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Assessment of Aeromedical Evacuation Transport Patient Outcomes With and Without Cabin Altitude Restriction

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14. ABSTRACT

This study investigated whether there was a difference in inflight status, clinical outcomes, and mission costs between aeromedically evacuated (AE) patients transported with and without a cabin altitude restriction (CAR). The theater validating flight surgeon (TVFS) prescribes the CAR. Although general guidelines have been published regarding CAR, they are not evidence-based. A retrospective matched case-control study was conducted. From 1207 CAR patients (from 2007-2013) found in the U.S. Transportation Command Regulating and Command and Control Evacuation System database, 50 CAR patients with relatively complete data capture were randomly selected. These patients were matched with 50 non-CAR patients using International Classification of Diseases, Ninth Revision codes and, to some extent, aircraft. Demographics, preflight characteristics, inflight physiological characteristics, and postflight outcomes, as well as mission cost parameters, were assembled for analysis. Overall, these patients were young, Army, and, for the most part, suffering orthopedic trauma caused by improvised explosive devices. In addition, most were flown on C-17s under Priority precedence. All were Critical Care Air Transport Team accompanied with Injury Severity Scores exceeding 25. Excepting few differences, the CAR and non-CAR groups were very similar, suggesting that any difference in clinical or operational outcomes might well be related to the CAR prescription. There was no difference in length of stay, intensive care unit days, postflight transfusions, or discharge status. However, a statistically significant difference in the number of postflight procedures was observed; there were, on average, five postflight procedures per patient in the CAR group vsersus six in the non-CAR group. Furthermore, there was a significant difference in procedure profile between groups; specifically, there were a lesser number of major and minor procedures in the CAR group. No statistical difference was detected between groups when mission cost parameters were analyzed; however, *post hoc*, it appeared that these analyses were underpowered to detect a difference. AE may pose a "second hit" clinical threat for patients. It appears that CAR may have a salutary clinical effect by reducing the number of postflight procedures. The TVFS should consider this prescription for any seriously ill/injured patients.

15. SUBJECT TERMS
Aeromedical evacuation, cabin altitude restriction, CAR, theater validating flight surgeon, TVFS, patient morbidity

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1.0 EXECUTIVE SUMMARY

The U.S. military medical history has seen a gradual drop in wound lethality over the years; today, it is at its lowest ever. There are a number of reasons underpinning this observation. Care is farther forward than ever before, care is at a higher quality than ever before, and technological support is better than ever before. Intensive care unit level care is now delivered in the air with Critical Care Air Transport Teams (CCATTs). Lastly, aeromedical evacuation (AE) is more agile than ever before.

Over the past decades, there have been thousands of AE missions and, literally, tens of thousands of patients transported, with each patient having been cleared for flight, or validated, by the theater validating flight surgeon (TVFS). To minimize patient vulnerability at altitude, the TVFS uses both patient prescriptions and aircraft prescriptions. Patient prescriptions include such interventions as supplemental oxygen, head-first loading, and assignment of CCATT teams, while aircraft prescriptions include long, slow landings, limiting of overnight stops, and the focus of this study, cabin altitude restriction (CAR). The CAR is generally accompanied by a drop in the cruising altitude. As a consequence of this drop, conventional wisdom says there will be a cost—more fuel used, more physical stress on the aircraft, and, especially, flights that are longer and more expensive.

To examine the clinical and operational implications of the CAR, patient records from four different databases were merged. From the U.S. Transportation Command Regulating and Command and Control Evacuation System database, 1207 CAR patients were identified and, from these records, 50 patients with relatively complete records were randomly selected. These 50 CAR patients were then matched with 50 non-CAR patients by injury using International Classification of Diseases, Ninth Revision codes and, to some extent, aircraft. All patients were CCATT accompanied and all non-CAR patients were confirmed to have flown without a CAR.

Overall, these patients were young, mostly Army service members, and, for the most part, suffering orthopedic trauma caused by improvised explosive devices. In addition, most were flown on C-17s under the Priority precedence. Excepting a few differences—preflight surgeries, preflight blood product use, systolic blood pressure, 24-hour fluid intake, and initial hemoglobin—the CAR and non-CAR groups were very similar, suggesting that any differences in clinical or operational outcomes might well be related to the CAR prescription.

Looking at the clinical outcomes between groups, no difference was detected in length of stay, days in the intensive care unit, postflight transfusions, or discharge status. However, a statistically significant difference in the number of postflight procedures was found. There were, on average, five postflight procedures per patient in the CAR group versus six in the non-CAR group. Furthermore, a significant difference in procedure profile between groups was observed. Specifically, there were a lesser number of major and minor procedures in the CAR group.

Regarding the operational outcomes, increases in flight duration and flight cost were expected. However, what was found was the mission cost parameters between the CAR and non-CAR groups were not statistically different, most notably mission duration and mission cost per hour. However, *post hoc*, these mission cost analyses appeared underpowered to detect a statistically significant difference.

These results suggest that the AE flight may not be innocuous. Indeed, it may pose a "second hit" risk to our patients. This is most likely due to the hypoxia and hypobaria associated with cabin altitude, hypoxia meaning reduced oxygen availability and hypobaria favoring, through a number of mechanisms, fluid redistribution into the tissue space. In other words, there

is less oxygen being presented to a tissue-edema-mediated widened intercapillary distance. The result of this altered physiology is impaired oxygen diffusion and a potential drop in tissue oxygen delivery (DO_2). DO_2 is absolutely critical to the health and well-being of any patient. If DO_2 is inadequate, tissues suffer and already compromised tissues—commonly seen in AE patients—suffer even greater, perhaps to the point of increased patient morbidity and mortality. There are a number of ways to counter this potential drop in DO_2, this potential "second hit." Among them are fraction of inspired oxygen, hemoglobin level, hemoglobin saturation, plasma oxygen content, cardiac output, and cabin altitude. Within easy reach of TVFS prescribing are fraction of inspired oxygen (e.g., supplemental oxygen), hemoglobin level (e.g., transfusions), and cabin altitude (e.g., CAR).

To summarize the clinical and operational findings of this study, first, AE poses a potential "second hit" risk for transported patients. In fact, there were significantly more postflight procedures in the non-CAR group. Second, there is a tool in the TVFS's armamentarium that may well mitigate this potential "second hit" risk—that is, the CAR with its positive effect on DO_2. Third, further research is needed to investigate whether or not the CAR is more expensive in either flight time or flight cost.

2.0 INTRODUCTION

Even in the early 20th century, the possible physiological effects of altitude were being considered [1]. During the 1940s, as a consequence of air combat in World War II and the emergence of commercial airlines, interest in the flight environment grew exponentially. At the same time, patient movement by air became commonplace. Yet, the science behind how flight stressors affect various human systems, especially in ill or injured patients, remains incomplete and continues to emerge even today.

During flight, the lowered oxygen tension and reduced barometric pressure, associated with cabin altitude, are significant for their untoward influence on the performance and safety of airmen. Likewise, the cabin environment has similar implications for those who are physically unfit or are ill or injured [2]. To counter the hypoxia and hypobaria, cabin altitude restriction (CAR) may be prescribed. A CAR refers to any altitude below the generally flown cabin altitude of 8000 feet. The most frequent restrictions consist of, in order of prevalence, 5000 feet, 6000 feet, and 4000 feet [3]. General guidelines for use of the CAR have been published; however, they are not evidence based [4-8]. Traditionally, the CAR has had a limited spectrum of indications—penetrating eye injuries with intraocular air, free air in any body cavity, decompression sickness/air gas embolism, and severe pulmonary disease [9].

The goal of this retrospective matched case-control study was to determine whether or not a sample of critically ill and injured military patients transported via aeromedical evacuation (AE) derived any benefit from a CAR.

3.0 BACKGROUND

The U.S. military en route care system comprises three transportation phases: casualty evacuation, intratheater AE, and intertheater AE. Casualty evacuation consists of two components: CASEVAC and MEDEVAC. CASEVAC is casualty evacuation from the point of injury using any vehicle available (e.g., truck, car, boat, helicopter), generally without medical personnel present. CASEVAC takes the patient to the medics (e.g., battalion aide station), where

initial medical care is given. Medical evacuation, or MEDEVAC, is then engaged. Here, patients are accompanied by medical personnel and transported usually by truck, bus, or helicopter to a facility with higher level medical capability. Once the patient is stabilized, AE is the next step, whether it be intratheater (tactical AE) or intertheater (strategic AE). In either, AE uses fixed-wing aircraft to transport injured and ill patients to definitive care, with the ultimate destination being the United States. Medical care continues throughout the patient's AE flight by teams that include, but are not limited to, military nurses, medical technicians, Critical Care Air Transport Teams (CCATTs), and flight surgeons. All undergo specialized training that concentrates on the stresses of flight, patient care, available patient equipment, and the airframes commonly used for AE.

AE is the main means of moving patients from one level of care to the next, always bringing them to a higher echelon of care. Unfortunately, AE is not without its risks. Patients are exposed to a number of inflight stressors including gravitational forces, low humidity and temperatures, reduced barometric pressure and oxygen levels, increased vibration, trapped gas expansion, and serious noise, not to mention crowded spaces and the potential for inflight turbulence. Of importance is aircraft cabin pressurization, which is generally set around 8000 feet above sea level. This pressurization imposes both hypoxia (reduced oxygen availability) and hypobaria (intravascular fluid shifting into the extravascular space) upon patients. These two physiological phenomena can have an adverse impact on tissue oxygen delivery (DO_2), particularly critical to patients with compromised physiology (e.g., pulmonary disease, massive transfusions, significant trauma, or trapped gas). As a result, CAR is often prescribed to counter the effects of hypoxia and hypobaria on such patients. Interestingly, an ecological study by Butler et al. looking at patient transport data from January 2007 through February 2008 reported a 14-36% monthly postflight complication rate for AE patients. At the same time, they discovered a statistically significant inverse relationship between the rate of CARs prescribed and the rate of postflight complications, that is, as the rate of CAR prescriptions increased, the rate of postflight complications dropped [10].

It is hypothesized that hypoxia and hypobaria create an environment rife with potential for the so-called second hit [11]. In the face of critical injury or illness, any number of factors—hypoxia at altitude, trapped air volume expansion, hypobaria-enhanced Starling-mediated edema, altitude-induced inflammatory upregulation, intravascular evolved and/or infused bubbles, and ischemia-reperfusion injury—could easily produce a drop in DO_2, further injuring an already compromised patient [10]. Indeed, there are a number of animal and human studies that support this scenario, as discussed below.

Past animal studies have investigated altitude effects on compartment syndrome, traumatic brain injury (TBI), and infection. McGill and colleagues reported an average maximal pressure delta of 2.7 mmHg in uninjured myofascial compartments of nine pigs during simulated AE [12]. The pigs were exposed to a climb rate of 2500 ft/min to an altitude of 10,000 feet, and then level flight for 5 hours, followed by a controlled descent of 2500 ft/min until ground level was reached. Measurements were taken every 30 minutes for 6 hours. Although the response to altitude was small, there was a demonstrable movement of fluids into the interstitium. It was suggested that even though a change in compartmental pressure may go clinically unnoticed in uninjured patients, small pressure changes in severely traumatized patients might lead to compartment syndrome. However, the question remains whether a small change in compartment pressure (e.g., 2 to 3 mmHg) is actually clinically significant.

Another study induced injury in the anterior muscle compartment of 19 pigs to produce an intracompartmental pressure of 30 mmHg greater than the mean arterial pressure for either 5 or 6 hours followed by an 8-hour observation at either a simulated altitude of 7000 feet (test group) or ground level at 770 feet (control group). The simulated altitude did not increase the incidence of extremity compartment syndrome in the test group. Despite this finding, there was an increase in certain inflammatory protein markers in the test group's muscle. The clinical significance of this finding was unclear [13].

A TBI study using mice flown at 8800 feet for 5 hours compared the effects of immediate altitude exposure (3 hours post-injury) to those of delayed altitude exposure (24 hours post-injury). Findings demonstrated that the early exposure group had an increase in both neuroinflammatory response (rise in interleukin-6 and macrophage inflammatory protein-1a) and severity of secondary injury (rise in neuron specific enolase) over that of the delayed exposure group [14]. More recently, Skovira et al., using a ground equivalent oxygen TBI model (rat), demonstrated worsened cognitive deficits, worsened hippocampal neuronal loss, and worsened microglial/astrocyte activation with simulated flight (6 hours at 8000 feet) out to 7 days post-injury. Moreover, spatial memory deficits were exacerbated with successive simulated flights (first flight at 24 hours post-injury lasting 6 hours at 8000 feet followed by a second flight of 10 hours at 8000 feet 72 hours post-injury) and hyperoxia (100% oxygen during a 6-hour flight at 8000 feet) [15].

Using a complex wounded/infected caprine model taken to 8800 feet for 7 hours (flown 20 hours post-wounding), Earnest et al. demonstrated that hypoxia at altitude induced significant bacterial (*Pseudomonas aeruginosa*) growth [16]. Three groups of goats were used: a wounded ground control group, a wounded AE group, and a wounded AE group with supplemental oxygen. Supplemental oxygen significantly reduced the bacterial growth with AE, suggesting that countermeasures aimed at improving DO_2 (e.g., supplemental oxygen, CAR) may prevent infectious complications.

These animal studies suggest that altitude exposure may result in adverse physiological effects, but the degree of risk appears unclear and may depend not only on the type of injury, but also on the timing of flight and duration at altitude.

A limited number of human studies have been conducted on the effects of altitude during aeromedical transport. A retrospective study followed 21 post-traumatic and/or post-craniotomy patients with pneumocephalus undergoing AE from the combat zone. Intracranial pressure was monitored in 3 of the 21 patients; no sustained increase in pressure was detected during flight. The volume of intracranial air estimated for each patient ranged from 0.6-42.7 mL, with a mean (M) of 4.2 mL. No clinical neurologic deterioration was noted during transport or within 24 hours of reaching the destination. The authors concluded that the presence of intracranial air is not an absolute contraindication to air evacuation [17]. Of note, most reports of tension pneumocephalus describe an intracranial volume of air ranging from 25-65 mL.

In another study, Stroud et al. investigated the effect of altitude on cerebral oxygenation in helicopter-transported pediatric patients. Near-infrared spectroscopy was used to monitor cerebral oxygenation at ground level and at altitude in 17 children. While no statistically significant difference was detected in oxygenation measurements between the ground and altitude groups, there was a significant difference detected for those patients transported above 5000 feet. This suggests that acute altitude changes may affect tissue oxygenation during air transport [18].

Along the same line, Ritenour et al. retrospectively examined 336 patients from January 2005 through August 2006. Although the focus of this study was extremity compartment syndrome, the findings were pertinent for AE. There were 643 fasciotomies. Of those that required either a fasciotomy revision or initial fasciotomy after evacuation, there was a statistically significant higher rate of muscle excision and mortality, not to mention a higher rate of limb amputation in the latter group. The authors concluded that a more aggressive fasciotomy approach to extremity treatment was indicated [19]. These findings also suggest that the hypoxia and hypobaria of cabin altitude could well exacerbate the injury severity (aka second hit). Of note, the rate of CAR prescriptions during this time period was only 13-14% (unpublished data).

Pertinent to the notion of hypobaria-induced tissue swelling is Lundvall's work with lower body negative pressure experiments. Using 16 normal male volunteers, 70-75 mmHg lower body negative pressure was applied. While extravascular edema rose by about 460 mL, the plasma volume concomitantly dropped by around 490 mL [20]. Extrapolating to the AE cabin environment, the already damaged (and leaky) tissues found in the ill and injured can only be expected to swell even more than normal with altitude. This swelling will increase the intercapillary distance, further aggravating the hypoxia of altitude.

Lastly, Saenger investigated AE clinical outcomes in the continental United States during 8 months in 1993, describing adverse event frequency along with adverse outcomes. Seventy-three percent of the adverse events occurred in cardiac patients; most of the events required supplemental oxygen due to the development of chest pain. The adverse clinical outcome rate was 0.9 per 1000 patients; cardiac patients made up a disproportionate 37.5% (only 7.2% of evacuees). The author suggested that patients with limited cardiopulmonary reserve were at higher risk for adverse events during AE, and that during military operations other than war, AE patients were more likely to have limited cardiopulmonary reserve and be at even higher risk due to injuries, malnutrition, or limited medical care prior to flight. In other words, already compromised cardiac tissues were susceptible to a "second hit" during AE [21].

In summary, these limited animal and human studies suggest that altitude exposure may result in adverse physiological effects, but the degree of effect remains unclear and may depend not only on the type of injury/illness, but also on the timing of flight and duration at altitude. Furthermore, these studies strongly suggest that at least two potent characteristics of the cabin environment, hypoxia and hypobaria, may have a significant negative impact on DO_2 in the AE patient, especially the very sick patient. One means of potentially countering this negative impact is with a CAR. Yet, besides Butler's ecological study, there is no clear evidence that a patient's outcome will be improved with a cabin altitude less than 8000 feet [10]. Today, a CAR is considered for patients who have cardiopulmonary concerns, free air in any closed cavity (e.g., skull, peritoneal cavity, injury, embolism), or evolved gas (e.g., decompression sickness) or who potentially have compromised DO_2 at altitude [7,9,10]. However, conventional wisdom suggests that the CAR imposes operational limits upon an AE mission. Indeed, the CAR is often accompanied by a concomitant drop in cruising altitude. This drop is generally thought to increase fuel consumption, prolong the flight time, and increase physical stress upon the aircraft. Consequently, widespread employment of the CAR has been resisted.

Notably, this theater validating flight surgeon (TVFS) prescription has been minimally studied. Indeed, current clinical practice guidelines do not describe when a CAR is appropriate or what level of CAR should be prescribed, leaving this determination to the discretion of the TVFS. This study seeks to elucidate whether CAR adds benefit and, if so, at what cost.

4.0 METHODS

4.1 Institutional Review

This research was approved by the Air Force Research Laboratory Institutional Review Board (FWR20140077H) and was conducted at the U.S. Air Force School of Aerospace Medicine at Wright-Patterson Air Force Base in Dayton, Ohio, with SG5 funds provided by the Air Force Medical Support Agency.

This study involved a multi-phased approach to compare postflight clinical outcomes in aeromedically evacuated service members who were prescribed a CAR to those who were not. Phase I aimed to investigate potential differences in clinical outcomes between patients who were aeromedically transported with and without a CAR. Phase II explored inflight patient events as reported in the Patient Movement Quality Reports (PMQRs). Phase III sought to characterize the operational impact of CAR through a comparison of CAR versus non-CAR missions. Mission cost parameters were examined for both intratheater/intertheater AE transport and the various AE airframes. Throughout the study, data were cleaned, merged, and analyzed using SAS, version 9.3.1 (SAS Institute Inc., Cary, NC) and IBM SPSS Statistics for Windows, version 20.0 (IBM Corp., Armonk, NY).

4.2 Phase I

To compare clinical outcomes in patients transported with and without a CAR, a retrospective matched case-control records review was conducted looking at military patients flown between 2007 and 2013. Although the most common missions flown with a CAR were intertheater (in-theater to Ramstein, Germany), intratheater missions were not excluded.

The Transportation Command's Regulating and Command and Control Evacuation System (TRAC^{2}ES) database tracks regulated patient movement throughout the AE system and contains pertinent clinical history as well as information recorded by the TVFS specific to the patient's inflight needs. TRAC^{2}ES was used to identify patients who were transported with a CAR. Out of a total of 1207 CAR patients found within the TRAC^{2}ES database, 50 patients with relatively complete records were randomly selected. No record was missing more than 1% of its data fields and those records missing data fields were a heterogeneous mix (greatly reducing the chance for error bias). These 50 CAR patients were then matched with 50 non-CAR patients by injury using International Classification of Diseases, Ninth Revision (ICD-9) codes and, to some extent, aircraft. All patients were CCATT accompanied and all non-CAR patients were confirmed to have flown on a non-CAR mission.

Patients identified in the TRAC^{2}ES system as CAR (cases) and non-CAR (controls) subjects were cross-referenced with records from three clinical databases (Theater Medical Data System [TMDS], Department of Defense Trauma Registry, Military Health System Data Mart) to access inflight and in-theater medical care data. Preflight, inflight, and postflight variables were collected. Postflight outcome metrics—intensive care unit (ICU) days, ventilator days, hospitalization days, discharge status, procedures, and complications—were considered valid if they occurred before the patient departed Landstuhl Regional Medical Center or 7 days post-flight, whichever was shorter.

Continuous variables were described by mean (standard deviation [*SD*]), while categorical variables were described by number (percent). Comparison between groups used

t-tests, Mann-Whitney U-tests, and chi-square tests as appropriate. In addition, outcome data underwent regression analyses employing the conditional inference tree methodology [22]. Independent variable rank importance was then determined with the conditional random forest methodology [23]. *Post hoc* power calculations were performed with subset analyses where sample size deemed appropriate.

4.3 Phase II

Inflight patient status changes and adverse outcomes reported through the PMQRs, as maintained by the Air Mobility Command (AMC), were examined, recorded, and described. Categorical variables were described by number (percent), and comparisons between groups used chi-square tests.

4.4 Phase III

In Phase III, the impact of a CAR on mission resources was investigated. Mission data obtained from the 100 records taken from TRAC^{2}ES were used to identify 30 CAR and 30 non-CAR missions based on airframe, time of year, and point of embarkation/debarkation. The mission data were de-identified (blinded) and sent to the 618th Air and Space Operations Center Tanker Airlift Control Center Data Division (618 TACC) for fuel consumption, flight miles, and flight time data input. Five (2 CAR and 3 non-CAR) out of the 60 missions were not found by the 618 TACC and, thus, were not included in the analysis.

Mission data came from three sources:

1. The actual mission data were available for 30 of the 55 missions (6 with the C-130, 6 with the KC-135, and 18 with the C-17).
2. A standard burn rate of 5500 pounds per hour was used for 12 of the 55 missions based on guidance from the AMC/A3V (all with the C-130).
3. Flight planned values were used for 13 of the 55 missions (11 with the C-17 and 2 with the KC-135).

To determine the mission cost per mile, the standard prices of fuel for the Department of Defense for each year examined in this study were used [24,25].

Continuous variables were described by mean (*SD*), while categorical variables were described by number (percent). Comparison between groups used t-tests, Mann-Whitney U-tests, and chi-square tests as appropriate. *Post hoc* power calculations were performed with cost analyses where sample size deemed appropriate.

5.0 RESULTS

5.1 Phase I

5.1.1 Preflight Characteristics. As previously noted, 1207 CAR records were identified in TRAC^{2}ES, and, out of these records, 50 randomly selected CAR patients were matched with 50 non-CAR patients. All patients were CCATT accompanied and all non-CAR patients were confirmed to have flown on a non-CAR mission. Of the 24 cases where the reason for

prescribing a CAR was recorded, only a third involved one of the traditional indications for a CAR (e.g., trapped gas, severe pulmonary disease, and decompression illness). A comprehensive list of indications can be found in Appendix A.

The overall sample comprised male U.S. active duty service members, ranging from 18 to 42 years old, who were evacuated on a fixed-wing airframe between 2007 and 2013. The average age was 25 years and the majority of patients were serving in the U.S. Army. Most of the patients suffered a traumatic injury (72%), usually orthopedic (36%), predominantly from improvised explosive device/blast (77%). In addition, most were flown with a Priority precedence aboard the C-17 airframe. Study patients flew on three different airframes: C-130 (Urgent-15, Priority-19, Routine-0), C-17 (Urgent-25, Priority-31, Routine-1), and KC-135 (Urgent-3, Priority-6, Routine-0) (see Table 1).

Most CAR patients were transported during calendar years 2007 (11%), 2010 (13%), and 2011 (8%), while most of the non-CAR patients were transported during calendar years 2010 (15%), 2011 (10%), and 2012 (15%) (see Figure 1). There were no non-CAR patients from 2007. This was a consequence of ICD-9 matching of non-CAR patients to the randomly selected CAR patients; calendar year was not taken into account.

In addition to comparing demographics between the CAR and non-CAR groups, preflight characteristics were also assessed (see Table 2). The mean Injury Severity Score (ISS) was not significantly different between groups and was > 25, denoting critically injured patients. Likewise, there was no difference in time from injury to flight, averaging > 30 hours in both groups. Although there was no statistical difference in the number of patients either transfused or massively transfused, the number of preflight blood products was significantly higher in the non-CAR group. In addition, there was a significantly higher number of embarkation site preflight procedures in the non-CAR group. Interestingly, there was no difference in the procedure profile between groups. See Table 3 for a more detailed look at the preflight procedures.

5.1.2 Inflight Characteristics. Data related to the patients' physiological status during flight can be seen in Table 4. When looking at these data, most of the measured parameters proved statistically not significant. However, the patients who were transported on a CAR mission had a statistically lower systolic blood pressure than the non-CAR patients and a statistically higher 24-hour fluid intake. Despite the CAR patients having a higher initial hemoglobin at the beginning of flight than the non-CAR patients, there was no difference in transfusion characteristics between the CAR and non-CAR patients. In addition, there was no significant difference in peripheral oxygen saturation/fraction of inspired oxygen (SpO_2/FiO_2) ratios between those flown with a CAR and those without a CAR. Of note, altitude restrictions on CAR missions ranged from 2500 to 6000 feet above sea level (M = 4696 feet, *SD* = 669 feet).

5.1.3 Postflight Patient Outcomes. Outcome variables included the length of stay, the number of ICU bed days, postflight transfusions, discharge status, postflight procedures, and postflight complications. While no significant difference was detected for length of stay, number of ICU bed days, postflight transfusions, or discharge status (see Appendix B for additional information regarding specific discharge diagnoses), there was a significant difference in the number of postflight procedures performed at the debarkation site. Those transported with a CAR had fewer postflight procedures compared to those transported without a CAR (see Table 5).

Table 1. Demographics of CAR and Non-CAR Patients

Variable	CAR (*n* = 50)	Non-CAR (*n* = 50)	*p*-value
Age, M (*SD*)	25.74 (5.30)	25.78 (5.76)	0.971[a]
Range	19 – 40	18 – 42	
Service Component, *n* (%)			
USA	38 (76)	42 (84)	0.223[b]
USN	1 (2)	3 (6)	
USAF	1 (2)	1 (2)	
USMC	10 (20)	4 (8)	
Type of Injury, *n* (%)			
Blunt	2 (4)	1 (2)	0.740[b]
Trauma	34 (68)	38 (76)	
Penetrating	12 (24)	10 (20)	
Burns	2 (4)	1 (2)	
Injury Location, *n* (%)			
Head/Neurologic	19 (38)	13 (26)	0.088[b]
Orthopedic	12 (24)	24 (48)	
Torso	16 (32)	12 (24)	
Eye	1 (2)	0 (0)	
Other	2 (4)	1 (2)	
Mechanism of Injury, *n* (%)			
IED/Blast	35 (70)	42 (84)	0.109[b]
GSW	10 (20)	8 (16)	
NBI	1 (2)	0 (0)	
Other	4 (8)	0 (0)	
Flight Precedence, *n* (%)			
Urgent	23 (46)	20 (40)	0.687[b]
Priority	27 (54)	29 (58)	
Routine	0 (0)	1 (2)	
Airframe, *n* (%)			
C-130	17 (34)	17 (34)	0.999[b]
C-17	29 (58)	28 (56)	
KC-135	4 (8)	5 (10)	

Note: GSW = gunshot wound; IED = improvised explosive device; NBI = non-battle injury; USA = U.S. Army; USAF = U.S. Air Force; USMC = U.S. Marine Corps; USN = U.S. Navy.
[a]Values calculated using independent samples t-test.
[b]Values calculated using Fisher's exact probability test. Percentages may not add up to 100% due to rounding.

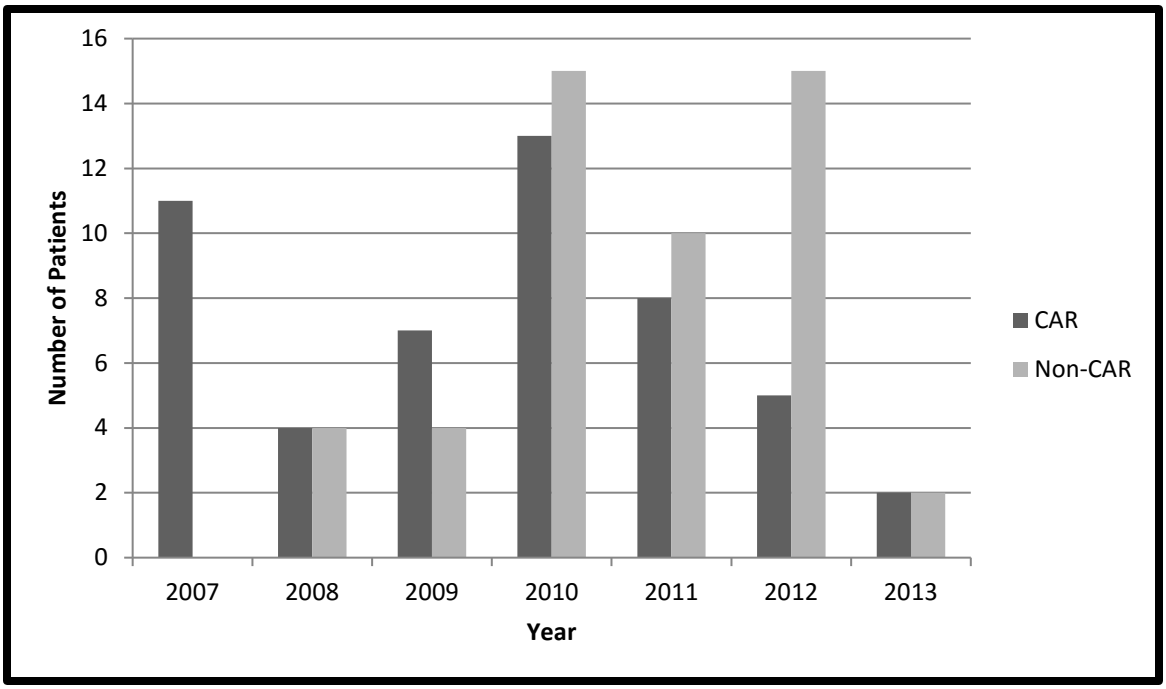

Figure 1. Number of CAR and non-CAR study patients per year.

Table 2. Preflight Characteristics of CAR and Non-CAR Patients

Characteristics (as taken from TMDS)	CAR (*n*=50)	Non-CAR (*n*=50)	*p*-value
Injury to Flight Time (h), M (*SD*)	31.97 (36.21) *n*=49	35.49 (26.34) *n*=50	0.581
ISS, M (*SD*)	28.74 (14.12) *n*=46	25.82 (12.10) *n*=50	0.441[a]
Embarkation Site Preflight Surgeries, M (*SD*)	3.10 (2.53)	4.22 (2.25)	0.007[a,b]
Embarkation Site Preflight Surgeries Profile, *n* (%)			
Major Surgeries	99 (62)	116 (54)	0.119[c]
Minor Surgeries	60 (38)	98 (46)	
Preflight Blood Product Use (units), M (*SD*)	6.62 (13.74)	15.98 (28.16)	0.037[b,d]
Massive Transfusion Patients (≥ 10 units blood), *n* (%)			
Yes	10 (20)	14 (28)	0.349[c]
No	40 (80)	36 (72)	
Patients Transfused, *n* (%)			
Yes	13 (26)	19 (38)	0.198[c]
No	37 (74)	31 (62)	

[a]Values calculated using Mann-Whitney U-test.
[b]Denotes statistical significance.
[c]Values calculated using the chi-square test.
[d]Values calculated using independent samples t-test.

Table 3. Preflight Surgical Procedures

Procedure	CAR (*n*=159)	Non-CAR (*n*=2144)
ORTHOPEDIC		
Major		
Amputation	12	20
External Fixator	14	16
Fasciotomy	10	12
Escharotomy/Arthotomy	1	1
Minor		
Debridement/Washout	24	35
Fracture Reduction	5	4
Wound Management	6	6
Other	1	1
ABDOMINAL		
Major		
Exploratory Laparotomy	12	12
Gastrointestinal Tract	8	12
Liver/Gallbladder/Pancreas	4	2
Spleen	1	2
Packing	1	2
Minor		
Endoscopy/Colonoscopy	1	1
Wound Management	0	5
OTOLARYNGOLOGIC		
Major		
Tracheostomy	2	4
Mandibular Fracture	1	1
Neck	0	3
Minor		
Wound Management	5	11
Nose/Sinus/Tongue	3	4
VASCULAR		
Major		
Major Artery	9	9
Major Vein	1	3
Minor		
Angiogram	0	6
Other	0	2

Table 3. Preflight Surgical Procedures (concluded)

Procedure	CAR (*n*=159)	Non-CAR (*n*=2144)
THORACIC		
Major		
Thoracotomy	2	3
Diaphragm	3	1
Lung	3	0
Pericardial Window	1	0
Minor		
Chest Tube	5	4
Bronchoscopy	2	1
Wound Management	1	1
NEUROLOGIC		
Major		
Craniotomy/Craniectomy	6	4
Ventriculostomy	3	2
Laminectomy	1	3
Other	0	3
Minor		
Wound Management	1	2
Traction	0	1
OPHTHALMOLOGIC		
Major		
Globe	3	1
Minor		
Other	2	0

Table 4. Inflight Physiological Characteristics of CAR and Non-CAR Patients

Characteristics (as taken from TMDS)	CAR (*n*=50) Mean (*SD*)	Non-CAR (*n*=50) Mean (*SD*)	*p*-value
Flight Time (h), M (*SD*)	5.72 (3.30) *n*=49	6.09 (3.03)	0.565
Systolic Blood Pressure (mmHg)			
Lowest	107.50 (18.19)	115.10 (15.47)	0.027[a]
Highest	130.78 (19.30)	137.62 (18.32)	0.072
Mean	119.14 (17.04)	126.36 (15.61)	0.029[a]
Heart Rate (bpm)			
Lowest	86.32 (19.32)	91.72 (19.71)	0.170
Highest	101.04 (21.99)	104.28 (18.75)	0.430
Mean	93.68 (20.23)	98.00 (18.85)	0.272
Ventilated, *n* (%)			
Yes	33 (66%)	39 (78%)	0.181[b]
No	17 (34%)	11 (22%)	
Ventilator Setting, M (*SD*)			
Tidal Volume (mL)	573.59 (70.78) *n*=32	546.84 (55.02) *n*=38	0.080
Positive End-Expiratory Pressure (cm H_2O)	5.47 (1.02) *n*=32	5.97 (2.15) *n*=39	0.197
FiO_2 (%)			
Initial	41.22 (16.62)	39.62 (9.60)	0.557
Final	45.10 (20.15)	39.42 (10.16)	0.079
SpO_2 (%)			
Initial	98.72 (1.85)	98.94 (1.30)	0.493
Final	98.86 (1.80)	101.02 (14.34)	0.293
SpO_2/FiO_2 Ratio			
Initial	269.99 (88.94)	264.34 (70.05)	0.725
Final	255.15 (94.69)	272.70 (85.01)	0.332
Fluctuation in SpO_2/FiO_2 Ratio	22.15 (45.59)	20.45 (45.91)	0.853
SpO_2 (%)			
Lowest	98.70 (1.63)	97.82 (2.64)	0.102
Highest	99.70 (0.64)	99.72 (0.61)	0.887
Mean	99.20 (1.08) *n*=33	98.77 (1.41) *n*=39	0.160
24-h Fluid Intake (mL)	5855.19 (5005.65)	4338.98 (1959.33)	0.049[a]
24-h Fluid Output (mL)	4134.58 (4129.33) *n*=48	2826.86 (2100.73)	0.054
Hemoglobin (g/dL)			
Initial	10.25 (2.55) *n*=35	9.03 (1.76) *n*=33	0.025[a]
Final	9.92 (2.28) *n*=21	8.65 (1.86) *n*=20	0.058
Inflight Blood Product Use (units), M (*SD*)	0.16 (0.55)	0.30 (0.97)	0.378
Patients Transfused, *n* (%)			
Yes	5 (10)	7 (14)	0.538[b]
No	45 (90)	43 (86)	

[a]Denotes statistical significance.

[b]Values were calculated using chi-square test. All other values were calculated using an independent samples t-test.

Table 5. Postflight Outcomes of CAR and Non-CAR Patients

Outcomes (as taken from TMDS)	CAR (*n*=50)	Non-CAR (*n*=50)	*p*-value
Length of Stay (days), M (*SD*)	3.70 (4.08) *n*=47	3.70 (2.54)	0.998[a]
Number ICU Bed Days, M (*SD*)	2.34 (2.20) *n*=47	3.08 (2.63)	0.138[a]
Postflight Blood Product Use (units), M (*SD*)	1.86 (9.50)	0.88 (3.73)	0.499[a]
Patients Transfused, *n* (%)			
Yes	6 (12)	6 (12)	1.000[b]
No	44 (88)	44 (88)	
Debarkation Site Postflight Procedures, M (*SD*)	4.98 (2.77)	6.08 (2.49)	0.032[c,d]
Postflight Procedure Profile, *n* (%)			
Major Surgeries	57 (23)	95 (31)	
Minor Surgeries	63 (25)	80 (26)	0.047[b,d]
Other Procedures	129 (52)	129 (43)	
	n=249	*n*=304	
Discharge Status, *n* (%)			
Home/Self-Care	8 (17)	6 (12)	
Transfer to Short-Term Facility	38 (81)	43 (86)	0.342[b]
Death	1 (2.1)	1 (2)	
Unknown	3 (6.4)	0 (0)	

[a]Values calculated using independent samples t-test.
[b]Values were calculated using the chi-squared test.
[c]Values calculated using the Mann-Whitney U-test.
[d]Denotes statistical significance.

To better understand the types of postflight procedures, procedures were categorized by system and then by gravity (major surgery versus minor surgery versus other procedure). Major surgery includes amputation and exploratory laparotomy, minor surgery includes chest tube insertion and peritoneal lavage, and other procedures include ventilator changes and angiogram. In total, 553 postflight procedures were performed at the debarkation site, with a significantly greater number of major and minor procedures seen in the non-CAR group. Thirty-four percent of CAR patients had eight or more postflight procedures, while 56% of non-CAR patients had eight or more postflight procedures (chi-square = 9.78, $p = 0.002$). The most common postflight procedures for both groups fell under Other Procedures, 52% for the CAR group and 42% for the non-CAR group. Table 6 illustrates the breakdown for the postflight surgical procedures performed for the CAR and non-CAR groups.

Interestingly, there were 1734 procedures performed at some point (preflight, postflight) on individuals who were flown on a CAR during their en route care journey, with 151 complications. There were 2360 procedures performed on individuals who were not flown on a CAR during their en route care journey, with 309 complications. In the CAR group, this amounted to 35 procedures per patient, 3 complications per patient, and 9 complications per 100 procedures. In the non-CAR group, there were 47 procedures per patient, 6 complications per patient, and 13 complications per 100 procedures.

Table 6. Postflight Surgical Procedures

Procedure	CAR (*n*=249)	Non-CAR (*n*=304)
ORTHOPEDIC		
Major		
Extremity	9	16
Myectomy	5	12
Miscellaneous	1	6
Minor		
Closed Reduction/Immobilization	2	3
Bone Graft Procedure	1	4
ABDOMINAL		
Major		
Exploratory Laparotomy	7	8
Bowel Resection	2	3
Ostomy Creation	3	3
Minor		
Endoscopy	8	8
Peritoneal Lavage	2	3
NEUROLOGIC		
Major		
Intracranial	3	5
Vertebral	3	11
Sympathetic Nerve Division	0	1
Minor		
Remove Head/Neck Device	1	4
Miscellaneous	2	0
OTOLARYNGOLOGIC		
Major		
Facial Fracture	5	5
Tracheostomy	1	3
Miscellaneous	2	0
Minor		
Rhinoscopy	1	0
Epstaxis Cautery	1	0
Dental Procedure	0	3
GENITOURINARY		
Major		
Ureter	0	2
Bladder	0	1
Hemodialysis	0	2
Minor		
Genitalia	2	2
Suprapubic Catheter	0	2

Table 6. Postflight Surgical Procedures (concluded)

Procedure	CAR (*n*=249)	Non-CAR (*n*=304)
VASCULAR		
Major		
Embolectomy	1	2
Hemorrhage Control	0	2
Vena Cava Interruption	3	3
Minor	0	0
THORACIC		
Major	0	0
Minor		
Bronchoscopy	1	7
Bronchial Lavage	1	0
Chest Tube Removal	1	0
OPHTHALMOLOGIC		
Major		
Full Thickness Lid Repair	2	0
Minor		
Ophthalmoscopy	2	0
WOUND		
Major		
Excisional Debridement	10	10
Minor		
Non-Excisional Debridement	19	21
Wound Care	6	4
Skin & Soft Tissue	12	14
Delayed Wound Closure	1	5
OTHER PROCEDURES		
Ventilator	26	22
Tubes & Catheters	34	30
Nutrition & Medications	11	11
Radiological Exams	37	31
Transfusion	16	23
Consultation	5	12

Regression analysis using the conditional inference tree methodology examined the influence of variables on the number of postflight procedures. The number of postflight procedures was the dependent variable of choice. Since the mean length of hospital stay for both groups was 3.7 days, time indexing was not employed. Among the 13 independent variables chosen for analysis (type of injury, location of injury, flight precedence, ISS, number of preflight surgeries, injury-to-flight time, flight duration, systolic blood pressure, ventilated or not, SpO_2/FiO_2 initial ratio (Ratio 1), SpO_2/FiO_2 final ratio (Ratio 2), 24-hour fluid intake, hemoglobin (Hgb) initial (Hgb 1), Hgb final (Hgb 2), and CAR), the covariate showing the largest association to the number of postflight procedures was whether a patient was ventilated or not ($p = 0.036$). With conditional inference trees, not every independent variable necessarily ends up in the model, so it is often valuable to rank the variables in terms of their importance. The conditional random forest method was employed to rank the 13 independent variables' strength of association with the number of postflight procedures. The variable with the highest association was whether or not the patient was ventilated. The second and third variables of most import were the two SpO_2/FiO_2 ratios and ISS. CAR was the sixth most influential variable (see Figure 2).

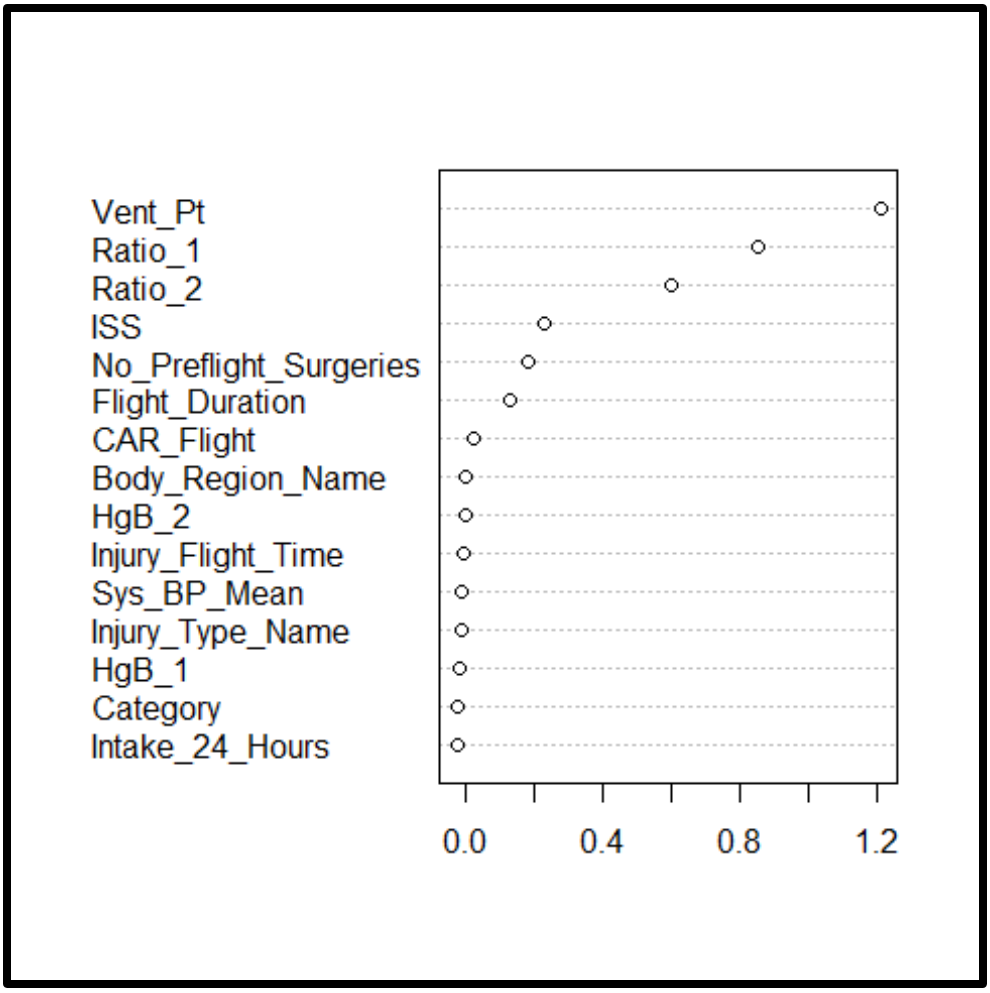

Figure 2. Rank importance of variables to number of postflight procedures.

These results prompted a closer look at mechanical ventilation (subset examination). Out of the 100 patients investigated in this study, all were either mechanically ventilated or received supplemental oxygen during AE. As seen in Table 4, the majority of patients in both the CAR and non-CAR groups were mechanically ventilated during flight. There were no statistically significant differences detected in outcomes between patients flown with or without a CAR whether mechanically ventilated or treated with supplemental oxygen. Interestingly, though, mechanically ventilated patients flown with a CAR had fewer postflight procedures, approaching statistical significance (see Table 7). However, it appeared that this subset analysis was underpowered to detect a statistical difference.

Table 7. Outcomes of CAR vs. Non-CAR in Ventilated and Supplemental Oxygen Patients

Postflight Outcomes	CAR M (*SD*)	Non-CAR M (*SD*)	*p*-value	Power (%)
No. of Postflight Procedures				
Ventilated	5.97 (2.38) *n*= 33	6.77 (2.18) *n*=39	0.079[a]	32
Supplemental Oxygen	3.06 (2.49) *n*=17	3.64 (1.96) *n*=11	0.517[a]	11
No. of ICU Days				
Ventilated	3.13 (2.28) *n*=32	3.38 (2.74) *n*=39	0.670	7
Supplemental Oxygen	1.40 (1.18) *n*=15	2.00 (1.95) *n*=11	0.339	15
Length of Stay				
Ventilated	4.13 (4.63) *n*=32	3.79 (2.67) *n*=39	0.708	7
Supplemental Oxygen	3.00 (2.27) *n*=15	3.36 (2.11) *n*=11	0.681	7

[a]Values calculated using Mann-Whitney U-test. All other values calculated using independent samples t-test.

Furthermore, mechanically ventilated patients in both groups had significantly higher numbers of postflight procedures than those treated with supplemental oxygen. At the same time, mechanically ventilated CAR patients spent significantly more days in the ICU than those on supplemental oxygen (see Table 8).

Lastly, since CAR altitude and flight duration might well affect inflight physiology and postflight outcomes, a piloted preliminary investigation was performed. Inflight fluctuation of SpO_2/FiO_2 ratio (a marker for pulmonary status change) and postflight procedures (a marker for clinical morbidity) were selected for dependent variables. There was a lesser degree of fluctuation in SpO_2/FiO_2 ratio and a lesser number of postflight procedures with CARs below 5000 feet, but statistical significance was not achieved. Regrettably, this subset analysis was underpowered to detect a difference. Additionally, flights in excess of 2.5 hours appeared to have greater fluctuations in SpO_2/FiO_2 ratio and greater numbers of postflight procedures; however, statistical significance was not found (see Table 9).

Table 8. Outcomes of Ventilated and Supplemental Oxygen Patients With or Without CAR

Postflight Outcomes	CAR M (*SD*)	*p*-value	Non-CAR M (*SD*)	*p*-value
No. of Postflight Procedures				
Ventilated	5.97 (2.38) *n*= 33	<0.001[a,b]	6.77 (2.18) *n*=39	<0.001[a,b]
Supplemental Oxygen	3.06 (2.49) *n*=17		3.64 (1.96) *n*=11	0.00
No. of ICU Days				
Ventilated	3.13 (2.28) *n*=32	0.009[b]	3.38 (2.74) *n*=39	0.125 (Power = 47%)
Supplemental Oxygen	1.40 (1.18) *n*=15		2.00 (1.95) *n*=11	
Length of Stay				
Ventilated	4.13 (4.63) *n*=32	0.379 (Power = 20%)	3.79 (2.67) *n*=39	0.624 (Power = 9%)
Supplemental Oxygen	3.00 (2.27) *n*=15		3.36 (2.11) *n*=11	

[a]Values calculated using Mann-Whitney U-test. All other values calculated using independent samples t-test.
[b]Denotes statistical significance.

Table 9. Effects of Altitude and Flight Duration on CAR Patients

Characteristic, M (*SD*)	Fluctuation in SpO_2/FiO_2 Ratio	*p*-value	No. Postflight Procedures	*p*-value
Altitude (ft)				
<5000 (*n*=14)	12.31 (24.69)	0.346[a] (Power = 24%)	4.57 (3.23)	0.642[b] (Power = 9%)
≥5000 (*n*=36)	25.98 (51.28)		5.14 (2.60)	
Flight Duration (h) (*n*=49)				
≤2.5 (*n*=13)	6.73 (17.22)	0.187[c]	3.54 (2.44)	0.134[d]
2.6-5.0 (*n*=9)	40.23 (86.53)		6.11 (2.37)	
5.1-7.5 (*n*=15)	32.13 (40.81)		5.47 (3.09)	
>7.5 (*n*=12)	8.00 (12.74)		5.17 (2.72)	

[a]Values calculated using independent samples t-test.
[b]Values calculated using Mann-Whitney U-test.
[c]Values calculated using analysis of variance.
[d]Values calculated using Kruskal-Wallis test.

With the non-CAR patients, Table 10 depicts worsened SpO_2/FiO_2 ratio fluctuations with flight durations over 2.5 hours, but shows little difference in the number of postflight procedures; again, statistical significance was not met. Table 10 shows specifics.

Table 10. Effects of Flight Duration on Non-CAR Patients

Characteristic, M (*SD*)	Fluctuation in SpO_2/FiO_2 Ratio	*p*-value	No. Postflight Procedures	*p*-value
Flight Duration (h)				
≤2.5 (*n*=11)	9.86 (20.17)	0.742[a]	5.91 (2.34)	0.249[b]
2.6-5.0 (*n*=6)	21.84 (31.77)		4.00 (3.35)	
5.1-7.5 (*n*=16)	17.68 (28.64)		6.50 (2.34)	
>7.5 (*n*=17)	29.41 (70.32)		6.53 (2.21)	

[a]Values calculated using analysis of variance.
[b]Values calculated using Kruskal-Wallis test.

5.2 Phase II: PMQR

All PMQRs from 2007 to 2013 were examined from the TRAC^{2}ES archived database. Twenty-four missions within the study had PMQR information associated with them; seven missions were flown with a CAR. None of the CAR or non-CAR patients had any events falling into injury categories A or B. Injury category A is defined as an event resulting in the death, near death, or major permanent loss of function, while injury category B is defined as an event resulting in temporary patient harm and initial or prolonged hospitalization. There were, however, 24 events in categories C, D, E, F, and Unknown. Of these, 7 were on CAR flights and 17 on non-CAR flights (chi-square = 5.48, $p = 0.02$), but only 3 were clinically relevant—1 chest pain (CAR) and 3 desaturations (non-CAR). Appendix C contains additional PMQR information.

5.3 Phase III: Mission Comparisons

As seen in Table 1, most of the patients were transported aboard a C-17 and were regulated as Urgent or Priority precedence; this observation was confirmed in the overall distribution of precedence (see Table 11).

Table 11. Airframes Flown During CAR and Non-CAR Missions

Airframe	Urgent (*n*=43) *n* (%)	Priority (*n*=56) *n* (%)	Routine (*n*=1) *n* (%)	Total (*n*=100) *n* (%)
KC-135	3 (3)	6 (6)	0 (0)	9 (9)
C-130	15 (15)	19 (19)	0 (0)	34 (34)
C-17	25 (25)	31 (31)	1 (1)	57 (57)

Using the study's 100 records, 30 CAR and 30 non-CAR missions were matched by airframe, time of year, and port of embarkation/debarkation. As seen in Table 12, the majority (53%) of missions were flown on the C-17, with 52% of CAR missions and 52% of non-CAR missions. The C-130 was the second most frequently used airframe, with 34% of CAR missions and 31% of non-CAR missions. Distribution of CAR and non-CAR missions by airframe was not significantly different (chi-square = 0.09, $p = 0.954$).

Table 12. Mission Precedence by Airframe

Airframe	CAR (*n*=29) *n* (%)	Non-CAR (*n*=26) *n* (%)	Total (*n*=55) *n* (%)
KC-135	4 (14)	4 (15)	8 (15)
C-130	10 (34)	8 (31)	18 (33)
C-17	15 (52)	14 (52)	29 (53)

Data from the 618 TACC demonstrated that mission duration ranged from 0.7 to 9.0 hours, with mission mileage ranging from 268 to 2796 miles. Comparison of mission cost parameters for the 55 missions (29 CAR and 26 non-CAR) is displayed in Table 13. There was no significant difference between CAR and non-CAR missions for any of the mission cost comparisons. *Post hoc*, however, mission cost analyses appeared to be underpowered to detect significant differences. Additional cost comparisons for CAR and non-CAR missions by airframe and intra/intertheater are available in Appendix D. No statistically significant differences were found for any of the mission cost comparisons, but, *post hoc* calculations demonstrated low power.

Table 13. Cost Comparison for CAR and Non-CAR Missions

Factor	CAR (*n*=29) M (*SD*)	Non-CAR (*n*=26) M (*SD*)	*p*-value	Power (%)
Flying Hours	4.78 (2.94)	5.15 (2.79)	0.638	---
Flight Miles	1753.55 (1182.36)	1922.73 (1137.03)	0.592	---
Fuel Consumption (gal)	11267.66 (8812.39)	11795.65 (8088.02)	0.819	6
Flight Miles/Gallon	0.215 (0.089)	0.209 (0.076)	0.813	---
Mission Cost/Hour	$5495.11 ($2797.19)	$6064.08 ($2955.34)	0.480	11

Although the cost comparison findings are of questionable value, they trend toward confirmation of an earlier Line of the Air Force assessment of CAR in 2007. Then, Headquarters AMC Test and Evaluation Squadron determined that CAR had essentially no mission impact for the C-17 flying either from Balad, Iraq, to Ramstein Air Base, Germany, or from Bagram, Afghanistan, to Ramstein Air Base, Germany (see Figure 3).

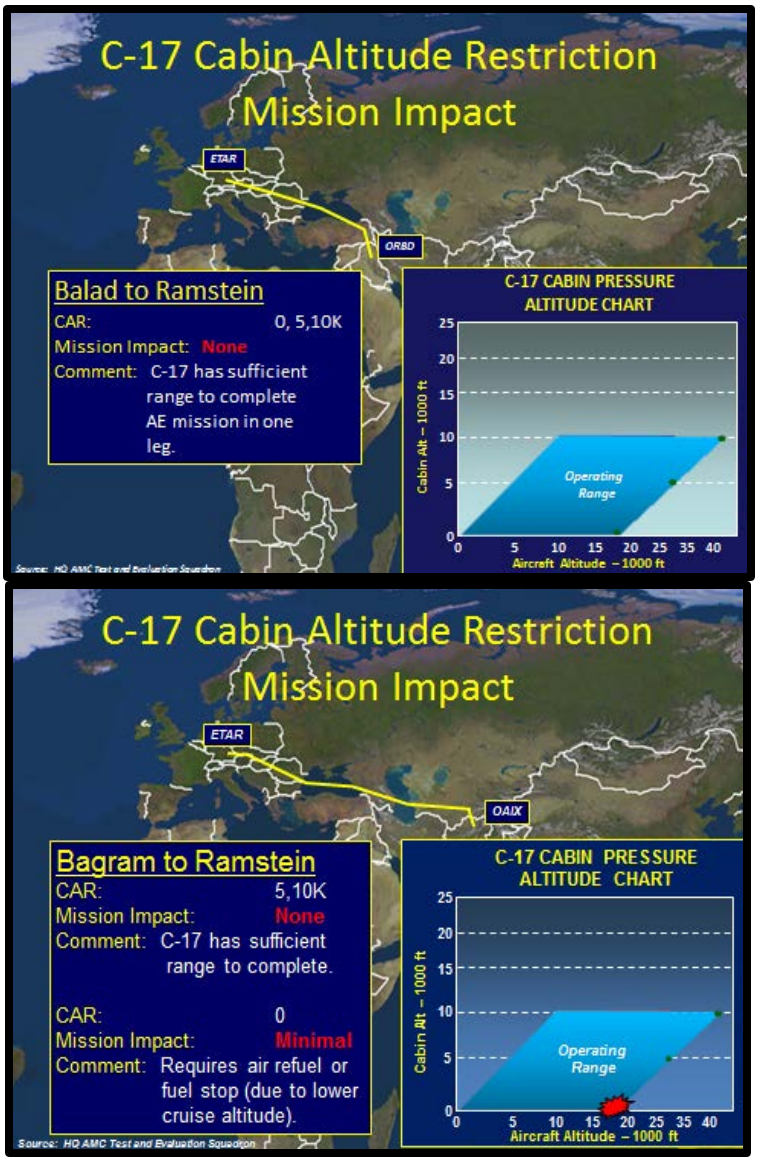

Figure 3. Mission impact of CAR as determined by Line of the Air Force, Headquarters AMC Test and Evaluation Squadron (2007).

6.0 DISCUSSION

The AE of very ill patients is not uncommon in today's military. Indeed, the U.S. Air Force's agile patient evacuation system is one of the major reasons for the lowest wartime lethality in recent history [26]. Although a physiologically stable patient is preferred, often a "stabilized," or physiologically volatile, patient must be evacuated. The direct impact of flight on these patients has not been thoroughly studied nor has the impact of the TVFS. It is the TVFS who warrants which patients are best prepared to weather inflight stressors all the while minimizing clinical risk. To accomplish this, the TVFS uses both patient prescriptions (such as supplemental oxygen, patient positioning, and assignment of CCATT) and aircraft prescriptions

(such as long, slow landings, no “remain overnights,” and cabin altitude restriction). Among the various prescriptions, CAR is most uniquely that of the TVFS. Traditionally, it has been used in the setting of trapped air (e.g., intraocular gas), evolved gas (e.g., decompression sickness), and severe pulmonary disease [9]. During the recent conflicts in Iraq and Afghanistan, the CAR has been more liberally prescribed than in the past. Since the CAR supposedly imposes operational constraints (such as lower cruising altitudes, more fuel consumption, longer flight duration, and increased aircraft physical stress), it should not be prescribed without reasonable expectation of patient benefit. This retrospective matched case-control study looked specifically at the clinical outcomes in patients flown with and without a CAR searching out that benefit. In addition, the study compared mission cost parameters between CAR and non-CAR flights.

In this study, 50 randomly selected CAR patients were matched to 50 non-CAR patients. The two groups proved very similar. Demographic characteristics (age, service, type of injury, injury location, and mechanism of injury) between groups exhibited no significant differences. Likewise, there was no significant difference in the aircraft employed or flight duration. Direct injury severity measures, ISS and SpO_2/FiO_2 ratio, proved equally grave between groups, with the ISS averaging around 27 and the SpO_2/FiO_2 ratio around 265. More indirect indices of patient severity (such as injury-to-flight time, flight precedence, heart rate, ventilator status, and ventilator settings) further confirmed group similarity by failing to demonstrate significant differences between CAR and non-CAR groups. That said, there were several indirect measures that were significantly different between groups. Inflight, the CAR group appeared sicker, having both a significantly lower systolic blood pressure and higher 24-hour fluid intake; however, the clinical importance associated with these differences appears low, as neither the diastolic blood pressure nor the 24-hour fluid output significantly differed between groups. On the other hand, suggesting greater injury severity in the non-CAR group were a significantly higher number of preflight surgeries and a higher number of preflight blood product transfusions. Preflight surgeries certainly have clinical relevance, but they are somewhat offset by the fact that there was no significant difference in surgical case profiles (major and minor surgeries) between groups. Moreover, the greater number of units transfused in the non-CAR group stands in contrast to the number of patients transfused or requiring massive transfusion, where no significant difference was detected. Indeed, the fact that there are subtle indicators suggesting sicker non-CAR patients preflight, while, at the same time, suggesting sicker CAR patients inflight, serves only to highlight the clinical volatility of these patients. Thus, excepting these few differences, the CAR and non-CAR groups were remarkably similar, strongly supporting the notion that any difference in clinical or operational outcome may well be related to the CAR prescription.

Looking at the clinical outcomes, no significant difference was found between the CAR and non-CAR groups for length of stay, days in the ICU, postflight transfusions, and discharge status. However, there was a significant difference in postflight procedures. On average, there were five postflight procedures per patient in the CAR group versus six in the non-CAR group. Furthermore, there was a significant difference in the procedure profile between groups. Specifically, there was a lesser number of major and minor procedures in the CAR group.

At the same time, regression analyses found five variables with greater influence over the number of postflight procedures than CAR (Figure 2). They were mechanical ventilation, SpO_2/FiO_2 ratio, ISS, number of preflight surgeries, and flight duration. Four of the five are patient clinical characteristics. Mechanical ventilation, low SpO_2/FiO_2 ratio, high ISS, and a high number of preflight surgeries all denote very sick, clinically volatile patients who often require

timely intervention. Adding the stressor of an AE flight can certainly exacerbate any of these factors and promote patient morbidity (e.g., postflight procedures). This was certainly confirmed when mechanically ventilated patients were found to have significantly more postflight procedures when compared to those treated with only supplemental oxygen, whether flown with or without a CAR. In addition, the longer the stressor of an AE flight continues, the greater the likelihood for patient morbidity seems reasonable, although not necessarily demonstrable with the study's data. Unfortunately, these five factors cannot necessarily be directly modified for the better by the physician, specifically the TVFS. Fortunately, however, the sixth most influential factor, CAR, can be imposed by the TVFS.

The salutary clinical effect of CAR might well be explained within the "second hit" conceptual framework [11]. The "first hit" is the initial injury resulting in both devitalized tissue and compromised tissue. With good clinical management, the compromised tissue is salvaged with minimized patient morbidity and/or mortality. However, should compromised tissue be subjected to another insult, or "second hit," salvage may not be possible, the result being added patient morbidity and mortality. The AE flight has a number of physiological stressors that could act as a "second hit"—acceleration forces, vibration, noise, thermal instability, reduced humidity, hypoxia, and hypobaria.

Hypoxia and hypobaria are perhaps the most prominent features associated with the cabin environment. Normally, the cabin is pressurized to around 8000 feet [9,27,28]. In an already compromised patient, the added altitude can potentially act in a number of ways to promote a "second hit." There is the hypoxia of altitude. At 8000 feet, the ground-equivalent FiO_2 is about 16%. This relatively hypoxic environment has the potential to lead to a reduced arterial oxygen partial pressure with concomitant ischemia, especially relevant to already compromised tissues [29,30]. This is particularly important in the face of the localized swelling associated with the injury itself and the generalized body swelling associated with major systemic injury [31,32]. The swelling (aka interstitial edema) results from leaky blood vessels and effectively increases the distance between capillaries [31,33]. The widened intercapillary distance coupled with the relative drop in FiO_2 can only add insult to already compromised tissues, potentially producing a "second hit." Now, add hypobaria to the mix. Starling forces, in the face of hypobaria, may well promote movement of fluid from the intravascular space into the extravascular, or interstitial, space, exacerbating the already widened intercapillary distance [10]. In addition, hypobaria appears to provoke an intrinsic inflammatory upregulation, as seen in acute mountain sickness, especially high altitude cerebral edema, and TBI animal models, suggesting a potential inflammatory basis for a "second hit" [11,15,34]. Other potential hypobaria-related "second hit" mechanisms include evolved and/or infused bubble growth as well as ischemia-reperfusion injury, both associated with inflammation and tissue edema [10].

Keeping these potential consequences of cabin altitude in mind, it is not unreasonable to expect a physiologic milieu in which oxygen diffusion into tissues is impaired, resulting in a potential drop in DO_2, even to the point of a second hit. If the drop is serious enough or the duration of drop is long enough, then a rise in postflight patient morbidity and/or mortality might be anticipated. There are a few animal studies supporting this notion. Using a TBI murine model, Goodman et al. showed that animals taken to 8800 feet for 5 hours (within 3 hours of injury) experienced a rise in inflammatory cytokines with a subsequent increase in neuron specific enolase (a marker for added neurologic injury) [11]. Around the same time, Earnest et al., using a complex wounded/infected caprine model taken to 8800 feet for 7 hours (flown 20 hours post-wounding), demonstrated that reversal of altitude-induced hypoxia using supplemental oxygen

could seriously inhibit bacterial growth and subsequent wound infection [16]. Finally, Skovira et al. used a rat TBI model taken to 8000 feet for 6 hours with surface equivalent oxygen (altitude FiO_2 = 28%) to demonstrate a worsening of cognitive deficit, hippocampal neuronal loss, and microglial/astrocyte activation [15]. These few studies suggest that both hypoxia and hypobaria of the unrestricted AE cabin have the potential to produce not only a "second hit," but also added morbidity. To date, only one human study has examined CAR. In this ecologic epidemiological study, Butler et al. found that as the monthly rate of CAR prescriptions rose, the monthly rate of postflight complications dropped [10]. Overall, these studies certainly suggest that a CAR might well have a beneficial clinical effect.

In the end, this effect is probably derived from a heightened DO_2, and it is the TVFS's job to maximize it. To do this, the TVFS must initially focus on the various components of DO_2—FiO_2, blood oxygen content (Hgb level, Hgb saturation level, and plasma oxygen content), and cardiac output. Plasma oxygen content (0.3 vol %) is a minimal contributor, as are Hgb saturation and cardiac output. Seldom is the saturation allowed to fall below 95% without intervention, and seldom is cardiac output seriously compromised during flight. This leaves FiO_2 and Hgb level as major factors within the TVFS's reach, prescribing supplemental oxygen and transfusion, respectively. However, the CAR is also a prescription that will enhance DO_2 by bringing, for all intents and purposes, the patient closer to ground level and, thusly, limiting the impact of hypoxia and hypobaria. The result is a patient care environment less conducive to patient harm. And, in this study, it appears that the CAR, as prescribed by the TVFS, may well have produced an environment favoring lesser patient morbidity, that is, fewer postflight procedures.

6.1 Limitations

Although the cohorts were carefully matched on ICD-9 codes and, to some extent, airframes, this retrospective case-control study relied on the accuracy and completeness of patient information contained in the various electronic medical record keeping systems. Any generalizations about the relationships presented in the study should be interpreted cautiously, as there were no assurances that all of the recorded patient information was accurate. A ceiling effect was imposed by the TMDS database on the diagnoses, preflight surgeries, and postflight procedures data; the number of diagnoses was restricted to a maximum of 8, preflight surgeries a maximum of 10, and postflight procedures a maximum of 8. As a consequence of this ceiling effect, there could be an incomplete clinical characterization of some patients. Additionally, provider notes and surgical reports were both outside the scope of the study and not readily available to the research team, which precluded the researchers from gathering more extensive clinical data (e.g., estimates related to free air/trapped gas). Also, all the patients were under the care of a CCATT, which may have independently abrogated some of the possible effects of the AE environment. Lastly, mission cost analyses appeared underpowered (ranging from as low as 6% to as high as 55%; see Table 13 and Appendix D) to detect statistical differences, making any conclusion from those analyses questionable.

6.2 Conclusion

This study continues the investigation into the TVFS's impact on patient outcome. One special means through which the TVFS can actuate clinical impact is the CAR. Although this study did not find a significant difference in length of stay, days in the ICU, postflight transfusions, or discharge status, it did find a significant difference in postflight procedures, with the CAR group undergoing both a lesser overall number of procedures and a lesser number of major and minor procedures. This effect is most likely a consequence of improved DO_2, making a "second hit" to already compromised tissues less likely. Thus, these results suggest a CAR benefit. That said, this study is just the beginning. Further research using a retrospective "*n* = all" big data approach comparing all CAR patients with an equal number of matched non-CAR patients and an equal number of matched non-CAR patients incidentally flown on a CAR as well as a prospective exploration of CAR employment is needed. Larger sample sizes with adequately powered subset analyses promise insights into the indications for a CAR, the level of CAR prescribed, the long-term outcomes of critical patients flown with a CAR, and the mission cost associated with the CAR.

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APPENDIX A
Reason for CAR, Inflight Oxygenation, Diagnosis, Discharge Status

Reason for CAR	Oxygenation during AE	Primary Discharge Diagnosis	Discharge Status
Pneumocephalus (*n*=2)	Ventilator	Open fracture T1-T6 with unspecified cord injury	Transfer to short-term facility
	Ventilator	Closed fracture of other facial bones	Home/self-care
L/low occipital skull fracture with air	Ventilator	Other and unspecified intracranial hemorrhage following injury without open intracranial wound with moderate (1-24 h) loss of consciousness	Transfer to short-term facility
Skull FX	Supplemental O_2	Closed fracture of malar and maxillary bones	Home/self-care
GSW Head (*n*=2)	Ventilator	Subarachnoid hemorrhage following injury with open intracranial wound with state of consciousness unspecified	Transfer to short-term facility
	Supplemental O_2	Open fracture of vault of skull with cerebral laceration and contusion with no loss of consciousness	Transfer to short-term facility
TBI	Ventilator	Closed fracture skull, jaw, orbit	Transfer to short-term facility
Penetrating foreign body, location in posterior orbit, cannot rule out air	Ventilator	Open fracture upper end of fibula/tibia	Transfer to short-term facility
Eye	Ventilator	Traumatic amputation of other fingers without complication	Transfer to short-term facility
Air in retroperitoneal	Ventilator	Laceration of liver minor with open wound into cavity	Transfer to short-term facility
Emphysema	Ventilator	Aftercare for injury and trauma	Transfer to short-term facility
Cardiac/respiratory	Ventilator	Burn involving 40-49% body surface	Transfer to short-term facility
Air in spinal column	Ventilator	Traumatic amputation of legs bilateral complicated	Transfer to short-term facility

Reason for CAR	Oxygenation during AE	Primary Discharge Diagnosis	Discharge Status
Polytrauma (*n*=8)	Supplemental O_2	Traumatic pneumohemothorax without open wound into thorax	Transfer to short-term facility
	Ventilator	Open fracture of base of skull with subarachnoid subdural and extradural hemorrhage	Death
	Ventilator	Multiple closed pelvic fractures with disruption of pelvic circle	Home/self-care
	Ventilator	Fracture of unspecified condyles of humerus open	Transfer to short-term facility
	Ventilator	Crushing injury of face and scalp	Transfer to short-term facility
	Supplemental O_2	Traumatic amputation of legs unilateral at or above knee without complication	Home/self-care
	Supplemental O_2	Traumatic amputation of legs bilateral without complication	Transfer to short-term facility
	Supplemental O_2	None noted	Unknown
Possible compartment syndrome	Supplemental O_2	Open wound to hip and thigh complicated	Transfer to short-term facility
Clot	Ventilator	Traumatic amuputation of other fingers without complication	Transfer to short-term facility
Decompression concern	Supplemental O_2	Traumatic pneumohemothorax with open wound into thorax	Transfer to short-term facility

Note: There were only 24 records that had information regarding why the individual was placed on CAR status.
Note: There were only 24 records that had information regarding why the individual was placed on CAR status.

APPENDIX B
Supplemental Patient Diagnosis Information

Diagnoses at Discharge (outcomes)	CAR	Non-CAR
Head & Neck (including cervical spine)	• Fatal head wound[a] • Head wound w/loss of consciousness (LOC) • Closed fracture (Fx) base of skull • Cerebral laceration s/LOC • Intracranial injury s/open wound w/mod LOC • Subarachnoid hemorrhage w/open wound • Open Fx w/cerebral laceration & contusion no LOC • Closed Fx of vertebra • TBI • Dissection of carotid artery • Anoxic brain damage • Brain death • Aphasia • Hemiparesis	• Cerebral laceration w contusion w/open wound s/LOC[b] • Closed intracranial hemorrhage w/brief LOC • Injury to carotid artery • Open wound to neck • Closed Fx w/spinal cord injury • Closed skull Fx s/intracranial injury or LOC • Open Fx of base of skull w/subarachnoid subdural and extradural hemorrhage w/LOC unspecified duration • Closed Fx of cervical vertebra s/cord injury • Cerebral edema • Cerebral infarction • Phlebitis and thrombophlebitis of intracranial venous sinuses • Intracerebral hemorrhage
Face	• Blow-out orbital floor • Closed Fx of malar & maxillary • Crush injury • Deep necrosis (3rd deg burn) s/loss of body part • Open wound to ear drum • Open wound to eye ball • Eye rupture w/loss of intraocular tissue • Open wounds of ocular adnexa • Open Fx nasal bones	• Open wound pharynx • Open Fx jaw • 2nd deg burn – multiple sites head and neck (no eye) • Closed Fx jaw • Open wound to ear drum • Closed Fx nasal bones • Open wound of larynx w/uncomplicated trachea

Diagnoses at Discharge (outcomes)	CAR	Non-CAR
Chest (including thoracic spine)	• Closed Fx s/cord injury • Closed Fx w/cord injury • Open Fx ribs • Open wound • Pneumothorax s/open wound • Traumatic pneumothorax w/open wound to thorax • Closed rib Fx • Open Fx of vertebra s/cord injury • Interstitial emphysema • Pulmonary embolism and infarction • Burn of larynx, trachea, lung • Contusion of lung s/open thorax wound • Pulmonary insufficiency following trauma/surgery • Pulmonary collapse • Alveolar and parietoalveolar pneumonopathy • Acute respiratory failure • VAP • Paroxysmal ventricular tachycardia/cardiac dysrhythmias • Sudden cardiac arrest	• Pneumothorax s/open wound • Traumatic pneumothorax w/open wound to thorax • Pulmonary insufficiency following trauma/surgery • Acute respiratory failure • Laceration of lung w/open wound to thorax • Iatrogenic pneumothorax • Closed Fx w/unspecified cord injury • Pulmonary collapse • Saddle embolus of pulmonary artery • Plural effusion • Unspecified pleural effusion • Pneumonitis (due to vomitus) • Pneumonia (organism unspecified) • Ventilator-associated pneumonia (VAP) (2) • Dependence on respirator
Abdomen (including lumbar spine)	• Open wound w/injury to duodenum, transverse colon, liver laceration • Open Fx lumbar spine w/cord injury • Closed Fx s/cord injury • Open wound w/retroperitoneum injury • Kidney injury w/open wound • Kidney injury s/open wound • Complete disruption of kidney parenchyma w/open wound • Unspecified injury to spleen s/open wound • Paralytic ileus • Traumatic anuria • Acute kidney failure	• Open wound/injury to colon & rectum, duodenum, small intestine • Open wound w/liver laceration • Small intestine, sigmoid colon injury s/open wound • Closed Fx of lumbar spine w/cord injury • Closed Fx of lumbar spine s/cord injury • Open Fx s/spinal cord injury • Unspecified injury to spleen s/open wound • Cauda Equina syndrome s/neurogenic bladder • Paralytic ileus • Acute kidney failure • Suppurative peritonitis

Diagnoses at Discharge (outcomes)	CAR	Non-CAR
Extremity (including pelvic skeleton)	• Fx w/disruption of pelvic circle • Complicated open wound hip & thigh • Open Fx sacrum & coccyx s/cord injury = • Traumatic amputation of fingers, arm, hand • Below knee amputations • Open Fx fibula,tibia, femur, humerus • Compartment syndrome • Compartment syndrome of upper extremity	• Acute venous embolism & thrombosis of deep vessels • Open Fx of humerus, tibia, fibula, femur • Closed Fx tibia • Open wound forearm • Open wound to wrist • Ureter injury s/open wound • Open Fx pubis • Multiple open pelvic Fx w/disruption of pelvic circle • Deep vein thrombosis-embolism lower extremity • Bladder & urethra injury s/open wound • Traumatic amputation of legs
External	• 2nd deg burns (multi-sites) • Pressure ulcer (2) buttock – stage 1	• Pressure ulcer (1) buttock – stage 1
Psychiatric	• Unspecified schizophrenia/depressive disorder-anxiety – self-inflicted injury	• Acute reaction to stress (physical restraints)
Other	• Acute post-hemorrhagic anemia • Post-operative infection • Traumatic shock • Fat embolism • Unspecified coagulation defects • Unspecified septicemia • Rhabdomyolysis • Acidosis • Hypoxemia • Subcutaneous emphysema • Thrombocytopenia • Unspecified fever • Hyperkalemia/alkalosis/hypernatremia-malnutrition • Feeding difficulties • Tobacco use • Retained foreign body • Subcutaneous emphysema	• Acute post-hemorrhagic anemia • Septicemia • Systematic inflammatory response syndrome, noninfectious process w/acute organ dysfunction • Traumatic shock • Other coagulation defects • Rhabdomyolysis • Malnutrition • Essential hypertension • Mixed acid-base balance disorder • Shiga toxin-producing *E. coli* • Tobacco use • Foreign body accidentally left during procedure • Disorders of plasma protein/phosphorus metabolism • Hypokalemia • Subcutaneous emphysema

[a](CAR Death): Fx at base of skull with subarachnoid, subdural, and extradural hemorrhage with prolonged (>24 h) LOCs/return to preexisting conscious level – cerebrospinal fluid rhinorrhea, compression of brain, lung contusion, open Fx of facial bones.

[b](Non-CAR Death): Other and unspecified cerebral laceration and contusion with open intracranial wound with no LOC. In addition, five patients were diagnosed with pneumonia. Each cohort had one patient diagnosed with VAP, and the non-CAR cohort had three added patients diagnosed with non-VAP. Ten patients were diagnosed with malnutrition (CAR = 4, non-CAR = 6). Fifty-two patients were diagnosed with anemia (CAR = 22, non-CAR = 30).

APPENDIX C
Summary of PMQ-R Information

Injury Category and Definition	CAR (*n*=7)	Status Change	Non-CAR (*n*=17)	Status Change
C: Event Resulting in Temporary Patient Harm and Emergency Evaluation and/or Treatment	*n*=1	Desaturation; Pt O_2 was unstable and complained of chest pain. Given 2 L/NC and shortly after had no chest pain or difficulty breathing.	*n*=0	
D: Event Did Not Result in Patient Harm, But Increased Monitoring Required	*n*=1	N/A; Pt was given incorrect medication for 5-10 min. No apparent ill effects to pt were noted.	*n*=2	Pt 1: N/A; Waiver was obtained for use of pacemaker. Pt 2: Desaturation; Pt by aircraft commander was repositioned for comfort and when reassessed was noted to have hypo oxygenation. Was elevated and given O_2 at 2 LPM.
E: Event Did Not Result in Patient Harm or Need for Increased Monitoring	*n*=2	Pt 1: N/A; 3899 physician orders were not signed off or dated, AE package didn't include Progress Note, no pt movement record completed until requested, conflicting medical orders. Pt 2: N/A; Antibiotic was administered late.	*n*=6	Pt 1: Baggage Issues; Pt and baggage were antihijacked onboard aircraft and documented on baggage form as CASF didn't have any available forms. Pt 2: N/A; Order stated medicine to be administered, but medicine was not in pt's possession. Pt 3: IV pump wasn't with pt at hand-off, used pump AE had available. Pt 4: Desaturation; O_2 saturation 83% and was given 3 L/NC to achieve O_2 saturation. Pt 5: N/A; Provider poked finger with clean needle during IV start. Pt 6: N/A; Incorrect medical documentation; given medicine to correct for missed dosage

Injury Category and Definition	CAR (*n*=7)	Status Change	Non-CAR (*n*=17)	Status Change
F: Event Did Not Reach Patient and Did Not Result in Patient Harm	*n*=3	Pt 1: Medical Delay; Waited on ground for CASF to transport pts to flightline/aircraft for about 1 h. No immediate action taken. Pt 2: Transportation Issues; Delay due to pts being added to flight and de-icing of aircraft. Pt 3: Unitron monitors stopped working.	*n*=7	Pt 1: Flight Crew Equipment/Mission/Duty; Frequency converter lost power but power to equipment was immediately restarted. Pt 2: N/A; Frequency converter blew a fuse, equipment was replaced. Pt 3: N/A; Ventilated pt. required waiver for AE transport, waiver was secured. Pt 4:N/A; Pt allergy was noted on 3899 I MAR. Pt 5: N/A; AE protocol used; Pt O_2 sats decreased, was placed on O_2 2 LPM/NC and sats increased. Pt 6: N/A; Pt was ordered for medication but medication did not come with pt from CASF. Medication not given. Pt 7: N/A; Waiver was approved for pulse oximeter used for study.
Unknown	*n*=0		*n*=2	Pt 1: N/A; Pt on vent. Pt 2: N/A

CASF = contingency aeromedical staging facility; IV = intravenous; LPM = liters per minute; N/A = not applicable; NC = nasal cannula; O_2 = oxygen; pt = patient; sats = pulse oximetry hemoglobin saturation.

APPENDIX D
Cost Comparisons for CAR and Non-CAR Missions

Comparison of CAR and Non-CAR Mission Costs Using Actual Values

Factor	CAR (*n*=13) M (*SD*)	Non-CAR (*n*=17) M (*SD*)	*p*-value	Power (%)
Flying Hours	5.8 (2.47)	5.8 (2.65)	0.97	---
Flight Miles	2151 (1036.18)	2203 (1066.77)	0.90	---
Fuel Consumption (gal)	13,122 (7504.20)	13,924 (7900.60)	0.79	6
Flight Miles/Gallon	0.19 (0.06)	0.20 (0.07)	0.89	---
Mission Cost/Hour	$6521.75 ($2816.48)	$6846.54 ($2855.72)	0.77	6

Comparison of CAR and Non-CAR Mission Costs for C-17 Missions Using Actual Values

Factor	CAR (*n*=8) M (*SD*)	Non-CAR (*n*=10) M (*SD*)	*p*-value	Power (%)
Flying Hours	6.3 (2.01)	7.4 (0.33)	0.21	---
Flight Miles	2363 (847.41)	2795 (1.50)	0.22	---
Fuel Consumption (gal)	16,767 (6457.38)	19,858 (1233.62)	0.25	27
Flight Miles/Gallon	0.16 (0.04)	0.14 (0.01)	0.39	---
Mission Cost/Hour	$8041.80 ($2534.51)	$8745.11 ($2111.30)	0.56	10

Comparison of CAR and Non-CAR Mission Costs for C-130 Missions Using Actual Values

Factor	CAR (*n*=2) M (*SD*)	Non-CAR (*n*=4) M (*SD*)	*p*-value	Power (%)
Flying Hours	1.4 (0.28)	1.1 (0.14)	0.42	---
Flight Miles	335 (65.97)	280 (19.57)	0.56	---
Fuel Consumption (gal)	1269 (373.13)	933 (146.81)	0.53	23
Flight Miles/Gallon	0.27 (0.03)	0.31 (0.04)	0.43	---
Mission Cost/Hour	$3053.83 ($22.10)	$3416.62 ($634.01)	0.39	21

Comparison of CAR and Non-CAR Mission Costs for KC-135 Missions Using Actual Values

Factor	CAR (*n*=3) M (*SD*)	Non-CAR (*n*=3) M (*SD*)	*p*-value	Power (%)
Flying Hours	7.3 (0.22)	6.9 (0.14)	0.15	---
Flight Miles	2796 (0.00)	2796 (0.00)	1.00	---
Fuel Consumption (gal)	11,303 (579.90)	11,463 (375.22)	0.76	7
Flight Miles/Gallon	0.25 (0.01)	0.24 (0.01)	0.74	---
Mission Cost/Hour	$4780.23 ($179.25)	$5091.21 ($188.24)	0.17	55

Comparison of CAR and Non-CAR Mission Costs for Intratheater Missions Using Actual Values

Factor	CAR (*n*=3) M (*SD*)	Non-CAR (*n*=4) M (*SD*)	*p*-value	Power (%)
Flying Hours	1.4 (0.23)	1.1 (0.14)	0.14	---
Flight Miles	313 (62.19)	280 (19.57)	0.54	---
Fuel Consumption (gal)	1194 (322.42)	933 (146.81)	0.37	26
Flight Miles/Gallon	0.27 (0.02)	0.31 (0.04)	0.23	---
Mission Cost/Hour	$2995.62 ($84.27)	$3416.62 ($634.01)	0.34	26

Comparison of CAR and Non-CAR Mission Costs Arriving at Germany Intertheater Missions Using Actual Values

Factor	CAR (*n*=10) M (*SD*)	Non-CAR (*n*=13) M (*SD*)	*p*-value	Power (%)
Flying Hours	7.1 (0.73)	7.3 (0.36)	0.50	---
Flight Miles	2702 (277.83)	2795 (1.46)	0.34	---
Fuel Consumption (gal)	16,700 (4206.04)	17,921 (3703.41)	0.50	11
Flight Miles/Gallon	0.17 (0.05)	0.17 (0.04)	0.71	---
Mission Cost/Hour	$7579.60 ($2336.90)	$7901.90 ($2409.79)	0.76	6

LIST OF ABBREVIATIONS AND ACRONYMS

618 TACC	618th Air and Space Operations Center Tanker Airlift Control Center Data Division
AE	aeromedical evacuation
AMC	Air Mobility Command
CAR	cabin altitude restriction
CASEVAC	casualty evacuation
CASF	contingency aeromedical staging facility
CCATT	Critical Care Air Transport Team
DO_2	tissue oxygen delivery
FiO_2	fraction of inspired oxygen
Fx	fracture
GSW	gunshot wound
Hgb	hemoglobin
ICD-9	International Classification of Diseases, Ninth Revision
ICU	intensive care unit
ISS	Injury Severity Score
IV	intravenous
LOC	loss of consciousness
LPM	liters per minute
M	mean
MEDEVAC	medical evacuation
NC	nasal cannula
O_2	oxygen
pt	patient
SD	standard deviation
SpO_2	peripheral oxygen saturation

PMQR	Patient Movement Quality Report
TBI	traumatic brain injury
TMDS	Theater Medical Data Store
TRAC^{2}ES	Transportation Command Regulating and Command and Control Evacuation System
TVFS	theater validating flight surgeon
VAP	ventilator-associated pneumonia