Advancing prehospital combat casualty evacuation: patients amenable to aeromedical evacuation via unmanned aerial vehicles

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DECLARATION OF INTEREST

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NOTICE AND SIGNATURE PAGE

ADVANCING PREHOSPITAL COMBAT CASUALTY EVACUATION: PATIENTS AMENABLE TO AEROMEDICAL EVACUATION VIA UNMANNED AERIAL VEHICLES

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14. ABSTRACT-

Introduction: The US military currently utilizes unmanned aerial vehicles (UAVs) for reconnaissance and attack missions. However, as combat environment technology advances, there is the increasing likelihood of UAV utilization in prehospital aeromedical evacuation. While some combat casualties require life-saving interventions (LSIs) during medical evacuation, many do not. Our objective was to describe patients transported from the point of injury (POI) to the first level of care and characterize differences between patients who received LSIs en route and those who did not.

Materials and Methods: We conducted a retrospective review of the records of traumatically injured patients evacuated between January 2011 and March 2014. We compared patient characteristics, complications, and outcomes based on whether they had an LSI performed en route (LSI vs. No LSI). We also constructed logistic regression models to determine which characteristics predict uneventful flights (no en route LSI or complications).

Results: We examined 1267 patient records; 47% received an LSI en route. Most patients (72%) sustained a blast injury and injuries to the extremities and head. Over 78% experienced complications en route; the LSI group had higher rates of complications compared to the No LSI group. Logistic regression showed that having a blunt injury or the highest AIS severity score in the head/neck region are significant predictors of having an uneventful flight.

Conclusion: Approximately half of casualties evaluated in our study did not receive an LSI during transport and may have been transported safely by UAV. Having a blunt injury or the highest AIS severity score in the head/neck region significantly predicted an uneventful flight.

15. SUBJECT TERMS- en route care, aeromedical evacuation, unmanned aerial vehicles, combat casualty care

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TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY

Advancing prehospital combat casualty evacuation: patients amenable to aeromedical evacuation via unmanned aerial vehicles

Gaps Addressed: 2017 AFMS CBA, 2008 Joint Force Health Protection Capability Gaps Requiring Medical R&D

ACC/AFMS 96 - Operating in Contested, Degraded, Operationally-limited (CDO) Environment
AMC/AFMS 174 - Patient Movement To Support Non- validated/non-regulated Patient Movement
JCM-2-8: Inadequate casualty evacuation (CASEVAC) by non-standard platforms

Modified Abstract

Background: The United States military currently utilizes unmanned aerial vehicles (UAVs) for reconnaissance and attack missions. However, as combat environment technology advances, there is the increasing likelihood of UAV utilization in prehospital aeromedical evacuation. UAVs may provide a viable means to reduce transport time to trauma capable medical facilities. Identification of patients who are unlikely to require life-saving interventions (LSIs) during transport may aid prehospital medical personnel in identifying those patients who can be rapidly evacuated in UAVs without medical personnel onboard. We sought to describe patients transported from the point of injury (POI) to the first level of care between January 2011 and March 2014 and to characterize any differences between those patients who received LSIs en route and those who did not to inform military planning on the value of UAV for casualty transports out of the battlefield.

Methods: We conducted a retrospective review of MEDEVAC patient care records for United States (US) military personnel who were injured in the Operation Enduring Freedom (OEF) theater of operations between January 2011 and March 2014. We abstracted the current study dataset (n=1267) from our prior study that examined MEDEVAC patient records from the POI to arrival at the first military treatment facility (MTF). Patients were categorized as receiving an LSI en route if they received at least one of the following during the flight to the first MTF: oxygen administration, airway access, cardiopulmonary resuscitation (CPR), defibrillation, chest needle decompression, chest tube, chest seal, tourniquet(s), non-hemostatic pressure packing, hemostatic agents, blood products, and medications delivered via intravenous (IV) or intraosseous (IO) access. We placed the patients who did not receive at least one LSI en route in the "No LSI" group.

Results:

- We examined the records of 1267 patients transported from the POI to the first level of care between January 2011 and March 2014.
- Casualties were 98.5% male with a median age of 24 (IQR 22-27).

- The majority sustained a blast injury (72.2%) and the most common injury locations were the lower extremities (60.7%), upper extremities (36.6%), head (15.5%), and face (15.5%).
- The most common interventions were non-hemostatic pressure packing (20.0% of sample), intravenous medications (18.0%), airway access (8.9%), oxygen administration (8.3%), tourniquets (6.6%), cardiopulmonary resuscitation (4.4%) and blood products (4.3%).
- Over 78% of all patients experienced at least one en route complication with the most frequent being moderate to severe pain (51.1% of sample), abnormal heart rate (32.0%), abnormal systolic blood pressure (26.9%), and low SpO_2 (14.0%).
- 676 patients (53%) did not receive any en route LSI.
- Certain factors, such as having a blunt injury or the highest AIS severity score in the head/neck region, were significant independent predictors of having an uneventful flight with either no LSIs, no complications, or neither.
- Receiving an amputation and having injuries to the chest, back, groin, or lower extremities significantly lowered the odds of having an uneventful flight.

Conclusions: Approximately half of casualties evaluated in our study did not receive an LSI during transport and may have been transported safely by UAV. Having a blunt injury or the highest AIS severity score in the head/neck region significantly predicted an uneventful flight.

Evidence Based Recommendations:

- It is possible to identify those patients who are unlikely to require interventions during transport and evacuate them rapidly with UAVs.
- Using UAVs to deliver blood products to POI medics would allow for increased use of this LSI intervention without increasing the medics pack load and/or allowing for resupply.

2.0 INTRODUCTION

The United States military currently utilizes unmanned aerial vehicles (UAVs) for reconnaissance and attack missions; however, as combat environment technology advances, there is the increasing likelihood of UAV utilization in prehospital aeromedical evacuation. Research into the capabilities of UAVs is limited thus far with the vast majority focusing on algorithms and methods of programming. A small number of studies evaluating the possible uses in the medical field exist. Thiels et al suggested that UAVs could be a viable mode to transport blood products to areas with limited supply.[1] Claesson et al compared UAV to EMS arrival times and found that the use of a UAV equipped with an automated external defibrillator (AED) may have the potential to reduce time to defibrillation in out-of-hospital cardiac arrest.[2] Other studies have focused on the ability of UAVs to support remote monitoring and surgical procedures. Lum et al successfully demonstrated the ability of two surgeons to perform surgery on inanimate objects using a wireless communication link to a surgical robot/UAV.[3]

UAVs may provide a viable means to reduce transport time to trauma-capable medical facilities. Unlike manned aircrafts, the risk associated with flying UAVs into hostile areas is much less likely to result in loss of human life. In the civilian trauma environment, there has been increasing emphasis on immediate evacuation of patients to trauma centers without delaying transport for unnecessary medical interventions.[4] Multiple studies have compared trauma transports completed by responders with a variety of training levels who either performed no interventions, performed basic interventions, or performed advanced interventions.[5-7] Transports were completed by family/friends utilizing personal vehicles, police, basic life support (BLS) capable providers, or advanced life support (ALS) capable providers. When adjusted for injury severity and compared to personal vehicle or police transport, EMS transport was not associated with superior outcomes (5-7). Other studies have found that when adjusted for injury severity, EMS transports were associated with increased mortality when compared to police or personal vehicle transports due to the delay in arrival to a medical facility.[8,9] In a study evaluating on-scene time and procedures performed on-scene, Funder et al found increased mortality among patients treated at the scene for more than 20 minutes. The number of procedures performed was also correlated with higher mortality.[10] Rappold et al reported that rapid transport with BLS care resulted in improved survival when compared to ALS transportation or ALS care. It was also found that ALS care for those most critically injured (ISS>30) was not correlated with decreased mortality.[11] Prolonged prehospital time has been associated with increased mortality for hypotensive patients.[12,13]

Additional research into the value and safety of UAVs to transport trauma casualties is needed. Furthermore, identification of patients who are unlikely to require LSIs during transport may aid prehospital medical personnel in identifying those patients who can be rapidly evacuated in UAVs without medical personnel onboard. Identifying these patients that do not need a manned vehicle would decrease the number of military personnel placed in harm's way to evacuate combat casualties and may decrease combat mortality by decreasing time to transport from the POI to a military treatment facility (MTF). We sought to describe patients transported from the POI to the first level of care between January 2011 and March 2014 and to characterize any differences between those patients who received LSIs en route and those who did not to inform military planning on the value of UAV for casualty transports out of the battlefield.

3.0 METHODS, ASSUMPTIONS AND PROCEDURES

We conducted a retrospective review of MEDEVAC patient care records for United States (US) military personnel who were injured in the Operation Enduring Freedom (OEF) theater of operations between January 2011 and March 2014. We obtained approval from the Wilford Hall Ambulatory Surgical Center Institutional Review Board (IRB) and conducted this study under the approved protocol.

We abstracted the current study dataset (n=1267) from our prior study that examined MEDEVAC patient records from the POI to arrival at the first MTF.[14] The dataset for this study included information on patient characteristics; injury type, location, and severity; flight characteristics; provider type; in-flight vital signs; POI and en route interventions; and en route complications. We used the Theater Medical Data Store (TMDS) to reconcile any missing or unavailable data. Additionally, we obtained clinical outcome data (hospital days, intensive care unit (ICU) days, ventilator days, discharge disposition, and mortality) from the Department of Defense Trauma Registry (DoDTR). These outcomes were available through the last MTF recorded in the DoDTR for each patient. Although we were unable to obtain DoDTR records for 117 patients, we only excluded them from analyses involving the DoDTR data and did not completely exclude them from the study. We implemented a standardized abstraction template and a quality assurance (QA) process to ensure consistency among abstractors, which included a secondary review of all records.[14]

En Route LSIs

Patients were categorized as receiving an LSI en route if they received at least one of the following during the flight to the first MTF: oxygen administration, airway access, cardiopulmonary resuscitation (CPR), defibrillation, chest needle decompression, chest tube, chest seal, tourniquet(s), non-hemostatic pressure packing, hemostatic agents, blood products, and medications delivered via intravenous (IV) or intraosseous (IO) access. Qualifying airway procedures included bag valve mask, nasal/oral airway, supraglottic airway, endotracheal intubation, and cricothyrotomy, and excluded nasal cannula and non-rebreather mask. We also categorized patients in the en route LSI group if their medical records included any of these interventions without specifying whether they occurred at the POI or en route. We did not count the administration of intravenous fluids en route as an LSI due to its association with poorer outcomes (15), nor did we include any interventions that occurred specifically at the POI. We placed the patients who did not receive at least one LSI en route in the “No LSI” group.

Statistical Analysis

We summarized nominal variables as count (percentage) and ordinal or non-normally distributed continuous variables as median [interquartile range]. Normality of continuous variables was determined using quantile plots, skewness, and kurtosis. As our main objective was to compare the characteristics, complications, and outcomes between patients who did and did not receive en route LSIs (LSI vs. No LSI groups), we primarily conducted univariable comparisons using either chi square or Fisher’s exact tests for nominal variables or Wilcoxon tests for ordinal or non-normally distributed continuous variables. We reported these results as differences with 95% confidence intervals and considered results statistically significant if the confidence interval did not include zero. Kaplan-Meier survival analyses were used to compare time-to-event data (hospital days, ICU days, ventilator days) between the two groups while censoring for mortality and the log-rank p-values were reported (significant at $p<0.05$).

Additionally, we conducted exploratory analyses to identify which characteristics best predict whether a patient will have an uneventful flight and thus would be amenable to transport via UAV. We used three endpoints as proxies for an uneventful flight: if a patient had no LSIs en route, no en route complications, and neither an LSI nor a complication en route. We constructed three logistic regression models with each of these endpoints as the dependent variable and included patient characteristics that were significantly associated with receiving an en route LSI as covariates using the direct entry method. These models were also clustered by the destination MTF (Role II or Role III). We tested for multicollinearity by ensuring that diagnostic statistics (variance inflation factor, tolerance, and condition index) were within acceptable limits and tested for the assumption of linearity for continuous variables using the Box-Tidwell method. We evaluated model fit using the area under the receiver operating characteristic (ROC AUC) and adjusted R^2. We reported adjusted odds ratios with 95% confidence intervals and considered results statistically significant if the confidence interval did not include 1. We conducted all statistical analyses in SAS version 9.4 (SAS Institute, Cary, NC).

4.0 MAJOR EVENTS/MILESTONES/SUCCESS

In preparation for and during the execution of this project, we completed the following deliverables and milestones:

- Kick Off Meeting – 03/18
- IRB/IACUC Approval – 04/18
- All experimental procedures completed – 08/19
- Data Analysis – 12/19
- Poster presentation :
  - MHSRS; Orlando, FL 2019
  - San Antonio Military Health System and Universities Research Forum (SURF); 2020
- Manuscript submitted to: Mil Med, Sept 2020
- Dissemination of Results – 08/19

5.0 RISK ASSESSMENT

5.1 Risk Analysis: This study presented no greater than minimal risks to the subjects. There were no interventions and no changes to the standards of care. The risk involved potential breaches of privacy and patient confidentiality should the data set be acquired by a person or agency outside of this research team. This risk was similar to basic patient care that would otherwise normally be carried out. The likelihood of that occurrence was mitigated by password protection of electronic files for identifiable information and de-identification of patient protected health information (PHI) prior to data analysis.

5.2 Technical Challenges

Due to the complexities of prospective combat research, our study was retrospective. As such, we were only able to determine an association between injury patterns and the need for LSI and en route care complications; we were not able to determine causation. We were also unable to determine which LSIs performed during transport could have or not have been performed prior to transport due to environmental and other circumstances. More importantly, we could not determine when a life-saving procedure was indicated but not performed for various reasons. Conversely, we were unable to characterize those that died on the battlefield that could have benefited from a more rapid UAV transport but had a delay in transported resulting in death on the battlefield. Additionally, our data was abstracted from the MEDEVAC record creating the potential for missing data due limited documentation medical teams. While all data abstractors were trained and periodic quality reviews occurred, there remained the potential for subjectivity in data abstraction from the patient care records.[16,17] Our data included subjects from 2011 to 2014. We chose these dates because of the large quantity of high fidelity aeromedical evacuation records available at this time and these records may not be reflective of injuries before or after those dates. Also, our study was not able to determine the impact of UAV transport on mortality as our goal was to see what proportion of patients could be evacuated by UAV without the need for LSIs. Finally, this study focused on military trauma patients, and our results may not be generalizable to the civilian community or to different circumstances occurring in future conflicts. For instance, our study demonstrated a mean transport time of 43 minutes. Future combat environments may have longer or shorter transport times depending upon the geography and the MEDEVAC aircraft or UAVs capabilities.

6.0 TRANSITION PLAN

6.1 Military Relevance

The potential logistical challenges of future conflicts are uncertain. Situations where air superiority is not guaranteed are anticipated. Evacuation systems in place during recent conflicts may not be an option. In this scenario the use of unmanned aerial vehicles for casualty evacuation may be plausible.

6.2 Transition Strategy

The results will be disseminated in the following formats:

1. The research community through national civilian and military academic conferences and meetings to include the Military Health Science Research Symposium (MHSRS).
2. Completed manuscripts submitted to peer-reviewed journals for publication.
3. The Defense Technical Information Center (DTIC) for publishing on their website.
4. Appropriate military leadership and training agencies.

7.0 RESULTS

We examined the records of 1267 patients transported from the POI to the first level of care between January 2011 and March 2014. Nearly half the sample (591/1267, 46.6%) received at least one LSI en route. The most common interventions were non-hemostatic pressure packing (20.0% of sample), intravenous medications (18.0%), airway access (8.9%), oxygen administration (8.3%), tourniquets (6.6%), cardiopulmonary resuscitation (4.4%) and blood products (4.3%). Fewer than 3% of patients received each of the following: hemostatic agents, chest needle decompression, intraosseous medications, chest seal, defibrillation, and chest tube.

The majority of providers were medics not trained to the level of paramedic (70.7%), followed by paramedics (23.8%) and physicians or nurses (3.1%). Transports occurred with the standard MEDEVAC/DUSTOFF team (81.2%), PEDRO (4.3%), AE (2.3%), or CASEVAC team (0.7%). The median time from injury to arrival at the first MTF was 43 minutes (IQR 32-62 minutes). There was no significant difference between the LSI and No LSI groups regarding the provider type, transport team, or transport time. About 55% of patients were transported to a Role II facility and 45% were transported to a Role III facility. Patients who received an LSI en route were more likely to go to a Role III facility than those who did not receive an LSI en route (51.9% vs. 39.2%, difference -12.7, 95% CI -18.2 to -7.3%).

The sample was 98.5% male with a median age of 24 (IQR 22-27). The majority of patients sustained a blast injury (72.2%) and the most common injury locations were the lower extremities (60.7%), upper extremities (36.6%), head (15.5%), and face (15.5%). About 12.6% of patients experienced an amputation. Overall, the median ISS was 9 (IQR 5-19) and median maximum AIS severity score (for the most severely injured body region) was 3 (IQR 2-4), most frequently occurring in the extremities (51.1%) and head/neck (15.6%). In contrast to the No LSI group, patients who received an LSI en route were more likely to have penetrating injuries, injuries to the chest, back, groin, and extremities, amputation, higher ISS, and higher maximum AIS. Patients in the No LSI group were more likely to have their maximum AIS score in the head/neck and face regions than those in the LSI group (Table 1).

The most common interventions provided at the POI were non-hemostatic pressure packing (40.2% of sample), tourniquets (33.7%), splints, slings, or casts (8.9%), and IV medications (6.8%). Compared to the No LSI group, patients who received an LSI en route were also more likely to receive supplemental oxygen and airway access, CPR, defibrillation, chest needle decompression, chest seal, and tourniquets at the POI. Patients who did not have an LSI en route were more likely to receive non-hemostatic pressure packing, spinal stabilization, and a splint, sling, or cast at the POI (Table 2).

Over 78% of all patients experienced at least one en route complication (as defined in Table 3), with the most frequent being moderate to severe pain (51.1% of sample), abnormal heart rate (32.0%), abnormal systolic blood pressure (26.9%), and low SpO_2 (14.0%). Patients who received an LSI en route had higher rates of all complications in comparison to the No LSI group (Figure 1). About 21.7% of patients had no complications during flight; this was more common for the No LSI group than the LSI group (28.6% vs. 13.9%, difference 14.7%, 95% CI 10.3-19.1%). Fifteen percent of patients (193/1267) had neither an LSI nor a complication en route to the first MTF.

Multivariable logistic regression models found that certain factors, such as having a blunt injury or the highest AIS severity score in the head/neck region, are significant independent predictors of having an uneventful flight with either no LSIs, no complications, or neither (Table S1). Conversely, receiving an amputation and having injuries to the chest, back, groin, or lower extremities significantly lower the odds of having an uneventful flight.

Patients who received an LSI en route spent more time in the hospital, ICU, and on a ventilator when compared to those who did not receive an LSI en route (Table S2). Nearly half of all patients (48.6%) received treatment in an ICU and 31.9% were on a ventilator for at least a portion of their hospitalization; both of these outcomes were more common in the LSI group than in the No LSI group. Overall mortality was 1.7%, with higher rates in the LSI group (2.9% vs. 0.8%, difference -2.1%, 95% CI -3.7 to -0.5%).

8.0 CONCLUSION/DISCUSSION

Our study found that approximately half of patients transported from the POI did not receive an LSI during transport and may have been suitable for transport by UAV from the battlefield. MEDEVAC's primary mission is to remove casualties from the combat environment.[18] While in the future, unmanned MEDEVAC platforms may use medical personnel or automated systems to perform medical interventions during transport, until such capabilities exist, one could identify those patients who are unlikely to require interventions during transport and evacuate them rapidly with UAVs. Such a strategy could have two significant effects. First, the rapid evacuation of combat ineffective casualties could relieve the burden on fellow unit members and medical personnel still engaged with the enemy. Second, rapid transport of appropriately selected casualties to a surgical team may decrease combat morbidity and mortality.

Our study found that those patients who had a higher ISS, higher max AIS, and suffered penetrating injuries to the chest, back, groin, and extremities were more likely to require an LSI, while those with blunt injuries and highest AIS located to the head/neck region were least likely to require an LSI. This information combined with clinical judgment and decision support tools may improve medics' ability to triage and prioritize evacuation of casualties in future conflicts.

The most common LSIs performed during transport included non-hemostatic pressure dressing, intravenous medication administration, airway access, oxygen administration, and the placement of tourniquets. The performance of several of these LSIs prior to transport obviate the need to perform the procedure en route. Alternatively, UAVs could fly with a medic on board or robotic technology capable of performing these procedures. Evaluation of our study results may assist in determining what robotic capabilities are necessary.

Transporting casualties without medical care is of significant concern. Most patients in our study experienced an en route complication; the most common complication was pain. While pain will not increase mortality, it has been linked to an increased risk of PTSD.[19] Treatment with pain medications or the self-administration of appropriately selected pain medications may decrease the frequency of this adverse complication. Abnormal heart rate and blood pressure were the next most common en route complications, both of which could be addressed prior to transport via hemorrhage control and blood product administration. Using UAVs to deliver blood products to POI medics would allow for increased use of this LSI intervention without increasing the medics pack load and/or allowing for resupply. The third most common en route complication was hypoxia. A significant majority of casualties require minimal oxygen via nasal cannula, which could be initiated prior to transport.[20] In those patients receiving oxygen via supraglottic devices and endotracheal intubation, previous research has demonstrated the successful use of closed loop ventilator technology to ensure adequate patient oxygenation without human intervention.[21]

During Operation Iraqi Freedom and Operation Enduring Freedom, combat casualty evacuation commonly occurred via helicopter.[14] Manned aircraft evacuation has several limitations. First, a typical MEDEVAC crew consists of two pilots and two medical personnel placing more individuals at risk during the mission. Second, helicopters use significant quantities of fuel, thereby limiting their range and ability to loiter in an aerial position or maintain flight-ready status. Recent world events and military operations have foreshadowed the potential need to provide prehospital combat medical care in austere environments for prolonged durations.[22] This planning concept, labeled prolonged field care (PFC), is currently incorporated into military planning and research efforts.[23] Presented with the task of minimizing combat casualties in a prehospital environment for up to 72 hours has led to military medical research of deploying advanced medical devices and resources into the combat environment. UAVs eliminate the need to place aircrew at risk; thereby enabling the evacuation of personnel from hostile environments where MEDEVAC helicopters would not be permitted to operate due the risk of being shot down.

As the military prepares to engage in the prolonged field care environment, POI medics will need training in advanced resuscitation, blood product administration, traumatic brain injury management, and other skills required to maintain casualties for prolonged durations. Conversely, UAVs could rapidly deploy advanced medical personnel and equipment to the POI; however, such an approach would place increased numbers of personnel at risk of enemy attack. As technology advances, robotics aboard UAVs could provide pain medications, blood products, oxygen, airway management, and even surgical procedures. Current research is also seeking potential means of including suspended animation/emergency preservation resuscitation which would theoretically allow for the safe reduction of physiologic functions thereby preventing death until the casualty reaches a medical facility where resuscitation could be administered.[24]

9.0 DELIVERABLES

9.1 Publications:

Maddry JK, Arana AA, Mora AG, Perez CA, Cutright JE, Kester BM, Ng PC, Schauer SG, Bebarta VS. Advancing prehospital combat casualty evacuation: patients amenable to aeromedical evacuation via unmanned aerial vehicles. Mil Med submitted Sept 2020.

9.2 Presentations:

Poster - Advancing Combat Casualty Evacuation: Patients Amenable to Aeromedical Evacuation via Unmanned Aerial Vehicles – C Perez, A Mora, J Cutright, P Ng, V Bebarta, J Maddry - Military Health System Research Symposium (MHSRS) - Orlando, FL; 2019

Poster - Advancing Combat Casualty Evacuation: Patients Amenable to Aeromedical Evacuation via Unmanned Aerial Vehicles – C Perez, A Mora, J Cutright, P Ng, V Bebarta, J Maddry - San Antonio Military Health System and Universities Research Forum (SURF); 2020

10.0 COST

This work was funded by a J9 award. Total funding awarded for this Project Code Number, J917EC03, in the amount of $336,000.00 were expended by September 29, 2019.

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FIGURES AND TABLES:

Table 1. Patient characteristics

Variable	No LSI en route (n=676)	Received LSI en route (n=591)	Difference (95% CI)
Male gender	663 (98.1)	585 (99.0)	-0.9 (-2.2 to 0.4)
Age	24.0 [22.0-28.0]	24.0 [21.0-27.0]	0.0 (0.0 to 1.0)
Injury type			
Blunt	22 (3.3)	4 (0.7)	2.6 (1.1 to 4.1)*
Blast	506 (74.9)	409 (69.2)	5.7 (0.7 to 10.6)*
Penetrating	157 (23.2)	188 (31.8)	-8.6 (-13.5 to -3.7)*
Burn	22 (3.3)	8 (1.4)	1.9 (0.3 to 3.5)*
Injury location			
Head	112 (16.6)	84 (14.2)	2.4 (-1.6 to 6.3)
Face	111 (16.4)	85 (14.4)	2.0 (-1.9 to 6.0)
Neck	39 (5.8)	31 (5.2)	0.5 (-2.0 to 3.0)
Chest	33 (4.9)	61 (10.3)	-5.4 (-8.4 to -2.5)*
Back	92 (13.6)	51 (8.6)	5.0 (1.5 to 8.4)*
Axilla	6 (0.9)	10 (1.7)	-0.8 (-2.1 to 0.5)
Abdomen	28 (4.1)	30 (5.1)	-0.9 (-3.3 to 1.4)
Pelvis	18 (2.7)	23 (3.9)	-1.2 (-3.2 to 0.7)
Groin	12 (1.8)	33 (5.6)	-3.8 (-5.9 to -1.7)*
Upper extremity	229 (33.9)	235 (39.8)	-5.9 (-11.2 to -0.6)*
Lower extremity/buttocks	373 (55.2)	396 (67)	-11.8 (-17.2 to -6.5)*
Amputation	44 (6.5)	116 (19.6)	-13.1 (-16.8 to -9.4)*
Military ISS	9.0 [5.0-14.0]	14.0 [6.0-25.0]	-4.0 (-5.0 to -3.0)*
Maximum AIS severity score	2.0 [2.0-3.0]	3.0 [2.0-4.0]	-1.0 (-1.0 to -1.0)*
Body region of maximum AIS			
1. Head/neck	126 (18.6)	72 (12.2)	6.5 (2.5 to 10.4)*
2. Face	43 (6.4)	17 (2.9)	3.5 (1.2 to 5.8)*
3. Chest	50 (7.4)	42 (7.1)	0.3 (-2.6 to 3.2)
4. Abdomen	53 (7.8)	32 (5.4)	2.4 (-0.3 to 5.2)
5. Extremities	330 (48.8)	318 (53.8)	-5.0 (-10.5 to 0.5)
6. External	66 (9.8)	58 (9.8)	-0.1 (-3.3 to 3.2)

Values are count (column percentage) or median [interquartile range]. Injury types and locations are not mutually exclusive. *Differences are significant if the 95% confidence interval does not include zero. Negative differences indicate that the characteristic is more prevalent in the "Received LSI" group.

Table 2. Comparison of interventions at the POI

Intervention	No LSI en route (n=676)	Received LSI en route (n=591)	Difference (95% CI)
O_2 administration†	1 (0.1)	28 (4.7)	-4.6 (-6.3 to -2.9)*
Airway access†	3 (0.4)	42 (7.1)	-6.7 (-8.8 to -4.5)*
CPR	0 (0)	20 (3.4)	-3.4 (-4.8 to -1.9)*
Defibrillation	0 (0)	1 (0.2)	-0.2 (-0.5 to 0.2)
Chest Needle	4 (0.6)	20 (3.4)	-2.8 (-4.4 to -1.2)*
Chest Tube	0 (0)	0 (0)	-
Chest Seal	13 (1.9)	29 (4.9)	-3.0 (-5.0 to -1.0)*
Tourniquets	178 (26.3)	249 (42.1)	-15.8 (-21.0 to -10.6)*
Non-hemostatic pressure packing	291 (43)	218 (36.9)	6.2 (0.8 to 11.6)*
Hemostatic agent	26 (3.8)	18 (3.0)	0.8 (-1.2 to 2.8)
IV medications	49 (7.2)	37 (6.3)	1.0 (-1.8 to 3.8)
IO medications	1 (0.1)	2 (0.3)	-0.2 (-0.7 to 0.4)
Blood products	0 (0)	3 (0.5)	-0.5 (-1.1 to 0.1)
Hypothermia prevention	20 (3.0)	17 (2.9)	0.1 (-1.8 to 1.9)
Spinal stabilization	40 (5.9)	14 (2.4)	3.5 (1.4 to 5.7)*
Splint/sling/cast	73 (10.8)	40 (6.8)	4.0 (0.9 to 7.1)*

Values are count (column percentage).

†O_2 administration and airway access only include bag valve mask, nasal/oral airway, supraglottic airway, endotracheal intubation, and cricothyrotomy.

*Differences are significant if the 95% confidence interval does not include zero.

Negative differences indicate that the intervention is more prevalent in the "Received LSI" group.

Table 3. Definitions of en route complications

Complication	Definition
Respiratory	As documented by provider (e.g., shortness of breath, agonal respirations, hyperventilation) Respiratory rate of <12 or >25 breaths per minute
SpO_2	As documented by provider (e.g., hypoxia and desaturation) SpO_2 <94%
Cardiac	As documented by provider (e.g., asystole, PEA, cardiac arrest)
HR	As documented by provider (e.g., low or abnormal pulse, tachycardia) Heart rate >100 or <60 beats per minute
SBP	As documented by provider (e.g., unstable blood pressure, hypotension, hypertension) Systolic blood pressure >139 or <90 mm Hg
Neurologic	As documented by provider (e.g., loss of consciousness, disorientation, seizure)
Behavioral	As documented by provider (e.g., combativeness, removal of medical equipment)
Pain	Moderate to severe pain as documented by provider Pain score >5
Bleeding	As documented by provider (e.g., uncontrolled bleeding, unsecured tourniquet)
Failed procedure	As documented by provider (e.g., failed IV or IO access, failed airway interventions)

Table S1. Multivariable logistic regression models predicting uneventful flights

Variable	Uneventful flights defined as… No LSI en route	No complications en route	No complications or LSI en route
Penetrating injury	0.7 (0.5-1.0)	1.7 (1.6-1.9)*	0.7 (0.3-2.0)
Blunt injury	6.7 (1.6-27.5)*	3.6 (2.7-4.8)*	2.2 (1.9-2.7)*
Blast injury	1.3 (0.8-2.3)	2.0 (1.1-3.8)*	1.0 (0.9-1.2)
Burn injury	2.5 (1.9-3.3)*	0.8 (0.5-1.2)	0.9 (0.7-1.1)
Chest injury	0.6 (0.5-0.6)*	0.8 (0.4-1.8)	0.5 (0.3-0.7)*
Back injury	1.1 (0.9-1.2)	0.5 (0.2-1.3)	0.5 (0.3-0.8)*
Groin injury	0.7 (0.2-2.5)	0.5 (0.1-1.9)	0.3 (0.1-0.9)*
Upper extremity injury	0.8 (0.5-1.4)	0.9 (0.5-1.5)	0.7 (0.4-1.1)
Lower extremity/buttocks injury	0.6 (0.5-0.8)*	0.8 (0.6-1.1)	0.6 (0.3-1.2)
Amputation	0.5 (0.4-0.5)*	0.6 (0.6-0.6)*	0.6 (0.3-1.5)
Military ISS	1.0 (1.0-1.0)	1.0 (1.0-1.0)	1.0 (1.0-1.0)
Maximum AIS score in head/neck region	1.5 (1.0-2.1)	1.5 (1.5-1.5)*	1.3 (1.2-1.4)*
Maximum AIS score in face region	1.3 (1.0-1.6)	1.0 (0.4-2.7)	0.9 (0.4-2.0)
ROC AUC	*0.70*	*0.66*	*0.69*
Adjusted R^2	*0.16*	*0.08*	*0.10*

All values are adjusted odds ratios (95% confidence intervals).
Covariates are binary and coded as yes/no with the exception of military ISS.
*Adjusted odds ratios are significant if the 95% confidence interval does not include 1.

Table S2. Comparison of clinical outcomes

Variable	No LSI en route (n=627)	Received LSI en route (n=591)	Log-rank p-value or difference (95% CI)
Total hospital days	7.0 [4.0-19.0]	13.0 [4.0-35.0]	<0.0001*
Total ICU days	0.0 [0.0-4.0]	2.0 [0.0-8.0]	<0.0001*
Total ventilator days	0.0 [0.0-0.0]	0.0 [0.0-3.0]	<0.0001*
Received ICU treatment (at any time)	253 (40.4)	306 (58.5)	-18.2 (-23.9 to -12.5)*
Was on ventilator (at any time)	152 (24.2)	215 (41.1)	-16.9 (-22.3 to -11.5)*
Mortality	5 (0.8)	15 (2.9)	-2.1 (-3.7 to -0.5)*
Returned to duty or discharged home	193 (30.8)	142 (27.2)	3.6 (-1.6 to 8.9)
Continued medical care	420 (67)	357 (68.3)	-1.3 (-6.7 to 4.2)

Outcomes are only listed for patients with data from DoDTR (n=1150).
Values are median [interquartile range] or count (column percentage).
*Differences are significant if the 95% confidence interval does not include zero or if p<0.05.
Negative differences indicate that the complication is more prevalent in the "Received LSI" group.

12.0 LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

AED - Automated external defibrillator

AIS – Abbreviated injury severity

ALS – Advanced life support

AUC – Area under the curve

BLS – Basic life support

CPR - cardiopulmonary resuscitation

DoDTR – Department of Defense Trauma Registry

ICU – Intensive care unit

IO – Intraosseous

IQR – Interquartile range

IRB – Institutional review board

ISS – Injury severity score

IV - Intravenous

LSI – Life Saving Intervention

MTF – Military treatment facility

OEF – Operation Enduring Freedom

POI – Point of injury

PFC – Prolonged field care

TMDS – Theater medical data store

UAV – Unmanned aerial vehicle