauma have found that while specific, it often has low sensitivity up to 48% and rarely altered management.[15]

Second, this study did not employ pre-hospital data and, given the importance of early identification, the finding of a narrowed PP prior to hospital arrival could potentially result in improved triage and availability of immediate blood products. However, due to inconsistencies and variability in data capture and reporting, together with the known discrepancies in the prehospital and hospital data, we did not examine the role of a narrowed PP prior to hospital arrival.[16] We have low suspicion that prehospital fluids may have had an impact on hospital admission vitals. Though a review of our study population demonstrated that patients with a narrowed PP were more likely to have received intravenous (IV) saline prior to arrival, it was an average amount 160 mL ± 301 mL of fluid. It is unlikely that our results were significantly skewed as prior studies have identified an increase of 7 mmHg arterial pressure and 3.2 mmHg venous pressure immediately following a 500 mL fluid bolus.[17]

Third, we did not examine the use of a narrowed PP in a wider patient population, specifically patients with blunt trauma. Given our hospital's population, comprised of greater than 50% penetrating trauma patients, we decided to study the use of narrowed PP as a predictor for MT within a population that had not yet been thoroughly studied. Had blunt trauma patients from our population been included, it is likely that the specificity of our findings would have been reduced. Moreover, given the incidence of GSW wounds in our population, it is possible that our results may not be generalizable to a larger population.

Finally, we defined a narrowed PP as <30 mmHg, while previous studies have used variable definitions whereas others have employed a PP index. Most recently, age specific cutoffs of 40 or 55 mmHg have been identified as an independent predictor for any quantity of blood transfusion.[10] Despite these limitations, our study

demonstrates the potential role of using a narrowed PP to identify patients who may require a massive transfusion or emergent operative intervention.

Conclusion

Among patients with penetrating trauma, the presence of a narrowed PP may indicate the presence of hemorrhagic shock and is independently associated with the need for massive transfusion and emergent operative intervention. We expect these findings may generalizable to similar populations. It is possible that narrowed PP may identify these patients before hypotension occurs in the progression of shock allowing for earlier intervention.

Further study is required to determine the optimal threshold values for defining a narrowed PP and to determine the usefulness of this hemodynamic parameter in predicting the need for life-saving therapies in trauma patients with both blunt and penetrating injuries.

Short summary

A retrospective analysis examining the utility of a narrowed pulse pressure for identifying the need for a massive transfusion or emergent surgery in patients with penetrating torso trauma. A narrowed pulse pressure was associated with the need for these emergent interventions.

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