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IMPROVEMENTS IN THE HEMODYNAMIC STABILITY OF COMBAT CASUALTIES DURING EN ROUTE CARE

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ABSTRACT Three Forward Aeromedical Evacuation platforms operate in Southern Afghanistan: UK Medical Emergency Response Team (MERT), US Air Force Expeditionary Rescue Squadron (PEDRO), and US Army Medical Evacuation Squadrons (DUSTOFF), each with a different clinical capability. Recent evidence suggests that retrieval by a platform with a greater clinical capability (MERT) is associated with improved mortality in critical patients when compared with platforms with less clinical capability (PEDRO and DUSTOFF). It is unclear whether this is due to en route resuscitation or the dispatch procedure. The aim of this study was to compare prehospital Shock Index (SI heart rate / systolic blood pressure) with admission values as a measure of resuscitation, across these platforms. Patients were identified from the Department of Defense Trauma Registry, who were evacuated between June 2009 and June 2011 in Southern Afghanistan. Data on platform type, physiology, and injury severity was extracted. Overall, 865 patients were identified: 478 MERT, 291 PEDRO, and 96 DUSTOFF patients and groups were compared across three injury severity scoring (ISS) bins: 1 to 9, 10 to 25, and 26 or greater. An improvement in the admission SI was observed across all platforms in the lowest ISS bin. Within the middle bin, both the MERT and PEDRO groups saw improved SI on admission, but not the DUSTOFF group. This trend was continued only in the MERT group for the highest ISS bin (1.39 ± 0.62 vs. 1.09 ± 0.42; *P* 0.001), whereas a deterioration was identified in the PEDRO group (0.88 ± 0.37 vs. 1.02 ± 0.43; *P* 0.440). The use of a Forward Aeromedical Evacuation platform with a greater clinical capability is associated with an improved hemodynamic status in critical casualties. The ideal prehospital triage should endeavor to match patient need with clinical capability.

KEYWORDS Shock, hemorrhage, resuscitation, prehospital care, combat casualty care

INTRODUCTION

The current conflicts in Afghanistan and Iraq have seen the lowest died-of-wounds rates for any conflict in recent times (1, 2). However, this metric is based on patients who are admitted to a medical treatment facility (MTF) and does not include patients who die in the prehospital phase of care who are termed "killed in action" (3). A recent analysis of 4,596 US military deaths in Iraq and Afghanistan found that 87.3% of patients died before an MTF, with 24.3% classified as potentially survivable (4). Improvements in prehospital care has the greatest potential to reduce overall battlefield deaths.

To reduce prehospital mortality, a number of studies have examined different Forward Aeromedical Evacuation (FAME) platforms. Mabry et al. (5) demonstrated a reduction in mortality in patients evacuated by critical care flight paramedics (CCFP) compared with a basic-level flight medic. A further study by Morrison et al. (6) identified a survival benefit in patients with an injury severity score (ISS) between 16 and 50 who were retrieved by a larger rotary-wing platform, crewed by a physician-led medical team, compared with paramedic/flight medic–led care.

Although these studies suggest that a higher prehospital clinical capability confers a survival advantage in critical casualties, it is unclear if the outcomes relate to the resuscitation rather than the respective tasking procedure involved in each assets deployment. The aim of this study was to use an established measure of cardiovascular performance—the Shock Index (SI)—to compare the change in prehospital and admission indices as a measure of resuscitation, onboard different FAME platforms in Southern Afghanistan (7).

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METHODS

This is a retrospective performance evaluation examining the prehospital and admission SI of three discreet FAME platforms transporting casualties from the point of injury (POI) to a Role III MTF in Helmand, Southern Afghanistan, over a 2 year period (June 2009 to June 2011). A Role III MTF is equivalent to a US civilian level II trauma center and is capable of providing comprehensive trauma care before out of theater medical evacuation (MEDEVAC). As SI is measure of hemodynamic stability, patients with isolated severe brain injury or unsurvivable injuries (i.e., ISS of 75) were excluded.

This performance evaluation was approved by and conducted in accordance with the policy and procedures set forth by the US Central Command Joint Combat Casualty Research Team and the Joint Trauma System.

FAME platform definitions

Three FAME platforms operate in Southern Afghanistan: the UK Medical Emergency Response Team (MERT) Enhanced, the US Air Force Expedition ary Rescue Squadron (call sign PEDRO), and the US Army Medical Evacuation Squadrons (call sign DUSTOFF).

The MERT Enhanced consists of an eight member crew headed by a phy sician (emergency medicine or anesthesia) and includes a nurse, two para medics, and a four man quick reaction force for security. This team is capable of delivering a sophisticated level of care including rapid sequence intubation, resuscitative thoracotomy, and blood product administration. This team is generally transported by a CH 47 Chinook, which is a fast and capacious air frame compared with other rotary wing platforms used in Afghanistan.

The PEDRO FAME platform is composed of a two man pararescue team (PJs) credentialed as paramedics onboard an HH 60 Pavehawk airframe; PJs are also trained in advanced military skills, as historically they have been responsible for "personnel recovery" missions. However, within Afghanistan, their mission has been extended to support general MEDEVAC, and because of their military capability, they are the preferred platform for retrievals in

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hostile environments (e.g., ongoing firefights). They are also trained to perform rapid sequence intubation and, as of December 2010, are capable of administering prehospital blood and tranexamic acid (TXA).

Finally, DUSTOFF crews are transported by a UH 60A Blackhawk. Although there is some variation as to the number and credentials of providers aboard, the crew is typically one or two emergency medical technician basic level flight medics. Unlike the previous two platforms discussed, the DUSTOFF team has limited firepower and does not possess the ability to administer advanced airway interventions or blood products in flight.

FAME tasking procedure

A single Patient Evacuation Control Center (PECC) is responsible for tasking and recording all en route care movement within Southern Afghanistan (8, 9). In the event that personnel require medical assistance, the requesting military unit contacts the PECC, and the process of point of injury evacuation is initiated. The PECC dispatchers use a combination of tactical (distance, terrain, enemy action, asset availability, etc.) and medical (mechanism of injury, injury details, and physiology) information from the incident reported to determine which rotary wing evacuation asset is best suited for each mission and coordinate tasking accordingly. The PECC taskings are not a random process, but calculated to provide the best asset balancing both tactical and clinical needs.

Evaluation data sources

The data set analyzed for this study comprises prehospital clinical data and POI transport information amalgamated from three prospectively captured data sources: 1 US Department of Defense Trauma Registry (DoDTR), 2 Patients Evacuation Coordination Center (PECC) tasking logs, and 3 patient care records/prehospital report forms.

The US DoDTR was established in 2004 primarily as a process improvement tool based on data abstracted from clinical records from Role III admission onward (10). The DoDTR was used to identify a consecutive population of combat casualties, who were admitted a Role III MTF (Bastion or Kandahar) with a spontaneous circulation. The DoDTR provided patient details, admission physiology (systolic blood pressure [SBP], heart rate [HR], and Glasgow Coma Scale [GCS] score), mechanism, and ISS (using civilian Abbreviated Injury Scale scoring), along with in hospital mortality. Afghan patients are termed local nationals, and military patients (e.g., US and UK military) are termed coalition military.

To determine the FAME provider, results from the DoDTR query were matched to deidentified MEDEVAC tasking logs provided by the PECC. Lastly, patient care records and prehospital forms were used to confirm the transport airframe listed in the PECC logs and extract detailed prehospital and transport physiology. When matched appropriately, the final data set established baseline patient demographics, injury patterns, and POI MEDEVAC details.

Study end points

The primary end point related to the change in admission SI compared with the prehospital SI and whether there was a reduction in the mean SI (i.e., an improvement) or an increase in the mean SI (i.e., a deterioration). The SI is a ratio between the HR and SBP and has been demonstrated to be a reliable measure of cardiovascular performance, validated in civilian (11 14), military (15), and prehospital settings (7, 16, 17). The reference range is considered between 0.5 and 0.7 with values of 0.9 and above associated with adverse outcome (7, 15 17). In practical terms, the physiological data used to generate the indices were recorded within minutes of either helicopter evacuation or hospital admission.

Statistical analyses

Initially, demographic characteristics, prehospital and admission physiology, injury mechanism and severity, and mortality were made across the FAME platforms. These groups were then stratified into three a priori ISS bins (1 9, 10 25, and ≥26), and further analyses performed.

Categorical data were summarized using crude rates and percentages. Mortality outcomes were compared using χ^2 tests. Continuous variables were tested for normality, and those that met the criteria for normality were summarized using means and SDs. Platform comparisons were analyzed using Student *t* test and analysis of variance. Nonnormally distributed continuous variables were analyzed using the Wilcoxon test, and medians with interquartile ranges were used to provide summary statistics. Statistical significance was set at $P \leq 0.05$. All data analyses for this study were performed using SAS 9.2 (Cary, NC).

RESULTS

The DoDTR query identified 1,061 unique patients with 60 deaths before MTF admission and eight interfacility transfers that were excluded, leaving 993 patients (Fig. 1). FAME platform could not be identified in 18 patients, and 74 patients had incomplete prehospital physiology. Further exclusions consisted of 16 patients with isolated severe traumatic brain injury and five patients with unsurvivable wounding. The remaining 865 patients constituted the final cohort and consisted of the following: 478 MERT patients, 291 PEDRO patients, and 96 DUSTOFF patients.

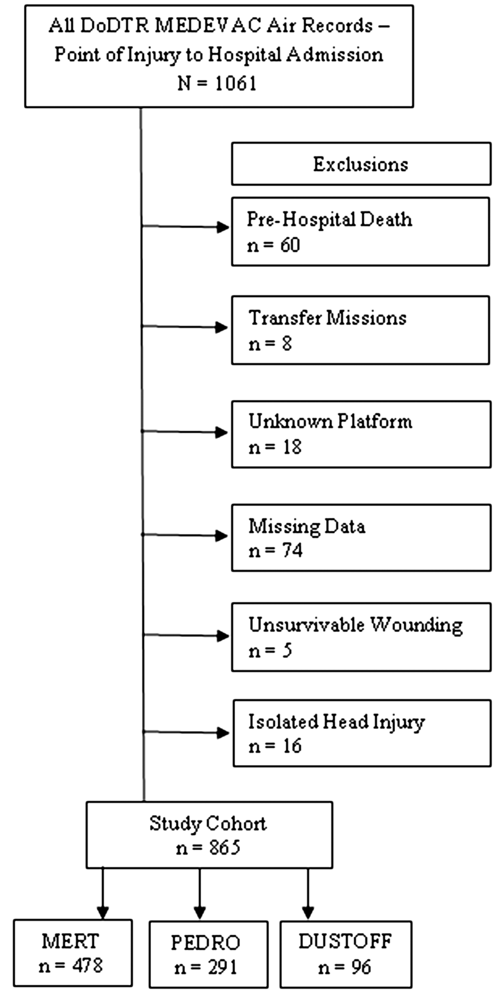

Fig. 1. Flow diagram of the cohort selection.

Basic population characteristics

Overall, the mean patient age for all three providers was similar (Table 1). DUSTOFF transported a slightly greater percentage of coalition military patients, compared with the PEDRO and MERT groups (82.8% vs. 73.5% and 72.6%, respectively, $P = 0.139$); however, the difference was not statistically significant. Across all three FAME providers, 65% (n = 563) of casualties transported during the evaluation period sustained explosive or blast-related injuries. When stratified by provider, the MERT transported the highest percentage of patients with blast-related injuries compared with DUSTOFF and PEDRO, respectively (71.8% vs. 62.5% and 55.0%; $P < 0.001$).

Injury severity and injury patterns

The median (interquartile range) ISS was 11 (3–19) in the MERT, with eight (3–14) for the PEDRO and six (3–9) for the DUSTOFF platforms ($P < 0.001$) (Table 1). Within specific body

Table 1. **Demographic characteristics and injury severity by FAME platform**

	MERT	PEDRO	DUSTOFF	
	n 478	n 291	n 96	*P*
Age	24.1 ± 4.8	23.6 ± 4.1	24.4 ± 5.8	
Coalition military	347 (72.6%)	214 (73.5%)	79 (82.2%)	0.139
Local national	131 (27.4%)	77 (26.4%)	17 (17.8%)	
Mechanism of injury				
Explosion	343 (71.8%)	160 (55.0%)	60 (62.5%)	<0.001
Gunshot	119 (24.9%)	92 (31.6%)	21 (21.9%)	
Other	16 (3.3%)	39 (13.4%)	15 (15.6%)	
Median ISS	11 (16)	8 (11)	6 (11)	<0.001
Head and neck	49 (10.3%)	21 (7.2%)	7 (7.3%)	0.301
Torso	107 (22.4%)	42 (14.4%)	12 (12.5%)	0.006
Extremity	227 (47.5%)	93 (32.0%)	21 (21.9%)	<0.001
Mortality	12 (2.5%)	6 (2.1%)	1 (1.0%)	0.657

regions, there was a similar rate of severe head and neck injuries across the MERT, PEDRO, and DUSTOFF platforms (10.3% vs. 7.2% vs. 7.3% respectively; *P* = 0.301). There were increasing proportions of torso and extremity injury across all groups, with the greatest increase seen in the MERT platform. Almost half of the MERT cohort had sustained a severe extremity injury (47.5%) in contrast to one in three in the PEDRO (32.0%) and one in five in the DUSTOFF (21.9%) platform (*P* = 0.006). Within the MERT group, 22.4% had sustained a severe torso injury compared with 14.4% in the PEDRO and 12.5% in the DUSTOFF groups (*P* = 0.006).

Mortality by FAME provider and injury severity bins

There was no difference in unadjusted crude mortality between the MERT, PEDRO, and DUSTOFF platforms (2.5% vs. 2.1% vs. 1.0%; *P* = 0.657) (Table 1). The cohort was then stratified into three ISS bins (1–9, 10–25, ≥26) and mortality compared (Fig. 2). Within the lowest bin (n = 442), there were very few deaths (n = 3) and no significant difference across the groups (*P* = 0.676). Within the middle bin (n = 336), there is a progressive increase in mortality observed from the MERT to PEDRO to DUSTOFF platform (2.9% vs. 5.7% vs. 7.1%); however, this does not achieve statistical significance (*P* = 0.566). A similar trend is observed in the highest bin (n = 102) with MERT and PEDRO mortality rates of 12.2% and 17.6% respectively; *P* = 0.625. There were no deaths in DUSTOFF group in the highest ISS bin, although there were only seven patients within this subgroup.

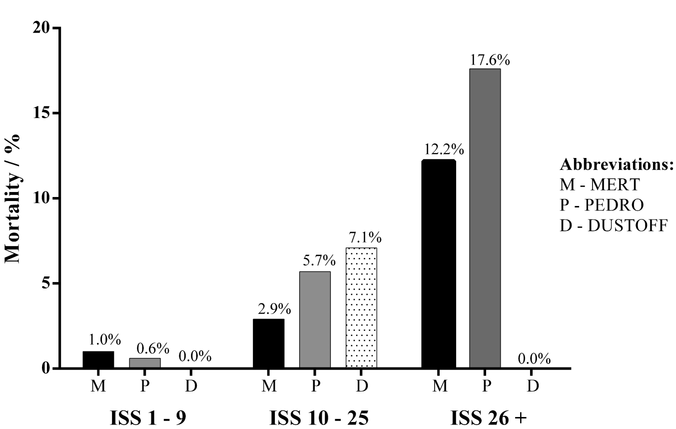

Fig. 2. Bar graph of mortality by FAME platform per ISS bin.

Table 2. **Prehospital and admission average physiological parameters by FAME platform**

	MERT	PEDRO	DUSTOFF	
	n 478	n 291	n 96	*P*
Prehospital				
HR, beats/min	105 ± 30	93 ± 23	96 ± 23	<0.001
Systolic, mmHg	108 ± 29	122 ± 25	125 ± 26	<0.001
Respiratory rate, breaths/min	22 ± 16	19 ± 6	19 ± 7	0.019
Admission				
HR, beats/min	100 ± 28	92 ± 25	94 ± 23	<0.001
Systolic, mmHg	128 ± 30	136 ± 28	134 ± 23	<0.001
Respiratory rate, breaths/min	20 ± 6	19 ± 6	22 ± 8	0.001

Prehospital versus emergency department admission physiology

When comparing prehospital physiology across the three FAME platforms, the MERT group had a significantly greater HR and respiratory rate and lower SBP than did the other two groups (Table 2). This pattern was similar with the emergency department admission values, with the exception of admission respiratory rate, which was highest in the DUSTOFF group.

When examining prehospital versus admission SI per ISS bin, there was global improvement across all platforms in the lowest bin (ISS 1–9), although all the mean values were less than 0.9 (Table 3). Within the middle bin (ISS 10–25), a significant improvement was observed within the MERT and PEDRO groups, where all prehospital mean values were greater than 0.9. The indices in the DUSTOFF group remained unchanged. In the highest bin (ISS ?26), the admission SI in the MERT group

Table 3. **Prehospital SI compared with admission SI per FAME platform by ISS bin**

	Prehospital SI	Admission SI	*P*
ISS 1 9			
MERT	0.84 ± 0.28	0.66 ± 0.24	<0.001
PEDRO	0.76 ± 0.25	0.64 ± 0.20	<0.001
DUSTOFF	0.78 ± 0.26	0.66 ± 0.28	0.001
ISS 10 25			
MERT	1.10 ± 0.48	0.91 ± 0.43	<0.001
PEDRO	0.86 ± 0.35	0.78 ± 0.40	0.013
DUSTOFF	0.82 ± 0.26	0.88 ± 0.41	0.805
ISS ≥26			
MERT	1.39 ± 0.62	1.09 ± 0.42	0.001
PEDRO	0.88 ± 0.37	1.02 ± 0.43	0.440
DUSTOFF	0.94 ± 0.30	0.86 ± 0.17	0.898

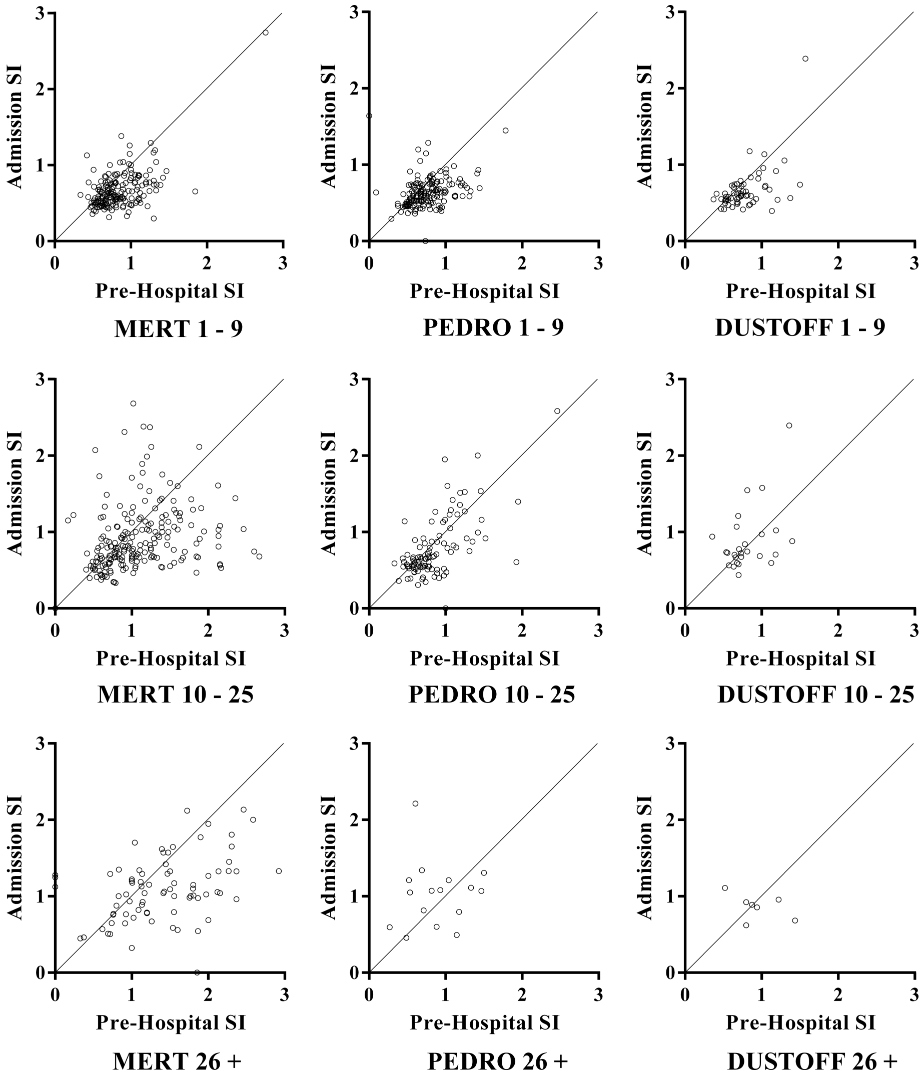

Fig. 3. Scatter plot of prehospital versus admission SI.

was significantly improved; however, a deterioration was observed within the PEDRO group, although this did not achieve statistical significance (Table 3). Again, the DUSTOFF group remained unchanged.

These data are also displayed graphically in a scatter plot of prehospital against admission SI (Fig. 3). The diagonal line is the line of "no change"—subjects plotted below this line have seen an improvement in SI. This illustrates the degree of dissimilarity between prehospital and admission SI, with a general trend of improvement noted in the MERT group. The PEDRO group tends to be evenly distributed around the line of no change. The DUSTOFF groups lacked numbers in the middle and upper ISS bins with which to draw trends.

DISCUSSION

This is the first study to examine the dynamic changes in physiology in patients sustaining a combat-related injury retrieved by different FAME platforms. This study has used the SI as an end point of resuscitation to demonstrate that the MERT platform achieved a significant improvement in hemodynamic status en route to an MTF from the POI in the ISS bin 10 to 25 and 26 or greater. The current study extends the work of Mabry et al. (5) and Morrison et al. (6), who have demonstrated a mortality improvement in specific subgroups of combat casualties retrieved by FAME platforms crewed by personnel with escalating clinical capability.

Mabry et al. using the US Joint Theatre Trauma Registry (now the DoDTR) examined 671 patients retrieved from the POI by US Army MEDEVAC assets crewed by either CCFP or emergency medical technician basic-flight medics (Standard MEDEVAC) (5). The unadjusted mortality was highest in 469 patients retrieved by the Standard MEDEVAC compared with the 202 patients retrieved by the CCFPs (15% vs. 8%; $P = 0.006$). When adjusting for known confounding variables in a logistic regression, the odds ratio of death in the CCFP group was 0.34 (95% confidence interval, 0.14–0.88). However, this study was based on a convenience sample of patients moved within two different geographical regions, and there was no discussion regarding the tasking procedure.

More relevantly, Morrison et al. (6) utilized the UK Joint Theatre Trauma Registry to examine the same platforms evaluated in the current study. They directly compared the MERT group (n = 1,093) to a combined group (n = 628) of the PEDRO and DUSTOFF platforms, stratified into three ISS bins (1–15, 16–50, and 51–75). They observed a reduction in mortality in the middle ISS group when patients were retrieved by the MERT group (12.2% vs. 18.2%; $P = 0.035$) (6). The current study demonstrated a similar trend in mortality, although statistical significance was not achieved, largely because of a smaller sample size than that in the study of Morrison et al. This is to be expected as these studies overlap by 21 months, although it is important to note that different registries were used as the primary data source, and they used different iterations of ISS scoring.

In aggregate, these studies suggest that the observed mortality benefit related to an improvement in the clinical care en route. However, neither study presents evidence demonstrating an improvement in a clinical parameter from the POI to admission. Additionally, there are significant nonclinical differences between providers, which could influence clinical outcomes. For example, the PEDRO platform used in these studies carries extrication equipment and thus is preferentially tasked to entrapped patients. A case of prolonged entrapment could adversely influence clinical outcome, irrespective of clinical capability.

To demonstrate a change in prehospital parameters, data are required from the POI, which is particularly challenging to collect. Sophisticated measures used routinely in hospital, such as serum lactate, are near impossible to perform. The most complete data recorded in the prehospital setting are basic physiological recordings—HR, blood pressure, respiratory rate, and GCS. However, the latter two can be compromised by therapeutic interventions, e.g., anesthesia to facilitate intubation will depress GCS, and artificial ventilation will manipulate the respiratory rate. Thus, HR and blood pressure are the best available measures, which also happen to be clinically relevant, as hemorrhage is the leading cause of potentially preventable death on the battlefield (18–20).

The combination of HR with SBP as an index of cardiovascular performance was first described in 1967 (18) and has since been applied to a variety of clinic settings (19). It has been shown to be a more sensitive measure of hypovolemia than HR or SBP in isolation (14). This is combined with an ease of calculation that lends itself to the prehospital arena (16), and SI has also been suggested as military triage tool (20). Within the military context, SI has been demonstrated as a sensitive and specific tool for operative decision making in the setting of torso trauma (15).

We have used SI as an end point of resuscitation on the premise that a reduction in SI indicates an improvement in cardiovascular stability and ultimately tissue oxygenation. This is supported by several studies where SI has been shown to correlate with lactate levels (19, 21, 22). The implication is that the MERT platform is better suited to resuscitate more severely injured patients. This is likely to relate to the broader array of interventions that this platform is capable of delivering—specifically, the use of prehospital blood products and hemorrhage control adjuncts. The MERT platform carried eight units of components split between packed red blood cells and plasma along with the adjunct TXA (23, 24). The PEDRO platform for the first 18 months of this study did not carry blood and currently carries two units of each component, along with TXA. A further analysis of the use of prehospital blood will be forthcoming.

However, the use of SI within this study has a number of limitations. Specifically, patients must have a spontaneous circulation and completely recorded data to calculate an SI. There were 74 patients excluded because of missing data, and it is unknown if this introduces a degree of bias. Furthermore, while an SI greater than 0.9 has been demonstrated to be associated with mortality, a dynamic change has not been previously correlated with outcome. However, as a trend toward an improvement in mortality was observed in the MERT ISS bin where significant improvements in SI also occurred, it is likely that this is the case.

There are further limitations to note within the reported study. Specifically, this is a retrospective evaluation that can suffer from incomplete and erroneous data. For example, there were three deaths within the ISS 1–9 category, suggestive of unexpected death. However, as the DoDTR is based on injuries abstracted from case notes, it may be the case that these patients' ISS was underestimated. The DoDTR is collected prospectively, and data were cross checked from several sources, which is designed to limit error. Finally, we were unable to report any timeline data, which we acknowledge is a key variable. Several previous studies have reported prehospital times from Afghanistan and shown them to be similar across FAME platforms, so we do not believe this is a source of bias between platforms (6, 25).

In conclusion, this is the first study from a theater of war to demonstrate that FAME platforms with discreet clinical capabilities can influence admission physiology in a population at risk of hemorrhagic shock. The majority of patients having sustained minor combat injury are well served by current FAME platforms. However, for patients sustaining severe injury, retrieval by a platform with a greater clinical capability (MERT) is associated with improved admission physiology. Further study is required to elucidate which components of this platform contribute most to the successful resuscitation of combat casualties.

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