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Dynamic trend or static variable: Shock Index Pediatric-Adjusted (SIPA) in warzone trauma

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ABSTRACT

Background: Civilian studies suggest that trending Shock-Index Pediatric Adjusted(SIPA) values can prove useful in the prediction of trauma outcomes. The purpose of this study was to evaluate the relationship between trends in SIPA and outcomes in pediatric warzone trauma.
Methods: Retrospective review of the Department of Defense Trauma Registry from 2008 to 2015, including all patients age ≤17years. SIPA was calculated both pre-hospital and upon arrival, then classified as "normal" or "abnormal" based upon previously validated thresholds. Patients were stratified into groups based on the trend of their SIPA (1-normal to normal, 2-normal to abnormal, 3-abnormal to normal, 4-abnormal to abnormal). Key outcomes including ICU admission, severe injury, mechanical ventilation, and mortality were then compared between groups.
Results: 669 patients were included, mean ISS 12 ± 10. The most common mechanism of injury was blast (46.5%). Overall, 43% were stratified into Group 1, 13.9% into Group 2, 14.8% into Group 3, and 28.0% into Group 4. Those patients with a persistently abnormal SIPA (Group 4) had significantly increased incidence of severe injury, ICU admission, need for mechanical ventilation, and mortality.
Conclusion: Trends in SIPA may be used to predict trauma outcomes for children injured in warzones, with persistently abnormal values associated with worse outcomes overall.

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1. Introduction

Shock index (SI) is a "compound" vital sign, which can be calculated by dividing a patient's heart rate (HR) by the systolic blood pressure (SBP). Though first described in Europe over five decades ago, interest has risen recently in the potential for SI to predict patient outcomes in a myriad of clinical settings; from mortality in maternal sepsis, to neurologic outcomes in stroke, and most notably trauma outcomes and resource utilization [1–6]. Using a standardized threshold value of between 0.8 and 1.0, patients are typically categorized as having either a normal or abnormal value. Abnormal or elevated SI has been found to be independently associated with a variety of trauma outcomes in adults, including injury severity, Intensive Care Unit (ICU) admission, blood product transfusion, and mortality [4–6]. The multitude of purported advantages of SI include ease and rapidity of calculation, repeatability, and avoidance of invasive monitoring or laboratory testing. In parallel with the wave of renewed interest in the utility of SI for adult patients is a rising surge to understand the potential for SI in the clinical evaluation of children, particularly in pediatric trauma.

The Shock Index Pediatric-Adjusted (SIPA), also known as the Age-Adjusted Shock Index, was devised by Acker et al. in 2015 to account for age-related physiologic variability in vital signs to establish different thresholds for an "abnormal" or "elevated" value [7]. Subsequent studies have found SIPA superior to an "unadjusted" SI (with a single uniform threshold) for the prediction of injury severity and need for blood transfusion in civilian pediatric trauma [8]. Recent work suggests that there may be a predictive benefit to trending SIPA in the civilian setting from the pre-hospital setting, to arrival in the Emergency Department, and throughout the initial phases of resuscitation [9–11].

The use of SIPA has since been validated in the prediction of resource utilization and outcomes for pediatric warzone trauma [12]. Pediatric trauma in combat zones differs from civilian pediatric trauma in certain key ways. These include, but are not limited to, the preponderance of blast and penetrating injuries, the resource constrained nature of care, and often limited exposure of military healthcare providers to pediatric trauma. Given these challenges, SIPA represents a particularly promising tool for the triage of children traumatically injured in warzones. The potential value

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Table 1
Age Categories with associated SIPA Threshold Values [9].

Age Category (years)	Heart Rate Range	Systolic Blood Pressure Range	SIPA Threshold Values
0–3	70–110	90–110	>1.2
4–6	65–110	90–110	>1.2
7–12	60–100	100–120	>0.9
13–17	55–95	100–135	>0.9

SIPA, Shock Index Pediatric-Adjusted.

of trending SIPA from the field (analogous to the pre-hospital setting) to arrival at the initial medical facility with surgical capabilities has not previously been described.

The purpose of this study was to evaluate the relationship between SIPA trends and outcomes in pediatric warzone trauma. We hypothesize that persistently abnormal SIPA values both in the pre-hospital environment and upon arrival to the initial level of care are associated with significantly worse trauma outcomes and greater resource utilization.

2. Methods

2.1. Study design

We performed a retrospective review of the Department of Defense Trauma Registry (DoDTR) from 2008 to 2015. The DoDTR is a comprehensive database including all United States (US) military servicemen and women, coalition forces, and foreign nationals that receive healthcare at US and joint combat surgical hospitals around the world [13]. The DoDTR has proven invaluable in the study of combat trauma and surgical care. We included all patients age 17 years and younger with records in the database. We excluded all those patients who lacked a recorded HR or SBP in the field and upon arrival to the initial level of care, as well as those patients whose first record of care was at a tertiary care facility (which we defined as a Role IV center and above). SIPA was first calculated both pre-hospital and upon arrival to the intial level of care with surgical capabilities (Role II or III Combat Surgical Hospital), and was then classified as either “normal” or “abnormal” based upon previously validated thresholds for each predefined age cohort (Table 1) [9,12]. Patients were stratified into four groups based on the trend of their SIPA values; Group 1- normal to normal, Group 2- normal to abnormal, Group 3- abnormal to normal, Group 4- abnormal to abnormal. Groups were further classified as either “favorable” (Group 1 and 3), or “unfavorable” (Groups 2 and 4).

2.2. Outcomes

The primary outcomes of the study were ICU admission, severe injury (defined as Injury Severity Score, ISS>15), need for mechanical ventilation, and mortality. Secondary outcomes included blood product transfusion (BPT), emergent surgical procedure (ESP), ICU and hospital length of stay (LOS), total ventilator days, ISS, severe injury by body region, and need for advanced imaging (specifically Computed Tomography, CT). BPT comprised Whole Blood (WB), Packed Reb Blood Cells (PRBCs), Fresh Frozen Plasma (FFP), Platelets, and Cryoprecipitate. ESP included craniotomy, exploratory laparotomy, thoracotomy, and fasciotomy. The incidence of both primary and secondary outcomes was first determined for the cohort as a whole, then compared based on SIPA classification (pre-hospital and arrival) and overall SIPA trend. Patient demographics (age category and gender), injury patterns, and mechanism of injury were likewise compared between groups.

2.3. Statistical analysis

Univariate analysis was conducted using either the Pearson’s Chi-squared test or the Fisher’s exact test for categorical variables and the Independent Student’s T-test or Analysis of variance (ANOVA) for continuous variables. Values were reported as either percentages or means with standard deviation as appropriate. Finally, the predictive facility of each trend was assessed by calculating the sensitivity, specificity, positive and negative predictive value (PPV, NPV), and Youden Index (YI) as it related to each of the primary outcomes of interest. The YI is a measure of overall testing accuracy and can be calculated by adding the sensitivity of a test to the specificity of that test minus 1. A p-value of less than 0.05 was deemed significant. Statistical analysis was executed utilizing Microsoft Excel ® (Redmond, WA) and IBM SPSS Version 24 (Armonk, NY). Approval of our study as IRB exempt was obtained prior to data abstraction and analysis.

3. Results

We identified 669 patients that met the inclusion criteria during the time period specified. For the cohort as a whole, the majority of patients were male (82.1%, 549), and approximately half (50.7%, 339) were in the age range of 7 to 12 years. The most frequently encountered injury pattern overall was penetrating injury (67.7%, 453), followed by blunt injury (24.4%, 163), and finally burns (7.8%, 52). Meanwhile, the most common single mechanism of injury was blast trauma (46.5%, 311), with gunshot wounds comprising around one-quarter of all injuries (23.3%, 156) (Table 2).

Overall, nearly half of patients required ICU admission (45.3%, 303), one-tenth required mechanical ventilation (10.0%, 67), and one-third were categorized as severely injured (30.5%, 204) with a mean ISS of 12 ± 10. The mortality rate for the entire cohort was 5.8% (39). Focusing on resource utilization, 39.2% (262) of patients received a blood product transfusion, with the majority of those receiving either PRBCs (35.9%, 240) or FFP (28.1%, 188). 20.6% (138) of all patients required emergent surgery, with exploratory laparotomy most frequently performed (12.1%, 81) (Table 3).

A similar proportion of patients had an abnormal SIPA based on prehospital (42.8%, 286) and arrival (41.9%, 280) vital signs. In the both the pre-hospital setting and upon arrival to the initial level of care with surgical capabilities, patients with an abnormal SIPA demonstrated a significantly higher incidence of ICU admission, need for mechanical ventilation, severe injury, and mortality as well as need for blood transfusion (all $p < 0.05$, Table 3).

Looking forward to SIPA trends, 43.3% (290) of patients were stratified into Group 1, 13.9% (93) into Group 2, 14.8% (99) into Group 3, and 28.0% (187) into Group 4. Patients with unfavorable trends (Group 2 and 4) composed 41.8% (280) of the total. Patients with worsening (Group 2) or persistently abnormal SIPA trends (Group 4), were significantly more likely to have been injured in a blast ($p = 0.005$). Though they made up a minority of overall cases, those patients aged 0 to 3 years and those that were females were more likely to have an unfavorable trend ($p < 0.001$) (Table 4). Again focusing on our primary outcomes of interest, those patients stratified in Group 2 and 4 were significantly more likely to require

Table 2
Patient Demographics, Injury Patterns, and Mechanisms of Injury by SIPA Classification Pre-Hospital and upon Arrival to Initial Level of Care.

Variable	Prehospital Normal SIPA	Abnormal SIPA	*p*-value	Arrival Normal SIPA	Abnormal SIPA	*p*-value	Overall
n (%)	383 (57.2)	286 (42.8)	NA	389 (58.1)	280 (41.9)	NA	699 (100.0)
Age Category, n (%)							
0–3 years	21 (5.5)	37 (12.9)	0.001	18 (4.6)	40 (14.3)	<0.001	58 (8.7)
4–6 years	66 (17.2)	39 (13.6)	0.237	64 (16.5)	41 (14.6)	0.590	105 (15.7)
7–12 years	194 (50.7)	145 (50.7)	1.000	198 (50.9)	141 (50.4)	0.938	339 (50.7)
13–17 years	102 (26.6)	65 (22.7)	0.279	109 (28.0)	58 (20.7)	0.037	167 (25.0)
Gender, n (%)							
Female	53 (13.8)	67 (23.4)	0.002	46 (11.8)	74 (26.4)	<0.001	120 (17.9)
Male	330 (86.2)	219 (76.6)		343 (88.2)	206 (73.6)		549 (82.1)
Injury Pattern, n (%)							
Blunt	108 (28.2)	55 (19.2)	0.008	105 (27.0)	58 (20.7)	0.068	163 (24.4)
Penetrating	252 (65.8)	201 (70.3)	0.242	255 (65.6)	198 (70.7)	0.180	453 (67.7)
Burns	22 (5.7)	30 (10.5)	0.028	28 (7.2)	24 (8.6)	0.559	52 (7.8)
Mechanism of Injury, n (%)							
Blast	169 (44.1)	142 (49.7)	0.159	158 (40.6)	153 (54.6)	<0.001	311 (46.5)
GSW	91 (23.8)	65 (22.7)	0.782	103 (26.5)	53 (18.9)	0.026	156 (23.3)
MVA	56 (14.6)	22 (7.7)	0.007	56 (14.4)	22 (7.9)	0.010	78 (11.7)

NA, Not Applicable; GSW, Gunshot Wound; MVA, Motor Vehicle Accident.

Table 3
Comparison of Outcomes by SIPA Classification: Pre-Hospital and upon Arrival to Initial Level of Care.

Variable	Prehospital Normal SIPA	Abnormal SIPA	*p*-value	Arrival Normal SIPA	Abnormal SIPA	*p*-value	Overall
Blood Product Transfusion, n (%)	116 (30.3)	286 (51.0)	<0.001	111(28.5)	151 (53.9)	<0.001	262 (39.2)
Whole Blood	1 (0.3)	0 (0.0)	1.000	1 (0.3)	0 (0.0)	1.000	1 (0.1)
PRBCs	104 (27.2)	136 (47.6)	<0.001	101 (26.0)	139 (49.6)	<0.001	240 (35.9)
FFP	84 (21.9)	104 (36.4)	<0.001	79 (20.3)	109 (38.9)	<0.001	188 (28.1)
Platelets	14 (3.7)	31 (10.8)	<0.001	11 (2.8)	34 (12.1)	<0.001	45 (6.7)
Cryoprecipitate	7 (1.8)	19 (6.6)	0.002	4 (1.0)	22 (7.9)	<0.001	26 (3.9)
Emergent Surgical Procedure, n (%)	72 (18.8)	66 (23.1)	0.178	73 (18.8)	65 (23.2)	0.096	138 (20.6)
Craniotomy	20 (5.2)	13 (4.5)	0.722	16 (4.1)	17 (6.1)	0.280	33 (4.9)
Exploratory Laparotomy	41 (10.7)	40 (14.0)	0.231	42 (10.8)	39 (13.9)	0.231	81 (12.1)
Thoracotomy	2 (0.5)	2 (0.7)	1.000	0 (0.0)	4 (1.4)	0.030	4 (0.6)
Fasciotomy	13 (3.4)	15 (5.2)	0.248	20 (5.1)	8 (2.9)	0.173	28 (4.2)
ICU Admission, n (%)	151 (39.4)	152 (53.1)	0.001	142 (36.5)	161 (57.5)	<0.001	303 (45.3)
ICU Length of Stay, mean (SD)	1.5 (3.0)	2.3 (3.7)	0.006	1.3 (2.3)	2.7 (4.3)	<0.001	1.8 (3.3)
Mechanical Ventilation, n (%)	31 (8.1)	36 (12.6)	0.068	20 (5.1)	47 (16.8)	<0.001	67 (10.0)
Total Ventilator Days, mean (SD)	0.9 (2.1)	1.5 (2.5)	0.005	0.6 (1.5)	1.8 (3.0)	<0.001	1.1 (2.3)
Hospital Length of Stay, mean (SD)	3.4 (4.8)	4.2 (5.4)	0.042	3.4 (4.6)	4.3 (5.6)	0.028	3.7 (5.1)
ISS, mean (SD)	12 (10)	13 (10)	0.063	10 (9)	15 (11)	<0.001	12 (10)
Severely Injured (ISS>15)	100 (26.1)	104 (36.4)	0.005	92 (23.7)	113 (40.0)	<0.001	204 (30.5)
Severely Injured Body Region (AIS≥3), n (%)							
Head/Neck	108 (28.2)	79 (27.6)	0.931	106 (27.2)	81 (28.9)	0.663	187 (28.0)
Face	3 (0.8)	2 (0.7)	1.000	3 (0.8)	2 (0.7)	1.000	5 (0.7)
Thorax	43 (11.2)	43 (15.0)	0.162	35 (9.0)	51 (18.2)	0.001	86 (12.9)
Abdomen	41 (10.7)	35 (12.2)	0.541	32 (8.2)	44 (15.7)	0.003	76 (11.4)
Extremity	68 (17.8)	69 (24.1)	0.053	63 (16.2)	74 (26.4)	0.001	137 (20.5)
External	9 (2.3)	20 (7.0)	0.006	13 (3.3)	16 (5.7)	0.177	29 (4.3)
Advanced Imaging, n (%)	280 (73.1)	205 (71.7)	0.373	269 (69.2)	216 (77.1)	0.023	485 (72.5)
Mortality, n (%)	15 (3.9)	24 (8.4)	0.019	16 (4.1)	23 (8.2)	0.030	39 (5.8)

PRBCs, Packed Red Blood Cells; FFP, Fresh Frozen Plasma; ICU, Intensive Care Unit; ISS, Injury Severity Score; SD, Standard Deviation; AIS, Abbreviated Injury Score.

ICU admission, mechanical ventilation, severe injury, and mortality (all $p < 0.05$). Patients in Groups 2 and 4 were also significantly more likely to have greater incidence of blood product transfusion (especially PRBC transfusion), ICU and hospital LOS, total ventilator days, and ISS score, $p < 0.001$ (Table 5). These patterns among both primary and secondary outcomes persisted and remained statistically significant when the Groups 2 and 4 were considered together as mutually unfavorable ($p < 0.05$, Table 6).

Our analysis of the testing characteristics revealed increased sensitivity and specificity of an abnormal SIPA on arrival compared to an abnormal pre-hospital value for all primary outcomes, with the exception of mortality in which case they were very similar. Furthermore, a persistently abnormal SIPA value (Group 4) demonstrated greater specificity and PPV for all primary outcomes as well as the key secondary outcome of BPT. However, the overall discriminative ability of a persistently abnormal trend was less than that demonstrated by an abnormal arrival value alone, as revealed by the Youden Index in each case being lower. Finally, "unfavorable" trends were found to have identical sensitivity and specificty as compared to an abnormal SIPA on arrival (Table 7).

4. Discussion

This work represents the first study of the utility of trending SIPA in pediatric warzone trauma, and as a result, the largest. The potential for SIPA trends to be used to predict morbidity and mortality in civilian pediatric trauma was first explored by Vandewalle et al. in 2018. In a single-center, retrospective study of 286 pediatric patients admitted with severe (ISS ≥ 15) blunt injuries, they found that patients whose SIPA progressed from normal to abnor-

Table 4
Patient Demographics, Injury Patterns, and Mechanisms of Injury by SIPA Trend.

Variable	Normal to Normal SIPA	Normal to Abnormal SIPA	Abnormal to Normal SIPA	Abnormal to Abnormal SIPA	*p*-value
n (%)	290 (43.3)	93 (13.9)	99 (14.8)	187 (28.0)	NA
Age Category, n (%)					
0–3 years	10 (3.4)	11 (11.8)	8 (8.1)	29 (15.5)	<0.001
4–6 years	51 (17.6)	15 (16.1)	13 (13.1)	26 (13.9)	0.628
7–12 years	151 (52.1)	43 (46.2)	47 (47.5)	98 (52.4)	0.662
13–17 years	78 (26.9)	24 (25.8)	31 (31.8)	34 (18.2)	0.062
Gender, n (%)					
Female	28 (9.7)	25 (26.9)	18 (18.2)	49 (26.2)	<0.001
Male	262 (90.3)	68 (73.1)	81 (81.8)	138 (73.8)	
Injury Pattern, n (%)					
Blunt	85 (29.3)	23 (24.7)	20 (20.2)	35 (18.7)	0.046
Penetrating	186 (64.1)	66 (71.0)	69 (69.7)	132 (70.6)	0.387
Burns	18 (6.2)	4 (4.3)	10 (10.1)	20 (10.7)	0.137
Mechanism of Injury, n (%)					
Blast	118 (40.7)	51 (54.8)	40 (40.4)	102 (54.5)	0.005
GSW	77 (26.6)	14 (15.1)	26 (26.3)	39 (20.9)	0.095
MVA	43 (14.8)	13 (14.0)	13 (13.1)	9 (4.8)	0.007

NA, Not Applicable; GSW, Gunshot Wound; MVA, Motor Vehicle Accident.

Table 5
Comparison of Outcomes by SIPA Trend.

Variable	Normal to Normal SIPA	Normal to Abnormal SIPA	Abnormal to Normal SIPA	Abnormal to Abnormal SIPA	*p*-value
Blood Product Transfusion, n (%)	75 (25.9)	41 (44.1)	36 (36.4)	110 (58.8)	<0.001
Whole Blood	1 (0.3)	0 (0.0)	0 (0.0)	0 (0.0)	0.727
PRBCs	67 (23.1)	37 (39.8)	34 (34.3)	102 (54.5)	<0.001
FFP	53 (18.3)	31 (33.3)	26 (26.3)	78 (41.7)	<0.001
Platelets	6 (2.1)	8 (8.6)	5 (5.1)	26 (13.9)	<0.001
Cryoprecipitate	2 (0.7)	5 (5.4)	2 (2.0)	17 (9.1)	<0.001
Emergent Surgical Procedure, n (%)	55 (19.0)	17 (18.3)	18 (18.2)	48 (25.7)	0.254
Craniotomy	14 (4.8)	6 (6.5)	2 (2.0)	11 (5.9)	0.455
Exploratory Laparotomy	32 (11.0)	9 (9.7)	10 (10.1)	30 (16.0)	0.270
Thoracotomy	0 (0.0)	2 (2.2)	0 (0.0)	2 (1.1)	0.078
Fasciotomy	13 (4.5)	0 (0.0)	7 (7.1)	8 (4.3)	0.103
ICU Admission, n (%)	98 (33.8)	53 (57.0)	44 (44.4)	108 (57.8)	<0.001
ICU Length of Stay, mean (SD)	1.2 (2.2)	2.7 (4.6)	1.5 (2.4)	2.7 (4.2)	<0.001
Mechanical Ventilation, n (%)	16 (5.5)	15 (16.1)	4 (4.0)	32 (17.1)	<0.001
Total Ventilator Days, mean (SD)	0.6 (1.4)	1.7 (3.3)	0.7 (1.6)	1.9 (2.8)	<0.001
Hospital Length of Stay, mean (SD)	3.0 (4.4)	4.4 (5.9)	4.2 (5.1)	4.2 (5.5)	0.027
ISS, mean (SD)	10 (9)	14 (12)	9 (8)	15 (10)	<0.001
Severely Injured (ISS>15)	70 (24.1)	30 (32.3)	22 (22.2)	82 (43.9)	<0.001
Severely Injured Body Region (AIS≥3), n (%)					
Head/Neck	81 (27.9)	27 (29.0)	25 (25.3)	54 (28.9)	0.921
Face	3 (1.0)	0 (0.0)	0 (0.0)	2 (1.1)	0.566
Thorax	28 (9.7)	15 (16.1)	7 (7.1)	36 (19.3)	0.004
Abdomen	25 (8.6)	16 (17.2)	7 (7.1)	28 (15.0)	0.023
Extremity	45 (15.5)	23 (24.7)	18 (18.2)	51 (27.3)	0.012
External	7 (2.4)	2 (2.2)	6 (6.1)	14 (7.5)	0.031
Advanced Imaging, n (%)	203 (70.0)	77 (82.8)	66 (66.7)	139 (74.3)	0.049
Mortality, n (%)	10 (3.4)	5 (5.4)	6 (6.1)	18 (9.6)	0.047

PRBCs, Packed Red Blood Cells; FFP, Fresh Frozen Plasma; ICU, Intensive Care Unit; ISS, Injury Severity Score; SD, Standard Deviation; AIS, Abbreviated Injury Score.

mal within the first 24 h of admission had significantly greater ICU and hospital length of stay (LOS) [10]. A follow up study by this group in 501 patients with moderate (ISS 10–14) blunt injuries again appreciated increased LOS associated with elevation of SIPA within 24 h of admission [11]. Notably, the correlation which was noted in this study was absent in the subgroup of patients with head injuries, suggesting more limited utility in this cohort. Both of these works provided a foundation for the further evaluation of the SIPA trends. However, both were similarly limited by their single-center nature and, relatively speaking, small sample sizes. Furthermore, neither included pre-hospital SIPA in their study design.

Many of these limitations were overcome in a subsequent study by Nordin et al. in a retrospective review from 2019 including 2917 pediatric blunt trauma patients from the Pediatric Trauma Quality Improvement Program (TQIP) database. In that study, patients with a persistently abnormal SIPA from the scene of injury to arrival at the ED were noted to have significantly increased need for ICU admission, mechanical ventilation, and mortality [9]. With its greater size, multi-institution character, and inclusion of pre-hospital SIPA, these findings built well upon the promising work by Vandewalle et al. And yet, the admittedly narrow focus of this study, only patients with severe (ISS > 15) blunt trauma were included, limits the generalizability its conclusions.

Only a single study has previously examined the role of SIPA in pediatric warzone trauma. In a retrospective cohort study of 2121 pediatric warzone trauma patients from the DoDTR, our group previously explored the utility of SIPA in the prediction of blood product transfusion and emergent surgery. We found that an elevated SIPA calculated upon arrival to the initial level of care with surgical capabilities was independently associated with increased need for blood transfusion (Odds Ratio[OR]= 2.36, $p < 0.001$) and emergent surgery (OR = 1.29, $p = 0.044$) [12]. Importantly, these results conformed to the growing body of literature which supports the supe-

Table 6
Comparison of Outcomes by SIPA Trend: Favorable versus Unfavorable.

Variable	Favorable SIPA Trends	Unfavorable SIPA Trends	*p*-value
n (%)	389 (58.1)	280 (41.8)	na
Blood Product Transfusion, n (%)	111 (28.5)	151 (53.9)	<0.001
Whole Blood	1 (0.3)	0 (0.0)	1.000
PRBCs	101 (26.0)	139 (49.6)	<0.001
FFP	79 (20.3)	109 (38.9)	<0.001
Platelets	11 (2.8)	34 (12.1)	<0.001
Cryoprecipitate	4 (1.0)	22 (7.9)	<0.001
Emergent Surgical Procedure, n (%)	73 (18.8)	65 (23.2)	0.175
Craniotomy	16 (4.1)	17 (6.1)	0.280
Exploratory Laparotomy	42 (10.8)	39 (13.9)	0.231
Thoracotomy	0 (0.0)	4 (1.4)	0.030
Fasciotomy	20 (5.1)	8 (2.9)	0.173
ICU Admission, n (%)	142 (36.5)	161 (57.5)	<0.001
ICU Length of Stay, mean (SD)	1.2 (2.3)	2.7 (4.3)	<0.001
Mechanical Ventilation, n (%)	20 (5.1)	47 (16.8)	<0.001
Total Ventilator Days, mean (SD)	0.6 (1.5)	1.8 (3.0)	<0.001
Hospital Length of Stay, mean (SD)	3.3 (4.6)	4.3 (5.6)	0.028
ISS, mean (SD)	10 (9)	15 (11)	<0.001
Severely Injured (ISS>15)	92 (23.7)	112 (40.0)	<0.001
Severely Injured Body Region (AIS≥3), n (%)			
Head/Neck	106 (27.2)	81 (28.9)	0.663
Face	3 (0.8)	2 (0.7)	1.000
Thorax	35 (9.0)	51 (18.2)	0.001
Abdomen	32 (8.2)	44 (15.7)	0.003
Extremity	63 (16.2)	74 (26.4)	0.001
External	13 (3.3)	16 (5.7)	0.177
Advanced Imaging, n (%)	269 (69.2)	216 (77.1)	0.023
Mortality, n (%)	16 (4.1)	23 (8.2)	0.030

PRBCs, Packed Red Blood Cells; FFP, Fresh Frozen Plasma; ICU, Intensive Care Unit; ISS, Injury Severity Score; SD, Standard Deviation; AIS, Abbreviated Injury Score.

riority of SIPA over SI (with a single, uniform threshold) for use in the prediction of resource utilization and outcomes in pediatric trauma [7–8,14–16].

Our present study sought to expand upon our promising preliminary work on the use of SIPA in pediatric warzone trauma, as well as the encouraging studies on the value of SIPA trends in pediatric civilian trauma. Broadly speaking, our findings are in agreement with those of Nordin et al. and others. We first found that an elevated SIPA in the pre-hospital setting and upon arrival to the initial level of care were each associated with increased incidence of each of our four primary outcomes, including ICU admission, mechanical ventilation, severe injury, and mortality, as well as the important secondary outcome of need for blood product transfusion. This work, therefore, represents only the second in the literature to our knowledge to examine the relationship of pre-hospital SIPA and pediatric trauma outcomes, and the only thus far to study this relationship in warzone trauma.

Moving on to the focus of the study, we found that patients with a persistently abnormal SIPA (Group 4) from pre-hospital to arrival had significantly worse outcomes, represented by greater incidence of ICU admission, mechanical ventilation, severe injury, and mortality. They likewise demonstrated increased need for blood product transfusion, ICU and hospital LOS, total ventilator days, ISS, and need for advanced imaging. This result is in direct concurrence with those studies previously described, suggesting that trending SIPA could play a valuable role in pediatric trauma assessment. As a result, we cautiously advocate for the use of SIPA trends as part of the initial evaluation of children injured in warzones, in which appropriate triage is essential.

However, this work differs in certain key ways from those published before. Notably, our inclusion of patients with penetrating trauma represents the first evaluation of SIPA trends in this cohort. Our findings again align with those previously described by Vandewalle and Nordin in the blunt trauma population, and encourage further study of SIPA trends in civilian pediatric penetrating trauma [9–11]. Unfortunately, no significant difference was noted in the incidence of emergent surgery or severely injured body region (AIS ≥ 3) based on SIPA trend. This differs from our own prior studies into SIPA in pediatric warzone trauma [12]. However, given our fairly small sample size compared to our prior investigations, it is likely that we were underpowered to capture any difference present in these lower incidence secondary outcomes.

We further appreciated that a pattern of stepwise increase in the incidence of many outcomes, including blood product transfusion, mechanical ventilation, and severe injury, can be seen as trends progress from persistently normal to persistently abnormal. It was this “meta-trend” which we found to be most interesting. Though our analysis of the testing characteristics was less encouraging than we would have hoped, it suggests that perhaps trending SIPA over multiple (three or more) time points may prove of even greater utility.

In addition to the conclusions described above, we sought to introduce the concept of “unfavorable” SIPA trends which included patients whose SIPA deteriorated from pre-hospital to arrival (Group 2) and those with a persistently abnormal SIPA (Group 4). Common sense would seem to dictate that this concatenation of trends would be associated with significantly worse outcomes in terms of morbidity and mortality, and indeed this was the case. However, a clear eyed comparison shows that little benefit was gained in terms of discriminative ability by this classification. This was undoubtedly due to the fact that unfavorable trends were essentially a reflection of the SIPA value upon arrival. However, knowing that pre-hospital resuscitative interventions have failed to normalize SIPA suggests additionally valuable information for the receiving physician, particularly in chaotic settings such as war zones. Further work is clearly necessary to determine the value, if any, of unfavorable versus favorable SIPA trends, ideally over multiple time points in care.

There are a number of limitations to our present line of inquiry which demand notice. Firstly, the small sample size of our

Table 7
Test Characteristics of SIPA and SI for Selected Outcomes of Pediatric Warzone Trauma.

Variable	Abnormal Pre-hospital SIPA	Abnormal Arrival SIPA	Unfavorable SIPA Trend	Persistently Abnormal SIPA (Group 4)
Blood Product Transfusion				
Sensitivity (%)	55.3	57.6	57.6	42.0
Specificity (%)	65.6	68.3	68.3	81.1
PPV (%)	51.1	53.3	53.9	58.8
NPV (%)	69.7	71.5	71.5	68.5
Youden Index	0.209	0.259	0.259	0.231
ICU Admission				
Sensitivity (%)	50.2	53.1	53.1	35.6
Specificity (%)	63.4	67.5	67.5	78.4
PPV (%)	53.2	57.5	57.5	57.8
NPV (%)	60.6	63.5	63.5	59.5
Youden Index	0.136	0.206	0.206	0.140
Mechanical Ventilation				
Sensitivity (%)	53.7	70.2	70.2	47.8
Specificity (%)	58.5	61.3	61.3	74.3
PPV (%)	12.6	16.8	16.8	17.11
NPV (%)	91.9	94.9	94.9	92.7
Youden Index	0.122	0.315	0.315	0.221
Severely Injured (ISS>15)				
Sensitivity (%)	51.0	54.9	54.9	40.2
Specificity (%)	60.9	63.9	63.9	77.4
PPV (%)	36.7	40.0	40.0	43.9
NPV (%)	73.9	76.4	76.4	74.7
Youden Index	0.119	0.188	0.188	0.176
Mortality				
Sensitivity (%)	61.5	59.0	59.0	46.2
Specificity (%)	58.4	59.2	59.2	73.2
PPV (%)	8.4	8.2	8.2	9.6
NPV (%)	96.1	95.9	95.9	95.6
Youden Index	0.199	0.182	0.182	0.194

PPV, Positive Predictive Value; NPV, Negative Predictive Value.

study cohort and the retrospective nature of our analysis limit the strength of our findings. As we have advocated in the past, a prospective examination of SIPA in pediatric warzone trauma (akin to that accomplished in pediatric civilian blunt trauma by Linnaus et al.) would be a challenging task [12,14]. Second, our inclusion of patients with less severe injuries (ISS < 15) and with burns limits strict comparison with the previously mentioned work on SIPA trends. As this was done purposefully with the intention of allowing for the most broad generalizability of our findings though, we feel it was a reasonable digression from the current literature. Third, the predominance of blast injuries in our study population is unique from civilian studies, and limits ability to apply our conclusions to the civilian trauma cohort. Finally, our knowledge of the pre-hospital interventions including intravenous fluid (IV) access and fluid administration, blood product transfusion, intubation, and tourniquet application as well as transport times was limited. Given that such interventions and transport times have a significant influence upon outcomes (including the normalization of SIPA values), this represents an important potential confounding influence on our study.

In conclusion, we found that trends in SIPA from may be used to predict trauma outcomes for children injured in warzones, with persistently abnormal values associated with worse outcomes overall. Our findings agree with those prior studies on the use of SIPA trends, while exploring the significance of such trends in penetrating trauma and particularly warzone trauma for the first time. We encourage further study in the utility of trending SIPA throughout the initial phases of pediatric trauma care and its consolidation within existing trauma algorithms.

Author contributions

Dr. Christopher Marenco and Dr. Woo Do conducted the literature search.

Dr. Matthew Eckert and Dr. Horton contributed to study design.

Dr. Christopher Marenco, Dr. Kaitlin Morte, Dr. Daniel Lammers, and Dr. Matthew Eckert participated in data acquisition.

Dr. Daniel Lammers, Dr. Woo Do, and Dr. Kaitlin Morte, Dr. Christopher Marenco contributed to data analysis and interpretation.

Dr. Christopher Marenco, Dr. Woo Do, and Dr. Daniel Lammers drafted the manuscript.

Dr. Matthew Eckert and Dr. John Horton critically revised the final manuscript.

Dr. Christopher Marenco, Dr. Woo Do, Dr. Daniel Lammers, Dr. John Horton, and Dr. Matthew Eckert reviewed and approved the final manuscript.

Disclosures

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