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The Complexities of Aeronautical Transfer of Acutely Unwell Neurosurgical Patients

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■ OBJECTIVE: **Neurosurgical care is difficult to access in many scenarios. Aeromedical evacuation of acutely unwell neurosurgical patients from remote, isolated, or poorly equipped locations can be considered. This article aims to provide a framework of logistical factors that deserve special consideration in the preparation of these patients for transfer.**

■ METHODS: **We searched all relevant medical literature, military reports, and travel industry documents on transfer of neurosurgical patients. This review was combined with a senior author's (M.J.) extensive relevant experience, to present important factors for neurosurgeons to consider during planning of aeromedical evacuation, highlighting potential preventable causes of deterioration en route.**

■ RESULTS: **Several criteria must be met for a transfer to be considered. The safe transfer of patients with craniospinal pathology requires efficient collaboration between the referring teams, the receiving units/departments, and the medical transfer service. Clear communication, qualified personnel, and appropriate transportation equipment must be available for the transfer. One must consider unique stressors during the air transfer, including the risk of hypoxia on certain types of flights. Vibration, loud noise, acceleration, and changes in barometric pressure en route may negatively affect the patient during transfer. Patient stabilization before transfer is a priority. Medical conditions that can potentially worsen in-flight should be corrected before transfer. The use of a checklist before departure is highly recommended and is included herein. The timing of transfer concerning the postoperative patient deserves special consideration.**

■ CONCLUSIONS: **Although there is little published information, this review provides useful criteria and parameters needed for safe aeromedical evacuation of neurosurgical patients.**

Key words
- Aeromedical evacuation
- Aeronautical transfer
- Craniospinal pathologies
- Equipment
- Flight stressors
- Logistics
- Neurosurgery

Abbreviations and Acronyms

DVT: Deep vein thrombosis
ft: Feet
Hb: Hemoglobin
IATA: International Air Transport Association
ICP: Intracranial pressure
ICU: Intensive care unit
IV: Intravenous

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INTRODUCTION

In our current highly mobile world, it is increasingly common for neurosurgeons to provide urgent care to patients who are far from home. When patients require a greater level of care than what the local health care facilities can offer, a national or international aeromedical evacuation could be an option.[1] Air medical transport is used in situations in which ground transportation is either less effective, when time is an important factor in improving the overall outcome of the patient, or when travel by land is impossible as the result of long distances/ difficult conditions. Neurosurgical emergencies are addressed by 2 different aeromedical transportation services: medical repatriations and medical evacuations.

An increasing number of people, including those of advanced age, are traveling or living abroad. Often, travelers with experiencing health emergencies prefer to be transferred home to continue their medical management. This is known as medical repatriation. During medical evacuation, also known as medevac, transfer is arranged to the nearest available hospital that has all necessary facilities and resources required for the medical management of the patient.

Military services and travel insurance companies have most of the experience in the aeronautical transfer of neurosurgical patients. This review draws on 15 years of travel insurance experience of repatriation of cranial and especially spinal injured patients to the United Kingdom as a basis for our recommendations.[2] This experience includes aeronautical transfer of more than 1000 patients. Approximately 300 of the patients had acute neurosurgical pathology; 150 of them had spinal injuries.[2] Between 50 and 60 of these patients underwent aeronautical transfer in person by one of the authors (M.J.).

The purpose of this study is to define important factors for safe aeromedical transportation of acutely unwell neurosurgical patients. We offer basic, experience-based recommendations for consideration when transferring a patient with acute cranial and/ or spinal pathology. This article aims to address the relative scarcity of information and lack of evidence-based guidelines in the literature and to equip the reader with a framework to approach the logistical factors which deserve special consideration in the preparation for aeronautical transfer.

METHODOLOGY

This study is a comprehensive/narrative review combined with experiential analysis. The aim was to identify and compile critical logistics and clinical factors involved in the aeromedical evacuation, with particular consideration for patients with neurosurgical pathology. A thorough literature search was conducted on PubMed and Scopus from inception to June 2024 using the terms "neurosurgical patient transfer," "aeromedical evacuation logistics," "flight stressors," "medical air transport safety," and related synonyms. The search initially yielded approximately 1662 documents. Only English-language articles were included. Documents were selected if they addressed any aspect of neurosurgical patient transfer, aeromedical evacuation protocols, or challenges in medical air transport. Specific focus was placed on studies discussing the physiological impacts of flight, equipment requirements, and patient preparation. Studies addressing rotary-wing helicopter transfers were excluded to maintain focus on fixed-wing aeromedical evacuation.

After a screening process and full-text assessment, 49 relevant articles were finally selected. Although 3 primary focus areas were identified—physiological impacts of flight, equipment requirements, and patient preparation—the content of many articles overlapped. As a result, articles were not strictly confined to a single category.

In addition, 21 military and insurance-related reports, such as protocols, recommendations, and technical training manuals, were included to provide broader perspectives on logistical considerations. This was combined with the senior authors' experience (M.J., K.P.) to present key factors in transferring acutely unwell neurosurgical patients, highlighting potential preventable causes of deterioration en route. Insights facilitated through the authors' professional networks and previous experience, offered context-specific considerations that may not be extensively documented in traditional literature. Case examples from the author's experience (M.J., K.P.) informed the development of clinical recommendations, particularly regarding in-flight stressor management, checklist development, and clinical decision-making for safe transfer.

The literature and experiential data (M.J., K.P., M.N.) were collected effectively addressing the study's main objectives. We identified clinical and logistical criteria for determining patient eligibility and preparedness for aeromedical transfer, with an emphasis on minimizing in-transit risk. Specific in-flight stressors, such as hypoxia, vibration, and altitude-related pressure changes, were categorized and analyzed for their potential impact on neurosurgical patients, with a focus on neurosurgical-specific vulnerabilities. A structured checklist was developed to guide practitioners in assessing neurosurgical patients for air transfer. This checklist integrates both evidence-based and experience-based elements to ensure the comprehensive patient evaluation and preparation process.

Historical Overview

The first documented air medical evacuation occurred in 1870, when Paris was occupied by Prussia. A total of 160 injured French patients were transferred by air using 66 balloons (ballons montés).[3,4] The first aeromedical transport, using a small aircraft to transport 6 injured soldiers in Serbia, was done in World War I (16 November 1915).[5] In 1917, during the colonization of Morocco, Dr. Eugene Chassaing (1876–1968) transformed a military airplane, model Dorand II, into a sanitary transport airplane for medical evacuation and carried out the first medical airlift in history.[6] In the 1920s, Dr. Chassaing, Major of the French Army at that time, converted 16 Bréguet 14 A.2 airplanes into sanitary transport airplanes. He organized the First International Congress on Sanitary Aviation in Paris (May 15–20, 1929) and he is considered the father of medical aviation.[6]

During World War II, the need for aeronautical medical transfer increased and the conditions of transfer improved with the addition of medical equipment to stabilize the patient. Rotary-wing aircraft were more commonly used for such purposes, and this concept led to the conception of helicopter emergency medical services.[7,8] Recent evidence shows that helicopter emergency medical services covers 3% of overall aeromedical transfers and saves approximately 3 lives per 100 activations.[9]

Historically, the first education program "Aéronautical Transport and Medical Repatriation" for medical doctors and other medical staff was founded at the Saint-Antoine Medical Faculty, currently the Sorbonne-Université, in Paris, in 1987.[3] Lectures are supplemented by a visit to insurance companies, to the aviation station in Le Bourget airport, an important center of both the aviation and the pharmaceutical industry,[10] and a presentation by the medical service of the Roissy-Charles-de-Gaulle airport.

Recent worldwide eruption of local and regional wars and conflicts has resulted in further developments in medevac of severely injured army and military personnel to specialized military medical centers. Recent advances in airlifting and aeronautical transport provide the opportunity for casualties but also civilians with acute neurosurgical conditions to be safely transported and efficiently managed in large, well-organized military neurosurgical facilities.[11]

FLIGHT LOGISTICS AND GENERAL PRINCIPLES

Air medical transport is risky, particularly for the uninitiated. Indeed, several adverse events associated with equipment failures and communication errors during flight have been reported. Unexpected weather changes, delays, and/or sudden deterioration of the patient could deplete medical supplies and/or increase the challenge of transfer. Backup equipment such as power supplies, oxygen tanks, monitors, etc., should be available on board. Compatibility between electrical equipment and electrical circuits of the aircraft and patient's mismanagement is another important issue. This failure has been estimated to be as high as 30%.[12] Process standardization, the establishment of checklists, and the application of specialized medical equipment specifications could mitigate this failure rate. Further research is needed to find the best cost-effective solution.

Medical air transfer is very expensive compared with ground ambulance services. Veldman et al.[13] calculated that 1 hour of operating a Learjet 35A, one of the smaller and more economical air ambulance jets, costs approximately €2500 ($3055 US dollars). The authors calculated a total amount of €45,900 ($56,100 US dollars) for a Chicago-to-Madrid flight. In this case, at least 2 stops for refueling are required, representing an additional risk for the patient, mostly attributable to delay but also the acceleration-deceleration stress, which may easily exacerbate the burdened condition of the patient. In the same study, the authors reported that although bigger aircraft, such as the Challenger 604, can reduce the number of stops, the cost increases to €5000 per hour ($6100 US dollars).[13]

Transfer efficacy depends on thorough planning of logistics (**Figure 1**).[14] Challenges can include a lack of fully trained and specifically educated staff, inadequate equipment, and limited collaboration.[15] Therefore, the strategy should encompass a 4-phase protocol: 1) determine the most available and effective air transport vessel; 2) assign qualified and well-trained clinicians; 3) determine the best receiving center for the patient; and 4) prepare receiving care unit staff for admitting the patient.[16]

In the context of a neurosurgical patient, one of the most important indications for an aeromedical transfer is to enable the

Figure 1. Patient's aeromedical transportation with aircraft Beechcraft King Air 350: (**A**) Arrival and preparation for boarding, (**B**) Boarding completed, (**C**) Aeromedical specialized crew, and (**D**) Ready for transfer. Copyright Hellenic Air Force/Press Office. Published with permission.

patient to access adequate specialist care at a tertiary center for definitive treatment of the underlying pathology. Access to a referral center depends on multiple factors, such as bed and resource availability matching the required level of care, weather conditions, and airport operations. A transfer may involve bypassing a closer center, and patients may need to travel further to reach the next available and appropriately resourced unit, a delay that might have a negative impact on the overall outcome of the patient.[17] Merali et al.[17] found that the median transfer time to a neurosurgical center in Ontario was 3.4 hours, depending on the geographic region of origin. In a 2-year study period, the authors identified 1103 emergent/urgent patient transfers and estimated that 17% of them bypassed the closer center. These patients traveled an average of 196 miles further (101 vs. 296 miles, $P < 0.001$) and waited approximately one additional hour (3.1 vs. 3.9 hours, $P < 0.001$) before arriving at a neurosurgical center. In some geographic regions, the bypassed transfers were associated with a greater risk of in-transit clinical decline (3.0% vs. 8.3%, $P < 0.05$) when compared with transfers that ended at the closest center.[17]

Meticulous and extensive communication is needed before transfer. In practice, the greatest challenge is to arrange a direct transfer to an intensive care unit (ICU) within a neurosciences center. This is attributable to the need for advance agreement to facilitate the necessary transfer arrangements and the need to secure a bed in a neurosurgical ICU in advance on a specified date, which poses considerable logistical hurdles. This significantly affects the timing of transfer.[18,19] In the acute setting, the focus should be on stabilizing the patient. A greater degree of stabilization of critically ill patients before transport is needed and the transfer should be delayed until the safest time possible.[18,19] Appropriate resuscitation and stabilization of the patient before transfer is the key for avoiding complications during the journey.[18,19] In some cases, it may be necessary to move the patient before they can safely be transferred by air. In such circumstances a land/sea transfer, although likely to be more time consuming, may be the most desirable option.

FLIGHT STRESSORS

Flight stressors are related to conditions en route that need special attention. Stressors during flight include the effects of altitude, gravity, humidity, temperature, acceleration, noise, and vibration. Except for noise and vibration, all these factors increase in fixed-wing aircraft as they reach higher altitude.[20,21] High altitude means less oxygen. Therefore, the most important risk is hypoxia. Generally, hypoxia may worsen neurologic injury in neurosurgical patients. Increased oxygen at altitude may be needed. The partial pressure of oxygen decreases with increasing altitude. At sea level, a healthy person inhales an average of 8 L/min of air, which drops by one quarter at 8000 feet (ft) as the result of the lower pressure.[22] A healthy person will tolerate this reduction by hyperventilating, while nonventilated patients easily compensate this reduction with increased oxygen supply, 2 L/min ($1/4 \times 8 = 2$ L/min).[23,24]

Cabin pressures are usually maintained at 8000-ft altitude. In some aircraft, the altitude can be lower to avoid discomfort in breathing, but this increases not only the flight time but also the fuel consumption. Pressurizing the cabin at a lower cabin altitude stresses the aircraft's fuselage as the result of the higher-pressure difference between the inside and outside of the aircraft. This phenomenon increases the risk of structural fatigue and reduces the aircraft's operational lifespan.[25,26] The 8000-ft cabin pressure standard is considered the best compromise that ensures a balance between passenger's comfort and structural integrity. Consequently, during the flight noticeable hypoxia in healthy passengers is very rare; however, it may adversely affect ill patients. Patients with comorbid conditions, including those with underlying heart failure, respiratory disorders, hematologic diseases, renal dysfunction, and/or sleep apnea, can have a greater risk of hypoxia, and additional oxygen will be required.[11,25] For example, in case of a rapid decompression of the cabin, additional oxygen is needed, which is supplied by the chemical oxygen generators or onboard oxygen bottles (**Figure 2**).[27]

There are a number of different types of oxygen, but only one is suitable for use in aviation. Aviators breathing oxygen is the only type suitable for use on aircraft because it is very dry and does not freeze in low temperatures.[23] Medical oxygen is never used on aircraft because it contains water droplets that could freeze.[23] Oxygen tanks are highly flammable and can cause an explosion or fire if not handled properly. Oxygen supports and intensifies a fire with any combustible material. A buildup of static electricity can result in a spark being generated, which could then cause a fire in an environment with high oxygen content. Moreover, technical oxygen (used for industrial or technical purposes) is contaminated and should never be used for breathing.[23]

Factors such as vibration, loud noise, acceleration, and changes in barometric pressure and partial pressure of oxygen may negatively impair the ischemic core and the surrounding zone of the penumbra in patients with stroke.[28] The hypobaric environment can have a deleterious effect on the penumbral zone.[28] Paradoxically, low-frequency vibrations may enhance the effect of thrombolysis.[28] Barotrauma is a unique source of pain and discomfort that might be dangerous in cranial trauma cases.[11] Patients with traumatic brain injury can experience transient marked increases in intracranial pressure (ICP) during take-off or landing.[29] This phenomenon is known as acceleration stress. Another issue is thermal stress; the ambient air temperature decreases by 2°C per 1000 ft.[29]

Flight stressor prevention and/or management is extremely important.[11] Supplemental oxygen or intubation may be necessary for preventing hypoxia. Cabin altitude restriction is important to prevent barotrauma and hypoxia. Blankets, positioning the patient away from bulkheads, and the use of earplugs might be helpful with additional flight-induced changes, including temperature shifts, vibration, and noise. Noise exposure also can produce problems with communication and patient evaluation. Auscultation with a stethoscope is often virtually impossible. The use of noninvasive blood pressure monitoring and/or an arterial line can help. Decreased humidity and gravitational forces can be managed with fluids and positioning (head forward on take-off, head aft on landing). In cranial cases, the patient should be positioned with feet forward and a 30° head-up tilt. Keeping the alert patient calm during the transport is a priority. Medication, when needed, such as antiemetics for air sickness; sedatives for discomfort, agitation, and destress; and analgesics for pain are

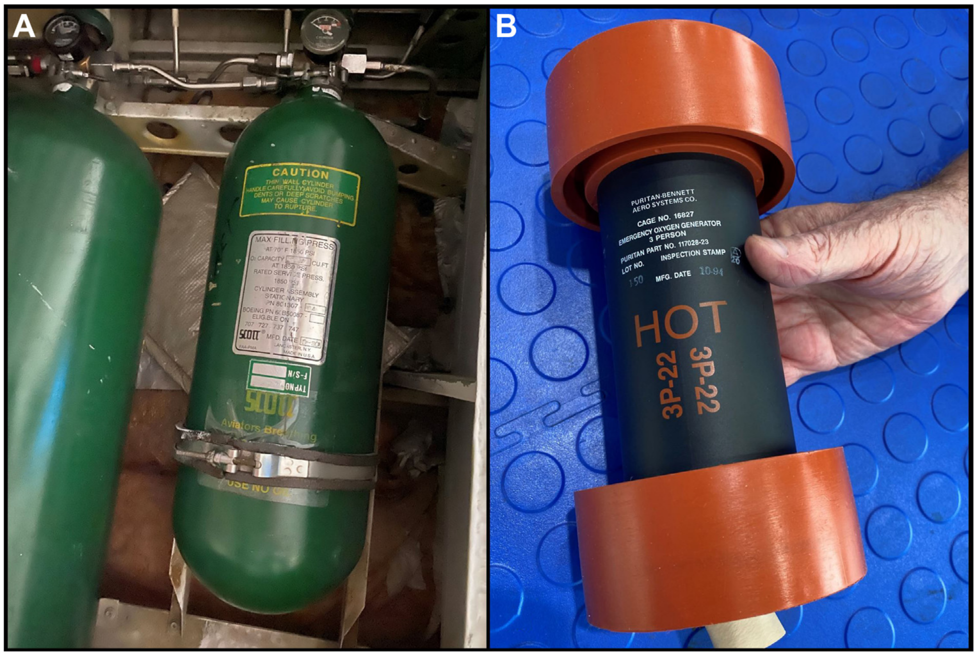

Figure 2. Emergency on-board oxygen suppliers: (**A**) Aviators breathing oxygen storage bottles, (**B**) Chemical oxygen generator. Copyright Hellenic Air Force/Press Office. Published with permission.

important interventions in providing safety and comfort for the patient during air medical transport.[29]

As the pressure decreases, gases tend to expand (Boyle's law).[30] The standard cabin pressure, maintained at 8000 ft, is lower than the internal pressure of body organs, air bubbles, and medical devices containing air. According to Boyle's law, air expands at altitude, causing barotrauma, which mainly affects air sinuses and the gastrointestinal track.[30] This expansion necessitates deflation of the balloon in an endotracheal tube by a few milliliters during ascent to prevent excessive tracheal pressure that could lead to necrosis, balloon rupture, or vagal stimulation, causing bradycardia.[31] Conversely, leakage around the cuff during descent predisposes to aspiration pneumonia.[31] To avoid these changes, another option is to fill the cuff with normal saline, maintaining a steady pressure throughout the flight.[31]

FITNESS TO FLY

When assessing an acutely unwell neurosurgical patient's fitness to fly, the following 4 general questions should be addressed.

Is the Patient Medically Stable?

Ideally, in several cases, this presupposes a minimum of 24–48 hours of stable hemodynamic and cardiopulmonary vital parameters.[32] However, many urgent cases do not have the luxury of time. If the patient is ventilated, the ventilation parameters should be steady. If the patient requires catecholaminergic support, the requirement for medication should not be increasing. In the case of seizures, it implies no ictal events in the preceding 24–48 hours.[18,19,32]

Is the Aeronautical Environment Likely to Cause a Deterioration?

There are several paradigms of deterioration upon air transfer. The most well-documented in the literature is the predictable deterioration in patients having substantial pneumocephalus.[33] A computed tomography scan of the head is often necessary to exclude the presence of intracranial air for pressurized cabin aircraft transport. Patients who are prone to seizures, operated or not, should not fly until seizure control is achieved. Adequate serum levels of appropriate anticonvulsant medication are required before transfer.[18,19,34] If a patient is not actively seizing but at risk of seizures, it is generally better to pretreat with anticonvulsants. The aeronautical environment may exacerbate the tendency to seizures.[31] Hypoxia, dehydration, pain, and agitation are some of the most common factors to exacerbate this process.[31] Other conditions that can potentially worsen above 8000 ft include cerebral vasospasm and brain edema.[35]

Does the Patient Have any Background/Underlying/Associated Medical Conditions that May Deteriorate en Route?

This is not always an absolute contraindication, but it does deserve careful consideration.[18,19,36] For example, it is absolutely necessary to check and correct any electrolyte imbalance prior to transfer, as it is difficult to identify them and impossible to test for them during the flight. Moreover, for patients who regularly undergo hemodialysis, this should be done early on the same day of air transportation.[21,37]

Are There any Conditions that Could Arise en Route and that would be Challenging to Address During an Aeromedical Transfer?

Examples include hemorrhage, edema, desaturation, requirement for a chest drain or external ventricular drain, the requirement to intubate and ventilate en route.[18,19,32] If the patient has any risk of losing airway patency, even if low, intubation before transportation is appropriate. These are patients with traumatic brain injury and/or comorbidities who might deteriorate as the result of in-flight hypoxia, or patients with multitrauma, especially those having maxillofacial injuries who might abruptly lose their airway en route.[38]

Generally, if there is a significant potential for the patient to deteriorate and require a procedure such as intubation, transfusion, or insertion of an external ventricular drain or chest drain en route, these procedures are better performed semi-prophylactically before transfer.

Several criteria must be met for a transfer to be considered "appropriate" (Figure 3). First, the transferring hospital must treat and stabilize the patient to minimize the risk of transfer. The receiving hospital must have an appropriately supported bed and qualified personnel and agree to the transfer. The transferring facility must send all relevant documentation.[39] Qualified personnel and appropriate transportation equipment must be available for the transfer.[39] Both current and any pre-existing conditions must be carefully assessed before transfer. Evaluation of every possible factor that could potentially cause deterioration of the patient during the transfer is important. The key is to be prepared for any unforeseen incident that may occur in such a confined, isolated, and somewhat unpredictable environment at high altitude.

CRANIAL AND SPINAL CHECKLISTS

Neurosurgical patients who require evacuation must be evaluated and stabilized as much as possible before air transfer. The use of a checklist before departure is highly recommended.[40] The pertinent checklist for neurosurgical patients depends on whether they have a cranial or spinal condition and if both then both checklists should be used. Trauma patients may have multisystem injuries including both cranial and spinal pathologies.

Checklist for Cranial Patients

Is there Air in the Head, Either Postoperative or Secondary to Trauma? Pneumocephalus expands at altitude and can cause a precipitous clinical deterioration.[41,42] Low cabin pressure causes the gas in any body cavity to expand up to 30%.[29] Therefore, if a patient underwent an emergency craniotomy, air travel should be delayed until postoperative pneumocephalus is resolved.[32,42,43] It is best to delay transfer of a patient with significant intracranial air, if possible, or if immediate transfer is required, this should be by land/sea. In most situations, intracranial air will have resolved up to 4 weeks after an acute insult/operation that introduced the air.[44] In cases of a cerebrospinal fluid leak, with air continuously being sucked into the head through an ongoing fistula, aeronautical transfer is contraindicated.

Are There Significant Comorbidities? Comorbid conditions, especially cardiac, respiratory, and/or gastrointestinal, can worsen the risks of air transfer.[11,31] The stability of any comorbid conditions, the possibility of deterioration, and any other medical need that the patient might have needs to be assessed to avoid in-flight complications.[31]

Is There Significantly Increased ICP ? Minor increases in ICP may not jeopardize the patient's condition, but intermediate or large increases in ICP pose a significant risk of serious deterioration and death. The typical air transfer acceleration stress and loud noise seem to play an important role in this process.[29]

Does the Patient have any Conditions that will be Negatively Impacted by the Aeronautical Environment, e.g., Vasospasm or Seizures?. In-flight stressors have a negative impact on the likelihood of brain ischemia.[28] The association between the reversible cerebral vasoconstriction syndrome presenting with severe and persistent headache during descent and continuing several hours after landing is well-described.[45,46] Altitude, particularly for long distances, seems to promote coagulation, which may stimulate prothrombotic mechanisms involved in subarachnoid hemorrhage and vasospasm.[47] If the patient is at risk of seizures, air transfer has to be postponed until this is no longer a concern.

Checklist for Spinal Patients

Is the Spine Stable, Fixed or not? If the Spine is not Fixed, How is it Immobilized? In patients with acute spinal trauma, immobilization with a rigid cervical collar and/or long backboard is required.[18,19] In stable cases, fixed or not, the patient should be transferred onto the transport trolley/stretcher, properly secured, and padded. Patients who have already been stabilized surgically should be assessed by a doctor with aviation medicine experience within seven days of surgery, and transferred at least 7 days postoperatively.[32] The patient should be able to tolerate unexpected severe turbulence and vibration associated with flight. Support by use of external braces is important.

Are There Significant Comorbidities? Comorbidities, such as cardiac, respiratory, and/or gastrointestinal disorders, can worsen the risk.[11,31] Appropriate stabilization of the patient before transfer is the key to avoid complications during the flight.

Could There be a Problem Related to Ascending Spinal Cord Edema, Autonomic Dysreflexia, Spinal Shock, Paralytic Ileus, Respiratory Compromise, and/or Pneumothorax? If the patient is physiologically stable before transfer, she or he is more likely to remain stable during the flight. However, there is still the need for awareness, recognition, and prompt action in case of complications. Correction of major complications takes precedence over transfer.[21,37] These include hemorrhagic cerebrovascular accident, pneumocephalus, barotrauma, pneumothorax, pneumoperitoneum, and any type of recent surgery within the preceding week.[38,48] Reduced neurologic stimulation/innervation and/or fatigue of respiratory muscles in greater spinal lesions is

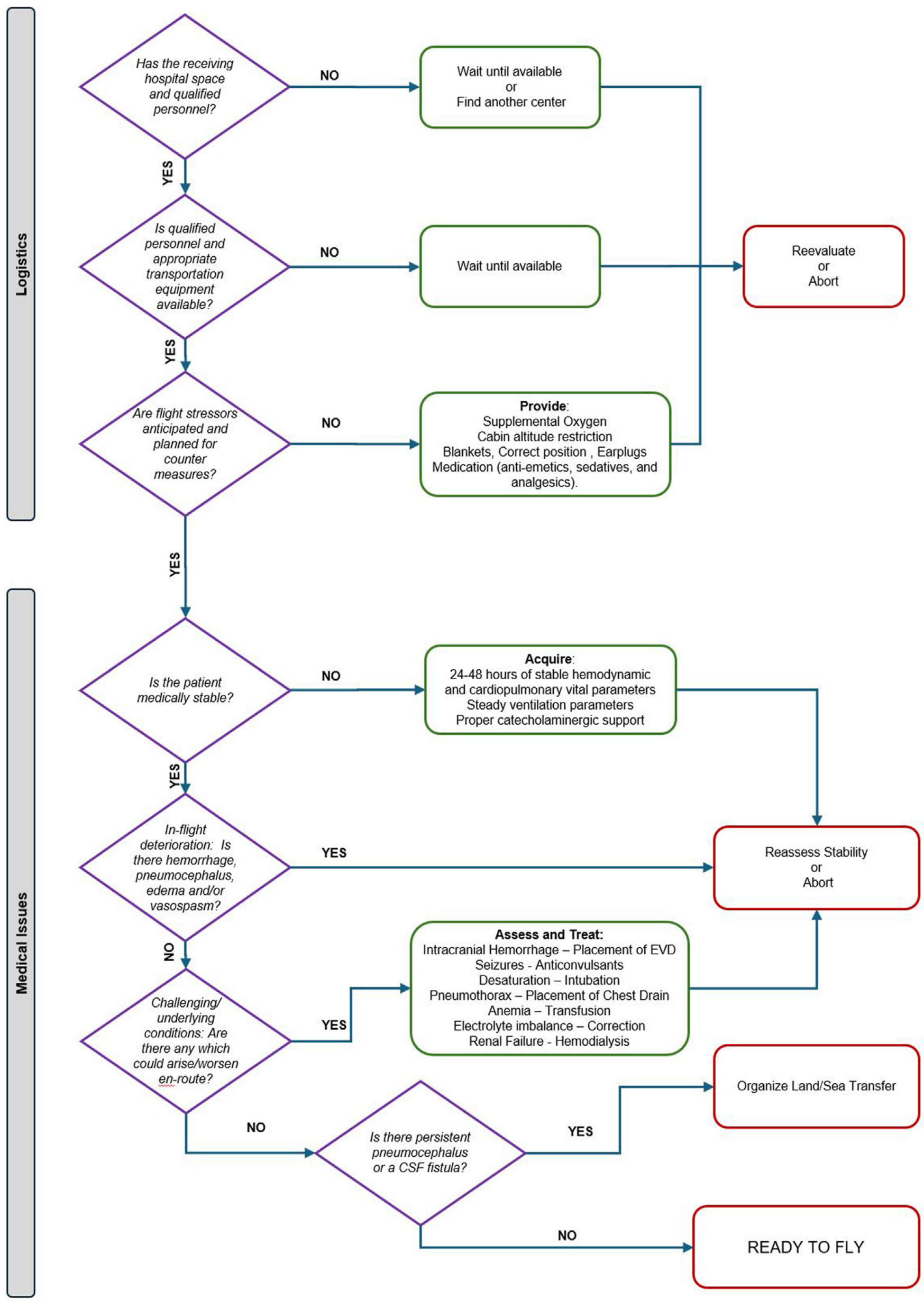

Figure 3. Algorithm for assessing the readiness of acutely unwell neurosurgical patients' air transfer. EVD, external ventricular drain; CSF, cerebrospinal fluid.

associated with an increased risk of respiratory failure. Paralytic ileus is very common in early stages after spinal injury and needs to be managed with nil-by-mouth and nasogastric and/or flatus tube insertion. Poor peripheral resistance and hypotension is normal in these cases. Fluid resuscitation does not improve blood pressure but also precipitates pulmonary edema; thus, it is not recommended.[2] It is generally better not to transfer these patients in the acute phase.

TIMING OF TRANSFER

Patients who are being prepared for air transport must be stabilized as completely as possible before evacuation.[29] Those who are hemodynamically unstable cannot transfer and those who are likely to require high levels of support, e.g., dialysis, transfusion, or resuscitation, should not undergo transfer in the remote aeronautical environment, if at all avoidable. Undoubtedly, parameters such as airway secured, hemorrhage controlled, shock treated, and fractures immobilized must have been checked and solved before transfer.[29]

Patients who have edema, whether it be of a limb, the spine, or the brain, should not be transferred by air, as the aeronautical environment exacerbates edema of any kind. Transfer should be delayed until the edema has resolved. Patients who are within 48 hours of a serious and severe insult/injury should not be transferred by aeronautical means, unless it is absolutely necessary. This is because they are subject to major cytokine release and at risk of increased edema, increased ICP, and/or extension of the effects of the insult, such as ischemia either myocardial or cerebral.[49] The transfer should wait until the swelling has regressed unless there is urgency around the transfer. Other mitigations are circumferential or bivalved casts; the use of splints is preferable.[29]

The timing of transfer concerning the postoperative patient deserves special consideration. Often the crucial question is whether the patient will transfer before or after a surgical intervention. If before, then assuming all relevant considerations have been made generally, the sooner the transfer is affected the better. If the patient is undergoing surgery locally then the best time to transfer is as late as possible, at least seven days postoperatively.[32,38]

SPECIAL CONDITIONS OF TRANSFER

The first thing to consider about the logistics of a patient transfer is how the patient will be ventilated and how they will be accommodated. The patient can be ambulant, stretchered/self-ventilating, or intubated and ventilated. Approximately 300 medical aeronautical repatriations with acute neurosurgical pathology into the United Kingdom occur each year.[2] Of these patients, 10% are intubated and ventilated.[2] The length/duration of the transfer is a very important consideration in scheduling.

Condition of Transfer

Intubated and Ventilated. This is the most onerous of aeronautical transfer and will by necessity involve an anesthetist and a nurse. When an anesthetist and a nurse transfer an intubated and ventilated patient, a lot of space is needed, not only for the recumbent patient but for all of the associated kit. The kit that is required for an aeronautical transfer of an acute neurosurgical patient varies depending on the patient's needs, the diagnosis, the condition, and the mode of transfer.[31,36] A doctor's kit, nurse's kit, and ventilation bag are required (Tables 1 and 2).

The aeronautical environment is very difficult to navigate with a ventilated patient. Ventilators used in medical evacuation should be certified by aeronautical agencies, like the U.S. Federal Aviation

Table 1. List of Basic Equipment Contained in a Doctor's Kit en Route

Bag Type	Category	Items
Main bag	Emergency equipment	Defibrillator/pads, suction device/catheters and drainage-collection unit, portable blood gas machine
	Diagnostic tools	Monitor (electrocardiogram, invasive and noninvasive blood pressure, pulse oximetry, capnography), thermometer, glucometer
	Respiratory equipment	Two portable ventilators, self-inflating bag, valve and mask, portable oxygen with regulator and backup tanks
	Airway management	Appropriate intubation equipment, equipment for finger thoracostomy
	Monitoring devices	Battery-powered multifunction monitor, battery-powered syringe pumps, battery-powered intravenous volumetric pumps
	Protective equipment	Sterile and unsterile gloves, insulating blanket
	Surgical/Wound care	Cervical spine collars, surgical/wound kit with bandages and dressings, chest drain kit
	Venous access	Venous access equipment
	Catheterization	Urinary catheters
	Additional tools	Earplugs, torch (to assess pupils)
Respiratory bag	Respiratory equipment	Equipment for airway management, nebulizer equipment, endotracheal tubes, tracheostomy set
Drug bag	Medication	Oral and intravenous drugs, needles and syringes, small sharps bin, sterile and unsterile gloves
Fluid bag	Intravenous supplies	Selection of intravenous fluids, lines, cannulas, needles, syringes, sharps bin

Table 2. List of Nurse's Kit Contents for Aeromedical Transfer

Category	Items
Diagnostic tools	Blood pressure machine, stethoscope, thermometer, saturation probe
Medical supplies	Simple oral drugs, flatus tube, nasogastric tube, urine leg bags, catheter change kit, selection of syringes and needles
Oxygen delivery	Selection of oxygen masks and tubing
Waste management	Small sharps bin, yellow bag for waste
Protective equipment	Sterile and unsterile gloves
Wound care	Small selection of dressings

Administration. Transport ventilators need to be able to compensate for altitude changes and provide accurate volume monitoring.[50,51] Basic recommended equipment for aeromedical transports is mandatory, while keeping the patient calm during the transport is a priority.[31] Noise, vibration, and limited space are just a few of the difficulties when evaluating and managing sedation depth of ventilated patients. If sedation is not adequate, this could lead to agitation, which increases the patient's blood and/or ICP, while at the same time the patient is at greater risk of self-extubation and removal of catheters, tubes and/or lines.[52]

A recent study reported that bispectral index monitoring during air transfer is reliable in sedated or anesthetized patients.[53] Transferring an intubated, ventilated patient almost always entails an air ambulance or occasionally a military aircraft. Very few commercial airlines now allow transfer of unwell patients, especially when ventilated.[54,55] Only Lufthansa and Air France allow the aeromedical transfer of these patients.[13,56-58] The transport of stable and ventilated critical care patients using commercial airlines represents a cost-effective and useful alternative to air/sea intercontinental transfer. Transportation on commercial airlines reduces not only the transport time but also the acceleration/deceleration trauma as a result of multiple fuel stops (which are a necessity for smaller aircraft and which typically effect air transfers, as they can only carry enough fuel to fly for 4—5 consecutive hours at a time) for long flights. Patients who will fly commercially have to wait for a flight to be available. However, the flight is on priority in case of medical transportation.[13]

Self-Ventilating, Stretchered. This type of transfer also requires an anesthetist or a qualified and properly trained physician and a nurse. When a doctor and a nurse transfer a stretchered, but awake, patient, an emergency resuscitation kit is required (**Tables 1** and **2**). Transport is usually by air ambulance. Patients who will fly commercially are generally accommodated by collapsing the last three rows of economy seating. The stretcher is provided by the airline company and is in the hold on the way to the patient. For transfer of the patient the last three rows of seats (3×3) are collapsed, an adjustment which usually takes the aircraft interior engineer approximately an hour to perform. The stretcher is then placed on top of the seats, bolted to the floor and immobilized with four straps and a shoulder harness to prevent the patient from being ejected off the bed if take-off is aborted. Travel insurance companies, airline medical services, as well as the online sites of global organizations/aeromedical transport companies, available 24/7, usually take care of all the logistics aspects of medical air transport and arrange all the planning and logistics.[59,60]

Self-Ventilating, Ambulant. A nurse alone is usually sufficient for ambulant transfers. This generally needs to be in business class to enable the patient to recline and to facilitate the required kit (**Table 2**). However, some spontaneously breathing patients should also have an anesthetist, particularly if there is a small but real risk of deterioration en route. Occasionally, if there is the potential for transfusion, a doctor will be part of the transfer team.

Many aeronautical evacuations to the United Kingdom need a 2-sector transfer; for example with Lufthansa, one to Frankfurt, and then another to an airport in the United Kingdom. Sometimes, there needs to be a combination transfer of a stretchered patient, on a commercial flight, e.g., Lufthansa to Frankfurt and then an air ambulance to the United Kingdom. Occasionally, long-road ambulance transfers to/from major airports are needed for commercial transfers. In these cases, an air ambulance can be desirable from a logistical viewpoint to avoid long road transfers and multi-sector routes on commercial flights.

Air ambulances have the advantage of being able to use small local airports and sometimes are more flexible in being able to adapt their route to avoid turbulence. In contrast, air ambulances are usually small aircraft, such as Learjets, which need to refuel approximately every 5 hours. This can make the transfer longer and occasionally necessitates several stops for refueling with the associated discomfort and risk for the transfer team and patient.

Over the past decades, the travel insurance industry has provided the traveler with cost coverage for treatment abroad and repatriation to the home country.[13] Usually, repatriation is included in standard travel insurance policies as part of the medical cover. However, it's worth noting that some insurers may list repatriation separately, so it's crucial for travelers to check that point.[61] All of these factors highlight the importance of fastidious planning.

SPECIAL CONSIDERATIONS FOR THE POSTOPERATIVE PATIENT

Repatriation, further treatment, and personal or professional issues are some of the reasons a postoperative patient may require an air transfer. Before and during the flight, preemptive measures should be taken to deal with postoperative pain and to minimize the possibility of postoperative complications. The air pressure changes during flight and the associated pathophysiologic changes mean the optimum timing for air travel of a patient after cranial and/or spine surgery, is extremely important.[32,38,62] The official aviation authority that determines which patient needs medical assessment before a flight is the International Air Transport Association (IATA).

Anemia in postoperative patients is common. According to the IATA, patients with postoperative anemia (hemoglobin [Hb] <8.5 g/dL) should be assessed by a doctor with aviation medicine experience before the flight. For Hb 8.5 g/dL, patients are accepted for travel with availability of oxygen. In general, Hb should be assessed more than 24 hours after surgery, which means that the patient should never be allowed to travel within the first 24 hours after surgery.[32] Postoperative patients have increased oxygen consumption because of surgical trauma. However, recent surgery is not a contraindication for air travel. When combined with other factors, such as postoperative anemia, medical history of cardiopulmonary disease, or advanced age, the patient's oxygenation en route is a critical consideration. For postoperative patients in whom there is a doubt about the ability to keep the patient well oxygenated during the transfer should have their trip delayed or have oxygen available during the flight.[63]

General anesthesia given during spinal surgeries is not a contraindication for air travel because of the short-term effect of anesthetic agents.[63] From day 7 after surgery, the patient can be allowed to travel under certain conditions: she/he must be able to sit upright during take-off and landing and tolerate specific conditions, such as unexpected severe turbulence and vibration. IATA recommends that a patient who has undergone spine surgery can be accepted on a commercial flight within the first 7 days postoperatively only after assessment by a doctor with aviation medicine experience.[32] Support braces that restrict the use of a lifejacket in case of emergency should be avoided.[32]

Complications associated with spine surgery could make the decision for air traveling harder. Thoracic spine surgery can be associated with lung complications like pneumothorax. The Aerospace Medical Association gives special consideration to the diagnosis of an acute pneumothorax, which is considered an absolute contraindication to air travel.[63] According to the British Thoracic Society and IATA, patients with a traumatic pneumothorax should delay their air travel for at least 2 weeks after radiographic resolution of the pneumothorax.[32,64] During air transfer, patients and medical teams are very remote from medical support. Careful consideration must be given to the risk of in-flight deterioration. In an adverse environment with limited oxygen, the inability to auscultate the chest effectively and limited equipment, increase the risk of deterioration en route.

The presence of postoperative cerebrospinal fluid leak is an absolute contraindication to air travel. Pressure changes can lead to backflow causing significant pneumocephalus and potentially increase the possibility for infection.[65] There is a case report in the literature in which the authors describe a severe headache during a flight in a patient 7 days after spinal epidural anesthesia that appeared because of cabin pressure changes that induced a dural leak.[66]

In cases who have undergone an emergency craniotomy before repatriation, it is recommended to delay aeromedical transfer for at least 14 days after surgery or until postoperative pneumocephalus has reabsorbed.[43] For maximum safety, the later of those dates is recommended.[67] According to IATA, a patient who has undergone cranial surgery is accepted on a commercial flight only if the cranium is free of air and the patient is in good general condition.[32] Cranial patients who are at risk of seizures should travel under treatment with anticonvulsant medication[31] because the threshold for seizures seems to be lowered by air travel.[34] These patients are accepted for travel on commercial airlines only if they are stable and well for at least 24 hours.[32]

Cranial and spine surgery can increase the risk of deep vein thrombosis (DVT), especially during air travel. Less-complex procedures, such as microdiscectomy and minimally invasive spinal surgeries, performed within 3 days before flying carry a low risk of DVT. The Aerospace Medical Association advice for these patients is mobilization and adequate hydration during the flight.[63] However, for patients who are paraplegic or hemiplegic, the risk of DVT increases. In these cases, aspirin or low molecular weight heparin and graduated compression stockings are highly recommended.[43] In contrast, major spinal operations are high risk for DVT and in such cases aspirin is usually replaced by low molecular weight heparin. Additional factors such as cardiovascular disease, estrogen hormone therapy and age can increase the risk further.[63] A systematic review and meta-analysis by Adi et al.[68] found that there is no evidence that traveling circa 3-hours, including air travel, increases the risk of DVT; however, there is evidence to suggest that flights of 8 hours or more increase the risk of DVT. Many of those who develop a DVT or pulmonary embolism related to air travel have either a history of previous blood clots or additional risk factors such as recent hospitalization, surgery, trauma, cancer, smoking, pregnancy, or the use of oral contraceptives or hormone replacement therapy.[69]

Table 3. Lessons Learned on the Management of In-Flight Risks

Points	Details	Measures
Communication and protocols	Clear communication, collaboration, and established protocols are essential for safe transfers.	Well-educated, certified, licensed, and credentialed personnel
Aircraft selection	Patient needs, oxygen supply, and equipment space needs to be into consideration.	Air-ambulance (Learjet), commercial flight, military aircraft (C-17, C-130, KC-135)
Mitigating flight stressors	Altitude, hypoxia, gravity, humidity, vibration with oxygen, positioning, temperature, and noise.	Oxygen, positioning - away from bulkheads, fluids, cabin altitude restriction, blankets, earplugs, medication
Assessing patient stability	Pre-flight interventions to ensure stability and reduce in-flight risk of deterioration	Intubation, electrolyte balance, hemodialysis, blood transfusion, chest drain and/ or external ventricular drain
Checklist for cranio-spinal patients	Pneumocephalus, hemorrhage, edema, desaturation, vasospasm, seizures, increased intracranial pressure, immobilization	Checklists to assess risks and delay transfer, if needed (Figure 3). Ground transfer may be an option.
Intracranial and spinal management	Control intracranial pressure and stabilize the spine; adapt transfer based on patient condition.	
Postoperative considerations	Anemia, pneumothorax after spine surgery, paralytic ileus, postoperative cerebrospinal fluid leak, postop pneumocephalus, seizures, deep vein thrombosis, pulmonary embolism	Delay flights postsurgery (24 hours for minor, 7—14 days for major); medical assessment prior to the flight is mandatory
Pain, air-sickness, and thrombosis	Ensure pain, air-sickness, and thrombosis management for patient safety.	Analgesics, anti-emetics, sedatives, low molecular weight heparin, aspirin, compression stockings, hydration

TYPE OF AIRCRAFT USED AND IMPLICATIONS

Aircraft used for evacuation has highly trained and skilled personnel, as well as specialized medical equipment. These are planned transfers in which an aeromedical transfer company can allocate equipment and personnel depending on the patient's medical needs.[21]

Airplanes can sustain speeds of >500 mph, which explains why they are used for long-distance transportations (>200 miles). They are also more time- and cost-effective. However, they are not practical for distances <200 miles as the result of restrictions in airport takeoff and landing.[70] The need to refuel every 4–5 hours of flight is nearly always a consideration for air ambulance transfers. Multiple stops for a long journey are associated with acceleration/deceleration forces and turbulence/vibration effects, which might be harmful to any patient's condition.

There are 3 different types of aircraft used for aeromedical transportation: 1) air ambulance, 2) commercial aircraft, and 3) military aircraft.

Air Ambulance

These are small, typically fixed-wing aircraft such as Learjets. There is little room for maneuver and little space for accompanying individuals and equipment. There is a limit to how much fuel can be carried and so these crafts typically need to land and take off again after 4–5 hours of flight. This is so that the aircraft can refuel and be reloaded with oxygen cylinders. Generally, Learjets are able to accommodate a maximum of 8000 L of oxygen, due to space constraints. That amount of oxygen will comfortably last for only 4 hours for a ventilated patient. These aircraft also usually do not have a bathroom on board so relatively frequent stops are unavoidable for a number of reasons.[2]

Commercial Flights

Currently, very few commercial airlines will accept medical transfers. Patients, accompanying medical staff, and equipment are usually housed at the back of the economy section. The passenger seats are removed or flattened and the cost of transfer depends on the number of seat spaces occupied. A commercial flight may not be available to the final destination and so a trip may need to be planned in successive flight routes or so called "legs."

Military Evacuation

Military evacuation is uncommon these days but is the most comfortable. Spacious and possibly the safest environment from the perspective of the patient and transferring medical staff.[11] According to the military philosophy, any aircraft that can transfer ambulatory patients can be used. In practice, the most commonly used types are the C-17 "Globemaster III," the C-130 "Hercules," and the KC-135 "Stratotanker" aircraft.[11]

CHALLENGES TO CLINICAL CARE EN ROUTE

The remote, altitude of 8000 ft presents unique challenges compared to the ward and ICU settings.[29,31] The aeronautical environment is remote from the equipment and assistance that patients sometimes need thereby their care can be compromised by the challenges faced in the aeronautical context.

The amount of space is often limited (Figure 1). For example, head end access is particularly difficult in an air ambulance, e.g., a Learjet, this makes intubation and any other procedure extremely challenging. In air ambulances, there is extremely limited height and clinicians are usually care for patients in a limited space on their knees. Access to the patient's left-hand side is often restricted due to the side of the stretcher needing to be positioned against the bulkhead.

The narrow width of the stretchers used for transfer makes it very difficult to care for a patient with high body mass index safely and pressure care is extremely difficult. Patients with significant medical or surgical conditions have Foley catheters, nasogastric tubes, provisions for intravenous (IV) medications, and nutrition. The narrow space between stretcher and clinician seating means that lines and cables are often tripped on, snapped or removed by clinicians tending to the patient. Inserting venous lines is also difficult as the result of vibration. Cleaning a patient after an episode of incontinence in such circumstances is exceptionally tricky, and this leaves them at risk of pressure sores and infections.

Limited space and lower pressure make gravity fed systems like IV fluids very unreliable. For this reason, IV fluid bags should be used with infusion pumps and not by drip rate. Moreover, the acceleration stress affects noninvasive blood pressure measurements, providing momentary false readings, but also cuff's pressure. A recently published study showed the benefit of using an automated control of endotracheal tube cuff pressure device during the flight.[71]

Undoubtedly, aeromedical transportation is not without risks, and the cost is significant. A list of in-flight risks and lessons learned in the management of these risks are shown in Table 3.

CONCLUSIONS

Aeromedical evacuation of an acutely unwell neurosurgical patient is an option requiring careful risk/benefit analysis. When there is a compelling reason for an air transfer, airlifting should be carefully considered, fastidiously planned, and precisely executed by experienced teams. Flight stressors are unique, en route peculiarities that need special attention and may negatively affect the patient during air transfer. The use of checklists before evacuation is highly recommended. On the basis of the scarcity of information and evidence-based guidelines in the literature regarding the mobile patient, we provide a framework of the pertinent factors, which deserve special consideration in preparation for and during air transfer. This effort is not intended to instruct the reader to effect an aeronautical transfer which should be and is currently undertaken by experienced dedicated teams.

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REFERENCES

1. Shelton SL, Swor RA, Domeier RM, Lucas R. Medical direction of interfacility transports: National Association of EMS Physicians Standards and Clinical Practice committee. *Prehosp Emerg Care*. 2000;4:361-364.
2. *(MJ MN) personal communication*. 2023.
3. Obadia E. Historique de l' assurance, de l' assistance et des transports sanitaires. In: Obadia E, Cha O, eds. *Le rapatriement sanitaire par transport aérien médicalisé, à usage civil et militaire. Pathologies, techniques et réglementation*. France: Elsevier Masson SAS; 2020:3-5.
4. Ballon monté. Available at: https://fr.wikipedia.org/wiki/Ballon_monté. Accessed May 19, 2024.
5. Wikipedia. Medical evacuation. History. Available at: https://en.wikipedia.org/wiki/Medical_evacuation. Accessed April 30, 2024.
6. Air University (af.edu). Aeromedical transport. Basic aspects of aeromedical transport. Available at: https://www.airuniversity.af.edu/Portals/10/JOTA/Journals/Volume.1.Issue.1/07-Arrocha_eng.pdf. Accessed May 20, 2024.
7. Cameron PA, Flett K, Kaan E, Atkin C, Dziukas L. Helicopter retrieval of primary trauma patients by a paramedic helicopter service. *Aust N Z J Surg*. 1993;63:790-797.
8. Aiolfi A, Benjamin E, Recinos G, De Leon Castro A, Inaba K, Demetriades D. Air versus ground transportation in isolated severe head trauma: a national trauma data bank study. *J Emerg Med*. 2018;54:328-334.
9. Florez-Perdomo WA, Garcia-Ballestas E, Konar SK, et al. Effect of helicopter transportation of acute ischemic stroke patients on mortality and functional outcomes: a systematic review and meta-analysis. *Air Med J*. 2022;41:476-483.
10. Paris-Le Bourget Airport — Groupe APD. Cargo. Our activities. Pharmaceuticals. Available at: https://www.parisaeroport.fr/en/professionals/business-aviation/le-bourget/. Accessed October 20, 2024.
11. Reno J. Military aeromedical evacuation, with special emphasis on craniospinal trauma. *Neurosurg Focus*. 2010;28:E12.
12. Hui FK, El Mekabaty A, Schultz J, et al. Helistroke: neurointerventionalist helicopter transport for interventional stroke treatment: proof of concept and rationale. *J Neurointerv Surg*. 2018;10:225-228.
13. Veldman A, Diefenbach M, Fischer D, Benton A, Bloch R. Long-distance transport of ventilated patients: advantages and limitations of air medical repatriation on commercial airlines. *Air Med J*. 2004;23:24-28.
14. Kunte SA, Anderson D, Brown-Espaillat K, Froehler MT. Total transfer time for ground vs. air transport for interhospital and scene transfers of acute stroke patients. *J Stroke Cerebrovasc Dis*. 2021;30:105704.
15. Thomas AS, Kopczak LR. *From Logistics to Supply Chain Management: The Path Forward in the Humanitarian Sector*. San Francisco, CA: Fritz Institute; 2005.
16. Barbarosoglu G, Ozdamar L, Cevik A. An interactive approach for hierarchical analysis of helicopter logistics in disaster relief operations. *Eur J Oper Res*. 2002;140:118-133.
17. Merali Z, Sharma S, MacDonald RD, Massicotte EM. Emergent and urgent transfers to neurosurgical centers in Ontario. *Prehosp Emerg Care*. 2016;20:245-253.
18. Joint Trauma System (.mil). U.S. Army Aeromedical Evacuation. Critical Care Flight Paramedic. Standard Medical Operating Guidelines. Available at: https://jts.health.mil/assets/docs/cpgs/Standard_Medical_Operating_Guidelines_(SMOG)_for_Critical_Care_Flight_Paramedics_2022.pdf. Accessed April 9, 2024.
19. ACEP. Air evac lifeteam protocols and standing orders. Available at: https://www.acep.org/siteassets/uploads/uploaded-files/acep/membership/sections-of-membership/airmed/protocols/airevaclifeteam.pdf. Accessed April 9, 2024.
20. Fromm RE Jr, Varon J. Air medical transport. *J Fam Pract*. 1993;36:313-318.
21. Fromm RE Jr, Varon J. Critical care transport. *Crit Care Clin*. 2000;16:695-705.
22. baillielab.net. Altitude air pressure calculator. Available at: https://baillielab.net/critical_care/air_pressure/?useralt=10000&units=ft. Accessed May 21, 2024.
23. Lufthansa Technical Training, Training Manual (LaS). M13.17 35 B2 E - Oxygen (ATA 35). In: Lufthansa Technical Training (LTT), ed. *Fundamentals M13 Aircraft Aerodynamics, Structures and Systems - EASA Part-66 CAT B2*. Hamburg, Germany: Lufthansa Technical Training, Dept HAM US; 2021:1-55. LTT Release.
24. Levitan RM. Avoid airway catastrophes on the extremes of minute ventilation. ACEPNow - The official Voice of Emergency Medicine; 2015. Available at: https://www.acepnow.com/article/avoid-airway-catastrophes-extremes-minute-ventilation/5/?singlepage=1. Accessed May 21, 2024.
25. Lufthansa Technical Training, Training Manual (LaS). M13.11 21 B2 E - air conditioning and cabin pressurization (ATA 21). In: Lufthansa Technical Training (LTT), ed. *Fundamentals M13 Aircraft Aerodynamics, Structures and Systems - EASA Part-66 CAT B2*. Hamburg, Germany: Lufthansa Technical Training, Dept HAM US; 2021:144-201. LTT Release.
26. Guides Aeronautic. Cabin environment control system. Aircraft Pressurization Systems (Part 1). Available at: https://www.aircraftsystemstech.com/2017/05/aircraft-pressurization-systems.html/; 2017. Accessed May 28, 2024.
27. Guides Aeronautic. Cabin environment control system. Aircraft Oxygen Systems. Available at: https://www.aircraftsystemstech.com/2017/05/aircraft-oxygen-systems.html/; 2017. Accessed May 21, 2024.
28. Leira EC, Stilley JD, Schnell T, Audebert HJ, Adams HP. Helicopter transportation in the era of thrombectomy: the next frontier for acute stroke treatment and research. *Eur Stroke J*. 2016;1:171-179.
29. usgovcloudapi.net. Aeromedical Evacuation. Chapter 4. Available at: https://medcoeckapwstorprd01.blob.core.usgovcloudapi.net/pfw-images/dbimages/ch4.pdf. Accessed April 9, 2024.
30. Mide Technology. Air pressure at altitude calculator. Available at: https://www.mide.com/air-pressure-at-altitude-calculator. Accessed May 17, 2024.
31. Araiza A, Duran M, Surani S, Varon J. Aeromedical transport of critically ill patients: a literature review. *Cureus*. 2021;13:e14889.

32. IATA. Publications. Medical manual for aviation. Medical Manual; 2020. Available at: https://www.iata.org/en/publications/medical-manual/. Accessed April 29, 2024.

33. Donovan DJ, Iskandar JI, Dunn CJ, King JA. Aeromedical evacuation of patients with pneumocephalus: outcomes in 21 cases. *Aviat Space Environ Med*. 2008;79:30-35.

34. Trevorrow T. Air travel and seizure frequency for individuals with epilepsy. *Seizure*. 2006;15:320-327.

35. Dukes SF, Bridges E, Johantgen M. Occurrence of secondary insults of traumatic brain injury in patients transported by critical care air transport teams from Iraq/Afghanistan: 2003-2006. *Mil Med*. 2013;178:11-17.

36. Ruskin KJ, Hernandez KA, Barash PG. Management of in-flight medical emergencies. *Anesthesiology*. 2008;108:749-755.

37. Dorlac WC, Mason PE, Dorlac GR. Preparation for long-distance aeromedical evacuation. In: Hurd W, Beninati W, eds. *Aeromedical Evacuation*. Cham: Springer; 2019:77-91.

38. Teichman PG, Donchin Y, Kot RJ. International aeromedical evacuation. *N Engl J Med*. 2007;356: 262-270.

39. Smith JM. EMTALA basics: what medical professionals need to know. Emergency Medical Treatment and Active Labor Act. *J Natl Med Assoc*. 2002;94:426-429.

40. Nathanson MH, Andrzeiowski J, Dinsmore J, et al. Guidelines for safe transfer of the brain-injured patient: trauma and stroke, 2019: guidelines from the Association of anaesthetists and the neuro-anaesthesia and Critical Care society. *Anaesthesia*. 2020;75:234-246.

41. Bichsel O, Hauck A, Oertel M. Air travel with pneumocephalus: a systematic review. *Acta Neurochir*. 2022;164:2395-2400.

42. Dabdoub CB, Salas G, do N, Silveira E, Dabdoub CF. Review of the management of pneumocephalus. *Surg Neurol Int*. 2015;6:155.

43. Silverman D, Gendreau M. Medical issues associated with commercial flights. *Lancet*. 2009;373: 2067-2077.

44. Amato-Watkins A, Rao VM, Leach P. Air travel after intracranial surgery: a survey of advice given to patients by consultant neurosurgeons in the UK. *Br J Neurosurg*. 2013;27:9-11.

45. Hiraga A, Aotsuka Y, Koide K, Kuwabara S. Reversible cerebral vasoconstriction syndrome precipitated by airplane descent: case report. *Cephalgia*. 2017;37:1102-1105.

46. Mainardi F, Maggioni F, Zanchin G. Reversible cerebral vasoconstriction syndrome (RCVS) and headache attributed to aeroplane travel (AH): does a link exist? *Cephalgia*. 2017;37:1311-1312.

47. Toff WD, Jones CI, Ford I, et al. Effect of hypobaric hypoxia, simulating conditions during long-haul air travel, on coagulation, fibrinolysis, platelet function, and endothelial activation. *JAMA*. 2006;295:2251-2261.

48. Parsons CJ, Bobechko WP. Aeromedical transport: its hidden problems. *Can Med Assoc J*. 1982;126: 237-243.

49. Imray C, Wright A, Subudhi A, Roach R. Acute mountain sickness: pathophysiology, prevention and treatment. *Prog Cardiovasc Dis*. 2010;52: 467-484.

50. Blakeman T, Britton T, Rodriquez D Jr, Branson R. Performance of portable ventilators at altitude. *J Trauma Acute Care Surg*. 2014;77(3 Suppl 2):S151-S155.

51. Blakeman T, Rodriquez D Jr, Petro M, Branson R. Evaluation of intensive care unit ventilators at altitude. *Air Med J*. 2017;36:258-262.

52. Chevron V, Menard JF, Richard JC, Girault C, Leroy J, Bonmarchand G. Unplanned extubation: risk factors of development and predictive criteria for reintubation. *Crit Care Med*. 1998;26:1049-1053.

53. Donat N, Cirodde A, Hoffmann C, et al. Bispectral index measurements are not degraded during aeromedical evacuations. *Anesth Analg*. 2018;126: 170-172.

54. Holm AP, Thangathurai D, Ybarra I. Transport of a ventilator-dependent patient from Los Angeles to Athens by commercial airline. *Respir Ther*. 1984; 14:39-43.

55. Kamochi M, Uchida S, Munaka M. An international repatriation of a cervical cord injury patient who was under mechanical ventilation. *J UOEH*. 2001;23:443-450.

56. Bouton M-C, Moussu C. Le personnel Navigant — le métier: contraintes et suivi medical Expérience à Air France. In: Obadia E, Cha O, eds. *Le rapatriement sanitaire par transport aérien médicalisé, à usage civil et militaire. Pathologies, techniques et réglementation*. France: Elsevier Masson SAS; 2020:29-36.

57. Special requirements Lufthansa. Global Healthcare. Lufthansa Global Healthcare and Medical Services. Stretcher transportation. Available at: https://www.lufthansa.com/ie/en/mobility-partner-program-healthcare. Accessed April 30, 2024.

58. Medical Air Service Worldwide. Transport in Lufthansa aircraft. Available at: https://www.medical-air-service.com/news/transport-in-lufthansa-aircraft_1477.html. Accessed April 30, 2024.

59. KLM Health Services. Airport Medical Services. Repatriation. Available at: https://www.klmhealthservices.com/en/airport-medical-services/repatriation/. Accessed April 30, 2024.

60. Wilde H, Roselieb M, Hanvesakul R, Phaosavasdi S, Pruksapong C. Expatriate clinics and medical evacuation companies are a growth industry worldwide. *J Travel Med*. 2003;10:315-317.

61. MoneySuperMarket. Travel insurance. Guides. Repatriation. Repatriation insurance. What is repatriation insurance? Available at: https://www.moneysupermarket.com/travel-insurance/repatriation/. Accessed April 30, 2024.

62. Skjenna OW, Evans JF, Moore MS, Thibault C, Tucker AG. Helping patients travel by air. *CMAJ (Can Med Assoc J)*. 1991;144:287-293.

63. Aerospace Medical Association Medical Guidelines Task Force. Medical guidelines for airline travel, 2nd ed. *Aviat Space Environ Med*. 2003;74(5 suppl):A1-A19.

64. Ahmedzai S, Balfour-Lynn IM, Bewick T, et al, British Thoracic Society Standards of Care Committee. Managing passengers with stable respiratory disease planning air travel: British Thoracic Society recommendations. *Thorax*. 2011;66(suppl 1):i1-i30.

65. Moser M. Fitness of civil aviation passengers to fly after ear surgery. *Aviat Space Environ Med*. 1990;61: 735-737.

66. Vacanti JJ. Post-spinal headache and air travel. *Anesthesiology*. 1972;37:358-359.

67. de la Cruz RA, Clemente Fuentes RW, Wonnum SJ, Cooper JS. Aerospace decompression illness. In: *StatPearls [Internet]*. Treasure Island (FL): StatPearls Publishing LLC; 2024.

68. Adi Y, Bayliss S, Rouse A, Taylor RS. The association between air travel and deep vein thrombosis: systematic review and meta-analysis. *BMC Cardiovasc Disord*. 2004;4:7.

69. Bartholomew JR, Evans NS. Travel-related venous thromboembolism. *Vasc Med*. 2019;24:93-95.

70. Varon J, Fromm RE Jr, Marik P. Hearts in the air. The role of aeromedical transport. *Chest*. 2003;124: 1636-1637.

71. Blakeman T, Rodriquez D Jr, Woods J, Cox D, Elterman J, Branson R. Automated control of endotracheal tube cuff pressure during simulated flight. *J Trauma Acute Care Surg*. 2016;81(5 suppl 2): S116-S120.

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