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Stresses of Flight during Aeromedical Transport: An Integrated Review

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for January 2015 to April 2018

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14. ABSTRACT

The complexity of the aeromedical transport environment presents medical providers with a unique set of challenges. The majority of these challenges are caused by the impact of the stresses of flight on various injury and disease states. The stresses of flight include hypoxia, gravitational forces, barometric pressure changes, thermal changes, vibration, humidity, noise, and fatigue. Unfortunately, there is limited knowledge of the influence of the stresses of flight on patient care during aeromedical transport. This study aimed to investigate the current knowledge base related to the impact of the stresses of flight on injury and disease management during aeromedical transport to identify key areas for future research. A literature search of the PubMed, Cumulative Index to Nursing and Allied Health Literature, Web of Science, and Defense Technical Information Center databases was conducted to identify existing studies published between 2003 and 2014 investigating the impact of the stresses of flight on injury and disease management during aeromedical transport. Whittemore and Knafl's five-step process for integrative reviews was used to identify relevant articles. In total, 7141 unique titles were pulled from the four databases. After reviewing the unique titles for the relevance to injury and disease management during aeromedical transport, 1088 abstracts were reviewed. A total of 928 abstracts did not apply to the area of interest and 160 full text articles were reviewed. Of the 160 full text articles reviewed, 97 articles were considered relevant to this study. The relevant articles suggest the predominance of literature is on hypoxia and barometric pressure. There were few articles on the other stresses of flight. Through the investigation of the stresses of flight and their impact on injury and disease within the aeromedical transport domain, gaps evident in the available research were identified. Understanding the current state of knowledge on the stresses of flight will enable solutions to improve patient care and safety during aeromedical transport.

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1.0 SUMMARY

The complexity of the aeromedical transport environment presents medical providers with a unique set of challenges. The majority of these challenges are caused by the impact of the stresses of flight on various injury and disease states. The stresses of flight include hypoxia, gravitational forces, barometric pressure changes, thermal changes, vibration, humidity, noise, and fatigue. Unfortunately, there is limited knowledge of the influence of the stresses of flight on patient care during aeromedical transport. This study aimed to investigate the current knowledge base related to the impact of the stresses of flight on injury and disease management during aeromedical transport to identify key areas for future research. A literature search of the PubMed, Cumulative Index to Nursing and Allied Health Literature, Web of Science, and Defense Technical Information Center databases was conducted to identify existing studies published between 2003 and 2014 investigating the impact of the stresses of flight on injury and disease management during aeromedical transport. Whittemore and Knafl's five-step process for integrative reviews was used to identify relevant articles. In total, 7141 unique titles were pulled from the four databases. After reviewing the unique titles for the relevance to injury and disease management during aeromedical transport, 1088 abstracts were reviewed. A total of 928 abstracts did not apply to the area of interest and 160 full text articles were reviewed. Of the 160 full text articles reviewed, 97 articles were considered relevant to this study. The relevant articles suggest the predominance of literature is on hypoxia and barometric pressure. There were few articles on the other stresses of flight. Through the investigation of the stresses of flight and their impact on injury and disease within the aeromedical transport domain, gaps evident in the available research were identified. Understanding the current state of knowledge on the stresses of flight will enable solutions to improve patient care and safety during aeromedical transport.

2.0 BACKGROUND

Aeromedical transport requires delivering optimal patient care in austere environmental conditions, which create unique challenges for medical providers. The majority of these challenges are centered on the physiological stresses encountered during flight: barometric pressure changes, decreased partial pressure of oxygen, thermal changes, decreased humidity, noise, vibration, gravitational forces (G-forces), and fatigue [1-3]. While any of these individual stressors could be taxing on an individual, the combination of these stresses of flight acts in a cumulative manner [2] and further complicates injury and disease management in a compromised patient. Over the last several years, advancements made in the aeromedical transport domain have improved survival rates for critically wounded patients, increasing the need for a higher level of nursing care during transport [2]. To provide optimum levels of care, an in-depth understanding of the impact of these stresses of flight on disease and injury management in transported patients is essential.

Providing medical care to wounded patients at altitude can be physiologically and psychologically stressing due to the direct impact of the stresses of flight on work performance of transport crews, health status of transported patients, and reliability of medical equipment. Temperature, pressure, volume, and relative mass of a gas dictate the physiologic response to barometric pressure changes at altitude. As altitude increases, the pressure on all gases, including oxygen, decreases. As the partial pressure of oxygen decreases, less oxygen is transferred to the body and can lead to hypoxia [4]. As governed by Boyle's Law, the decrease in ambient barometric pressure means there is an inversely proportional change in volume. The opposite is true when an aircraft descends from altitude. This is of significant importance to aeromedical transport since enclosed air spaces such as in the gastrointestinal tract, lungs, skull, middle ear, sinuses, and teeth expand in direct proportion to the decrease in pressure [3]. Any enclosed air spaces in medical equipment are subject to the changes in barometric pressure as well [4], complicating the use of an already limited supply of medical resources available during aeromedical transport.

Just as ambient barometric pressure decreases as altitude increases, so does ambient temperature. Temperatures inside aircraft can vary anywhere from 59°F to 95°F depending on the time of flight, which can affect various disease states that may be exacerbated by hyperthermia or hypothermia. As ambient temperature decreases, air loses its ability to hold moisture, and after just 2 hours of flying time, there is less than 5% relative humidity. After 4 hours of flight, there is less than 1% relative humidity. Decreased humidity and temperature can aggravate the condition of an injured patient [3], making injury and disease management more difficult. This is especially true during long-duration flights such as in military aeromedical transport by aeromedical evacuation (AE) or critical care air transport (CCAT) teams.

The aeromedical transport environment is unique compared to a standard healthcare environment due to the use of various mechanisms of transportation including rotary and fixed-wing aircraft. Additional noise created by the aircraft's engines, propellers/rotors, and ventilation systems and possible turbulence can impede communication between the patient and the provider and cause auditory fatigue and potential hearing loss [3,4]. Ambient noise levels seen in aeromedical transport aircraft can reach upwards of 100 dB, and prolonged exposure to these high ambient noise levels may impede the performance of medical providers and cause nausea, vomiting, headache, fatigue, and general discomfort [3].

Aeromedical transport aircraft also cause vibration, which is a major flight stressor since it mimics shivering [1]. When individuals are exposed to a source of vibration, mechanical energy is transferred and the body responds with an increase in muscle activity, which causes an increase in metabolic rate and peripheral vasoconstriction [3]. Vasoconstriction hinders the body's cooling mechanism of vasodilation and, in turn, may impair the body's ability to sweat, causing heat exhaustion and dehydration [1,4]. Other negative effects of vibration include fatigue, shortness of breath, chest pain, abdominal pain, motion sickness, irritability [4], orthopedic problems [1], and malfunction of medical equipment [4].

G-force is considered one of the stresses of flight since it is applied to the body during ascent and descent and during a change in speed or direction of the aircraft [4]. In aeromedical transport, acceleration and deceleration along the longitudinal axis (fore/aft) are the most important G-forces to take into consideration [3]. During ascent, blood rushes from the lower extremities to the head in patients in the supine position with their head toward the back (aft) of the aircraft. While this may be a beneficial position for individuals with cardiac disease, as the pooling of blood would occur in the upper extremities [4], this is of particular concern in patients with neurological trauma, as swollen or bruised brain or spinal cord tissue could be further damaged [3]. Individuals with neurological trauma should be positioned with their head toward the front (fore) part of the aircraft to pool blood in the lower extremities during takeoff [4].

Fatigue is an individual stress of flight, but is also an end result of all of the other stresses of flight since they all induce fatigue to some degree [3]. In aeromedical transport, flight crews may be subjected to erratic schedules or changes in time zone, which may create fluctuations in their natural circadian rhythm and cause fatigue. Fatigue can lead to an overall degradation of work performance in medical providers due to delayed response time, judgment errors, and channeled attention [3]. Fatigue, compounded with the unavailability of resources typically available during ground care and the additional stresses of flight, can severely impact the ability to provide a high level of patient care during aeromedical transport. Fatigue and sleep irregularities also have been linked to health issues such as stomach problems, menstrual irregularities, colds, flu, weight gain, and cardiovascular problems [5], which could negatively affect injured and immunocompromised patients.

While there has been research conducted on altitude and flight physiology as previously discussed, there is a lack of information available on how the physiological stresses encountered at altitude directly impact the gamut of injuries and diseases seen by medical providers during aeromedical transport. The goal of this study was to review the current state of literature investigating the stresses of flight influencing injury and disease management during aeromedical transport. The specific aims of the study were as follows:

1. Conduct an integrated review of scientifically valid existing studies investigating the influences of the stresses of flight on injury and disease management during aeromedical transport.
2. Identify gaps in the current state of literature on the impact of the stresses of flight on injury and disease management during aeromedical transport.
    a. Which stresses of flight have not been researched with respect to impact on injury and/or disease management?
    b. Which injury conditions are most affected by stresses of flight based on current literature?
    c. Which diseases are most affected by stresses of flight based on current literature?
    d. What are the most common injuries and disease conditions of AE patients?
    e. Of the most common injuries and diseases for AE patients, which conditions have limited knowledge regarding the impact of the stresses of flight?

3.0 METHODS

A literature search of the PubMed, Cumulative Index to Nursing and Allied Health Literature (CINAHL), Web of Science, and Defense Technical Information Center (DTIC) databases was conducted to identify scientifically relevant research studies that investigate the impact of the stresses of flight on injury and disease management during aeromedical transport, specifically during AE. Search terms included the following: aeromedical evacuation, flight nursing, stresses of flight, hypoxia, oxygen changes, barometric pressure, pressure changes, thermal, gravitational forces, noise, humidity, dehydration, vibration, fatigue, patient care, air transit, air ambulance, physiological stress, psychological stress, as well as combinations of these terms. Inclusion criteria for article selection were English language, 2003-2014 publication period, and representative articles including retrospective reviews, prospective reviews, animal laboratory studies, human laboratory studies, and human field studies.

Relevant articles were considered for inclusion based on Whittemore and Knafl’s five-step process for integrative reviews. The steps in the process are 1) problem identification, 2) literature search, 3) data evaluation, 4) data analysis, and 5) presentation of findings [6]. Using an integrative review method allows for a more comprehensive understanding of complex healthcare topics of concern to medical providers and has the potential to drive future research, evidence-based practices, and policy initiatives [6]. The two authors used the aforementioned search terms to pull potentially applicable articles from the four databases utilizing the search function within the EndNote X7© reference manager. EndNote X7© was used to house all of the articles throughout this research effort. Once the articles from the four databases were pulled, the authors conducted a title and abstract review. Based on the abstract review, applicable articles were reviewed by the authors and an additional five researchers who all had extensive experience with conducting research for the unique en route care (ERC) domain.

The full text review involved grading each article on its strength of evidence, which was evaluated using a modified version of the strength of reviewed evidence described by Stetler et al. [7] (Table 1). Each article was graded on its quality of evidence, which was evaluated using the Johns Hopkins nursing quality of evidence appraisal tool [8] (Table 2). The grading sheet for the full text review was created by the author team using Microsoft Excel™ and had the following fields: article title, author, source, date, volume, number, injury condition identified, disease condition identified, stress of flight identified, type of study, sample population and size, strength of evidence, applicability to aeromedical transport on fixed-wing aircraft, methodology, limitations, intervention given, results, similarities and differences between aeromedical transport and situation in the study, reviewer name, quality of evidence, and recommendations for future studies. The articles related to traumatic brain injury (TBI) were separately reviewed by one member of the study team as part of a parallel research effort to investigate the impact of stresses of flight on the management of TBI.

Once the full text reviews were completed, the information from the grading sheets was consolidated into a summary table developed by the authors using Microsoft Excel. The summary table contained the following fields: article title, author, source, date, volume, number, type of study, stress of flight, injury conditions, disease conditions, sample population and size, aim of the study, methodology, results, applicability to aeromedical transport, strength of evidence, quality of evidence, evaluator name, and future considerations for research. The author team then reviewed the summary table and checked for errors in data entry. Using the summary table, the author team met to discuss the potential knowledge gaps evident from the review of the literature.

Table 1. Strength of Evidence [7]

Evidence Rating	Evaluation Criteria
Level I	Evidence from a systematic review or meta-analysis of all relevant RCTs or evidence-based clinical practice guidelines based on systematic reviews of RCTs
Level II	Evidence obtained from at least one well-designed RCT
Level III	Evidence obtained from well-designed controlled trials without randomization
Level IV	Evidence from well-designed case-control and cohort studies
Level V	Evidence from systematic reviews of descriptive and qualitative studies
Level VI	Evidence from a single descriptive or qualitative study
Level VII	Evidence from the opinion of authorities and/or reports of expert committees

RCT = randomized controlled trial.

Table 2. Quality of Evidence [8]

Grade	Nomenclature	Definition for Research Evidence	For Non-Research Evidence
A	High	Consistent results, sufficient sample size, adequate control, and definitive conclusions; consistent recommendations based on extensive literature review that includes thoughtful reference to scientific evidence	Expertise is clearly evident
B	Good	Reasonably consistent results, sufficient sample size, some control, and fairly definitive conclusions; reasonably consistent recommendations based on fairly comprehensive literature review that includes some reference to scientific evidence	Expertise appears to be credible
C	Low/Major Flaw	Little evidence with inconsistent results, insufficient sample size, conclusions cannot be drawn	Expertise is not discernible or is dubious

4.0 RESULTS

4.1 Problem Identification

Findings from ERC research studies have identified a lack of research studies on the influence of the stresses of flight on injury and disease management for transported patients. The goal of this study was to review the current state of literature investigating the stresses of flight influencing injury and disease management during aeromedical transport, specifically patients transported by AE crews, and identify any gaps in literature. Understanding knowledge gaps will highlight areas to focus research to provide solutions for AE providers and transported patients.

4.2 Literature Search

Using focused key terms associated with the stresses of flight and the AE domain, 15,756 articles were pulled from the four databases, and after eliminating duplicates within and across each database, 8615 article titles were reviewed by the two authors. After the title review, 7527 articles were removed as they did not apply to the AE domain. In total, 1088 abstracts were then reviewed by the two authors, and 928 were excluded. Reasons for exclusion were as follows: general overview articles, articles did not apply to injury and/or disease management, abstracts were related to high altitude, abstracts had no abstract available for review, and one abstract was a duplicate abstract. Then 160 full text articles were reviewed by the multidisciplinary study team, with 11 articles relating to TBI and 149 relating to other injury and/or disease conditions. Out of the 160 full text articles, 63 were excluded from the final analysis because 18 articles were not related to specific stresses of flight and 45 were not related to specific injury and/or disease management within the aeromedical transport domain. In total, 97 articles were found to be applicable to the research study based on the analysis of the article summary table (Figure 1).

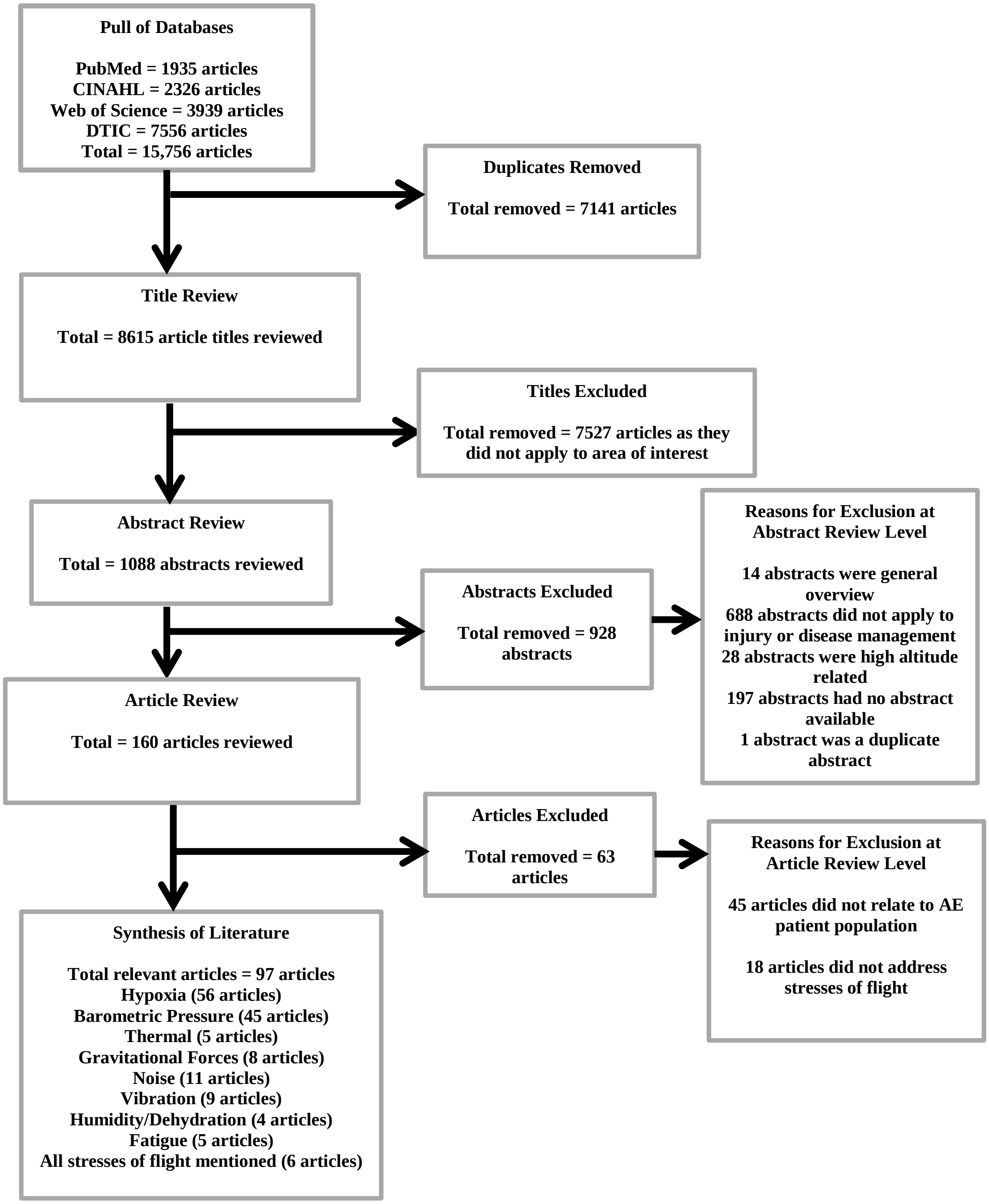

Figure 1. Selection of articles for review.

4.3 Data Evaluation

Prior to data analysis, the author team reviewed the article summary table to determine the accuracy of data entry by the study team. The team identified certain keywords that were often misspelled, such as “hypobaria” being input as “hypbaria.” The team also identified that “acceleration” was often used to characterize “G-forces.” Some members of the study team also used “hypobaria” to describe barometric pressure changes and “dehydration” and “humidity” were used interchangeably. The author team recoded the aforementioned words to coincide with their associated stress of flight prior to analyzing the full text articles.

Ninety-seven articles were identified as applicable for inclusion. Final articles were graded on strength of evidence (Levels I-VII) and quality of evidence (A-C). The final articles were a wide variety of quantitative and qualitative studies including animal laboratory, case reports, device evaluations, human field, human laboratory, and literature reviews. No articles were excluded based solely on their grade of strength or quality of evidence.

4.4 Data Analysis

To analyze the final 97 articles, the articles were categorized by stress of flight: hypoxia, barometric pressure changes, thermal changes, fatigue, dehydration/humidity, G-force, vibration, and noise. Some of the articles discussed multiple stresses of flight, with 56 articles mentioning hypoxia, 45 articles mentioning barometric pressure, 11 articles mentioning noise, 9 articles mentioning vibration, 8 articles mentioning G-forces, 5 articles mentioning thermal changes, 5 articles mentioning fatigue, 4 articles mentioning humidity/dehydration, and 6 articles mentioning all 8 stresses of flight.

4.5 Presentation of Findings

Once the articles were sorted by stress of flight, they were then divided into subgroups to look at articles that only had one stress of flight listed. Tables 3-11 provide summaries of the literature based on individual stresses of flight and then articles that had a combination of stresses listed. Reviewers provided expert opinion on results and future implications for ERC in the “Future Implications” column. The majority of articles, n=23 (24.74%), were rated with a strength of evidence as Level V, which is evidence from systematic reviews of descriptive and qualitative studies. The majority of articles, n=56 (57.73%), were rated with a quality of evidence as A, which means there were consistent results, sufficient sample size, adequate control, and definitive conclusions and consistent recommendations based on extensive literature review that includes thoughtful reference to scientific evidence (Table 12).

Table 3. Summary of Relevant Articles for Hypoxia

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications
Kleinsaser et al.	2004	Human Field	Respiratory issues	N/A	IV	B	This experiment was carried out at moderate altitude of 9383 ft, which is slightly higher than typically seen in AE. Recommend duplicating study for 8000 ft.
Maimir-Jané et al.	2004	Descriptive Modeling	Respiratory issues	N/A	VI	B	Experiment had yet to be completed. Recommend future studies to investigate the effectiveness of the proposed formula in the study in a simulated environment utilizing an animal model.
Birot et al.	2004	Animal Lab	Insult due to hypoxia	N/A	II	A	Results suggest that under experimental conditions, translational or post-translational events limit the physiological significance of the increased levels of vascular endothelial growth factor 188 mRNA shown in right ventricles.
Dillard et al.	2005	Literature Review	N/A	Chronic obstructive pulmonary disease (COPD)	VII	B	Discusses partial pressure of oxygen (PaO_2) requirements for patients with chronic respiratory issues.
Snyder et al.	2006	Human Lab	High altitude pulmonary edema	N/A	IV	A	Found 17 h of hypoxic exposure led to decreases in lung fluid in healthy adults, suggesting future research for the AE/CCAT simulated environment. May suggest further research for hypoxia and pulmonary edema.
Magalhaes et al.	2007	Animal Lab	Muscle issues associated with hypoxia	N/A	II	A	Investigate the impact of less severe hypobaric hypoxic conditions equivalent to those that most humans face on mitochondrial function and vitamin E to include whole muscle tissue or blood.
Mohr	2008	Literature Review	N/A	Pulmonary disease	VII	B	Future work is needed to validate 50-yd walk test or 6-min walk test to determine the actual clinical outcomes based on these preflight evaluations. Specific air travel considerations should be made in specific pulmonary disorders such as COPD, asthma, restrictive and interstitial lung disease, pulmonary hypertension, and pneumothorax. Supplemental oxygen delivery in-flight should be examined with future work needed on controlling in-flight oxygen delivery.
Resnick et al.	2008	Human Field	Ex-preterm neonates	Neonatal lung disease	III	B	Additional critical care patient diseases and injuries need to be examined for their changes in-flight based on the Hypoxia Challenge Test recommendations.

Table 3. Summary of Relevant Articles for Hypoxia (continued)

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications
Barnes et al.	2008	Human Field	Polytrauma	N/A	IV	C	Study investigated use of computer interface with pulse oximeter and ventilator data in patients evacuated from Iraq to Germany. Found incidences of hypoxia during transport. Found a computer interface is feasible in the austere aeromedical environment. Implications to military operations and civilian homeland defense include understanding casualty oxygen requirements for resource planning in support of AE. Portable oxygen generation systems may be able to provide adequate oxygen flow for transport, reducing the need for compressed gas. Future studies of oxygen conservation systems including closed loop control of fraction of inspired oxygen are warranted.
Hewett et al.	2009	Human Lab	Cognitive impairment due to hypoxia	N/A	II	A	Study methodology may have been insensitive. Recommend conducting study using hypobaric hypoxia and a more sensitive means of cognition evaluation.
Kelly et al.	2009	Human Lab	N/A	COPD	III	A	Suggests impaired diffusion will desaturate most at altitude, but gain most with oxygen supplement. Testing this in ventilated patients may be a fruitful area of research.
Dorlac et al.	2009	Retrospective Records Review	Severe pulmonary impairment, acute respiratory distress syndrome (ARDS)	Pneumonia	VII	A	Limited conclusions, as there was no comparison group and sample size was small. Acute Lung Rescue Team is required for approximately 1% of CCAT patients.
Goodman et al.	2010	Literature Review/Expe rt Opinion	TBI	N/A	V	A	Exposure to hypobaric environment in AE may impose additional physiologic risk and a second hit inflammatory stimulus.
Temme et al.	2010	Human Lab	Cognitive impairment due to hypoxia	N/A	IV	A	Found precision in which pilots performed tasks was degraded due to hypoxia, which indicates further research for individuals performing tasks under hypoxic stress.
Hospenth et al.	2011	Literature Review	N/A	Infections	V	A	Potential for oxygen prophylaxis of infectious complications. Need studies to confirm the utility of prophylactic oxygen to prevent or moderate post-flight infection complications.
Goodman et al.	2011	Animal Lab	TBI	N/A	IV	B	Found after TBI alone, levels of serum interleukin (IL) 6 and neuron-specific enolase increased 6 h after injury. Need to transition animal lab to human studies.
Barillo et al.	2011	Retrospective Records Review	ARDS	N/A	VI	B	Found use of high frequency percussive ventilation is feasible and effective in AE.

Table 3. Summary of Relevant Articles for Hypoxia (continued)

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications
Allan et al.	2011	Literature Review	Severe lung injury, acute lung injury, ARDS	N/A	V	A	Found extracorporeal membrane oxygenation is neither the panacea for early ARDS nor the norm for even ARDS-experienced institutions, but it represents an advanced therapy for use in patients with severe, refractory ARDS with life-threatening gas exchange abnormalities.
Bauer	2012	Expert Opinion	TBI	N/A	VII	B	The authors described the use of their training program for endotracheal intubation in patients with trauma and TBI. Authors found their training program improved endotracheal intubation success rates, but overall success was less than the 90% benchmark. They switched from using direct to video laryngoscopy and reported that their rates were approaching the 90% benchmark.
Makley et al.	2012	Animal Lab	Hemorrhagic shock	N/A	II	A	Recommend future studies to investigate simulated AE transport effects of most commonly encountered resuscitated polytrauma patients.
Vanden et al.	2013	Human Field	N/A	Flight phobia, agoraphobia, claustrophobia, panic disorder	III	A	Found no direct link between hypoxia and increased fear of flying. Found 67% of controls had a blood oxygen saturation of 94% or lower at cruising altitude; 63% of flight phobic individuals had a blood oxygen saturation of 94% or lower at cruising altitude, which indicates a clinical level of hypoxia.
Walrath et al.	2013	Case Study of 1 Navy F/A-18C Pilot	Barotrauma, decompression sickness, arterial gas embolism	N/A	VI	A	Recommend conservative approach to future cases, including supplemental oxygen therapy, close observation, and consideration of hyperbaric oxygen therapy.
Self et al.	2013	Human Lab	Cognitive impairment due to hypoxia	N/A	IV	A	Found the level of hypoxic stress seen in subjects during 5 min exposure to 25,000 ft impacted brain physiology. Results argue for a possible role of the protein S100b as a reporter of brain hypoxia events but does not indicate severity of injury. Future work is needed to investigate the role of specific proteins as reporter of injury as well as looking to possible predictors for injuries in healthy and injured/ill patients during lower altitude exposures of hypoxia.
Hovis et al.	2013	Human Field	N/A	Color vision issues	II	A	Recommend repeating study in mesopic light and/or at 8000 ft.

Table 3. Summary of Relevant Articles for Hypoxia (concluded)

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications
McCarron et al.	2014	Animal Lab	Respiratory issues, ARDS, hemorrhagic shock	N/A	II	A	Experiment had yet to be completed. Interesting study to investigate the effects of AE on neurophysiology and lung function in swine models of TBI with and without hemorrhagic shock and/or ARDS (polytrauma). Recommend following up to see what has been done with study.
McGill et al.	2011	Animal Lab	Compartment syndrome	N/A	III	A	This study looked at the effect of altitude and hypoxia on uninjured myofascial compartments in porcine. Found increase in compartment pressure due to altitude change. The clinical relevance of the study's average 2.7 mmHg maximum deviation from opening pressure needs further investigation.

Table 4. Summary of Relevant Articles for Barometric Pressure Changes

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications
Andersson et al.	2003	Descriptive Modeling	Trauma, intracranial hemorrhage	N/A	VI	A	Created a model for the hydrodynamics of the intracranial system incorporating intracranial air and performed simulations of variations in intracranial pressure during air transport. This study supports a preserved sea-level pressure during air ambulance transportation. Further research is needed to confirm results in animals and humans.
Henning et al.	2004	Human Field	N/A	Respiratory failure	III	A	Found potential for pressure transducer incorporation into the endotracheal tube (ETT) cuff for ERC.
Hsieh et al.	2005	Literature Review	N/A	Venous thrombosis	I	A	Found routine patients might well benefit from graduated compression stockings for long-haul flights. Reviewers recommend future retrospective study to see if deep venous thrombosis is an issue in these populations first.
Helling et al.	2005	Case Report with Literature Review	Fracture of frontal sinus	Pneumocephalus	V	B	Evaluation of sinus fracture complications for frequency and severity. Potential clinical practice guideline for decompressive sinus catheter use.

Table 4. Summary of Relevant Articles for Barometric Pressure Changes (continued)

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications
Hinninghofer et al.	2006	Human Lab	N/A	Stomach emptying	III	A	This setting is pertinent to the routine patient, but not the priority or urgent (critical) patient. Reviewers recommended incorporating this guidance without further study.
Zadik et al.	2007	Retrospective Review of Case Studies	Barodontalgia, barosinusitis	N/A	VI	B	Found 8.2% of the participating military aircrew reported barodontalgia. Stated that all military aircrew from all flight platforms have the potential to experience barodontalgia. Flight surgeons and dentists, including those involved in AE missions, should be aware of this phenomenon and use preventive measures among aircrew members to reduce the incidence and severity.
Donovan et al.	2008	Human Field	Pneumocephaly	N/A	V	A	Recommended creating clinical practice guidelines when determining transport times and requirements.
Zadik	2009	Literature Review	Barodontalgia, aerodontalgia, facial barotrauma, dental barotrauma	N/A	V	B	Found there is limited research on barodontalgia and further research is needed.
Zadik	2009	Literature Review	Barodontalgia, barotrauma	N/A	V	A	Recommended that divers and aircrew medical examiners should recommend their aviator and diver patients be periodically examined by a dental practitioner who is familiar with the subject.
Zadik	2010	Literature Review	Barodontalgia, tooth squeeze, aerodontalgia	N/A	V	C	Results found that future research is needed for researchers, educators, and clinicians to understand barodontalgia and provide preventive measures for individuals.
Kimoto et al.	2011	Human	N/A	Migraine headache	III	A	Guidance is not applicable to AE, especially aircrew, as migraines are usually disqualifying. Guidance may be applicable to transported patients.
Konishi et al.	2012	Retrospective Records Review	Middle ear surgery, tympanoplasty, and graft healing rates	N/A	IV	A	This article maintains that early commercial air travel after tympanoplasty at cabin pressure maintained at a maximum altitude of 2500 m has no influence on graft healing. This information is important for AE transport of patients post tympanoplasty in issues of transport delays and altitude restrictions.

Table 4. Summary of Relevant Articles for Barometric Pressure Changes (concluded)

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications
Abrames et al.	2012	Case Studies	Penetrating eye trauma	N/A	VI	A	Orbital trauma management in a combat hospital offers challenges; recommends closure of globe and antibiotic administration. Definitive care may not occur until patient is aeromedically evacuated out of the theater. If there is air in the globe, consideration must be given to cabin altitude restriction.
Schneider et al.	2013	Animal Lab	Musculoskeletal injury	N/A	II	A	This animal model may provide foundational information for future testing in human skeletal muscle, both to determine the effects of hypobaria on normal skeletal muscle and to investigate the effects of hypobaria on injured muscle.
Koo et al.	2013	Animal Lab	Arthritis induction to right limb	N/A	IV	A	Pain management considerations for patients with chronic inflammatory pain conditions during AE transport. Additional larger scale study needed to confirm hypothesis that high atmospheric pressure improves painful conditions and pressure effects by quantitative and qualitative analysis.
Brendt et al.	2013	Retrospective Chart Review	Injuries associated with ETT cuff pressures	N/A	V	A	This study found the high prevalence of excessive cuff pressures during air medical retrieval can be avoided by the use of cuff pressure manometers.

Table 5. Summary of Relevant Articles for Noise

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications
Tomei et al.	2005	Human Field	N/A	Hypertension	IV	B	Increased sound levels demonstrated high risk of hypertension in male pilots. While this information is not generalizable to the female population of aircrew or patients, it does indicate that individuals at a higher risk of hypertension before flight may experience an increased risk due to continued exposure to noise.
Houtsma et al.	2006	Equipment Evaluation	Respiratory and cardiac issues	N/A	III	C	Solitary subject tested performance of ultrasound stethoscope at 90 dB and 100 dB in comparison to standard and electronic stethoscopes. Feasibility confirmed, but more extensive study of the technology is required.
Brady et al.	2010	Animal Lab	ETT misplacement, progressive pneumothorax, hemothorax, tension pneumothorax	N/A	III	B	Study had not been completed. Eight swine were to be studied and evaluated with noise-immune stethoscope (NIS) and ultra-wideband medical radar. Recommend follow-up on outcome of study. En Route Care Research Division researchers have already conducted study using the NIS and found it not to be feasible for AE/CCAT. Since this study was published, the NIS is no longer being contracted by the Army and a new device is being evaluated for use in AE/CCAT.
Sittig et al.	2011	Equipment Evaluation	Respiratory issues in infants	N/A	VI	A	Need to examine sound levels on frequently used aircraft for AE/CCAT at both the incubator and the cabin crew level. Preventive measures should be examined and taken within the AE/CCAT environment to decrease the amount of noise that infants as well as other patients are experiencing during transport, as noise exposure has been linked to detrimental physiologic effects in premature infants, including apnea, bradycardia, and sudden variations in heart rate, blood pressure, respiratory rate, and oxygen saturation. Reviewers recommended that this article be used as a resource for future efforts.
Tourtier et al.	2014	Human Field	Crackles, wheezes, right lung silence, left lung silence, systolic murmur, diastolic murmur, Austin-Flint murmur	N/A	II	B	This study found the electronic Littman stethoscope may provide some additional capabilities to listen to heart and lung sounds on the C-135. Noise profiles are different between aircraft, but it does demonstrate some benefit for AE providers with future research needed.

Table 6. Summary of Relevant Articles for Vibration

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications
Kang et al.	2011	Literature review and expert opinion	spinal column injury, spinal cord injury	N/A	VII	B	Authors did not recommend spinal immobilization for patients with isolated penetrating trauma. Recommended selective prehospital spine immobilization, which involves spinal immobilization with backboard, semi-rigid cervical collar, lateral supports, and straps or tape when there is suspicion of spinal column or spinal cord injury in the combat casualty and when resources permit. Needs of patient need to be considered prior to flight with spinal immobilization techniques.

Table 7. Summary of Relevant Articles for Gravitational Forces

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications
Brown et al.	2004	Human Lab	N/A	Changes in cerebral autoregulation	III	B	The changes to cerebral blood flow described in the study may apply to takeoff and landing in the AE setting; however, there are fewer altitude fluctuations in AE that correspond to the constant state in the study. However, changes in cerebral autoregulation are critical enough that the possible application of the results to AE must be considered.
Mclean et al.	2011	Case Study	Bi-ventricular device needed	N/A	VII	B	Patients dependent on ventricular assist devices with feet facing aft consider at least, in awake patients, contraction of their calf muscle on takeoff, or in sedated patients, the use of sequential pneumatic compression stockings or even a leg raise during this period of the transport. Ensure patients are not hypovolemic prior to transport and monitor closely for signs of hypovolemia created by the low-humidity environment in a pressurized aircraft. Patient heat loss from the extracorporeal ventricular assist device circuits was not an issue due to simply covering the patient with blankets.
Li et al.	2011	Descriptive Modeling	TBI	N/A	VI	A	The decrease of interstitial fluid pressure inside the edema zone by changing patient position from supine to prone has the potential to alleviate the damage to central nervous system nerves. These observations indicate that considering the patient's head position during intensive care and at rehabilitation might be of importance to the treatment of edematous regions in TBI patients. This is of importance to transported patients across ERC, as patients with TBI should be orientated in certain ways to ensure there are not additional negative patient outcomes.
Blakeman	2013	Human Field	TBI	N/A	VI	B	Some patients in the in-hospital portion of the study and in the AE portion experienced intracranial pressure (ICP) elevations, while some did not. All but one patient experienced ICP fluctuation of ±50% of baseline ICP.

Table 8. Summary of Relevant Articles for Fatigue

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications
Waterhouse et al.	2004	Literature Review	Immobility	N/A	V	B	Provides recommendations for mitigating travel fatigue associated with long-distance air travel. Recommendations include adjusting one's internal body clock through exposure to light and ingestion of melatonin, sufficient planning, stretching and isometric exercises in one's seat, increasing fluid intake, and sleeping only during the night on long flights.
Karavidas et al.	2010	Human Lab	Respiratory Issues	N/A	III	C	Increasing workloads increased respiratory rate and minute ventilation. Lowest evaluation scores were associated with end-tidal partial pressure of carbon dioxide < 32 mmHg, while highest evaluation scores were associated with lower respiratory rates and minute ventilation. Reviewers recommended the study be repeated under more realistic environmental conditions with better power.

Table 9. Summary of Relevant Articles for Thermal Changes

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications
Schmelz et al.	2007	Animal Lab	Hypothermia, TBI, hypovolemic shock	N/A	III	B	Future research is needed to look at other products to prevent hypothermia and to look at products in human field studies with other injury and disease states seen throughout AE.
Carlson et al.	2012	Case Study	Blunt trauma with commotio cordis and pulmonary contusion	N/A	VI	A	Found once there is return of spontaneous circulation in the comatose patient after ventricular fibrillation cardiac arrest, typically from ischemic heart disease, mild hypothermia for 24 h has been shown in several RCTs and subsequent cohort studies to improve neurologic outcomes. The cerebral protection provided by hypothermia is thought to be multifactorial in nature. May be something to consider for future patients.

Table 10. Summary of Relevant Articles for Humidity/Dehydration

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications
Lindseth et al.	2013	Human Lab	Cognitive impairment	N/A	IV	A	Based on the results of this study and related cited studies, flight preparation should include a plan to maintain adequate fluid intake before and throughout flights to maintain optimal flight performance. Recommend to focus future fluid intake research on female participants, older generation of pilots, effects of pilots' environmental conditions on the onset of dehydration, and monitoring of caffeine/nicotine usage.

Table 11. Summary of Relevant Articles for Combination or All Stresses

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications	Stress
Schmelz et al.	2003	Literature Review and Expert Opinion	Polytrauma	N/A	VII	A	Recommends future research: Nurses position the patient in the center of the cargo compartment, away from the bulkhead, toward the front of the aircraft, the warmest location during flight. While en route the patient needs to be on an aerovac mattress, repositioned frequently, and have his/her heels elevated at all times. Additional padding may be needed. Hyperoxygenation-hyperinflation is effective in preventing suctioned-induced hypoxemia.	All
Siedenburg et al.	2005	Literature Review and Expert Opinion	N/A	Infections	V	B	This study was a supplemental issue looking at tropical medicine and issues concerning individuals traveling to certain tropical climates. May be beneficial for AE/CCAT crews traveling to tropical climates and issues to look out for especially as we move toward the A2AD [anti-access area denial] environment where patients may not be able to receive immediate care.	All
Pritts	2013	Unknown	Hemorrhagic shock, inflammation, TBI	N/A	IV	C	Reviewers recommended additional studies as specific methodology was not discussed in this paper.	All
Bunch et al.	2013	Literature Review	Pneumothorax	N/A	V	A	Stated there needs to be more scientific research to reach an evidence-based conclusion on pneumothoraxes and flying.	All
Blakeman et al.	2013	Literature Review	Mechanically ventilated patients	N/A	V	B	Recommended using devices with longer battery life, use capnography for patients with need of partial pressure of carbon dioxide control. Need two caregivers with specialized transport – use of checklist monitoring.	All
Palmer	N/A	Literature Review	Polytrauma	N/A	V	B	Study aimed to look at state of literature on diagnostic and treatment devices for en route critical care of patients within theater. Recommend following up with study findings.	All
Iqbal et al.	2003	Literature Review	Venous thrombosis	N/A	V	A	Reviewers recommend future study to examine prospectively the oxygen saturation of routine patients during flight, focusing on sleep and associated deep vein thrombosis (DVT) risk.	Barometric pressure, humidity, hypoxia
Muhm et al.	2007	Human Lab	N/A	Acute mountain sickness	II	A	Future work is needed to study the effects of high altitudes on critically ill patients like those transported during AE. Additionally, other biomarkers related to pain/discomfort need to be examined to gain quantitative insight into the effects of a high-altitude environment.	Barometric pressure, hypoxia

Table 11. Summary of Relevant Articles for Combination or All Stresses (continued)

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications	Stress
Seth et al.	2009	Descriptive Interviews	TBI, pneumocephalus	N/A	VI	B	Only 3 airline companies offered specific, relevant advice. The best was Virgin Atlantic, which stated they needed guidance from a doctor to include need for hemoglobin levels, doctor's letter, and travel only after 10 d post-op. Found limited research for when to fly after a craniotomy.	Barometric pressure, hypoxia
Petrassi et al.	2011	Literature Review	Acute hypoxic hypoxia	N/A	V	A	Found several areas need to be investigated further: 1) augment validated neuropsychological metrics with actual flight task metrics under moderate hypoxic conditions, 2) determine efficacy of potential neuropsychological performance-enhancing agents for both acute and chronic hypoxia, and 3) investigate a mixed gas formulation with varying concentrations of carbon dioxide to investigate the contribution of hypocapnic effects on hypoxic performance at moderate altitudes. May also want to look at the possibility of suitable universal regulations regarding supplemental oxygen use in-flight. As current hypoxia recognition training is done at a simulated altitude of 25,000 ft, it should also be augmented with a method that can produce subtle hypoxic impairment to represent true mission conditions.	Barometric pressure, hypoxia
Kalns et al.	2011	Animal Lab	Extremity compartment syndrome	N/A	III	B	All subjects developed extremity compartment syndrome with 6 h compressive injury, 30% with 5 h compressive injury. Found no difference in extremity compartment development or microscopic changes between normobaric and hypoobaric animals. Hypobaric animals did display an increase in inflammatory markers (IL-6, IL-1, tumor necrosis factor-alpha, insulin-like growth factor-binding protein 4, bone morphogenetic protein 4, nitric oxide-tyrosine). Would like further experiments at the 8000- to 10,000-ft level as this study looked at 7000 ft.	Barometric pressure, hypoxia
Pontremolesi et al.	2012	Literature Review	Hypobaric hypoxia	N/A	V	A	Found by the end of the hypobaric chamber experience, the hormone concentrations returned to prestress values as expected for a physiological acute stress response that is typically transient in nature.	Barometric pressure, hypoxia

Table 11. Summary of Relevant Articles for Combination or All Stresses (continued)

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications	Stress
Britton et al.	2014	Device Evaluation	Pneumothorax, ETT cuff injuries	Ventilator-associated pneumonia (VAP)	VI	A	This study found that there was a reduction in cuff pressures during and following descent. They found that pressures were lower than at baseline. Study suggests that the high pressures at altitude stretch the cuff, resulting in lower pressures after descent despite no change in the volume of air. Study recommended that closed loop control of cuff pressure may represent an answer to management at altitude, but further testing is needed.	Barometric pressure, hypoxia
Britton et al.	2014	Device Evaluation	Pneumothorax, ETT cuff injuries	VAP	VI	A	Recommended that new techniques need to be developed for ETT cuff management.	Barometric pressure, hypoxia
Blakeman et al.	2014	Device Evaluation	Mechanical ventilation	N/A	VI	B	Found 731™ ventilator compensated for changes in altitude delivered tidal volume within 10% at the adult settings at all altitudes. Recommended 731 ventilator for AE.	Barometric pressure, hypoxia
Jenkins	2004	Literature Review and Expert Opinion	Infections, stroke, myocardial infarction (MI)	Chronic diseases	VII	B	Focus is commercial air travel by passengers with chronic medical issues. Offers guidance on timing of travel following acute medical events (e.g., MI, stroke).	Barometric pressure, vibration, hypoxia, gravitational forces
Intas et al.	2013	Literature Review	Compartment syndrome, TBI	N/A	V	B	Brief overview of the various physiological risk factors associated with AE. Recommended the staff that accompanies a patient must be experienced and properly trained. Everyone must know cardiopulmonary resuscitation and be prepared to intervene if necessary. Found each hospital follows its own policy on the transport of seriously ill patients and what and how many people need to accompany them.	Humidity, hypoxia, vibration, thermal, barometric pressure, noise, gravitational forces
Schmelz	2002	Animal Lab	Lung injury; hypovolemic shock	N/A	II	A	Found some form of hyperoxygenation is needed prior to endotracheal suctioning to prevent suction-induced hypoxemia. The results demonstrated the effectiveness of preventive hyperoxygenation procedures during high altitude. Future studies could look at the hemodynamic effects of hyperinflation in more severe levels of shock. Future research is needed to determine the factors that contribute to a decrease in oxygenation in closed suction technique.	Hypoxia, barometric pressure

Table 11. Summary of Relevant Articles for Combination or All Stresses (continued)

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications	Stress
Mortazavi et al.	2003	Literature Review	N/A	COPD; pulmonary and cardiac disorders	VII	B	Altitude-related hypoxia can have significant implications in patients with cardiorespiratory diseases. It is recommended to maintain the inflight PaO_2 above 50-55 mmHg at all times. If a drop of PaO_2 below these levels is anticipated, in-flight oxygen should be supplemented. Sea-level oxygen saturation is a good initial screening test. Additional investigations with predictive equations and/or hypoxia challenge testing can help decide on the need for in-flight oxygen. Cardiac patients are at risk of ischemia and arrhythmia due to hypoxia and its resultant activation of the sympathetic system. Future studies looking at patients with diverse cardiorespiratory diseases as well as studies done at altitude would help validate current recommendations.	Hypoxia, barometric pressure
Essebag et al.	2003	Retrospective Records Review	N/A	Cardiac patients	V	A	Long-distance transport of cardiac patients via fixed-wing aircraft is safe 2-3 wk after MI. Otherwise, transferring providers must weigh the risks of elective transport against the benefits. Recommend use of prospective studies to further identify risk factors associated with long-distance transport following MI.	Hypoxia, barometric pressure
Hernandez et al.	2004	Animal Field	Mechanical ventilator	N/A	III	C	General increase in tidal volume with decreased environmental pressure. Limited results. Recommend follow-up with authors for additional information.	Hypoxia, barometric pressure
Lopez-Ramos et al.	2005	Animal Lab	Middle cerebral artery occlusion	N/A	II	A	Acute exposure to either hypobaria or hypoxia induces effects on nitric oxide levels similar to or greater than those caused by acute hypobaric hypoxia.	Hypoxia, barometric pressure
Seccombe et al.	2006	Literature Review	N/A	COPD, cystic fibrosis, bronchopulmonary dysplasia	V	B	Provided recommendations for future research looking at adverse events associated with the use of supplemental oxygen. Discusses the current recommendations from the American, Canadian, and British Thoracic Societies for PaO_2 levels during flight. AE/CCAT environment needs to look at adverse events associated with not using supplemental oxygen/ incidence of hypoxia during flight even in healthy patients.	Hypoxia, barometric pressure

Table 11. Summary of Relevant Articles for Combination or All Stresses (continued)

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications	Stress
Rodriquez et al.	2009	Device Evaluation	Mechanical ventilation, ARDS	N/A	III	A	Found the performance of the Impact 754™ was superior to the LTV-1000™ during simulated altitudes representing a CCAT mission. Maintaining appropriate tidal volumes is critical for patient safety, and excess tidal volumes can result in hypocarbia, reduced cerebral blood flow, hypokalemia, cardiac arrythmias, and a leftward shift of the oxyhemoglobin dissociation. CCAT teams need to be aware of the ventilator performance and limitations of their devices during flight to ensure effective ventilation during transport and positive patient outcomes.	Hypoxia, barometric pressure
Singh et al.	2009	Retrospective Records Review	Respiratory, cardiovascular, trauma, neurologic, surgical, obstetrics, other	N/A	VI	A	Found in-transit hemodynamic deterioration was most frequent critical event, followed by major resuscitative procedure. Found rate of 1 event per 12.6 h of transport time. Female sex, administration of assisted ventilation before transport, and baseline hemodynamic instability were all significantly and independently associated with critical events. Transport in a fixed-wing aircraft, duration of transport, on-scene calls, and type of crew were also associated with critical events. These factors may garner future interest in specific factors that could be associated with an increase of in-flight critical events.	Hypoxia, barometric pressure
Deviri et al.	2009	Case study	N/A	Chylothorax	VI	B	Case study of one patient with chylothorax transported via commercial fixed-wing airline. Recommend seeing how often this happens in AE/CCAT environment.	Hypoxia, barometric pressure
Dukes	2010	Retrospective Records Review	TBI	N/A	IV	A	Hyperthermia was most common secondary insult occurring. No significant difference in type of insult occurring between aircraft was noted.	Hypoxia, barometric pressure
Schreijer et al.	2010	Human Field	Venous thrombosis	Coagulation activation	IV	A	Results did not support the hypothesis that stress, infection, or air pollution is involved in the prothrombotic state, which can occur during long-haul air travel. Suggests hypoxia coupled with systemic inflammation, platelet activation, and enhanced coagulation after air travel may be involved in prothrombotic state. Suggests need for future research investigating hypoxia and measuring levels of oxygen saturation to correlate levels of coagulation activation.	hypoxia, barometric pressure

Table 11. Summary of Relevant Articles for Combination or All Stresses (continued)

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications	Stress
Wilder-Smith et al.	2012	Human Field	N/A	Respiratory infections, common cold, immune impairment	IV	A	The actual AE environment, especially in those who are already immunocompromised or under additional stress, may see different results than found in this study. Future research is needed to fully understand the role hypobaric hypoxia plays in individuals who are already at an increased risk for immune impairment or under stress.	Hypoxia, barometric pressure
Teson et al.	2013	Human Lab	N/A	Dry eye disease	IV	A	This study demonstrated a 2-h simulated flight with a cabin pressure similar to that seen during AE/CCAT flights increased the symptoms seen in dry eye disease patients. While this study demonstrated that further research is needed, especially for flights greater than 2 h, it did not provide recommendations to decrease symptoms or remedies for patients.	Hypoxia, barometric pressure
Tompkins et al.	2005	Literature Review	DVT	Diabetes, cardiac disease, respiratory disease, pregnancy, hypersensitivity disease	V	B	Reviewers state this article provides a good overview of some of the stresses of flight and hazards associated with air travel. It also discusses preexisting risk factors that could be seen during AE transport. Would be a valuable resource for flyers, as it provides recommendations for how to decrease the risk of an adverse event during flight.	Hypoxia, barometric pressure, fatigue, noise, thermal
Shepherd et al.	2003	Literature Review	DVT	N/A	V	B	Provided recommendations/ preventive measures to discuss with healthcare providers for patients who are flying on long-distance flights. Paper provided background information on the physiological impact of barometric pressure changes and hypoxia, which reviewers state could be a valuable reference.	Hypoxia, barometric pressure, humidity
Hatzfeld et al.	2014	Literature Review	Spinal injury, TBI, perfusion	N/A	V	A	Perfusion monitoring is key future technology mentioned along with tactical critical care delivery.	Hypoxia, barometric pressure, thermal
Van Dyke	2010	Literature Review	Miscarriage	N/A	IV	B	Recommend mitigate risks such as opting out of flight assignments, use of supplemental oxygen, use of helmets/headsets to reduce noise exposure, use of foam abdominal wraps or padded seats to decrease noise/vibration exposure to the fetus, distancing the provider to jet fuel and exhaust exposure, attempts to work day shifts only, and decreasing the weight the individual carries. Future research should investigate the occurrence of negative pregnancy outcomes associated with AE flight crew/providers and their pregnant patients to identify potential variables and provide recommendations for flight.	Hypoxia, barometric pressure, vibration, fatigue, noise

Table 11. Summary of Relevant Articles for Combination or All Stresses (concluded)

Author(s)	Year	Methodology	Injury	Disease	Strength	Quality	Future Implications	Stress
McNeill	2007	Human Lab	Polytrauma	N/A	II	A	Recommend additional study to investigate performance of critical nursing care delivery during aeromedical transport.	Hypoxia, noise, fatigue
Higgins	2010	Case Study and Expert Opinion	Battle injuries	N/A	VII	B	Good resource when thinking about tactical critical care teams and policies, and this is a review of the MEDEVAC [medical evacuation] environment.	Hypoxia, vibration
Nelson et al.	2014	Device Evaluation	Respiratory and cardiac injuries	N/A	III	A	In addition to the noise and vibration data collected for the UH-60, this study also provided a brief overview of current stethoscope technologies and challenges in noise reduction when considering stethoscope technologies for medical evacuation on fixed-wing airframes during AE and CCAT. This study demonstrated that elevated noise levels are manifested in both acoustic and vibrational components and that using a reference accelerometer for active noise control could be beneficial to reduce vibration and noise in the system. Future research is required to optimize placement of the reference sensor within the device.	Noise, vibration
Johannigman	2008	Expert Opinion	Edema	N/A	VII	A	General overview; suggests research into hypobaria effects on edema and autonomous functioning equipment worth present and future attention.	Noise, vibration, barometric pressure
Hinghofer-Szalkay	2011	Literature Review	TBI	N/A	V	A	This concept is particularly pertinent in potential effects of the takeoff and landing on the central nervous system (e.g., TBI and cord injuries) and microvasculature (e.g., extremity, abdomen).	Vibration, gravitational forces
Dubost et al.	2013	Human Field	Explosions and gunshot wounds	N/A	VI	A	Patients were French wounded warriors transported to France. Recommend replicating study with CCAT patients.	Vibration, gravitational forces

Table 12. Strength and Quality of Evidence Ratings

Strength/ Quality	N	%
Strength		
I	1	1.03
II	12	12.37
III	16	16.49
IV	16	16.49
V	24	24.74
VI	16	16.49
VII	12	12.37
Quality		
A	56	57.73
B	35	36.08
C	6	6.19

This research study sought to answer the following questions as part of aim 2:

a. Which stresses of flight have not been researched with respect to impact on injury and/or disease management?
b. Which injury conditions are most affected by stresses of flight based on current literature?
c. Which diseases are most affected by stresses of flight based on current literature?
d. What are the most common injuries and disease conditions of AE patients?
e. Of the most common injuries and diseases for AE patients, which conditions have limited knowledge regarding the impact of the stresses of flight?

The review of literature found the answer to aim 2a to be vibration, humidity/ dehydration, thermal changes, fatigue, G-forces, and noise. This is because there were very few articles found relating to any of the stresses of flight except hypoxia and barometric pressure, with respect to impact on injury and/or disease management in the AE environment. The majority of articles relevant to the impact of the stresses of flight on injury and disease management throughout the AE environment focused solely on hypoxia (n=26, 26.8%), a combination of hypoxia and barometric pressure (n=21, 21.6%), and solely barometric pressure (n=16, 16.5%). A total of 13 articles (13.4%) discussed a combination of the stresses, and 6 articles (6.2%) discussed all of the stresses. Five articles (5.2%) were directly related to noise, four articles (4.1%) were directly related to G-forces, two articles (2.1%) were related to fatigue, two articles (2.1%) were related to thermal changes, one article (1.0%) was related to humidity/dehydration, and one article (1.0%) was related to vibration.

Unfortunately, the limited literature on all of the stresses of flight except hypoxia and barometric pressure made it difficult to definitively answer aims 2b-2e. For aims 2b, 2d, and 2e, TBI is the signature injury of operational conflicts associated with AE and subsequently the stresses of flight. TBI and multiple organ dysfunction syndrome are leading causes of death in warfighters sustaining combat injuries, with mortality rates of TBI as high as 30% [9]. For aims 2c and 2e, the diseases that were associated with the stresses of flight and AE were pulmonary diseases and diseases associated with mechanical ventilation, with management of mechanically ventilated patients remaining a challenge for AE providers [10]. The study team reviewed the occurrence of injuries and diseases to see if there were any trends with the types of diseases associated with specific injuries. The only trend identified was mechanical ventilation and need for ETT cuff and VAP.

Besides TBI, the most common injuries discussed in the literature were barodontalgia, facial barotrauma, respiratory failure or other injuries necessitating mechanical ventilation, injuries associated with ARDS, pneumothorax, and poly/blunt trauma. The diseases that were discussed the most were pulmonary diseases associated with mechanical ventilation such as COPD, pneumonia, and VAP.

5.0 DISCUSSION

The findings highlighted several knowledge gaps related to the impact of the stresses of flight on injury and disease management for AE. The majority of the literature focused on hypoxia and barometric pressure changes, with few articles on the remaining stresses of flight. Findings also highlighted the lack of articles from the healthcare provider's perspective, and no articles were found from the patient's perspective. Future research should be conducted to explore the impact of the stresses of flight on injury and disease management during AE from the point of view of the healthcare provider and the patient.

Based on the lack of literature on humidity/dehydration, fatigue, noise, vibration, G-forces, and thermal changes, there are several recommendations for future research efforts. Some research efforts relating to dehydration/humidity, thermal changes, and fatigue could focus on characterizing negative patient outcomes when patients are dehydrated and/or fatigued to identify if dehydration and/or fatigue affects certain injuries and/or diseases more than others. Other research efforts include investigating the changes in the cognitive performance of dehydrated and/or fatigued healthcare providers. Lindseth and others recommended focusing future research on female and older participants, studying the effects of individuals' environmental conditions on the onset of dehydration, and monitoring caffeine/nicotine usage [11].

There were very few articles related to noise and vibration and their effects on injury and disease management. Sittig et al. recommended future research on characterizing noise profiles on airframes used for infant patients [12]; however, this research should be expanded to characterize both noise and vibration at various locations where patients may be placed during AE transport. The effects of vibration on individuals transported with spinal injuries were examined, and authors did not recommend spinal immobilization for patients with isolated penetrating trauma. The review team recommended selective prehospital spine immobilization when there is suspicion of spinal column or spinal cord injury in the patient and when resources permit. Future research should be conducted to understand the specific needs of patients prior to flight with spinal immobilization techniques [13].

In looking at future research for specific injuries, specifically for facial barotrauma, barodontalgia, and other dental-related injuries, Zadik found 8.2% of the participating military aircrew reported barodontalgia and stated that all military aircrew from all flight platforms have the potential to experience barodontalgia. It was recommended that flight surgeons and dentists involved in AE missions be aware of this phenomenon and use preventive measures among aircrew members to reduce the incidence and severity [14-17]. Walrath looked at the impact of the stresses of flight on barotrauma and related injuries in a Navy pilot and recommended a conservative approach to future cases including supplemental oxygen therapy, close observation, and consideration of hyperbaric oxygen therapy [18].

TBI was another frequently researched injury type. Hatzfeld found that perfusion monitoring is a key future technology for TBI in tactical environments [2], and it was recommended future research efforts relating to TBI should examine the use of perfusion monitoring. In Dukes' study, hyperthermia was the most common secondary insult occurring in isolated TBI patients, and it was recommended that hyperthermia be mitigated to optimize patient outcomes [19]. Goodman found the exposure to hypobaric environment in AE may impose additional physiologic risk and a second hit inflammatory stimulus in TBI patients and recommended future research studies characterize the systemic inflammatory response to TBI [9]. Research examining optimal head positions in patients with head injuries found the decrease of interstitial fluid pressure inside the edema zone by changing patient position from supine to prone has the potential to alleviate the damage to central nervous system nerves. Authors found that considering the patient's head position during intensive care and at rehabilitation might be of importance to the treatment of edematous regions in TBI patients [20], and future research examining optimal head placement during each segment of the en route continuum of care is needed.

6.0 LIMITATIONS

This research study focused on the integrated review of full text articles within four databases—DTIC, CINAHL, PubMed, and Web of Science—published from 2003 to 2014. Since 2014, it is hypothesized that additional articles on the impact of stresses of flight on injury and/or disease management for AE have been published. Future research is needed to review the state of evidence published since 2014 and should expand the number of databases that are explored. Additional research studies could also review abstracts, conference proceedings, or articles found by reviewing reference lists in applicable articles.

7.0 CONCLUSION

In summary, there are several knowledge gaps that remain relating to the impact of the stresses of flight on injury and disease management during aeromedical transport. The majority of literature focused on hypoxia and barometric pressure changes and in patients transported with head injuries. Future research is needed to characterize and understand the impact of fatigue, noise, vibration, G-forces, humidity/dehydration, and thermal changes on patient outcomes in patients with various types of injuries and diseases. By understanding the impact of these environmental stresses in AE patients, solutions to mitigate negative effects of the stresses of flight can be developed and patient care can be improved for our transported warfighters.

8.0 REFERENCES

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LIST OF ABBREVIATIONS AND ACRONYMS

AE	aeromedical evacuation
ARDS	acute respiratory distress syndrome
CCAT	critical care air transport
CINAHL	Cumulative Index to Nursing and Allied Health Literature
COPD	chronic obstructive pulmonary disease
DTIC	Defense Technical Information Center
DVT	deep vein thrombosis
ERC	en route care
ETT	endotracheal tube
ICP	intracranial pressure
MI	myocardial infarction
NIS	noise-immune stethoscope
PaO_2	partial pressure of oxygen
TBI	traumatic brain injury
VAP	ventilator-associated pneumonia