Complication Rates in Altitude Restricted Patients Following Aeromedical Evacuation

William P. Butler; Lawrence W. Steinkraus; Esther E. Burlingame; Brittany L. Fouts; Jennifer L. Serres

INTRODUCTION: Military aeromedical evacuation, especially that associated with the present Middle East conflict, is seeing increasing research. This ecological study initiates research into the validating flight surgeon by looking at cabin altitude restriction (CAR), arguably the validating flight surgeon's prescription with the highest patient-mission impact, and its association with postflight complications.

METHODS: CAR rates from January 2006 through February 2008 were determined from the U.S. Transportation Command Regulating and Command and Control Evacuation System database. Postflight complication rates—the rate of patients with postflight complications (PFC) and the postflight complications per 100 patients (PFC-100)—from January 2007 through June 2008 were calculated from the Landstuhl Regional Medical Center trauma database. CAR and complication rates were examined before, during, and after the authors' deployment. In addition, the relationship between CAR and postflight complication rates was investigated; as the rates were nonlinear, a Spearman correlation was performed.

RESULTS: CAR rates during the authors' deployments were significantly up compared to the authors' predecessors or successors; their predecessors and successors did not differ statistically. Likewise, the PFC rate during the authors' deployments was significantly lower than that of the before or after time frames. Furthermore, a statistically significant inverse relationship between CAR and PFC rates (Spearman rho = −0.587) as well as CAR and PFC-100 rates (Spearman rho = −0.568) was demonstrated.

DISCUSSION: CAR rate was inversely correlated to PFC and PFC-100 rates. This finding suggests that aggressive prescribing of CARs may have a salutary effect on postflight complication rates and bears further investigation.

KEYWORDS: cabin altitude restriction, postflight complications, aeromedical evacuation.

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Today, military combat medical care is the best it has ever been. Indeed, as of late August 2014, wound lethality in the present conflicts was 9.3%.[8] There are a number of reasons for this spectacular success: surgical care is more forward than in times past; care is of higher technical skill and has a higher level of technological support than previously; the Critical Care Air Transport Teams have enabled movement of "stabilized," albeit very sick, patients in numbers never before seen; and aeromedical evacuation has become more flexible than ever before.

Aeromedical evacuation is the main means of moving patients from one level of care to the next, always bringing them to a higher echelon of care, and moving very ill patients has become commonplace in today's military. Unfortunately, aeromedical evacuation is not without its risks. There are a number of in-flight stressors—gravitational forces, low humidity and temperature, reduced barometric pressure and oxygen levels, increased vibration, trapped gas expansion, and serious noise, not to mention crowded spaces and the potential for turbulence—that can pose problems for the patient. When a patient is brought into this environment, it is the validating flight surgeon who specifies a patient-aircraft configuration most likely to facilitate the safest possible patient transport.[18–20] Indeed, the validating flight surgeon reviews the patient's clinical situation, prescribes in-flight stressor countermeasures (including both

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patient and aircraft interventions), and determines the final flight status of the patient ("go" or "no go"). In short, the validating flight surgeon "validates" that the patient is clinically ready for fixed wing Air Force regulated flight.

Although much has been written about modern combat surgery and the critical care teams, aeromedical evacuation has seen relatively little scrutiny and the role of the validating flight surgeon even less. While deployed in 2007, Butler and Steinkraus served as validating flight surgeons ("Study VFSs") and used the various patient-aircraft prescriptions available to them quite liberally. **Table I** depicts many of the interventions prescribed. It was their impression that they were more aggressive than either their predecessors or successors, particularly when prescribing cabin altitude restrictions (CAR). Such restrictions limit the altitude at which an aircraft's cabin is maintained. Specifically, they refer to cabin altitudes below the federally mandated 8000 ft (2438 m) (14 CFR 25.841).[6,13] The Study VFSs' decisions on cabin altitude involved the manipulation of three factors they considered critical to tissue oxygen delivery—fraction of inspired oxygen, hemoglobin level, and cabin altitude—with the goal of exceeding 7.3 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$ (the ceiling below which human critical tissue oxygen delivery exists).[22]

During an operationally driven study using CAR as a surrogate for aggressive validating flight surgeon prescribing, this impression proved correct. Furthermore, it was their impression that being aggressive was "good" clinically. These impressions prompted this ecological study (an initial, exploratory, hypothesis-generating epidemiological study of group characteristics) to begin research into the role and value of the validating flight surgeon by looking at the CAR, arguably the validating flight surgeon's prescription with the highest potential patient-mission impact, and its association with postflight complications.

Table I. Prescriptions Available to and Used by the Validating Flight Surgeon.

CATEGORY	PRESCRIPTION
Medical adjuncts	• Cardiac monitor; suction; pulse oximeter • Medical attendant (tech, nurse, doctor)
Medical interventions	• Protected airway (nasotracheal/orotracheal intubation) • Supplemental oxygen and positive end-expiratory pressure • Sedation/restraints in flight • Deep venous thrombosis prophylaxis • Blood components and medications in flight • Further ground stabilizing—fluids, vasopressors, blood, tertiary survey
Middle ear interventions	• Equalization maneuvers (Valsava, Toynbee, Frenzel, etc.) • Afrin™ and Neo-Synephrine for opening ostia • Myringotomy
Patient paraphernalia	• Chest tube—suction or Heimlich valve (no clamping of tubing) • Jackson-Pratt™ drain—open on ascent and descent • Hemevac™ drain—open on ascent and descent • Colostomy bag—prepare to decompress on ascent (pinhole, "burp") • Bivalve casts; control air splints
Positioning interventions	• Seizure precautions • Spine precautions • Head first loading • Headrest to elevate and protect head • Head-of-bed elevation (eye, face, and/or head injury, pulmonary dysfunction • OSL™ litter (regular litter = 250 lb; overweight litter = 400 lb) • Stryker™ frame; vacuum spine board • Blankets
Aircraft manipulations	• Cabin altitude restriction • Full use of runway length • Modify rate of climb and descent • Cabin airflow patterns • Aerial refueling • No RONs (remain overnights); no stops

METHODS

The two primary variables were carefully selected. CAR rate was chosen as the primary independent variable, as it is a logical surrogate denoting an aggressive validating flight surgeon. CAR is a prescription almost unique to the VFS, seldom prescribed by others, and it is also a prescription that is associated with a subtle and, sometimes, not so subtle systemic resistance. This resistance stems from the notion that a CAR may increase fuel consumption, mission flight time, mission cost, aircraft structural stress, potential for turbulence, and refueling needs (either in flight or on a ground stop). Thus, a ready willingness to repeatedly prescribe CARs in the face of organizational pressure suggests an aggressive validating flight surgeon.

Postflight complication rate served as the outcome, or dependent, variable. There are two ways of examining this outcome. The first is the rate of patients with postflight complications (PFC) and the other is postflight complications per 100 patients (PFC-100). The former measure is the more common way of looking at outcomes, while the latter is unusual. PFC looks directly at those patients who suffer postflight complications, while PFC-100 deals with the complications themselves. Patients aeromedically evacuated often have multisystem injuries. Should the unopposed, or minimally countered, flight stressors produce added insult to injuries, multiple organ system postflight complications could be expected in a single patient. PFC-100 captures this effect; PFC does not. Although PFC was the outcome of choice, it was decided to look at both.

It is important to note that postflight complications could result from preflight ground transport/clinical care, in-flight clinical care, and/or postflight ground transport/clinical care. However, variation in this care continuum has been minimized through the Joint Theater Trauma System and widely disseminated clinical practice guidelines. Essentially, system variation exists primarily with the validating flight surgeon and the flight environment itself, a prime manifestation of both being the CAR.

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Following Air Force Research Laboratory Institutional Review Board approval (with appropriate data use arrangements in place), the U.S. Transportation Command Regulating Command & Control Evacuation System data from January 2006 through February 2008 were examined. The number of patients aeromedically evacuated to Landstuhl Regional Medical Center (Landstuhl) each month was extracted along with the number of CAR prescriptions levied on patients (the CAR dataset). This permitted the calculation of a monthly CAR rate (CAR prescriptions/total patients transported to Landstuhl). Only Priority (requiring evacuation within 24 h to preserve life, limb, or eyesight) and Urgent (requiring evacuation as soon as possible, but no later than 12 h, to preserve life, limb, or eyesight) patients were studied, thus limiting the study to patients most vulnerable to the physiological impacts of flight.

Over a similar time period, from January 2007 through June 2008, data were obtained from Landstuhl's Joint Theater Trauma Registry that included the number of patients arriving each month, the number of patients with postflight complications, and the specific complications suffered (the Complication dataset). The monthly rates of complications, both PFC (number of patients with complications/total patients arriving at Landstuhl) and PFC-100 (number of complications/100 patients arriving at Landstuhl), were calculated. **Table II** shows the variety of postflight complications.

Some basic demographics within the datasets were then explored followed by an analysis of the CAR and postflight complication rates relative to the Study VFSs' deployment. Next, the relationship between CAR and postflight complication rates was investigated. Because the data proved nonlinear in nature, the Spearman correlation was used.

Data were analyzed using the Statistical Package for Social Sciences, version 20 (IBM SPSS Statistics 20, IBM Corp., Somers, NY). Descriptive statistics (mean $\pm$ SD) were calculated. Within defined time frames, internal comparisons of CAR, PFC, and PFC-100 were made with the Student's *t*-test, while CAR vs. PFC and CAR vs. PFC-100 correlations were performed with the Spearman correlation. Statistical significance was set a priori at $P < 0.05$.

RESULTS

Although demographically similar, the two datasets proved to be somewhat heterogeneous. The CAR dataset included 2329 patients, while the Complication dataset had 2722. Median age for the CAR dataset was 24.0 yr (range 5-63, $Q_1 = 21.0$, $Q_3 = 29.0$), while median age in the Complication dataset was 24.0 yr (range 6-65, $Q_1 = 21.0$, $Q_3 = 30.0$); they were not statistically different (Median test, $Z = -0.53$, $P = 0.59$). As for gender, men made up 98.1% of the CAR dataset and 97.7% of the Complication dataset; however, when women and unknowns were factored into the mix, the two datasets were found to be statistically different ($\chi^2 = 16.48$, $P = 0.0003$). Despite the statistical difference, there appears to be no practical clinical consequence to this finding.

Table II. Postflight Patient Complications as Recorded at LRMC.

CATEGORY	*N*	%
Pulmonary		29
Atelectasis	177	
Pleural Effusion	85	
Pneumothorax	23	
Pulmonary Edema	18	
Pulmonary Embolus	17	
Aspiration/Aspiration Pneumonia	13	
Acute Respiratory Distress Syndrome	12	
Acute Respiratory Failure	8	
Hemothorax	7	
Infectious		20
Acinetobacter	73	
Pneumonia	49	
Wound Infection	46	
Cellulitis	20	
Sepsis	20	
Bacteremia	12	
Urinary Tract Infection	8	
Disseminated Fungal Infection	5	
Clostridial Difficile Colitis	5	
Line Sepsis	4	
Intraabdominal Abscess	2	
CNS Infection	2	
Soft Tissue Infection	1	
Empyema	1	
Resuscitative		19
Anemia/Blood Loss	232	
Hypovolemia	4	
Shock (traumatic)	2	
Blood Transfusion Reaction	2	
Postoperative Hemorrhage	1	
Coagulation		18
Coagulopathy	189	
Deep Vein Thrombosis	36	
Acute Arterial Occlusion	4	
Gastrointestinal		4
Ileus	28	
Dehiscence/Evisceration	11	
Pancreatitis	3	
Jaundice	2	
Small Bowel Obstruction	1	
Orthopedic		2
Compartment Syndrome	18	
Fat Embolus Syndrome	2	
Renal		2
Acute Renal Failure	17	
Renal Failure	2	
Metabolic		1
Hyperkalemia	11	
Hypothermia	6	
Dermatologic		1
Decubitus/Skin Breakdown	15	
Neurologic		1
Progression of Original Insult	10	
Seizures	2	
Cardiac		<1
Cardiopulmonary Arrest	2	
Major Arrhythmia	2	
Miscellaneous		3
Other	29	
Adverse Drug Reaction	3	
Total Complications	1242	100

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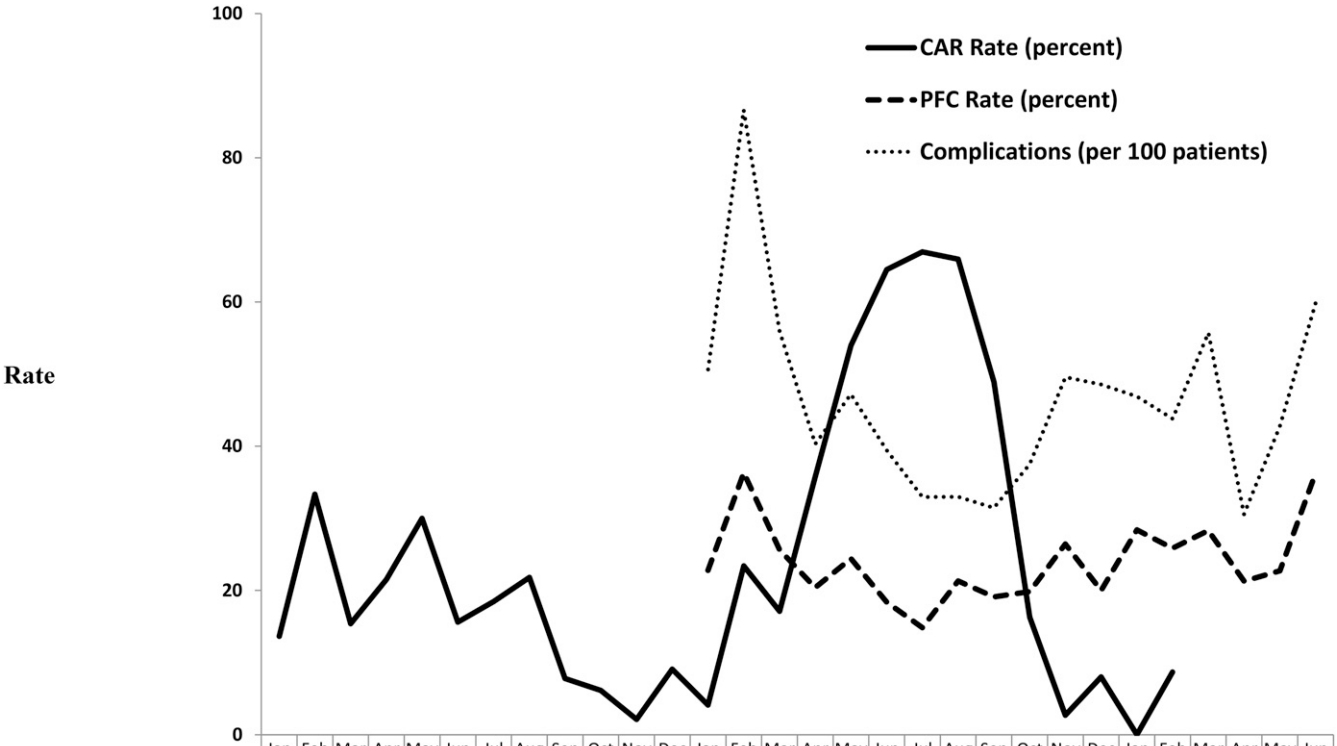
Going into this study, it was hypothesized that there was no difference in CAR or postflight complication rates before, during, or after our deployment (null hypothesis). In this way, it would be possible to refute the impressions of aggressive validating flight surgeon prescribing and "good" clinical results. The Study VFSs' deployed from January 2007 through September 2008. The two datasets collected fully addressed both the during and after time frames; however, because Landstuhl's data were unreliable prior to January 2007, it was not possible to strictly assess the before time frame. But it was recognized that the conceptual framework upon which aggressive validating flight surgeon prescribing was based was largely developed during early 2007, specifically January through March. Consequently, it was decided to include that time as "before," giving the study a small cadre of postflight complication rates that could be considered before. Thus, January 2006 through March 2007 was defined as before, April 2007 through September 2007 as during, and October 2007 through June 2008 as after. **Fig. 1** graphically displays the monthly rates of CARs and postflight complications.

The CAR rate ranged from 0–67% per month (mean = 23.5%, SD = ±20.2); the most prescribed CAR was 5000 ft (1524 m) (48%, peaking June 2007) followed by 4000 ft (1219 m) (27%, peaking May 2007) and 6000 ft (1829 m) (22%, peaking August 2007). The PFC rate ranged from 15–36% per month (mean = 24.0%, SD = ±5.6) and the monthly PFC-100 rate ranged from 31-87 complications per 100 patients (mean = 46.3/100 patients, SD = ±13.0). The specific monthly rates can be seen in the tabular portion of Fig. 1. Four categories of complication dominated, as seen in Table II: pulmonary, infectious, resuscitative, and coagulation.

Looking at the CAR rates before, during, and after, it was found that the Study VFSs' use of the CAR prescription differed significantly from their predecessors [$t(19) = 8.2$, $P < 0.0001$] and successors [$t(9) = 8.0$, $P < 0.0001$]; the Study VFSs' predecessors and successors did not differ statistically [$t(18) = 2.0$, $P = 0.063$]. Likewise, the PFC rate during the Study VFSs' deployment was significantly different from the before [$t(7) = 2.6$, $P = 0.036$] or after [$t(13) = 2.4$, $P = 0.033$] time frames; the before and after PFC rates did not differ statistically [$t(10) = 0.8$, $P = 0.471$]. Interestingly, the PFC-100 rate during the Study VFSs' deployment was significantly different from the before time frame [$t(7) = 3.3$, $P = 0.013$], but not the after time frame [$t(13) = 2.1$, $P = 0.057$], while the before and after PFC-100 rates did differ statistically [$t(10) = 2.3$, $P = 0.042$].

The datasets matched over the January 2007 through February 2008 time frame, making the correlational analysis possible when incorporating before, during, and after data. As the monthly rates over time did not appear linear (see Fig. 1), statistical evaluation using the Spearman correlation was



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
CAR Rate (percent)	13.6	33.3	15.4	21.5	30.0	15.6	18.5	21.8	7.8	6.1	2.1	9.1	4.1	23.4	17.1	35.7	54.0	64.5	66.9	65.9	48.9	16.3	2.7	8.0	0.0	8.7				
PFC Rate (percent)													22.8	36.3	25.7	20.4	24.4	18.4	14.8	21.3	19.1	19.9	26.4	20.0	28.4	25.8	28.3	21.3	22.7	36.2
Complications (per 100 patients)													50.6	86.6	56.0	40.3	47.2	39.5	33.0	33.0	31.5	37.5	49.6	48.6	46.9	43.8	55.8	30.6	42.7	59.8

Fig. 1. Graphic depiction of the relationship of CAR rates to PFC and PFC-100 rates.

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performed. A statistically significant inverse relationship between CAR and PFC rates (Spearman rho = −0.587, P = 0.027) was demonstrated. Also demonstrated was a statistically significant inverse relationship between CAR and PFC-100 rates (Spearman rho = −0.568, P = 0.034). In other words, as the rate of CAR prescriptions rose, the rate of patients with postflight complications as well as the rate of postflight complications per 100 patients dropped.

To ensure the recorded postflight complications were indeed "postflight," length of stay at Landstuhl was examined. If the length of stay took the patient sufficiently distant from the flight, then a postflight complication could well be unrelated to the flight and the prescribed CAR. Overall mean length of stay was 3.5 d (SD, ±4.5; range 1-113)—with no statistical difference among the before, during, or after time frames—intimating existence of a postflight complication-CAR relationship.

DISCUSSION

The aeromedical evacuation of very ill patients has become commonplace in today's military. This is a consequence of forward-based surgical care, general acceptance of damage control surgery, sophistication of care, echelon of care system, liberal employment of critical care teams, and ready availability of aeromedical evacuation.

Although a physiologically stable patient is preferred, not infrequently a "stabilized," or physiologically volatile, patient is flown. The direct impact of flight on these patients has not been thoroughly studied nor has the impact of the validating flight surgeon who warrants patients are optimally prepared to withstand in-flight stressors while minimizing clinical risk; this study looked specifically at the latter.

The findings from this study seem to corroborate the observational gestalt, that is, the singularly aggressive validating flight surgeon prescribing during the Study VFSs' deployment and the generally "good" clinical outcomes. It was demonstrated that the Study VFSs' predecessors and successors used CARs at significantly lower rates. Furthermore, it was discovered that the rate of patients with complications (PFC) before and after was significantly greater than that during the Study VFSs' deployments. As a result, the null hypothesis was rejected.

However, this effect was not quite as straightforward when looking at the rates of the number of complications per 100 patients (PFC-100). Here it was found the PFC-100 rate during the before time frame was significantly higher than both the during and after times. This probably reflects incidence trends in the complications themselves. Although 12 categories of complication were found, only 4 occurred in double digits (see Table II). Over the time period studied, pulmonary and infectious complications received intense clinical scrutiny, in particular *Acinetobacter* infections, ventilator-associated pneumonia, and lung protective ventilation. From this scrutiny came a number of new clinical practice guidelines and a trending down of incidence. As both pulmonary and infectious complications often are a second or third complication in the same patient, it is not unreasonable that focused preventive clinical attention would reduce their incidence and, thus, reduce the number of complications in even the sickest of patients. This would be reflected in the PFC-100 rates, but not necessarily in the PFC rates.

Interestingly, during the same time period, an up-trending in the incidence of resuscitative and coagulation complications was seen, probably reflecting, to some extent, the comfort with the conceptual assertion that aggressive validating flight surgeon prescribing could have a positive clinical impact. In other words, the Study VFSs were more willing to transport the very sick earlier (arriving at definitive tertiary care sooner) by aggressively configuring the patient-aircraft environment using available tools, not the least component being the cabin altitude, believing that the patient would remain clinically safe.

When examining the overall relationship of CAR to both PFC and PFC-100 via the Spearman correlation, a statistically significant inverse relationship between the CAR rate and postflight complications rates was discovered. In short, as the rate of CAR prescriptions increased, the rate of postflight complications decreased. These findings support the notion that an aggressive validating flight surgeon can have a positive impact on patient outcome and, by inference, they further support the notion that the flight environment, without proper risk mitigation strategies, can have a detrimental effect on the sick patient.

To understand how this observation could happen, it is important to understand the "second hit" concept. It starts with an initial injury, a "first hit" (e.g., gunshot wound, myocardial infarction, etc.). With that injury, there is an inner zone of dead tissue surrounded by compromised tissue surrounded by unimpaired tissue. With appropriate care and no further insults, the compromised tissue recovers. However, with another insult, a "second hit," the compromised tissue is further injured and may even die. Two classic clinical entities are the burn injury and the traumatic brain injury.[9,21]

Cabin altitude can act as a potential second hit in several ways. First, normal cabin altitude generally does not exceed 8000 ft (2438 m).[6,13] At that altitude, the ground-equivalent fraction of inspired oxygen is about 16%. The result is a relative hypoxia causing a clinically relevant lowered arterial oxygen partial pressure that can lead to ischemia, especially in compromised tissues.[15] Using a complex wounded/infected caprine model taken to 8800 ft (2682 m) for 7 h (flown 20 h postwounding), Earnest et al. demonstrated altitude hypoxia and concomitantly induced significant wound bacterial growth. When supplemental oxygen was introduced, hypoxia was reversed and bacterial growth considerably inhibited and a potential "second hit" mitigated.[7]

This hypoxic effect is potentially enhanced by the injury itself. In the early healing process, every injury results in localized swelling.[17,28] In those major systemic injuries (e.g., large burns, major trauma, etc.), there is generalized body swelling.[1] Both phenomena result from leaky blood vessels and produce interstitial edema.[16,28,30,33] The edema effectively increases the distance between capillaries, thus creating a tissue space where

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oxygen either cannot diffuse into or is seriously reduced.[17] The result is a further hypoxia that, in compromised tissue, can produce tissue ischemia, dysfunction, and even death. Altitude-related hypobaria, when added to this mix, potentially augments adverse effects. Indeed, the Starling's fluid flux physiological equation shows that intravascular fluid should move into the interstitial space during aeromedical evacuation.[10,12] A rise in both capillary hydrostatic pressure and capillary permeability are key contributors to this fluid shift.[5,29,32] Though as yet undemonstrated, an accompanying drop in interstitial hydrostatic pressure may play a role[3,10,12]; lower body negative pressure studies, though not equivalent to going to altitude, lend some credence to this effect.[24–26,31] Hypobaria-induced fluid movement into tissues only serves to amplify an already widened intercapillary distance. In fact, Ritenour et al. retrospectively examined 336 patients from January 2005 through August 2006. Although the focus of this study was extremity compartment syndrome, their findings are pertinent here. There were 643 fasciotomies. Of those that required a fasciotomy revision after evacuation, there was a significantly higher rate of muscle excision and mortality.[34]

Thus, with altitude, hypoxia and hypobaria can potentially create a physiological milieu that can lead to inadequate tissue oxygen delivery and a consequent "second hit." To date, the specific critical level of tissue oxygen delivery in humans has not been determined, but it is known to be under 7.3 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$.[22]

Although constrained tissue oxygen delivery is almost certainly the final common pathway to "second hit" injury, the altitude and clinical physiology just described is almost just as certainly not the entire story. There are several other possible factors that need to be considered. Among them is the induction of inflammatory factors. The fact that acute mountain sickness is seen with terrestrial altitudes routinely found in aircraft cabins suggests that the various acute mountain sickness inflammatory markers—cytokines, hypoxia-inducible factor-1alpha, vascular endothelial growth factor, and inducible nitric oxide synthetase—might also be seen with aeromedical evacuation.[11,23] This high altitude physiological response could well contribute to further injury. In fact, Goodman et al. have demonstrated increased production of macrophage inflammatory factor-1 alpha and interleukin-6 in a traumatic brain injury murine model taken to 8800 ft (2682 m) for 5 h (flown 3 h postinjury). Furthermore, they showed a rise in neuron specific enolase, suggesting a "second hit" neurological injury.[9]

Another potential factor is the evolution of venous gas emboli ("bubbles"). Despite the fact that Webb and Pilmanis in their many studies never documented venous gas emboli below 10,250 ft (3124 m), there are cases of decompression sickness (evolved bubbles being de facto etiology) seen at or below 8000 ft (2438 m).[4] In addition, it is well known that transfusions infuse bubbles into the circulation (as high as 84% nitrogen), perhaps as much as 4 ml per unit of warmed whole blood.[27] In patients with massive transfusions, bubbles already in the circulation will grow with altitude and may well serve as a nidus for further bubble evolution. It is also common knowledge that bubbles not only can cause direct tissue damage, but also can induce inflammatory response, producing further injury.[2]

Lastly, the ischemia-reperfusion phenomenon may well be in play during an aeromedical evacuation flight. The hypoxia and hypobaria at altitude, not to mention the altitude-induced inflammation and bubble effects, can produce tissue ischemia. Upon landing, reperfusion with oxygenated blood may well set the stage for the leukocyte-mediated tissue injury common to the ischemia-reperfusion phenomenon, producing another means of "second hit" in the patient.

Common to each factor described is a critical fall in tissue oxygen delivery. If the drop is serious enough or the duration of drop is long enough, a "second hit" to already compromised tissues is inevitable, with postflight complications being manifest. It is the validating flight surgeon's job to configure the patient-aircraft environment, using appropriate and practical mitigation strategies, to reduce the risks from in-flight physiological stressors. To do this, the validating flight surgeon must maximize tissue oxygen delivery. The initial focus must be on the various components of tissue oxygen delivery—fraction of inspired oxygen, blood oxygen content (hemoglobin level, hemoglobin saturation level, and plasma oxygen content), and cardiac output. Plasma oxygen content (0.3 vol %) is a minimal contributor as are hemoglobin 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 fraction of inspired oxygen and hemoglobin level as major factors within the validating flight surgeon's reach, prescribing supplemental oxygen[7] and transfusion,[14] respectively. Another prescription in the validating flight surgeon's arsenal is the CAR, for all intents and purposes bringing the patient closer to ground level, thus limiting the impact of hypoxia and hypobaria. The CAR, combined with additional prescriptions (e.g., supplemental oxygen, patient positioning, long, slow takeoff/landing, head-of-bed elevation), can perhaps even replicate near ground level settings. The result would be patient care environments less conducive to patient harm. The authors firmly believe this sort of aggressive approach to validating flight surgeon prescribing contributed to the study's findings.

This project was designed as a hypothesis-generating ecological study and, as such, has limitations. Among these are the two primary assumptions: CAR as a good surrogate metric for aggressive validating flight surgeon prescribing and postflight complications (PFC and PFC-100) as a good surrogate for poor postflight clinical outcome. As discussed earlier, it was felt these were appropriate assumptions. However, with them come limitations. Almost assuredly, there was an undercounting of CARs, as those patients without a CAR prescription flying with patients having a CAR prescription de facto experienced a CAR. Postflight complications could well be overcounted, as some of them may be unrelated to flight and others may be found in routine patients who were not considered in the study's CAR patient population. In addition,

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the databases could be incomplete, inconsistent, or duplicative. Indeed, prior to January 2007, due to nonstandardized data recording and missing data in the initial phase of the present conflict, Landstuhl self-declared its database inadequate. Lastly, the findings cannot necessarily be extrapolated to the individual patient. To avoid such an ecological fallacy, the study must exhibit both internal and construct validity.[35] Internal validity assumes no obvious confounding variable. CAR prescription, by our definition, presupposes aggressive use of all prescriptions available to the validating flight surgeon so that any potential confounding intervention (e.g., supplemental oxygen) would most likely also be prescribed. It is perhaps the case that one of the other interventions conjoined with the CAR is responsible for our findings; the present study was not designed for nor had the breadth of data to address this question. Similarly, although a postflight complication could derive from another confounding etiology, the generally short stay at Landstuhl (mean length of stay = 3.5 d) seems to implicate the aeromedical evacuation flight and its accompanying stressors. Construct validity assumes that the aggregate variables (e.g., CAR rate and postflight complications rates) are consistent with the individual variables. CAR rate represents aggressive validating flight surgeon prescribing and PFC/PFC-100 rates incorporate all potential complications. While patients seldom are prescribed a CAR in isolation, they never have the potential for all possible complications. Consequently, it is believed that the study has good internal validity, but not-as-good construct validity, limiting the immediate application of results into individual patient care.

In conclusion, this study begins the investigation of the validating flight surgeon's impact. It demonstrated a statistically significant inverse relationship between validating flight surgeon prescribed CAR rates and postflight complication rates (both PFC and PFC-100). Despite a number of limitations the data have strengths—they are somewhat heterogeneous in nature and there are a large number of subjects. However, these strengths combine to weaken the correlational analysis, making the statistically significant result that much more powerful, suggesting validating flight surgeons be aggressive in their prescribing practices (particularly in the use of the CAR). However, to apply these results to a specific patient may well be premature (ecological fallacy), yet they certainly justify further research in this arena.

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