Course Manual prepared by Karyn Hathaway (Flight CNS) & Sarah Rodgers (Senior Flight Nurse)

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More information on the Wellington Flight Course can be found at http://www.wellingtonicu.com/Education/Courses/Flight/
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Section One: Background
Objectives of the Aeromedical Transport Training Course

- To introduce air medical personnel to the aviation environment.
- To provide a thorough understanding of the importance of helicopter and fixed-wing safety, pre-flight briefing and dangerous goods and identifying and avoiding hazards in and around the aircraft.
- To describe aviation physiology, how the gas laws effect air medical personnel and patients, and identify the appropriate treatment or intervention.
- To provide an understanding of the stressors of flight on air medical personnel and patients, and to describe ways to prevent these adverse effects.
- To introduce air medical personnel to the principles and preparation of a patient for air transfer.
- To provide an overview of the varying speciality patient groups that may require aeromedical transport and discuss their flight and transfer preparation and management.
- To experience emergency procedures during a crash landing in water, and discuss survival on the land.
- To apply the knowledge gained during this course in practice through scenarios and simulation in the CCDHB air ambulance simulator

Introduction to CCDHB’s Flight Service

The CCDHB Flight Service was established in 1994 and provides a tertiary interhospital patient transfer service based at Wellington Hospital. This resource is an integral part of CCDHB’s ability to provide tertiary-level care for secondary hospitals in Blenheim, Nelson, Masterton, Kenepuru, Hutt, Whanganui, New Plymouth, Hastings and Palmerston North. Patients within CCDHB’s area also require access to specialised services that cannot be provided in Wellington (such as spinal injuries, diving injuries and paediatric oncology to Christchurch; children requiring transfer to Starship Hospital in Auckland).

The population for this region (as of June 2015) is 1.15 million people. Transports are undertaken by fixed wing aircraft, helicopter and in some circumstances road ambulance.

There is inherent risk associated with the interhospital transfer of patients that increases with their acuity. Many patients are acutely ill and all require significant clinical expertise in a challenging environment far removed from the support that is immediately available in a hospital. International standards, aligned with policy statements from all three relevant Australasian medical authorities (the colleges of Intensive Care, Emergency Medicine & Anaesthesia), dictate that only specialist teams should be used for the interhospital transport of patients; this is the role that the CCDHB Flight Service fulfils.

The majority of the CCDBH Flight Service workload involves the retrieval or transport of acute and critical patients. The number of referrals to the service and the number of missions undertaken has steadily increased year on year.
There are a number of other flight services within our region who provide secondary transfer services.
Introduction to Aeromedical Retrieval Services in New Zealand

Aeromedical transport is a functional extension of Emergency and Critical Care Services. This is especially so in a tertiary referral centre such as Capital & Coast District Health Board (CCDHB).

- Sophisticated and technologically advanced treatments are available at regional referral centres; retrieval teams must meet the same standard of care and excellence.

- It is essential that treatment begins at the point of origin and continues en-route to ensure viable arrival.

- This demands training of doctors, nurses and crew, as well as funding, developing and equipping of a communication and administrative network.

  “The quality of management during inter-hospital transport must be equal to or better than that at the point of referral”. (The RAC Report May 1994.)

- Aeromedical services are divided into three categories:
  Tertiary retrieval is paramount and part and parcel of a tertiary referral centre
  Secondary transport – Inter-hospital transfers
  Primary retrieval – part of the acute trauma management system

- Hospital transfers by air are rarely primary retrieval, as 95% are inter-hospital transfers. Patients therefore require a higher level of care than can be provided by Emergency Medical Service (EMS) crew.

- Within New Zealand there are tertiary flight services based in Waikato, Wellington, Christchurch and Dunedin. There are specialist PICU, NICU and ECMO retrieval services based in Auckland.

- Many regional DHBs have secondary flight services and are able to transport lower acuity patients and patients returning to their DHB of domicile. These are most often nurse only flight services. There are some who have the capability to undertake acute and ICU level transport when appropriate resources are available.
Consent for Treatment

Based on the current Capital & Coast District Health Board policy the same considerations apply to care during transport as it forms part of the patient’s necessary treatment.

Point 8.1 – Informed Consent Policy

♦ Specific reference 3.6 on emergencies: - ‘May receive treatment without consent if it is necessary to ensure improvement or prevent deterioration and the treatment is in accordance with good medical practice.’

♦ Ref 3.11 and 3.12 - ‘A Welfare Guardian appointed by the Family Court can give consent.’

♦ Ref 3.27 - ‘Although every consideration will be given to the wishes of the immediate family of patients, it is noted that spouses, family and friends cannot consent to treatment on the behalf of a patient.’

Point 8.3 – Procedure when Consent is not practical

♦ Ref 3.3.4 - ‘The reason why patient cannot give consent should be recorded.’

♦ Ref 3.4 - ‘Declaration form signed by staff.’

♦ Ref 3.7 - ‘Everyone has the right to refuse medical treatment.’

Point 8.4 – Refusal of Treatment

♦ Ref 4.5 - ‘The circumstances surrounding patient’s decision to decline must be clearly and fully documented.’

♦ Ref 4.6 - ‘The patient does not sign a form.’
Section Two: Safety
Helicopter Safety

1. *Watch the Pilot*
   - Follow his/her directions, proceed when the pilot indicates.

2. *Approach from the Front*
   - The pilot cannot see you at the back and the tail rotor is lethal.

3. *Approach from the Downhill Side*
   - On a slope, approach and leave the helicopter on the downhill side.

4. *Blinded by Dust*
   - Crouch and wait until you can see again and re-establish contact with the pilot.

5. *Board a Hovering Helicopter*
   - Do this slowly, one person at a time.

6. *Secure all Clothing, Equipment*
   - These can be caught in the rotor wash.
   - Carry all long objects horizontally.

NO SMOKING IN OR AROUND THE AIRCRAFT
Fixed Wing Safety

1. **Pilot**
   - Follow his/her instructions.

2. **Approach**
   - Be aware of
     - Other personnel in and around the aircraft
     - The positions of support vehicles
     - Other aircraft.

   Never enter, exit or conduct activities around a running engine.

3. **Restraints**
   - Patients must be restrained with the approved stretcher fittings and maintained during the flight.
   - Crew must remain buckled up during take-off and landing and when not administering nursing care.
   - Advise pilot if moving around cabin.

4. **Communication**
   - Be familiar with the equipment
   - Refrain from talking during taxi, descent, ascent, landing and high-density air traffic operations.

5. **Equipment**
   - All equipment must be secured and stowed.

6. **Danger**
   - Fuel
   - Oxygen
   - High exhaust temperature
   - Jet blasts
   - Loose objects, such as clothing and equipment.

NO SMOKING IN OR AROUND THE AIRCRAFT
Pre-Flight Briefing

Pre-flight briefing of persons on board an aircraft is a legal requirement, (CAA Reg 91.211, Dec 1977). This is generally delegated to the crew, if not, then the flight nurse should carry out the task.

Before boarding consider:

- Sensible clothing of patient and staff, warm not nylon
- Effects of flying when recovering from minor cold, ear, sinus infection
- No alcohol prior to flight
- No smoking during the flight
- Ensure luggage is not overweight, no hazardous materials, e.g. matches, lighter fluid, aerosol cans
- If no toilet on board, ensure comfort stop before leaving.
- Cell phones

Discuss implications of the environment:

- Noise level, ear protection, communication
- Affects of turbulence, seatbelt secure
- Ways to unblock ears if they feel full, pain.

Approaching the aircraft:

- Approach on the pilot’s direction
- Be aware of other aircraft, vehicles in the vicinity
- Avoid the propeller area at all times
- Escort all patients and relatives to the aircraft
- Instructions on the use of steps, handholds, stretcher loading
- No loose clothing or blankets
- If blinded by dust, crouch down and wait for assistance.

On board

- Instruction on how to fasten and release seatbelt. To remain fastened throughout the flight
- Instruction on emergency exits and how they operate
- All loose equipment to be stowed away and secured, no article to obstruct the exits
- Location of emergency oxygen and how it is activated
- Location of life jackets for all person on board and how they operate, not to be inflated until out of the aircraft
- Location of vomit bags
- Briefing card to read.

Pilot and medical crew

- Use of electronic equipment, cell phones
- Cabin altitude pressurisation requirements
- Rate of ascent and descent
- Implication of turbulence
- Heating/air conditioning needs
- Possibility of diversion due to weather, suitability facility
- ETA and liaison with transport requirements.
Pre-flight briefings are often hurried through or ignored, but it is a legal requirement. It must be part of the flight nurses’ professional responsibility to ensure that all onboard are informed about the environment they are in and have as much safety information as is practical, in order to give them the best possible chance of survival should anything go wrong. It is too late once an emergency happens.
NO

Dangerous Goods on aircraft

These substances can be extremely dangerous on aircraft.

Are you carrying them in your luggage or on your person?

If you have any of these items, declare them! Carrying these substances may be an offence and may result in prosecution.
Dangerous Goods

Articles listed below are considered dangerous goods particularly when flying and when in a non-pressurised space, such as the nose locker.

Patients/Relatives

Patients/relatives luggage should be checked for the following, removed and stowed in the pressurised cabin:

• Compressed gases, such as Butane gas in camping cylinders
• Corrosives such as acids, alkalis, mercury and wet cell batteries, which contain mercury
• Explosives, including guns, ammunition including blank cartridges, fireworks
• Flammable liquids and solids such as lighter fuel, matches, paint thinners, fire lighters
• Oxidising materials, such as bleaching powder, peroxides
• Poisons and infectious substances, such as insecticides, weed-killers and live virus materials.

Retrieving patients who have been involved in a chemical spill, petrol spill:

• Care must be taken to remove as much of the chemicals as possible before loading into the plane, due to the confined space.

Medical Crew

As medical crew, we should be aware that some of the drugs and equipment we carry come under the label of dangerous goods because of their ability to cause damage to the aircraft in some form if inappropriately used or spilled.

• Drugs, such as calcium, potassium, paraldehyde if spilled can be corrosive to aircraft materials
• Oxygen – danger of fire
• Mercury, such as that in thermometers and sphygmomanometers is corrosive to aluminium
• Blood poses an infection risk
• Administration of blood under pressure during flight without careful monitoring may result in spillage. Blood is corrosive to plane fittings
• Body fluids, such as vomit and urine, are also corrosive to the plane and the smell is difficult to remove.
Annual competency requirements for Flight Nurses (Clinical Support Crew)

Air Ambulance/Air Search and Rescue Standard: Minimum education, training and ongoing competency requirements for air ambulance and air-SAR activities (2013).

Name:

Aircraft safety briefing

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**Signature of Pilot/Crewperson**

FW ___________________  Heli_________________

**Other training requirements**

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The Phonetic Alphabet

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Fitness To Fly

Am I fit to fly...?

I
Illness
(no symptoms)

M
Medication
(no medication - or safe medication)

S
Stress
(no overstress, eg, worries arguments, etc)

A
Alcohol or Drugs
(a no-no!)

F
Fatigue
(good night's sleep, etc)

E
Eating
(sensible eating habits)

...Yes, I'M SAFE to Fly.
It’s Only A Cold!

By Dr. Dougal Watson

So your throat is sore, your nose running and your head throbbing as if to burst. You can’t help speaking with a characteristic nasal twang causing friends and colleagues alike to comment or ask “Got a cold have we?” Between coughs and sniffles you’re forced to reply “Yair but it’s not a problem. It’s only a little cold, I should be over it in a couple of days!”

This is a familiar story around most homes and workplaces and indeed a cold usually isn’t much of a problem. The situation could be very different if, however, you plan to travel in an aircraft while suffering from this usually inconsequential ailment.

I’d like to tell you a little bit about colds, what they are, what they do to your body and most importantly how these effects can alter your suitability to pilot an aircraft. This should allow you to make an informed decision, the next time you’ve got a cold, concerning your fitness to fly.

A cold is proper cause for taking the responsible action of voluntarily and temporarily grounding yourself from flying. I’ve suffered the pain and distress of bilateral haemotympanum (that’s bleeding into the eardrums of both ears, the stage before perforation or rupture of the eardrums) during an aerobatic spin sequence when, unknowingly, I was brewing a cold. I’ve also seen usually stout military aircrew reduced to tears of pain during descent because having a cold rendered them unable to clear the pressure in their facial sinuses. Although a minor ailment to most folk, a cold is a potential disaster to aviators (and those that fly with us).

What Is A Cold?

A cold is an infection, caused by any one of a hundred or so related rhinoviruses. It usually takes one or two days for a cold to incubate or brew once you’ve ‘caught’ it.

The first symptoms you notice are usually tiredness and irritability along with a tickly, scratchy throat, blocked or runny nose and a mild headache. The runny nose (rhinorrhoea) usually increases over the next couple of days and then settles rather rapidly as the whole illness resolves. Bouts of sneezing may also occur. A fever is unusual during the common cold. A small number of people (around 1-2%) will develop bronchitis at the same time and have a cough that produces quantities of sputum (phlegm).

Most of us use the word ‘cold’ in reference to any illness or infection of the nose, throat, ears and lungs that involves a runny nose or mild cough. Many other viruses are also able to cause diseases similar to the common cold. The illness caused by these other viruses is often more severe than a common cold and may involve quite marked cough, fever, sore throat or even pneumonia.

The common cold, along with any of the above mentioned viral upper respiratory tract infections, is often more severe in children.

You won’t be surprised to hear that colds are more common in the Winter and Autumn. Nobody is certain why this is the case, but it may have something to do with the increased time we all spend indoors close to other people during the colder months.

For the purpose of this article I’m not going to distinguish between all of these related but different illnesses. I’m simply going to use the word ‘cold’ to denote any or all of the above – after all, they have similar relevance to aviators.

What Happens During the Infection?

The offending virus usually gains access to your body through the lining tissues of your upper airways, especially the nose or throat. It invades the cells there and sets about doing what viruses do best, trying to
produce more of its kind and send them forth into the world to infect other cells and produce even more viruses. To do this the virus must hijack machinery and equipment within the cell. This machinery is reserved for the cell’s privileged use and the hijacking may set off alarms and alert the body’s defence (or immune) system.

As the virus multiplies the cell may rupture and millions of new viruses spill into the bloodstream or nearby tissues. This release of new viruses may also alert the immune system’s equivalent of ‘customs and immigration’, ever watchful for viruses without visas. The release of new viruses causes the cell to die and the immune ‘homicide squad’ may also be called. The alerted immune system then mobilises to seek and destroy all viruses, bits of viruses and hijacked infected cells. This is usually achieved rapidly and the illness rarely lasts much longer than a few days. This response almost invariably results in swelling of the infected areas as the battle rages between the immune system and the infecting virus.

Once a virus has been vanquished, the immune system ‘remembers’ it and is able to recognise its closer relatives for a time. It is still possible for a not-so-closely-related virus to cause another cold soon afterwards and the memory eventually fades so that the same virus may again cause a cold some time in the future.

You can spread a cold to others because as you breath out virus particles may leave your nasal area in the air or within tiny fluid droplets. If someone near you breaths in some of the virus particles, the whole process may start afresh in their nasal passages.

**How Can A Cold Affect Flying?**

The two features of a cold that are most important to aviators are the overflow of new viruses into the bloodstream and the swelling of nose and throat tissues. The first of these, the release of new viruses from their host cell into the body is often called the ‘viraemic phase’. This viraemic phase usually results in the headaches and general feeling of tiredness, lethargy and unwellness that is usually associated with a cold.

Anything that makes you feel tired and unwell is a distraction from flying and may well impair your decision making abilities at a critical moment. The viraemic phase of a cold is no exception and our mental and physical performance is always impaired. As aircrew we can ill afford any impairment of our performance that may affect our safety and that of the craft we fly and those that choose to fly with us.

As the tissues lining the nasal area swell the tiny openings to the ears (eustachian tubes) and the sinuses (ostia) become narrowed and may close over. Closure of these small tissue lined tubes makes ear and sinus pressure equalisation difficult or impossible. Inability to equalise our ears and sinuses during ascent or descent may result in pain and tissue damage. The term barotrauma (as in barometer) is used to refer to these pressure related tissue damage.

The pain of sinus and ear barotrauma can be of crippling intensity leaving the sufferer unable to devote attention to the task of flying. The tissue damage, which could include rupture of the eardrums or the filling of a sinus with blood, may adversely affect our short and long term ‘fitness to fly’. It’s really not worth the risk.

**What Can You Do?**

The first action for an aviator with a cold is the simplest, but often the most difficult. When you have a cold you are most certainly not fit to fly. It’s as simple as that; the risks are just not worth it. To fly whilst suffering a cold a professional aviator would be exposing his passengers, cargo and employer to an added, avoidable risk while a sports aviator exposes himself, his passengers and his craft to the same unnecessary risks.

As an air passenger you are still exposed to the same risks during a cold. It is unlikely, though, that as a passenger you could cause the wreck of an aircraft or the injury of others. Should you choose to travel by air as a passenger while you’ve got a cold there are a few things you might find useful knowing.
There is no cure (yet) for the common cold! Our immune system is the only avenue we have for ridding our body of the cold virus. To function at its peak our immune system must be maintained by a sensible and well-balanced diet. Large doses of vitamins or mineral supplements do not cure the common cold. The body also requires adequate rest for its immune system to remain in peak condition.

Antibiotics do not cure colds! Viruses are immune to antibiotics. It is only when the cold is likely to become complicated with a second, overlapping bacterial infection that antibiotics have any place at all in the management of colds. Anyone healthy enough to maintain an aircrew licence is extremely unlikely to suffer any bacterial complications of a common cold.

It is only if the cold symptoms are sufficiently severe that medication has any place in treatment of a cold. Even then the only effect that medicine will have is some relief of the symptoms. Medication can’t cure or dispel a cold. Aspirin or Paracetamol will help to relieve a headache or sore throat and may settle a mild fever. Decongestants will reduce some of the swelling of the nasal lining tissues and may make it easier to equalise the ears or sinuses. It may also be possible to relieve an irritating cough with a cough mixture or tablets.

**Conclusion**

- A cold is an upper respiratory tract infection caused by any of a large number of viruses.
- There is no cure for a cold, the body’s immune system must be allowed to fight the infection.
- Adequate rest and a sensible diet are the best ways to help your immune system.
- Flying with a cold is just not worth the risk.

This article was originally published as:  
Section Three: Flight Physiology and the Stressors of Flight
Aeromedical Transport – ‘Do it on the Ground not in the Air’

Objectives

- Describe the significance of gas laws in aeromedical transport and understand the effect of altitude.
- Demonstrate knowledge of the stresses of flight.
- Demonstrate how to safely prepare a patient for transport.
- Discuss in-flight and post-flight care.

Flight Physiology

In-depth knowledge of flight physiology together with adequate time spent preparing the patient is essential to provide optimal patient care in the aeromedical environment.

Normal physiological responses to change altitude are further complicated when transporting an already compromised patient.

It is not simply a case of using any aircraft and whatever medical staff might be available.

**STRESSORS OF FLIGHT**

- Hypoxia
- Barometric Pressure
- Fatigue
- Thermal
- Dehydration
- Noise
- Vibration
- G-Forces
- Third Spacing
Gas Laws

It is important to know the major gas laws that govern some of the physiological responses in the aeromedical environment.

Boyle’s Law
*A constant temperature/volume is inversely proportional to pressure, therefore as altitude increases gas expands. The reverse is true when the aircraft descends.*

- Pressurised aircraft minimises these effects
- Affects respiratory rate
- Intravenous flow rates
- Expansion of gases in hollow organs, such as stomach causing nausea/vomiting
- Sinus pressure due to head colds/blocked sinuses
- ET tube cuff expansion
- Increased pain.

Charles’ Law
*At a constant pressure, the volume of a gas is directly proportional to its absolute temperature.*

- Increases in temperature makes molecules move faster
- Greater force is exerted leading to volume expansion and vice versa
- Gas cylinders will read low when cold although volume remains unchanged.

Dalton’s Law
*Pressure of a gas mixture equals the sum of partial pressures of gases making up the mixture*

- Oxygen percentage is consistent at all altitudes
- Total atmospheric pressure is reduced at altitude, so is the oxygen available for respiration as oxygen molecules are further apart
- Hypoxia occurs.

Henry’s Law
*The weight of gas dissolved in a liquid is directly proportional to the weight of the gas above the liquid.*

- Solubility restricts amount of gas that will dissolve, e.g. bottle of soda
- Cap on – the gas above liquid creates equilibrium
- Cap off – gas pressure decreases above liquid causes gas bubbles to be released
- A physical example of this law – decompression sickness.

Graham’s Law
*Diffusion rate of gas through liquid is directly related to the solubility of the gas and inversely proportional to square root of its density or gram molecular weight.*

- Carbon dioxide is 19 times more diffusible than oxygen due to solubility factor.
Hypoxia

Hypoxic Hypoxia
Reduction in oxygen pressure in inspired air or lungs causing inadequate gas exchange across alveolar membrane.

- Altitude sickness – an acute syndrome which results from lack of oxygen within the tissues secondary to a decreased partial pressure of oxygen in the inspired air
- Asthma

Anaemic Hypoxia
Reduction in the oxygen carrying capacity of the blood.

- Decreased Hb – haemorrhage/anaemia
- Modified Hb – carbon monoxide poisoning.

Stagnant Hypoxia
Inadequate circulation leading to reduction in blood flow through the tissues.

- Cardiac failure, shock, venous pooling
- Cardiac arrest

Histotoxic Hypoxia
Reduction in the ability of the tissues to use available oxygen supply. Respiration and oxygen tension is normal.

- Cyanide poisoning
- Alcohol/drugs

Oxygen Requirements

- Increasing altitude requires oxygen increase
- Following equation determines oxygen requirements at a given altitude:

  \[
  \text{Current \( \text{FiO}_2 \times \text{Current Barometric Pressure} = \text{FiO}_2 \) required}
  \text{Destination Altitude Barometric Pressure}
  \]

Altitude Physiology and the Stresses of Flight


Introduction

Aspects of transport medicine provide the air medical crew member with many unique challenges. This is especially true with respect to considerations related to altitude and flight physiology. An in-depth understanding of flight physiology is essential for the air medical crew to provide optimal patient care in the aviation environment. This objective is intensified since the normal physiological responses to a changing altitude are further complicated when transporting an already compromised patient. In addition to having a direct influence on the patient and the flight crew, some medical equipment also may be affected.

In general, the terms stresses of flight is commonly used to identify the conditions and physiological affect that the air transport environment may place on the patient and the flight crew. In addition to these stresses, there are a series of self-imposed stresses that can further influence crew performance, patient outcome and overall safety.

Altitude physiology and the stresses of flight will have their greatest impact during fixed-wing transport. However, it is important to realise that rotor-wing transport is not immune to these stresses. Also, an understanding and knowledge of these topics may be of some benefit for those transport personnel who use ground ambulances.

History

The effects of altitude on the human body have been noted for centuries. In 1783, the first, manned hydrogen balloon ascended to an altitude of 9,000 feet (2,750 metres).1 During this two hour flight, the solo pilot began to experience the physiologic affects of his new environment, which included a drop in temperature during ascent and a feeling of sharp pressure in one ear as he descended. Ten years later, a physician pilot and his passenger documented the first objective physiological changes at altitude. On the ground, the pilot's pulse was counted to be 84 beats per minute, and at altitude the pulse now was measured to be 92 beats per minute.

The dangers of high-altitude travel were demonstrated in 1804. At an altitude of more than 20,000 feet (6,000 metres), the crew experienced vomiting, frostbite of their hands and feet and loss of consciousness. It also was observed that the flame in their lantern went out. Nearly 60 years later, two Englishmen ascended to 31,000 feet (9,450 metres) in a balloon. During this ascent, numerous physiologic changes were observed.

At 19,000 feet (5,640 metres), the pulse increases to 100 beats per minute. At 19,500 feet (5,850 meters), breathing was affected, palpitations were perceived, hands and lips turned blue, and the crew experienced difficulty reading on-board instruments. “Sea-sickness” was experienced at 21,500 feet (6,510 metres); and at 28,500 feet (8,700 metres), there was extreme muscle fatigue and a period of insensibility lasting seven minutes.
Background

Before directing our attention toward the stresses of flight, it is important to have the background knowledge pertaining to the atmosphere, the physical gas laws and cabin pressurisation. A general understanding of these three topics helps illustrate how the human body responds to the atmospheric changes and begins to explain several of the stresses of flight.

The Atmosphere

The air medical crew must possess knowledge of the earth’s atmosphere and awareness of the effects that altitude can have on human physiology. This information will provide the essential foundation for the adaptations necessary for optimal patient care in the air medical environment.

The atmosphere is composed of a variety of gases. Up to an altitude of approximately 70,000 feet (21,319 metres), these gases exist in a uniform percentage. Nitrogen gas has the largest percentage (78.08%), followed by oxygen (20.95%). Argon, carbon dioxide, hydrogen, neon and helium – all in very small percentages – represent the remaining gases in the atmosphere.

The atmosphere can be characterised several ways. It may be described by the layers that are included within the atmosphere or by the physiological zones that predict the effects of altitude on the human body. Many of these predictable effects are based on atmospheric properties that can be observed at any given altitude. Atmospheric pressure or barometric pressure is the force or weight exerted by the atmosphere at any given point. Temperature and volume changes also will be observed at the varying altitudes. Altitude-related properties are shown in Table 1. The graphical relationship between altitude, inspired pO₂ and barometric pressure is represented in Figure 1.

![Figure 1: The relationship between altitude, inspired pO₂ and barometric pressure](image-url)
<table>
<thead>
<tr>
<th>Altitude</th>
<th>Barometric Pressure</th>
<th>Temperature</th>
<th>Gas Expansion Rate</th>
</tr>
</thead>
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<td>PSI</td>
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<td>1.85</td>
</tr>
<tr>
<td>50,000</td>
<td>15,240</td>
<td>87</td>
<td>1.68</td>
</tr>
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</table>
Layers of the Atmosphere

The Troposphere

The troposphere is the closest atmospheric layer to the earth. In general, this layer extends to an altitude of approximately 30,000 feet (9,144 metres) at the north and south poles, but only 6,000 feet (1,829 metres) above the equator. This difference is due to the rising of heated air. In the troposphere, the temperature will decrease approximately 3° to 4°F (2° C) for every 1,000 feet (305 metres) increase in altitude. In addition, a significant change in barometric pressure will start to be seen. Helicopter transport and a considerable amount of fixed-wing transport is performed within this layer.

The Stratosphere

The troposphere forms the boundary between the troposphere and the next layer – the stratosphere. The stratosphere extends from about 35,000 feet (10,650 metres) to about 50 miles (80km) above sea level. The temperature now has achieved a constant -69°F/-56°C, while barometric pressure continues to drop in the initial portion of this layer. No turbulence is experienced in the stratosphere. The majority of jet aeroplanes will routinely travel within this layer at 35,000 feet to 45,000 feet (10,540 metres to 13,715 metres) altitude.

The Ionosphere

The ionosphere ranges from 50 miles to 600 miles (80km to 960km) above the earth and forms a protective shield from ultraviolet radiation. From 600 miles to 1,200 miles (960km to 1,200km) above earth is the exosphere, which represents the vacuum of space.

Physiological Zones of the Atmosphere

There are four physiological zones that compose the earth’s atmosphere. These zones are characterised by the pressure changes that take place within the altitude boundaries and the physiologic effects on the human body.

The physiological zone

The physiological zone, or the efficient zone, extends from sea level to approximately 12,000 feet (3,658 metres). Within this zone, the barometric pressure decreases from 760 torr to 483 torr (torr = mmHg). This is the most acceptable zone for normal physiological function unless an individual acclimatises to a higher altitude or supplemental oxygen is used. With prolonged exposure, only minor problems may occur, especially if an individual continues to ascend, exerts him or herself, or stays too long.

The physiological deficient zone

A dramatic drop in barometric pressure and temperature is seen in the physiological deficient zone. Extending from 12,000 feet to 50,000 feet (3,658 metres to 15, 240 metres), the barometric pressure drops from 483 torr to 87 torr. Normal physiological function will be impaired seriously at the upper limits of this zone, if there is no appropriate intervention. Most commercial and private aviation occurs in this zone and the physiological zone.

The partial space equivalent zone & the total space equivalent zone

The partial space equivalent zone and the total space equivalent zone represent the final two physiological zones of the atmosphere. The partial space equivalent zone extends from 50,000 feet to 120 miles (15,240 metres to 192km), where a pressurised environment is mandatory to compensate for the barometric changes that can affect the body. The total space equivalent zone, extends from 120 miles (192km) above sea level and beyond. Weightlessness occurs within this zone, which represents “true space.”
The Physical Gas Laws

With an understanding of the characteristics of the earth’s atmosphere, knowledge of the gas laws helps explain the various changes that may be experienced at different altitudes.

**Boyle’s Law**

Boyle’s Law relates to the expansion of gases. It states that the volume of a given gas varies inversely as its pressure. The formula for Boyle’s Law is:

\[ P_1V_1 = P_2V_2 \]

When \( P_1 \) equals the initial barometric pressure; \( V_1 \) equals the initial volume of gas; \( P_2 \) is equal to the final barometric pressure; and \( V_2 \) is the final volume of the enclosed gas.

It is observed that as an aircraft ascends in altitude, the ambient (surrounding) barometric pressure will decrease and, using Boyle’s Law, the volume of gas within an enclosed space will expand.

As the aircraft descends from altitude, the reverse will be true. (See Figure 2)

![Boyle's Law](image)

Figure 2: Boyle’s Law

Using Boyle’s Law, gas expansion ratios can be calculated for the different altitudes. At the altitudes that helicopters usually fly (up to a few thousand feet above sea level, except in mountainous regions), the amount of gas expansion will be relatively small (10% to 15%). At 8,000 feet (2,438 metres) above sea level, the gas expansion will be 30%. This height is an important consideration for unpressurised aircraft and also represents the approximate cabin altitude for many pressurised aircraft flying at 35,000 feet to 40,000 feet (10,650 metres to 12,192 metres). The relationship between altitudes and gas expansion is depicted in Figure 3.

In the air medical environment, Boyle’s Law can affect any medical equipment or body cavity that has an enclosed air space. Intravenous flow rates, the pressure in military antishock trousers and endotracheal tube cuff expansion can be altered. Body cavities that can be affected include the stomach, intestines,
middle ear, sinuses and a closed pneumothorax. The respiratory rate and depth also may be affected. Other potential spaces include pneumocephaly, pneumointestinalis and subcutaneous emphysema.

An understanding of Boyle’s law helps explain the mechanism by which air is exchanged between the atmosphere and the lungs. When an enclosed air space doubles in size (e.g., the lungs), the pressure within the container will be halved. As the chest expands and increases in size from the movement of the thoracic cage and diaphragm, pressure within the chest cavity will decrease, becoming less than the surrounding ambient pressure. As a result, air will rush in until the pressure within the lungs is again equal to the surrounding atmosphere.

**Dalton’s Law**

Dalton’s Law of Partial Pressure describes the pressure exerted by gases at various altitudes, stating that the total pressure of the gas mixture is the sum of the individual or partial pressure of all the gases in the mixture. Mathematically, Dalton’s Law can be represented as:

\[
P_t = P_1 + P_2 + P_3 + \ldots + P_n
\]

When \( P_t \) is equal to the total pressure; and \( P_1 \ldots P_n \) represents the partial pressure of each gas in the mixture containing “n” gases.

Within a mixture of gases, each gas will exert a pressure equal to its own percentage of the total gaseous concentration. At sea level, where the total barometric pressure is 760 torr, the percentage of oxygen is equal to 20.95%. The partial pressure of oxygen (\( P_{O_2} \)) at sea level can be calculated as:

\[
P_{O_2} = 20.95\% \times 760 \text{ torr} = 159.22 \text{ torr}
\]

From sea level to 70,000 feet (21,319 metres), the percentage of each gas within the atmosphere remains constant.
Table 2: Atmospheric Composition at Sea Level & 10,000 Feet

<table>
<thead>
<tr>
<th>Gas</th>
<th>Percentage within the Atmosphere</th>
<th>Partial Pressure (torr)</th>
<th>At sea level</th>
<th>At 10,000 feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>78%</td>
<td>593</td>
<td>408</td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td>21%</td>
<td>160</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>Other gases</td>
<td>1%</td>
<td>7</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Total in the atmosphere</td>
<td>100%</td>
<td>760</td>
<td>523</td>
<td></td>
</tr>
</tbody>
</table>

As the altitude increases and the total barometric pressure decreases, the partial pressure of the gaseous components will decrease, exerting less pressure. At an altitude of 10,000 feet (3,048 metres), the atmospheric pressure is 523 torr (table 2). The percentage of oxygen remains 20.95%, but the partial pressure of oxygen will decrease as follows:

$$\text{PO}_2 = 20.95\% \times 523 \text{ torr} = 109.56 \text{ torr}$$

**Figure 4: Dalton’s Law**

The decrease in partial pressure at altitude is an important consideration for oxygen delivery into the body. A pressure differential is required for oxygen to cross the alveoli into the bloodstream. As a result of this decrease in the partial pressure of oxygen, less oxygen is transferred to the body.

In addition, as altitude increases and pressure decreases, gas expansion causes the available oxygen to decrease as gas molecules move farther apart in a given volume of air. Therefore, less oxygen is available to enter the lungs with each breath. The net result of these pressure changes and the gas laws is hypoxia. (See Figure 4)
**Henry’s Law**

Henry’s Law explains the solubility of gases within a liquid. This law states that the quantity of gas dissolves in 1 cm$^3$ of a liquid is proportional to the partial pressure of the gas in contact with the liquid ...$^2$. The amount of gas that will dissolve in a liquid is determined by the partial pressure of a gas and solubility of the gas.

A carbonated beverage bottle is a common example of Henry’s law. The gas above the liquid creates an equilibrium with the gas dissolved in the liquid while the cap is on. When the cap is removed, the pressure decrease in the gas above the soda allows the gas bubbles within the liquid to be released. The *bends*, a decompression sickness, is another example. A scuba diver ascending too quickly can cause nitrogen gas bubble formation in the blood.

Henry’s Law further explains the gas transfer between the alveoli and the blood. Gases have a tendency to move from an area of higher concentration to that of lower concentration. As the partial pressure of a gas changes (Dalton’s Law), the amount of that gas in solution also will change.

**Cabin Altitude**

The first protection against the influences of a changing altitude is the creation of an artificial atmosphere or cabin altitude. In a pressurised fixed-wing aircraft, compressed air is pumped into the cabin to maintain a cabin altitude significantly less than the flight altitude. There are three factors that work together to maintain a constant pressure within the aeroplane: the amount of compressed air that can be introduced based on the aeroplane’s fuselage construction, a known leak rate of air from the aeroplane and a controlled outflow of air.

The amount of pressurisation in the aircraft often is set by the pilot. Therefore, the cabin altitude may vary as the flight altitude changes. In most pressurised aircraft a cabin altitude of approximately 8,000 feet (2,438 metres) can be achieved while flying at an actual altitude over 40,000 feet (12,192 metres).$^4$

A malfunction of the pressurisation equipment or aircraft structural damage from a cracked window or foreign object may result in a loss of cabin pressure or decompression. The effects of a decompression will depend on several factors; total cabin volume, size of the structural defect in the hull, flight altitude, and the pressure differential between the flight altitude and the cabin altitude.

During a rapid decompression, there is a loss of pressure, within one to three seconds, through a large defect. This results in an explosive noise, a rapid temperature drop and flying debris towards the hole. The aircraft will fill with fog due to moisture condensation in the expanding cabin atmosphere. Crew members, patients and equipment that are not properly restrained may be tossed about the cabin or even pushed out if they are near a large cabin defect.

Hypoxia is the most important clinical consequence of rapid decompression at high altitude. Oxygen tension in the blood will drop very quickly. Depending on the altitude, a person’s effective performance quickly may be compromised. In a rapid decompression, supplemental oxygen must be applied first to the pilot and the medical crew and finally to the patient.

Another significant event caused by rapid decompression will be the rapid expansion of air within an enclosed space. All catheters, chest tubes and nasogastric tubes then should be unclamped. These related topics are discussed in greater detail in the next section.

**Stresses of Flight**

To have a better understanding of the impact the stresses of flight can have on both the patient and the medical crew, it is important to appreciate the link between “stress” and work performance. Stress results
from perceived imbalance between a demand and the ability to meet that demand. Stress can cause fatigue and suboptimal work performance.

Dr P A Hancock studied heat stress and task performance. He concluded that familiarity with the stressor reduces the physiological impact of the stress and that consistent practice or familiarity with the task reduces the behavioural impact of the stress. These conclusions may be expanded to relate to many of the “routine” functions undertaken in medicine and air medical transport. Patient simulations in advanced cardiac life support, advanced trauma life support, emergency medical services disaster drills and downed aircraft drills are designed to familiarise the participants to the “task” being practised. Similarly, a thorough knowledge and understanding of the stresses of flight may prevent related complications during either helicopter or fixed-wing medical transport.

As previously introduced, there are two types of stresses associated with the aviation environment and air medical transport. They are the “stresses of flight” and “self-imposed stresses.” It is important to realise that these stresses are cumulative and may lead to significant compromise.

Several authors and organisations have identified various stresses of flight. The Air Medical Crew National Standard Curriculum identifies nine stresses of flight: barometric pressure, hypoxia, thermal, dehydration, noise, vibration, gravitational forces, third spacing and fatigue.

**Barometric Pressure**

The effects of a changing altitude during air medical transport may be related directly to the physical gas laws. The impact of barometric pressure changes can affect the medical crew, patient and equipment in many ways. With respect to the body’s physiologic response to changing pressures, there are several types of “injuries” that can develop. These injuries can result in actual tissue damage or may cause only pain to the individual.

There are three distinct terms often used when discussing the effects of barometric pressure. Dysbarism represents the general topic of pressure-related injuries. Barotrauma refers to the injuries that are a direct result of the mechanical effects of a pressure differential. The complications related to the partial pressure of gases and dissolved gases are called decompression sickness.

There are three mechanisms by which barometric pressure affects the body. The first follows Boyle’s Law, dealing with gas within an enclosed space and changes in ambient pressure. If air is unable to escape, a positive pressure develops that may result in a rupture or the compression of adjacent structures. The second mechanism follows Henry’s Law when gas dissolved in blood is released. The third mechanism applies to barometric changes in an underwater environment (eg scuba diving) and addresses abnormal tissue concentrations of various gases. The latter topic will not be discussed in this article.

**Barotitis Media**

Barometric pressure changes can result in disturbances of the middle ear, commonly referred to as *barotitis media, middle ear squeeze or ear block*. The tympanic membrane separates the middle ear from the outer ear. The eustachian tube, which forms a connection between the middle ear and the external atmosphere by way of the nasopharynx, usually functions as a one-way valve. This allows gas to escape, but not return to the middle ear. Gas will expand in the middle ear behind the tympanic membrane as altitude increases. During ascent, gas normally will escape through the eustachian tube every 500 feet to 1,000 feet (150 metres to 305 metres), or when there is a pressure differential of approximately 15 torr to 20 torr. This will allow for the equalisation of pressures between the middle ear and the surrounding atmosphere.

As altitude decreases, the gas within the middle ear contracts, creating a negative pressure within the middle ear, pulling the tympanic membrane inward. Under normal circumstances, the eustachian tube will not allow the passive movement of air back into the middle ear. However, the eustachian tube can be opened actively allowing equalisation with the middle ear by using positive pressure originating from the nasopharynx or by using the jaw muscles.
Under normal situations, pressure in the middle ear is equalised without incident. However, equalisation may be compromised if the eustachian is obstructed by swelling of the mucosa, the presence of polyps, previous trauma, allergies, upper respiratory infection, a sinus problem of smoking. Therefore, flying is not recommended for crew members who are symptomatic of any of these conditions.

Barotitis media can affect both the crew and patient if they do not equalise pressure successfully. A fullness in the ears may occur as equalisation takes place during ascent. A conductive hearing loss may occur as result of decreased vibration of the eardrum. Severe pain, tenderness, vertigo, nausea, tinnitus, perforation of the eardrum and bleeding can occur during either ascent or descent if pressures are not equalised. Typically, individuals will become symptomatic when the pressure differential approaches 100 torr. The severity of symptoms will depend on the individual’s initial condition, rate of ascent or descent and individual compensatory mechanisms.

Air medical crew members should be familiar with the early symptoms of barotitis media. The treatment is directed toward the equalisation of pressure between the middle ear and the atmosphere. Ideally, attempts should be made to equalise pressures before the symptoms become severe. Equalisation may be accomplished by yawning, swallowing or performing the valsalva manoeuvre. The Frenzel manoeuvre is another suggested treatment. This manoeuvre is performed by forcing closed the glottis and mouth while contracting the superior pharyngeal constrictors and the muscles of the floor of the mouth. The use of a topical vasoconstrictor nasal spray may be beneficial when used 15 minutes before descent. These nasal sprays also may be helpful if used 15 minutes before take-off. If there is concern for barotitis, sleeping patients should be awakened five minutes before descent, so they can swallow more frequently. Infants can be given a bottle during take-off and landing to achieve similar results. While swallowing may reduce the likelihood of barotitis media, it may increase the incidence of gastrointestinal (GI) distress after take-off due to increased air in the stomach.

A slow descent from altitude – 500 feet/minutes (150 metres/minute) – always is recommended to minimise the onset of symptoms. If the descent is too rapid, the pilot may have to increase altitude again to allow equalisation of pressure in the middle ear before attempting to descend again.

If pain persists after a flight, decongestants and analgesics may be used. Individuals who remain symptomatic should refrain from further altitude exposure until all signs and symptoms have resolved. Erythema of the tympanic membrane resolves within one to three days, while it will take two to four weeks when there is blood behind the tympanic membrane. A perforated tympanic membrane should be allowed to heal before flying again. This may take several days to weeks.

**Barotitis Externa**

The external auditory canal is normally a patent, air-filled cavity that communicates with the surrounding environment. If the external canal is obstructed, the enclosed air space will be subject to the increased ambient pressure during ascent to altitude, resulting in an external ear squeeze or *barotitis externa*. This obstruction can be due to cerumen, earplugs or other foreign bodies. For this reason, tightly fitting earplugs are not recommended during take-offs, landings or significant changes in altitude.

**Barosinusitis**

Air normally can pass in and out of the sinus cavities without difficulty, resulting in minimal effects, if any, as a response to barometric pressure changes. However, if a person has a cold or sinus infection, the lining of the mucous membrane may become swollen. As a result, air may be trapped that will expand as altitude increases. Failure of the air-filled frontal or maxillary sinuses to equilibrate results in pain in or pressure above, behind or below the eyes. This is commonly referred to as sinus squeeze. Pain may persist for hours and may be accompanied by a bloody nasal discharge or epistaxis. The ethmoid and sphenoid sinuses rarely contribute to this type of barotrauma.

The treatment for barosinusitis is similar to the treatment of barotitis media. The most effective method includes the use of a vasoconstrictor nasal spray and returning to a higher altitude.
**Barodentalgia**

Air trapped in dental fillings, caries, abscesses or crowns may result in a severe toothache. This type of barotrauma is referred to *barodentalgia* or tooth squeeze. It’s often associated with recent dental extraction, dental fillings, periodontal infection, periodontal abscess or tooth decay. While this is a rare problem, the pain can be severe. Treatment is directed toward preventative dental care, descending to a lower altitude and pain control. Following dental procedures, a minimum of 24 hours is advised before air transport.

**Barogastralgia**

Barogastralgia refers to the effects that barometric pressure change will have on the gastrointestinal system. Under normal circumstances, the stomach and intestines contain approximately one quarter of gas. Gas expansion during ascent may cause discomfort, abdominal pain, belching, flatulence, nausea, vomiting, shortness of breath or hyperventilation. Significant distension of the abdominal contents may result in venous pooling that may lead to syncope. In addition, tachycardia, hypotension and syncope may result from a vasovagal response to severe pain.

Barogastralgia is rarely a serious problem. However, ingesting a large amount of carbonated beverage, chewing gum (and swallowing air), eating large meals and pre-existing GI problems may all increase the amount of gas in the intestines. Therefore, to prevent intestinal complications due to gas expansion, it is recommended to avoid these practices whenever possible. Wearing clothes that are loose and non-restrictive, belching or passing flatus may help prevent or relieve symptoms. Patient with a bowel obstruction or recent abdominal surgery must have a patent and unclamped nasogastric tube placed prior to transport. After a major surgical procedure, air trapped could persist. It is advisable to delay high-altitude, fixed-wing transport for 24 hours to 48 hours for these patients.

**Barometric Effects on the Respiratory System**

The most critical impact that altitude will have on the respiratory system is hypoxia, which will be addressed in detail later. In addition, special attention should be paid to the patient with a suspected or documented pneumothorax. Due to expansion of the trapped gas, a patient with an existing closed pneumothorax is prone to further collapse if exposed to high altitude transport. Generally, once a chest tube is placed, most patients can be transported safely by helicopter or fixed-wing aircraft. If a chest tube is placed, it is important to carefully monitor the patient for evidence of hypoxia or malfunction / occlusion of the chest tube. In addition, artificially ventilated patients must be monitored for the possible development of a tension pneumothorax.

During helicopter transport from the scene of an accident, it may not always be possible or practical to place a chest tube prior to transport. With normal ascent of 1,000 feet to 2,000 feet, the barometric pressure change will be minimal, and the change in volume of the pneumothorax will be less than 10%. If this were the only factor that might change, the patient may not be affected adversely. It is essential, however, for the crew to closely monitor the patient for any clinical deterioration during transport.

**Barobariatrauma**

Barobariatrauma is a potential complication of barometric changes in the presence of obesity. Adipose tissue has a high concentration of nitrogen. Changes in ambient barometric pressure may weaken the adipose cell membrane allowing nitrogen to be released into the blood stream. Additionally, fat emboli may develop from the release of large concentrations of lipids.

To minimise the risk of barobariatrauma, it is recommended that the obese patient be placed on 100% oxygen for approximately 15 minutes prior to air medical transport. This will help remove nitrogen from the patient and reducing the risk by as much as 50%.8
The symptoms of barobariatrus will be similar to those that may be seen with decompression sickness or with fat emboli. The obese patient should be observed for severe dyspnoea, chest pain, tachycardia, pallor and petechiae in areas of the neck, upper thorax or axilla.

**Considerations During Pregnancy**

Foetal hypoxia may be a concern during air medical transport of pregnant patients or for pregnant flight crew members. However the results of available research suggests that there is no significant risk to the mother or to the foetus as a result of air medical transport.

It has been shown that the arterial partial pressure of oxygen in the foetus is significantly lower than that of the mother. A normal fetus at sea level has an arterial oxygenation (PaO₂) of 32 torr in the umbilical arterial circulation. The mother’s PaO₂ will be approximately 100 torr. At an altitude of 8,000 feet (2,438 metres), the mother’s PaO₂ will drop to 64 torr and a saturation of approximately 90%, while the fetal PaO₂ will drop only from 32 torr to 25.6 torr. Another study looking at this topic showed no evidence of fetal hypoxia with cabin altitudes of 1,100 feet to 7,000 feet (335 metres to 2,134 metres) for flights up to 80 minutes long. In addition to the lower arterial partial pressure of oxygen in the foetus, it has been shown that the oxygen dissociation curve for fetal haemoglobin differs from that for mature haemoglobin. Consequently, fetal haemoglobin is more fully saturated at a lower PaO₂ than is the mother’s.

**Barometric Effects on Medical Equipment**

Air enclosed within a confined space in any piece of medical equipment will be subject to the changes in atmospheric pressure. This phenomenon may complicate medical care, creating challenging and unusual problems for the air medical crew.

Endotracheal tube cuffs will be affected by the change in altitude and should be evaluated to prevent balloon rupture of excessive pressure on the tracheal wall during ascent. During descent, an inadequate air seal may develop. Replacing the air in the endotracheal tube cuff with water will eliminate this potential complication during air medical transport. The air in intravenous containers will expand on ascent resulting in an increased flow rate. On descent, the flow will slow as air volume is decreased. Military antishock trousers and pneumatic splints also may be affected by pressure changes. At altitude, a compartment syndrome may develop and distal circulation may be compromised. On descent, inadequate support may occur from inadequate air pressure in the pneumatic splints.

**Decompression Sickness**

A loss of cabin pressurisation may result in a variety of decompression sicknesses, as gas dissolved in blood is released. The altitude threshold for this complication is approximately 18,000 feet (5,486 metres). However, this is rarely a problem under 25,000 feet (7,620 metres) unless there has been recent exposure to compressed gas (eg scuba diving). An exposure of 30 minutes to three hours at altitudes from 26,000 feet to 47,500 feet (7,925 metres to 14,467 metres) will result in a 1.5% incidence of decompression sickness, with the severity increasing with increased altitude and prolonged exposure.

The bends refers to a musculoskeletal syndrome involving the joints and is caused by the release of nitrogen gas from the blood into the tissues surrounding the joint. A sharp, throbbing or dull ache is a common presentation. In addition, there may be associated numbness or tingling. The most common joints affected are the knees, shoulders and elbows. Symptomatic relief may be obtained by splinting the extremity or by applying pressure over the affected joint. Massaging or moving the affected extremity often exacerbates the pain. The bends occur up to 75% of all decompression injuries.

The chokes is caused by gas embolisation that obstructs the pulmonary vasculature. Classic symptoms include shortness of breath, cough and substernal chest pain, tightness or burning sensation. The shortness of breath is described as a feeling of suffocation and the individual becomes tachycardiac, tachypnoiec and hypoxic. An uncontrollable dry cough is common, which is exacerbated by deep inspiration. The chest pain is most frequently appreciated with deep inspiration, increased activity and smoking. There is no radiation of the pain to the neck, arms or abdomen.
Cutaneous forms of decompression sickness may cause a variety of skin rashes with or without tingling, numbness and itching. The release of gas bubbles also can cause subcutaneous emphysema, often involving the neck and other sites. If the neck is involved, the individual may complain of difficulty breathing or swallowing, and may notice a change in phonation.

Table 3: Effects of Altitude on Oxygenation

<table>
<thead>
<tr>
<th>Altitude (feet)*</th>
<th>Barometric Pressure (torr)</th>
<th>PAO₂ (torr)</th>
<th>PaO₂ (torr)</th>
<th>PaCO₂ (torr)</th>
<th>Oxygen Saturation</th>
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<tr>
<td>0</td>
<td>760</td>
<td>159.2</td>
<td>103.0</td>
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<td>98%</td>
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<tr>
<td>1,000</td>
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<td>98.2</td>
<td>39.4</td>
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<tr>
<td>2,000</td>
<td>706</td>
<td>147.9</td>
<td>93.8</td>
<td>39.0</td>
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<tr>
<td>3,000</td>
<td>681</td>
<td>142.7</td>
<td>89.5</td>
<td>38.4</td>
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</tr>
<tr>
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<td>137.4</td>
<td>85.1</td>
<td>38.0</td>
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<tr>
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<td>81.0</td>
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<tr>
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<td>76.8</td>
<td>37.0</td>
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<tr>
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<td>72.8</td>
<td>36.4</td>
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<td>68.9</td>
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<td>54.3</td>
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<td>51.0</td>
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<td>40.0</td>
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<td>37.8</td>
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<td>35.9</td>
<td>30.0</td>
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<td>34.3</td>
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<td>31.2</td>
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<tr>
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<td>282</td>
<td>59.1</td>
<td>30.4</td>
<td>27.0</td>
<td></td>
</tr>
</tbody>
</table>

*Refer to Table 1 for conversion from feet to metres

Other vital organs, including the brain, may be affected by decompression sickness. This may result in headache, visual disturbances (blurred vision, blind spots), sensory disturbance, partial paralysis, confusion, face or jaw pain, seizures or loss of consciousness.
High-flow oxygen (100% FIO2) and rapid descent represent the emergency treatment for all forms of decompression sickness. Treatment in a hyperbaric chamber will be necessary for severe symptoms that do not resolve.

Scuba divers should pay special attention to the possibility of decompression illness. An underwater dive to a depth of 30 feet (9 metres) with compressed air will cause the body to absorb twice the normal amount of nitrogen. As a result, flying above 8,000 feet (2,438 metres) will be equivalent to a non-diver flying at 40,000 feet (12,192 metres) in an unpressurised aircraft. Nitrogen gas bubbles may escape into the body resulting in a decompression sickness. The Federal Aviation Administration recommends that scuba divers delay flying as follows: at least 12 hours after diving to a depth greater than 30 feet (9 metres), or at least 24 hours after an ascent requiring staging.14

Hypoxia

There are numerous types of hypoxia, all of which may complicate air medical transport. Regardless of the cause, hypoxia represents an oxygen deficiency in body tissues sufficient to cause impairment of physiological function15. There are four physiologic classifications of hypoxia that can be described based on their various aetiologies16, 17.

Classification

Hypoxic hypoxia, also referred to as altitude hypoxia, is caused by an inadequate gas exchange at the alveolar-capillary membrane. The combined effects of the physical gas laws explain the etiology of this type of hypoxia at altitude. An inadequate supply of oxygen to the blood results in an oxygen deficiency to the tissues. Common causes include an airway obstruction, ventilation/perfusion defect or an inadequate oxygen partial pressure in inspired air. Hypoxic hypoxia represents the most common and most serious cause of hypoxia encountered at altitude. This may become apparent above an altitude of 10,000 feet (3,048 metres). If there is no compensatory mechanism or treatment, the blood oxygen saturation will drop precipitously. At sea-level oxygen saturation of 98% will drop to 87% at 10,000 feet (3,048 metres) and at 22,000 feet (6,706 metres) will be only 60%16. The effects of the various altitudes on PAO2 (arterial oxygen) are listed in Table 3.

The second classification of hypoxia is hypaemic hypoxia. A reduction in the oxygen-carrying capacity of the blood causes this type of hypoxia, which is also termed anaemic hypoxia. Blood loss, anaemia, drugs, dyshaemoglobinemias, excessive smoking and carbon-monoxide poisoning are common causes of hypaemic hypoxia.

Poor circulation in the body can cause an oxygen deficiency that is termed stagnant hypoxia. An inadequate cardiac output that cannot meet tissue requirements, occlusion of a blood vessel, venous pooling, arterial spasm or long periods of positive-pressure breathing can cause stagnant hypoxia.

The final classification of hypoxia is histotoxic hypoxia. In this situation, there is adequate oxygen on hand, but the body tissues are unable to utilise the available oxygen. Carbon monoxide poisoning, cyanide poisoning, alcohol ingestion and narcotics may result in this form of hypoxia.

Signs and Symptoms

During air medical transport, the most threatening factor of hypoxia is its insidious onset. The medical crew may be involved in flight activities and may not notice the early onset of signs or symptoms in the patient or themselves. No one is exempt from the effects of hypoxia, even though the onset and severity of symptoms may vary with individuals. Some individuals may tolerate a few thousand feet more altitudes than others. However, all patients and crew members will begin to experience symptoms of mild hypoxia if exposed to a high enough altitude.
Regardless of the cause of classification of hypoxia, the symptoms are generally the same. However, there are many factors that may influence an individual's susceptibility to hypoxia. Many predisposing medical illnesses will be exacerbated at altitude, including pneumonia, chronic obstructive pulmonary disease, acute asthma, pneumothorax, heart attack, shock and blood loss. Numerous social factors also will play an important role in one's susceptibility. Physical activity, physical fitness, metabolic rate, diet, nutrition, emotions and fatigue influence one's threshold for hypoxia. A physically fit individual normally will have a higher tolerance to altitude-related problems, while increased physical activity will raise the body's demand for oxygen and cause a more rapid onset of symptoms. Alcohol ingestion may promote histotoxic hypoxia. Smoking produces carbon monoxide, reducing the blood's capacity to combine with oxygen. An individual's metabolic rate will increase with exposure to temperature extremes, increasing oxygen requirements and, therefore, reducing the hypoxic threshold.

Respiratory Response

An increased rate and depth of respiration is the initial respiratory system response to hypoxia. The threshold for increased ventilation is usually an altitude between 4,000 feet to 5,000 feet (1,219 metres to 1,524 metres). The response may be minimal until an altitude of approximately 8,000 feet (2,438 metres), when the arterial oxygenation saturation drops to 93%. The maximum response occurs at approximately 22,000 feet (6,706 metres). At this elevation, the minute volume (respiratory rate multiplied by tidal volume) will approximately double. A change in tidal volume is responsible for the majority of this increase, rather than an increased respiratory rate.‡ Hyperventilation will result in a reduction of the partial pressure of carbon dioxide (PaCO₂), causing respiratory alkalosis and a shift of the oxyhemoglobin dissociation curve to the left. The result will allow an increased binding of oxygen with haemoglobin for transport to the tissues, but a decrease in the amount of oxygen released at the tissue level for a given saturation.

One of the effects of hypoxia on the respiratory system is to promote significant vasoconstriction of the pulmonary vascular bed. This will result in an elevation of the pulmonary arterial pressure and a subsequent increased workload on the right side of the heart. Providing supplemental oxygen acutely may relieve the hypoxia, but simultaneously may decrease alveolar ventilation. A respiratory acidosis may develop, again promoting pulmonary vasoconstriction and further increasing the pulmonary artery pressure.

An important consideration during air medical transport deals with medications that the patient may be given. Central nervous system depressants may inhibit the respiratory response to hypoxia that normally occurs at altitude. This emphasises the need to recognise the early symptoms of hypoxia, to properly monitor the patient and to aggressively treat patients who are hypoxic.

Central Nervous System Response

A common threshold for the onset of cerebral hypoxia is a PO₂ between 50 to 60 torr‡. Higher oxygen partial pressures also may be associated with hypoxic effects, based on an individual's predisposing medical condition(s), social factors, physical condition and activity level. The potent vasodilatory effects of hypoxia will overcome the hypocapneic vasoconstriction and result in an increased cerebral blood flow.

Hypoxia results in a decreased ability to function. The brain and the eyes will be affected significantly due to the high oxygen requirements of the organs. The initial central nervous system (CNS) signs and symptoms that may be observed include hyperactivity, restlessness, excitation, talkativeness and euphoria. The progressive effects of CNS hypoxia are directly proportional to the severity and duration of the hypoxic events. As CNS hypoxia persists, a patient or crew member will exhibit worsening mental confusion, impaired judgement, decreased attention span, impaired memory, depression, deterioration of visual field and/or depth perception, inability to interpret various other sensory input (eg sound, taste) and, finally, unconsciousness. Eventually, cerebral activity will cease and death will follow.

At higher altitudes, an individual's performance can be compromised greatly as a result of hypoxia. Effective performance time (EPT) refers to the amount of time an individual will be able to execute critical functions in an oxygen-deficient environment. This applies to pilots, as well as medical crew members,
when subjected to the same oxygen-deficient environment. Both patient care and safety of the transport could be compromised seriously if the crew is unable to initiate preventative or corrective action in flight.

As with the variable onset of symptoms, there are several factors that can influence EPT. Effective performance time will decrease at higher altitudes, with a faster rate of ascent, and with increased physical activity. In addition, the use of tobacco, ingestion of alcohol or certain medications and fatigue will shorten the EPT. The most dramatic effect on EPT is rapid decompression. The sudden loss of the artificial cabin altitude (pressurised aircraft) will result in an oxygen-deficient environment quickly. The EPT for an individual exposed to the varying altitudes is shown in Table 4.

### Table 4: Effective Performance Time

<table>
<thead>
<tr>
<th>Altitude (feet)*</th>
<th>Effective Performance Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>18,000</td>
<td>20-30 minutes</td>
</tr>
<tr>
<td>22,000</td>
<td>5-10 minutes</td>
</tr>
<tr>
<td>25,000</td>
<td>3-5 minutes</td>
</tr>
<tr>
<td>28,000</td>
<td>2.5-3 minutes</td>
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<tr>
<td>30,000</td>
<td>1-2 minutes</td>
</tr>
<tr>
<td>35,000</td>
<td>30-60 seconds</td>
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<tr>
<td>40,000</td>
<td>15-30 seconds</td>
</tr>
<tr>
<td>45,000</td>
<td>9-15 seconds</td>
</tr>
</tbody>
</table>

*Refer to Table 1 for conversion from feet to metres

**Cardiovascular Response**

Compared to the respiratory and central nervous systems, the cardiovascular system is relatively resistant to hypoxia. The cardiovascular response to hypoxia may be observed in two stages. An initial increase in cardiac output will be caused by escalation in the heart rate and selective vasoconstriction. This increase in the heart rate will begin at an altitude of about 4,000 feet (1,219 metres) and will achieve a maximum rate at approximately 22,000 feet (6,706 metres)\(^{16}\). As a result of the increase in cardiac activity, the cardiovascular system will require more oxygen. The myocardium, which is already hypoxic, will then respond with a decreased heart rate, hypotension and arrhythmias.

**Physiologic Stages of Hypoxia**

Having described the signs and symptoms of hypoxia, it is possible to describe the physiologic responses that can be anticipated at different altitudes. There are four physiologic stages of hypoxia.

**Indifferent Stage**

The *indifferent stage* of hypoxia typically illustrates the physiological findings that are seen between sea level and an altitude of 10,000 feet (3,048 metres). Normally, throughout this stage, the individual is usually unaware of his or her symptoms and there may be no perceived impairment. Within this stage, oxygen saturation usually will reach between 90% to 98%, if there are no significant predisposing medical conditions. The heart and respiratory rates will increase in response to the hypoxia. At approximately 4,000 feet to 5,000 feet (1,219 metres to 1,524 metres) elevation, there may be an onset of visual disturbance, including blurred vision and tunnel vision. At 5,000 feet (1,524 metres), night vision may be reduced by 10% and by 10,000 feet (2,048 metres) the night vision can decrease by as much as 28%\(^{16}\).
Compensatory Stage

The *compensatory stage* finds the crew member or patient subjected to an altitude between 10,000 feet to 15,000 feet (3,048 metres to 4,572 metres). In addition to the symptoms seen in the indifferent stage, a variety of new symptoms begin to develop. Despite the myriad symptoms, this stage of hypoxia may not be identified readily and easily overlooked. There will be a more significant increase in respiratory rate and heart rate, as well as an increased systolic blood pressure and increased cardiac output. Oxygen saturation of an uncompromised person will be between 80% and 90%. Night vision now will be decreased as much as 50%. An individual may begin to experience subjective symptoms including nausea, dizziness, listlessness, headache, fatigue, air hunger, apprehension, and hot and cold flashes. Following a 10 to 15 minute exposure at 12,000 feet to 15,000 feet (3,658 metres to 4,572 metres), CNS symptoms will be evident. Impaired co-ordination, increased irritability, poor judgement and decreased efficiency all may be seen.

Disturbance Stage

During the *disturbance stage*, individual compensatory mechanism and physiological response can no longer compensate for the oxygen deficiency, and individuals usually become aware of their hypoxic symptoms. These symptoms typically are associated with exposure to an altitude of 15,000 feet to 20,000 feet (4,572 metres to 6,096 metres) and an oxygen saturation between 70% to 80%. Some individuals, however, may have a loss of consciousness without ever experiencing any subjective symptoms.

The most common subjective symptoms include headache, nausea, vomiting, air hunger, amnesia and decreased level of consciousness, which is most common with children. Objectively symptoms may be noted pertaining to the senses, CNS, personality traits and psychomotor function. The senses will become diminished and an individual may experience weakness, numbness, tingling, decreased sensation (eg touch and pain) and impaired visual acuity. A decay in psychomotor function may be seen by a deterioration in coordination, speech and handwriting. Delayed reaction time, worsening short-term memory and slower thinking all correspond to impaired mental functions. Individuals may show evidence of altered personality traits, exhibited by over-confidence, depression, aggressive behaviour, belligerence and euphoria. Cyanosis may be noted, but should not be relied on as a prominent clinical indicator of the disturbance stage.

Critical Stage

The most serious stage of hypoxia is the critical stage. Previous symptoms that may have been overlooked can no longer be ignored. Objective findings now may include an inability to remain upright, jerking of upper limbs, seizures, rapid unconsciousness, coma and death. These findings correspond to an altitude of 20,000 feet to 25,000 feet (6,096 metres to 7,620 metres), and an oxygen saturation between 60% to 70%.

Treatment

In air medical transport, the primary “treatment” for hypoxia should be directed toward prevention. Recognition of subjective and objective symptoms should become the second priority. It is essential to use all of the appropriate and available resources to closely monitor the patient during transport, including physical exam, pulse oximetry and end-tidal CO\textsubscript{2} detector.

Whether hypoxia is secondary to altitude or any other etiology, supplemental oxygen remains the cornerstone of treatment. The goal of oxygen therapy is to increase the alveolar concentration of oxygen, decrease the myocardial workload and decrease the demand on the pulmonary system.

The oxygen adjustment equation can be used to calculate the FIO\textsubscript{2} required at any given cabin altitude or destination altitude as follows:
(\(\text{FiO}_2 \times P_{\text{Bar}1}\)) \div P_{\text{Bar}2} = \text{FiO}_2 \text{ required when } \text{FiO}_2 \text{ is the patient’s current fraction of inspired } O_2; \ P_{\text{Bar}1} \text{ represents the current barometric pressure; } P_{\text{Bar}2} \text{ is the altitude or destination barometric pressure; and } \text{FiO}_2 \text{ required will be the new } \text{FiO}_2.

For example, a patient is currently receiving an \(\text{FiO}_2\) of 44% at a referring hospital at sea level. This patient will be transported in an aircraft at a cabin altitude of 7,000 feet (2,134 metres). The new required \(\text{FiO}_2\) necessary to achieve the same oxygen saturation will be:

\[
(0.44 \times 760 \text{ torr}) \div 586 = 0.57
\]

These calculations are useful during air medical transport. However, their use may seem less important when using pulse oximetry. When monitoring the patient with pulse oximetry, crew members tend to rely on monitor readings to alter therapy. However, this may not reflect adequately the patient’s oxygen requirements. Therefore the routine use of the oxygen adjustment equation is recommended.

If supplemental oxygen is applied at an appropriate \(\text{FiO}_2\), and hypoxia is still evident, the medical crew must consider the possible etiologies: a malfunction of the on-board oxygen system, deterioration in the patient’s condition, patient intolerance of a change in barometric pressure, or another etiology for the hypoxia must be diagnosed and treated accordingly.

Additional steps in the treatment of hypoxia should include reducing the altitude of the aircraft or increasing the cabin pressurisation. Whenever possible, it is recommended that the medical crew monitor the cabin altitude and communicate with the pilot any specific altitude limitations or requirements. Descending to a lower altitude will effectively increase the partial pressure of oxygen. Flight altitudes below 10,000 feet may be most preferable. Increasing the artificial cabin altitude by raising the cabin pressurisation may also be beneficial when this is possible mechanically. At times, a combination of all of these treatment alternatives may be necessary for optimal patient care.

**Noise**

Noise and vibration may represent the most difficult and troublesome stresses encountered in the air medical environment. Noise may be considered any loud, unpleasant or unwanted sound. In transport, noise may be annoying, cause speech interference and promote hearing loss. Excessive noise, within any transport vehicle air or ground, may interfere with and complicate patient care.

During transport, it may be impossible to accurately auscultate the lungs or blood pressure. Inadequate communication between the medical team and an awake patient may interfere with the detection of changes in symptoms or condition. As a result, the crew must rely on other means to monitor and assess patient condition. Close observation for alteration in the patient’s respiratory rate, chest expansion, level of consciousness, discomfort and abdominal distention, may indicate a possible change in the patient’s condition. Blood pressure can be monitored through invasive or non-invasive devices. Pulse oximetry provides valuable information about the patient’s oxygenation and respiratory status and CO₂ detectors may be helpful when assessing intubated patients.

In helicopters and fixed wing aircraft, the main source of noise comes from the engines, rotors/propellers, air turbulence and on-board ventilation systems. In addition, noise from aviation radios and medical equipment (eg., monitors, ventilators, alarms, and so on) all contribute to airborne “noise pollution.”

As with many of the stresses of flight, there is individual variation in tolerance and effect of noise. The longer the exposure and the more intense the noise, the greater the potential damage. Prolonged and intense exposure to noise may result in a deterioration of work performance, headaches, fatigue, nausea, visual disturbances, vertigo, general discomfort and ear damage, either temporary or permanent. Therefore, it is recommended that some form of noise attenuation devices be worn by both the crew and patient during aircraft operation. Options for hearing protection include earplugs, headsets and helmets.


**Vibration**

Vibration, which is inherent to all transport vehicles, may interfere with patient assessment and some routine physiological functions. The most common sources of vibration during air medical transport are the aircraft engines and air turbulence. During helicopter transport, vibration is most severe during transition to a hover or during turbulent weather conditions. In fixed-wing transport, vibration increases during high-speed, low-level flight and during cloud penetration in turbulent weather.

During transport, aircraft vibration may interfere with invasive and non-invasive patient monitoring. In-flight vibration also has been shown to cause dysfunction of activity-sensing pacemakers\(^\text{18}\).

Exposure to moderate vibration results in a slight increase in metabolic rate and is similar to a startle reaction or mild exercise. Low frequency vibration may promote the onset of fatigue, irritability, shortness of breath, motion sickness, chest pain or abdominal pain.\(^\text{19}\) Low frequency vibration of the eye may result in blurred vision.

Vibration may interfere with body thermoregulation, and its effects may be aggravated by either hot or cold temperatures. In the hypothermic patient, vibration may worsen the patient’s condition. In a hyperthermic patient, aircraft vibration may cause circulatory vasoconstriction. This could override the body’s compensatory cooling mechanism, impairing the ability to sweat.

Little can be done by pilots or crew members to eliminate or decrease the amount of vibration in the aircraft. To minimise the effects of vibration, efforts should be made to avoid or reduce direct contact with the airframe. Padding should be placed on any part of the airframe that may come in contact with the individuals on board. Adequate padding in the form of cushioned seats and stretcher pads should be used. Direct contact with the bulkhead of the aircraft should be avoided by placing blankets or other cushions appropriately. Patients and crew members should be restrained properly at all time to minimise the effects of vibration.

**Gravitational Forces**

The impact and importance of gravitational force (G-forces) as a stressor during air medical transport is often discussed. During routine flight operations, G-forces will not impact significantly the patient or the crew. However, an understanding of gravitational forces will explain how such forces may be relevant to crew and patient positioning with the aircraft, as well as to safety and survival.

One ‘G’ represents the force that an individual exerts when seated and is a result of gravitational force imposed on the body. G-forces are applied to the body on ascent and descent and during a change in speed or direction. Acceleration is the rate of change in velocity and is measured in Gs.

During any sudden or excessive change in direction or speed an individual or object will be subject to the effects of gravitational forces. Therefore, G-forces are an important consideration in routine operations, accident prevention and accident survival.

Federal regulations stipulate that “each item of mass inside the cabin that could injure an occupant is restrained when subjected to the following ultimate inertial load factors.”\(^\text{20}\)

Newly Type-Certified rotor-wing aircraft must meet or exceed the following loads: 16 Gs forward, 20 Gs downward, 8 Gs sideways and 4 Gs upward. This exceeds the previous requirements of 4 Gs forward, 4Gs downward, 2 Gs sideways and 1.5 Gs upward. Load requirements for seating in fixed-wing aircraft are as follows: 9 Gs forward, 6 Gs downward, 3 Gs sideways and 3 Gs upward.

During deceleration (landing) an unrestrained or improperly restrained person in a forward-facing seat may be injured or ejected from his or her seat. In contrast, a rear-facing seat may provide better restraint during crash deceleration.
In theory, patient positioning within the aircraft may enhance or minimise the effect of G-forces during take-offs (acceleration) and landings (decelerations). For patients with cardiac disease, myocardial perfusion is improved during acceleration by positioning the patient with their heads towards the back (aft) portion of the aircraft. As negative G-forces are increased, pooling of blood occurs in the upper part of the body. In head-injury victims or fluid-overload patients, it may be desirable to augment positive G-forces, which would pool blood in the lower extremities. This is accomplished by positioning the patient with his or her head toward the front (fore) portion of the aircraft. In a head-injured patient, this may reduce the risk of a transient increase in intracranial pressure during takeoff.5

**Thermal Considerations**

Helicopter and fixed-wing transport can expose the aircraft, crew and patient to temperature extremes that may result in clinical and operational complications. These temperature extremes may be due to inherent seasonal changes, geographic considerations or altitude variation.

Exposure to extremes in temperature – hot and cold – will result in an increased metabolic rate, causing increased oxygen demand and consumption. This may further compromise an already hypoxic patient. In addition, prolonged exposure results in impaired performance, motion sickness, headache, disorientation, fatigue, discomfort and irritability.

Many factors can exacerbate or mitigate exposure to temperature variation, such as air circulation, duration of exposure, condition and type of clothing and physical condition. Whenever possible, the air medical crew should take steps to prevent potential complications related to thermal stress. The aircraft cabin should be kept at a comfortable temperature, minimising exposure to the ambient environmental extremes. To prevent hypothermia, appropriate layers of clothing or blankets should be used to limit heat loss. In addition, wet clothing or moist dressings should be removed. Prolonged exposure to high temperatures may require increased oral or intravenous fluids to prevent dehydration. The use of increased ventilation, cool water mist or moist dressings may be of benefit.

The effects of thermal exposure can be magnified by other stresses, including vibration, dehydration, and alcohol and drug intoxication. In addition, climatic temperature variations can create air turbulence that can impact negatively on the aircraft, crew or patient.

**Dehydration**

High-altitude transports expose the patient and crew to low humidity. As altitude increases and air cools, moisture in the air decreases significantly. As a result, pressurised aircraft draw in dry, outside air creating an extremely dry, pressurised cabin. In addition, dry medical oxygen will predispose the patient to dehydration. Signs of dehydration include thirst, dry mouth, dry mucous membranes, sore throat, hoarseness and dry or scratchy eyes.

As a result of dehydration, hypothalamic stimulation may occur, resulting in an increased metabolic rate and increased oxygen requirements. Additionally, respiratory secretions may become thick, resulting in less efficient gas exchange. All these may contribute to hypoxia.

To prevent dehydration during air medical transport, fluid intake (oral or IV) must be monitored carefully and all patients should receive humidified medical oxygen. These recommendations are especially important during long transports. Patients who exhibit signs of dehydration should be managed aggressively before exposing them to further circulatory changes at altitude.

**Third Spacing**

Long-distance or high-altitude air medical transport may precipitate third spacing, which represents the loss of fluids from the intravascular spaces into the extra-vascular tissues. This occurs in response to a decreasing ambient pressure surrounding the vessel walls. This may cause leakage of fluid from the intravascular space into the surrounding tissues. Additionally, increased intravascular pressures or increased permeability of the vessel walls may also contribute to fluid loss.
The onset and complications of third spacing may be aggravated by pre-existing medical problems or other stresses of flight. Patients with pre-existing fluid leakage, including cardiac patients or those with nephrotic disease, may be at increased risk for third spacing. In addition, exposure to excessive G-forces, vibration and temperature extremes may also exacerbate third spacing of fluids. Signs and symptoms include oedema, increased heart rate, decreased blood pressure and dehydration.

**Fatigue**

By understanding the elements that cause and contribute to fatigue, the air medical crew member may be able to mitigate the impact of this stressor. Fatigue is a state or condition that follows a period of excessive mental or physical activity or inactivity. While fatigue is considered one of the stresses of flight, it also may be considered an end product of the contributing factors that make up the stresses of flight. Hypoxia, G-forces, barometric changes and dehydration contribute to fatigue. In addition, the emotional and physical stress of prolonged patient care in the air medical environment may add to crew fatigue.

**Self-Imposed Stress**

A patient or crew member’s self-imposed stresses can influence greatly their physiological performance during air medical transport. Therefore, a clear understanding of these stresses is important for optimal patient care.

Self-imposed stresses are often under direct control of the individual. The acronym “DEATH” may be useful to remember these stresses that include: Drugs, Exhaustion (fatigue), Alcohol, Tobacco, and Hypoglycaemia (diet/dehydration).

Medications (prescription and non-prescription) and the medical conditions for which they are taken may interfere with performance, perception, decision-making and motor skills. Crew members must be aware of the side effects, overdose reactions, allergic response and synergistic effects of medication they may be taking.

Exhaustion or fatigue must be avoided to prevent errors in judgement, poor attention span and a decrease in work capacity and performance.

In general, the first type of fatigue to develop, *acute fatigue*, is accompanied by a feeling of being tired, desire for rest, inattention, distraction, errors in timing, need for greater stimuli, neglect of secondary tasks, loss of accuracy and control and unawareness of error accumulation. Acute fatigue is usually remediated by adequate sleep. Flight crews may be subject to rotating shifts or changes in time zone that can affect their sleeping patterns and further complicate a transport.

*Chronic fatigue*, potentially more serious than acute fatigue, represents a self-imposed stress rather than a stress of flight. Presenting signs and symptoms include: physical and mental tiredness, insomnia, depression, irritability, poor judgement, loss of appetite, weight loss, and slowed reaction time. In some cases, the underlying cause may be related to personal factors (e.g. family, money and so on).

Causative agents for both acute and chronic fatigue must be addressed accordingly so as not to compromise patient care or jeopardise personal or transport safety.

The effects of alcohol ingestion tend to be exacerbated “at altitude”. One drink at 10,000 feet (3,048 metres) is equivalent to two to three drinks ingested at sea level. Similarly, the effects of tobacco are magnified during flight. The carbon monoxide by-product of smoking at sea level may result in mild hypoxia similar to that seen at an altitude of 8,000 feet (2,438 metres). This may occur with as few as three cigarettes.
Diet represents the final self-imposed stress. An inadequate diet can result in nausea, headache, dizziness, errors in judgement and loss of consciousness. Precautions should be taken to avoid the development of hypoglycaemia or dehydration.

**Conclusion**

The stresses of flight create a significant challenge to those providing medical care to the critically ill or injured. An in-depth knowledge of flight physiology, stresses of flight and self-imposed stresses enables the air medical crew to provide optimal patient care in its unique environment. The crew must anticipate and prevent potentially serious complications by vigilant patient monitoring and the initiation of appropriate treatment.

**References**

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<td>RR and depth cardiac output</td>
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<td>↓ oxygenation of the tissues to the extent that normal function is impaired</td>
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<td>Exercise Vibration</td>
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<td>Aerobic metabolism ceases</td>
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<td>• Descent ambient pressure ↑</td>
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<td>Trapped gases 8,000 feet gas →</td>
<td>• At a constant temperature the volume of</td>
<td>Inflammation of Mucosa</td>
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<td>• Air within the ear ↓</td>
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<td>increase by 30%</td>
<td>gas is inversely proportional to the</td>
<td>U.R.T.I.</td>
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<td>• Equalise pressure by moving air into middle ear via the</td>
<td>Pain</td>
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<td></td>
<td>absolute pressure</td>
<td>Age – young have smaller eustachian tubes</td>
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<td>eustachion tube</td>
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<td>• ↓ Pressure with</td>
<td>Unconscious – unable to equalise pressure</td>
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<td>• Close due to ↑ pressure</td>
<td>Vertigo</td>
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<td>• ↑ Altitude gases expand</td>
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<td>Blood</td>
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<td>• ↑ Pressure ↓ altitude gases contract</td>
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<td>• Barotitis Media</td>
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<td>18,000 feet trapped gas →</td>
<td>Barogastrolgia</td>
<td>Rapid ascent</td>
<td>Blocked sinuses</td>
<td>• Maxillary frontal sinuses during ascent gas expands</td>
<td>Pain</td>
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<td>twice its original volume</td>
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<td>Altitude</td>
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<td>escaped through the ostia</td>
<td>Swelling of mucous membrane,</td>
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<td>Food, high fibre</td>
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<td>Detachment</td>
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<td>Tight clothing</td>
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<td>Gl infection, surgery anxiety</td>
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<td>Bowel obstruction</td>
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<td>• Gas expands with altitude in the body Boyle’s Law</td>
<td>Abdo pain on ascent</td>
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<td>↓ BP</td>
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<td>• Normal 4-500mls in the bowel</td>
<td>PR gas</td>
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<td>↓ Ventilation</td>
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<td>↑ Pressure on the diaphragm</td>
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<td>Perforated viscus</td>
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<td>Decreased Barometric pressure cont.</td>
<td>• Pulmonary Barotrauma</td>
<td>Rapid ascent Emphysema/CORD Cysts Asthma Respiratory tract infection Foreign body lodged</td>
<td>Pneumothorax Pneumomediastinum Pneumopericardium Subcutaneous Emphysema Air embolism arterial Cerebral Haemorthorax</td>
<td>• ↑ Trapped gases within the lungs • Causes lung tissue to tear and gas escapes – pleural cavity • Tissues, interstitium</td>
<td>↑ Resp rate ↓ Motor activity ↓ Sensation Vestibular – balance Equilibrium Hypoxic hypoxia Sudden collapse hypotension ↓ Cardiac output tachycardia</td>
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<td>• Barodontalgia</td>
<td>Recent dental work Poor oral hygiene Infection Injury</td>
<td>Removal of filling</td>
<td>• Trapped gases under filling/infection expands • Pressure on dental nerve</td>
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<td>• ↑ Barometric pressure • ↓ Barometric pressure rupture</td>
<td>Cuff leak ↓ tidal volume ↑ Airway pressure Air embolus Blood back</td>
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<td>Henry’s Law</td>
<td>• Quality of gas dissolved in a liquid not chemically combined is proportional to the partial pressure of the gases above. • As partial pressure of Rapid depressurisation above 15,000 – 20,000</td>
<td></td>
<td>Hypoxia</td>
<td>Rapid temperature drop. Mist formation Flying debris Disorientation ↓ LOC Hypoxia</td>
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<td>Evolved gases from solution</td>
<td>nitrogen ↓ within the atmosphere to below levels in the body it is diffused from the blood and tissues to the lungs to equilibrate levels</td>
<td>Altitudes greater than 18,000 feet, Duration at altitude, Age/fat percentage, Exercise, Cold extreme, Hypoxia, Infection, Injuries, Recent S.C.U.B.A. diving</td>
<td>Decompression illness, Musculoskeletal – bends, Cutaneous – creeps, Neurological – stagers</td>
<td>Growing gas bubbles in tissues displace and deform adjacent structures impinging on nerve ends</td>
<td>Pain in joint, Limb weakness, Motor sensory, Disturbance, Paraplegia – mono, Spasticity, Bladder, rectal control, Altered reflexes, Paresthesias, visual, Disturbance, CNS seizure, Vestibular, Unconsciousness</td>
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<td>Evolved gases from solution cont.</td>
<td>Excess nitrogen is unable to be off loaded rapidly enough; nitrogen comes out of solution to form bubbles</td>
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<td>Bubbles then follow Boyle’s Law</td>
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<td>Pulmonary</td>
<td>Gases evolving out of tissues/blood and embolising in the lungs</td>
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<td>Barotrauma – chokes</td>
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<td>Cardiovascular – shock</td>
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<td>Hypotension, S&amp;S of an MI ↓ Saturation</td>
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<td></td>
<td>Haemocritic</td>
<td>Platelets and blood cells clump on the surface of the bubble</td>
<td>DIC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>POP</td>
<td>Air in plaster expands, bivalve the plaster when less than 48 hours hold</td>
<td>Constriction of distal limb ↓ Pules ↓ Capillary refill ↓ Warmth ↓ Pain ↓ Sensation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Penetrating injury: Eye</td>
<td>Air around injury site ↑ pressure</td>
<td>Exudate of eye matter ↑ Injury ↑ Pain</td>
</tr>
<tr>
<td>Decreased Barometric pressure</td>
<td></td>
<td></td>
<td>Head</td>
<td>↑ Air expansion ↑ ICP</td>
<td>Pupil changes ↓ GCS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Chest</td>
<td>↑ Air expansion</td>
<td>↓ Chest expansion/ air entry Dyspnoea/haemoptysis Subcutaneous Emphysema</td>
</tr>
<tr>
<td>Aviation related stresses</td>
<td>The problem defined</td>
<td>Predisposing factors</td>
<td>Clinical problems arising</td>
<td>Relevant pathophysiology</td>
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<tr>
<td>Vibration</td>
<td>• Form of motion that repeatedly alternates in direction</td>
<td>Low frequency vibration 0.5 – 2.0Hz Direct contact with structure Take off High speed Manoeuvres Low level flying Type of aircraft Duration of mission Turbulence</td>
<td>Impaired communication Involuntary motion ↑ BP, HR ↑ Muscular activity to maintain posture Equipment – NIBP inaccurate IV fluids erratic Dislodging of lines, tubes Arrhythmias Fractures</td>
<td>• Vibration of entire musculoskeletal system ↑ Metabolic rate Hyperventilation ↑ BP, HR • Skull resonates at frequencies between 20-30Hz • Eyeball between 60-90Hz</td>
<td>Impaired motor performance, communication Rubbing injury ↑ Pain, bleeding Visual disturbance ↓ Appetite Nausea Headache Vomiting Displacement</td>
</tr>
<tr>
<td>G-Force</td>
<td>• Effect of acceleration on the body depends upon the magnitude and duration of acceleration • Mainly aerobatics • Positive G • Prolonged acceleration</td>
<td>Low tolerance of G-Force Low BP Hyperventilation Fatigue Heat stress Hypoxia Hangover Drugs Dehydration Males less tolerant than females Poor straining technique</td>
<td>Hypotension ↑ Muscle activity Motion sickness ↓ Cerebral perfusion Confusion Syncope</td>
<td>• Hydrostatic pressure ↓ in vessels below level of heart ↑ Blood pools in legs and abdomen Reducing venous return ↓ CO cerebral perfusion ↑ Alveolar dead space ↓ Oxygen saturation</td>
<td>Tachycardia Vasco constriction Blurred, tunnel vision +4-5G loss of vision ↓ LOC Hypoxia Motion sickness +6G Unconsciousness</td>
</tr>
<tr>
<td>Signs and Symptoms</td>
<td>Relevant pathophysiology</td>
<td>Clinical problems arising</td>
<td>Predisposing factors</td>
<td>The problem defined</td>
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</tr>
<tr>
<td>Bradycardia – asystole</td>
<td>↑ Pressure above the heart, blood congestion</td>
<td>↑ ICP</td>
<td>Negative G</td>
<td>G-Force</td>
<td></td>
</tr>
<tr>
<td>Vision</td>
<td>↓ Flow to the heart</td>
<td></td>
<td>Prolonged deceleration</td>
<td></td>
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</tr>
<tr>
<td>Brain function</td>
<td>↓ Oxygen to the brain</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Congested blood collects around the eyes and lids</td>
<td></td>
<td>Inability to hear, chest, bowel and BP alarms – unable to hear, visual alarms not always working</td>
<td>Exposure</td>
<td>Sounds which are:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impaired</td>
<td>Type of aircraft</td>
<td>Unpleasant</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Communication system</td>
<td>inadequate hearing protection</td>
<td>Disturbing</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Age-neonate</td>
<td>Unwarranted</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Communication system</td>
<td>Aeromedical – engines, propulsion, aerodynamic, pressurisation, communication systems, medical equipment</td>
<td></td>
</tr>
<tr>
<td><strong>Aviation related stresses</strong></td>
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<tr>
<td><strong>Thermal changes</strong></td>
<td>Charles’ Law</td>
<td>Exposure</td>
<td>Gas expansion in equipment</td>
<td>• Posterior hypothalamus – the body’s thermostat</td>
<td>Cylinders read ↓ when exposed to ↓ temp, ↑ when warm</td>
</tr>
<tr>
<td>In aviation with the ↑ in altitude, the ambient temperatures ↓ 1-98 degrees Celsius per 1000’</td>
<td>- Volume of a given mass of gas is directly proportional to absolute temperature</td>
<td>External environment</td>
<td>Hyperthermia 41-43 degrees Celsius</td>
<td>• Thermo receptors monitor the skin temp central</td>
<td>Vasodilatation</td>
</tr>
<tr>
<td></td>
<td>- Extreme temperature during transportation</td>
<td>Ambient temperature</td>
<td>↑ Metabolic rate</td>
<td>• Thermo receptor in the hypothalamus, CNC internal organs</td>
<td>Tachypnoea</td>
</tr>
<tr>
<td></td>
<td>- Convection – transfer of heat energy by direct air current</td>
<td>Exercise</td>
<td>Vasodilatation ↑</td>
<td>• ↓ Temp</td>
<td>Heat exhaustion</td>
</tr>
<tr>
<td></td>
<td>- Conduction – direct contact</td>
<td>Head injury</td>
<td>↑ Metabolic rate</td>
<td>• ↓ Heat production, ↓ muscle tone, ↓ voluntary movement</td>
<td>Fainting, headache, dizziness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Age – elderly, lower</td>
<td>↑ Oxygen demand</td>
<td>• → Interferes with hypothalamic thermoregulatory centres</td>
<td>↑ BP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Metabolic rate – infants, large body surface inflammation</td>
<td>Less tolerance to G-Force due to vasodilatation</td>
<td>centres</td>
<td>Nausea</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dehydration, electrolyte loss induced resp alkalosis</td>
<td></td>
<td></td>
<td>Muscle spasm, thirst, fatigue syncope</td>
</tr>
<tr>
<td></td>
<td>- Evaporation – insensible loss sweating</td>
<td>Prolonged exercise</td>
<td>Breakdown of hypothalamic thermoregulation vasoconstriction process</td>
<td></td>
<td>Heat stroke</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hot humid environment</td>
<td></td>
<td></td>
<td>No sweating</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spinal injury</td>
<td></td>
<td></td>
<td>Hyperthermia</td>
</tr>
<tr>
<td></td>
<td>- Radiation – heat waves greenhouse effect in aircraft</td>
<td>Taxi time</td>
<td></td>
<td></td>
<td>↑ HR</td>
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<tr>
<td></td>
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<td>Prolonged aircraft standing time</td>
<td></td>
<td></td>
<td>Dehydration</td>
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<td></td>
<td></td>
<td>Endocrine failure</td>
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<td></td>
<td>DIC</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>↓BP</td>
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<tr>
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<tr>
<td>Thermal changes cont.</td>
<td>Alcohol ingestion</td>
<td>Vasoconstriction</td>
<td>Hypothermia</td>
<td>↓ Metabolic process</td>
<td>Initial response HR BP</td>
</tr>
<tr>
<td></td>
<td>Trauma</td>
<td>↓ Heat loss</td>
<td>&lt; 33°C ↓ LOC &lt; 32°C</td>
<td>Shivering</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Exposure</td>
<td>↓ shivering ceases,</td>
<td>&lt; 28-30°C ↓ resp rate</td>
<td>Skin cold – vasoconstriction</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>pupils dilate</td>
<td>and cardiac output &lt; 28°C</td>
<td>↓ Performance disorientation</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>↓ Resp centre, HR, cardiac output</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Hyperglycaemia</td>
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<td></td>
<td></td>
<td>Arrhythmias</td>
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<td></td>
<td></td>
<td>VF</td>
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<tr>
<td></td>
<td>Frost bite</td>
<td>Excessive cooling of one particular area – forming ice crystals and dehydration</td>
<td>Tissue damage</td>
<td></td>
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</tr>
<tr>
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<tr>
<td>Toxic gases in aviation</td>
<td>Controlled combustion of fuel, engine exhaust gases Carbon dioxide Carbon monoxide Aldehydes Acetylene Oxygen Nitrogen Water</td>
<td>Cabin fire, post crash fire Aldehydes – burning of wood, nylon, polyester resin Nitrogen oxides – burning of polyurethane compounds Hydrogen cyanide combustion of synthetic products, plastic natural fibres (wool)</td>
<td>Hypoxic hypoxia</td>
<td>Inadequate oxygen available to oxygenate the tissue</td>
<td>See S&amp;S of hypoxia Irritation to eyes, upper resp tract Irritation to mucous membrane</td>
</tr>
<tr>
<td>Turbine or piston engine Carbon monoxide poisoning</td>
<td>Piston engines – heating Leak into cabin “Hot” refuelling and loading</td>
<td></td>
<td>Histotoxic poisoning</td>
<td>Cellular poison interfering with electron transport chain within the mitochondria cellular energy production</td>
<td>Mild headaches – severe, nausea visual disturbances, confusion tachycardia, collapse convulsion, a respiratory failure</td>
</tr>
<tr>
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<tr>
<td>Toxic gases cont.</td>
<td>Aviation fuel</td>
<td>Inhalation of vapour</td>
<td></td>
<td>Dizziness, nausea, frontal headache, irritation of eyes, disorientation, speech disorders, vision disturbances, convulsions and unconsciousness</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Contamination of skin</td>
<td></td>
<td></td>
<td>Contact dermatitis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anti icing</td>
<td>Altitude ice on aircraft structure</td>
<td>Contains methanol ingestion</td>
<td>Forms formic acid during metabolism – metabolic acidosis – inhibits cytochrome oxides</td>
<td>Inhalation – blindness, irritation of mucous membranes, headache, dizziness, tremors, nausea, narcosis, unconsciousness, kidney, liver damage</td>
</tr>
<tr>
<td></td>
<td>Anti detonant fluids</td>
<td>Used to improve air mix – piston engines</td>
<td>Ingestion</td>
<td>Ethylene glycol metabolises to glycolic acid – glyoxylic acid – glycine or – enters citric acid cycle</td>
<td>Headache, vomiting, tachypnoea, hypotension, nystagmus, stupor, seizures, coma, pulmonary oedema, ARF, cardiac arrhythmias</td>
</tr>
<tr>
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<tr>
<td><strong>Decreased humidity</strong></td>
<td>As altitude ↑, air cools, moisture in the air ↓</td>
<td>Pressurised plan draws air from outside Dry medical oxygen Dehydration Artificial airway</td>
<td>Dehydration Inspissation of secretions atelectasis Mucous plugs Age Burns</td>
<td>• Result of dehydration • Hypothalamus is stimulated • ↑ Metabolic rate • ↑ Oxygen demand</td>
<td>Thirst Dry mouth Dry mucous membranes Sore throat Hoarseness Dry, scratchy eyes Tachycardia ↓ Urine output</td>
</tr>
<tr>
<td><strong>Spatial disorientation</strong></td>
<td>Abnormal acceleration forces encountered in flight can produce erroneous visual, vestibular or proprioceptive signals which may interfere with the correct interpretation of the position, altitude and movement</td>
<td>Inadequate visual cues-flying at night in cloud. U.R.T.I., Fatigue and hypoxia</td>
<td>Disorientation</td>
<td>Affects vestibular function and produces asymmetrical pressure changes in the middle ear</td>
<td>Visual disturbances Nausea/anxiety/fear Nystagmus Vertigo Reduce attention span and performance</td>
</tr>
<tr>
<td><strong>Motion sickness</strong></td>
<td>A response to real or apparent (visual) motion to which a person is not adapted</td>
<td>Poor individual tolerance – fear/ anxiety limited adaptation sustained Motion/turbulence Noxious stimuli – smells/noise/vibration Fatigue Alcohol</td>
<td>Nausea/vomiting Increased HR Anxious Unable to perform duties</td>
<td>Actual or perceived changes in linear and angular acceleration producing conflicting signals from the eyes, vestibular apparatus and proprioceptors Minimise sensory conflict (limit head movement and maintain visual orientation with the horizon)</td>
<td>Pallor Sweating Headache/dizziness Nausea/vomiting Increased salivation Drowsiness</td>
</tr>
</tbody>
</table>
# Recommended Altitude Restrictions for Medical Conditions

<table>
<thead>
<tr>
<th>Altitude</th>
<th>Conditions</th>
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</thead>
<tbody>
<tr>
<td>10,000 Feet</td>
<td>Any Symptomatic cardio-respiratory disease</td>
</tr>
<tr>
<td>8000 Feet</td>
<td>Marked Ventilatory restriction: Pregnancy, Pleural Effusion, Pleural Fibrosis, More than mildly symptomatic cardio-respiratory disease</td>
</tr>
<tr>
<td>6000 Feet</td>
<td>Myocardial Infarction 8-24 weeks ago, Space occupying lung lesion, Angina Pectoris</td>
</tr>
<tr>
<td>4000 Feet</td>
<td>Anaemia, Acute traumatic Brain Injury, CVA, Decreased level of consciousness, Recent Eye Surgery, Severe Pulmonary emphysema</td>
</tr>
<tr>
<td>2000 Feet</td>
<td>Gas in body cavities unable to be drained, Severe Cardiac disease with cyanosis or recent decompensation, MI up to 8 weeks ago, Retinal Injury, Clinical Cyanosis, Cor-pulmonale, Respiratory Acidosis, Bullous Emphysema, Ventricular Arrhythmias’, Congestive Heart Failure, Traumatic Brain Injury and raised ICP, Post Craniotomy, CSF leak, Severe Facial Injuries, GI disturbances: Strangulated Hernia, Acute Appendicitis, Recent GI Surgery, Peptic Ulcer Disease, Diverticulitis, Intestinal obstruction</td>
</tr>
<tr>
<td>Sea Level</td>
<td>Untreated Pneumothorax, Pneumocephaly, Decompression Illness, Air Emboli, Perforating Eye Injuries, Venous or arterial grafting less than 21 days ago, Chest Tubes removed less than 72 hours previously, High altitude pulmonary oedema (HAPE), High altitude cerebral oedema (HACE)</td>
</tr>
</tbody>
</table>


Section Four: Transfer Process
Transfer Information

Road Ambulance Transfers

Clinical Criteria (patient must meet at least one of the following)

➢ Patient requires special positioning (i.e. prone, semi-prone)
➢ Patient requires monitoring in transit
➢ Patient requires medical intervention during transit (i.e. oxygen, airway care, intravenous therapy)
➢ Patient is unable to use other transport (i.e. private car, disability vehicle) due to a mental or physical condition not covered by the above (i.e. physical access/egress issues)

Client Criteria

• Transfer of Inpatients between Hospitals and Health Services (HHS’s)

The Ambulance Service providing services for the referring HHS is responsible for the transfer of the patient to the treating HHS.

The Ambulance Service providing ambulance services for the treating HHS (Wellington Free Ambulance for C&CDHB) is responsible for the return of the patient to the HHS or origin.

• Attendance at Outpatient Clinics

Transfer of patients between their home and outpatient appointments as recommended by HHS medical staff.

First visit: The Ambulance Service providing services for the referring HHS is responsible for the return journey.

Subsequent visits: The Ambulance Service providing services for the HHS responsible for ongoing treatment of the patient is responsible for the return journey.
CCDHB Acute retrieval flow chart (during business hours)

**Flight Coordinator**
- Receives request for transfer
- Completes Call Sheet with basic patient information, location and destination
- Confirms bed availability at receiving hospital
- Contacts **Flight Nurse** to pass on initial information
- If FN not immediately available, more details must be obtained in order to discuss with ICU SMO (complete pre-flight assessment)
- Contacts Life Flight to alert them of pending transfer with initial indication of urgency rating
- Consideration should be given for any factors that may necessitate one aircraft over the other – ie. altitude restriction, time critical, weight/size limits
- Discuss with ICU SMO and establish need for Flight Doctor
- Assists Flight Nurse to prepare for transfer and immediate departure

**Flight Nurse**
- Receive Call Sheet from Flight Coordinator
- Contact referring hospital and complete patient assessment
- Discuss with **ICU consultant**, establish urgency, need for doctor
- Confirm pick up time and email booking form
- Contact **Flight doctor** and confirm ETA
- Gather appropriate equipment and prepare for departure
- Advise referring and receiving wards of transfer and ETA

**Life Flight**
- Obtains patient information via booking form
- Review urgency rating and available aircraft
- Confirms ability to complete transfer and timing with Flight coordinator
- Arranges all flight requirements – aircraft, crew, pilots
- Books road ambulances

**At referring hospital**
- Flight team advise Wellington ICU of patient status and any other requirements prior to return
- Give tentative ETA
- Crew advise LF and ambulance of ETA (and operator if helipad to be used)

**Post flight**
- Handover patient to medical and nursing staff
- Complete all documentation
- Enter all details on Flight database
- Restock drugs, bags, folder
- Advise family, referring hospital and DNM of return
CCDHB After Hours Retrieval Flow Chart

Requests for transfer may be received from doctors or DNMs at the referring hospital or accepting specialists within CCDHB. Calls may come via the Flight Hotline or directly to the ACNM or ICU consultant.

### ICU ACNM
- Answers Flight Hotline or receives referral from SMO, DNM
- Completes Call Sheet with basic patient information
- Contacts Flight Nurse

### Flight Nurse
- Contacts Life Flight from home to alert them of transfer, can give basic information and indication of urgency if known
- Return to hospital within 20mins and collect Call Sheet from ICU
- Contact referring hospital and complete patient assessment
- Discuss with ICU consultant, establish urgency, need for doctor
- Advise DNM of transfer and confirm bed if retrieving to CCDHB
- Confirm Flight with Life Flight, pick up time and email booking form
- Contact Flight doctor if not on site and confirm ETA

### Life Flight
- Obtains patient information via booking form
- Review urgency rating and available aircraft
- Confirms ability to complete transfer and timing with Flight Nurse
- Arranges all flight requirements – aircraft, crew, pilots
- Books road ambulances

### FN responsibilities prior to transfer

#### Fixed Wing
- Confirm pick up time at Transit Lounge
- Adviser referring ward and receiving wards and ETA
- Collect flight bags, drugs, phone, folder
- Consider other equipment: Vacu-mattress, syringe drivers, NIV bag, paeds specific

#### Helicopter
- Confirm pick up time on the roof
- Notify Operator of Heli landing, time and reason
- Advise referring and receiving wards of ETA
- Collect bags, drugs, phone, folder
- Consider other equipment: Vacu-mattress, syringe drivers, NIV bag, paeds specific
- Meet Heli on roof, ensure wearing life jacket and helmet
Section Five: Patient Assessment & Management
Pre-flight management

Factors that need to be considered:

- Communication
- Modes of transport
- Makeup of flight team - Any special population groups that require alternative or additional medical and/or nursing specialist expertise
- Equipment
- Medications
- Assessment and preparation of patient
- The clinical need of the patient - why does the patient need to be transferred
- Can the patient be safely transferred to the accepting area with the current level of care maintained or exceeded during the transport period
- Do the benefits of transport outweigh the risks of the flight to the patient
- Is the accepting area the most appropriate place for the patient post transfer; based on the clinical status of the patient (pre and peri flight) and skill and expertise of the accepting ward. Consider their Early Warning Score (EWS)

The key aspects of managing these patients effectively relies on expert skills such as communication, clinical assessment, collaboration with the multi-disciplinary team, clinical decision making and contingency planning.

Good communication is essential to ensuring the safe and efficient transfer of the patient. Communicating effectively with accepting and referring areas, ambulance crews, helicopter and fixed wing pilots and crew members is vital to ensure a smooth transfer with the patient arriving at the accepting area at the appropriate time.

The overall objective is to ensure that you have appropriately trained personnel transporting a patient safely while maintaining or exceeding the current level of care.

SAFETY cannot be underestimated and if at any time you feel unsure or unsafe, ask.
Phone assessment (ISBAR tool adaptation)

- Identify self & designation
- Situation
  - Patient location and destination
  - Accepting doctor
  - Treatment plan on arrival at destination e.g. OT or angio vs. ward
- Background
  - Current diagnosis & treatment
  - Medical history
  - Any history of violence/aggression to self or others.
    Safety of the patient and crew is a priority
- Assessment
  - Primary survey & secondary survey (ABCD, bloods, drugs, lines)
- Recommendations
  - Any additional treatments required or changes to treatments E.g. lines, bloods, x-rays, intubation, additional vasopressors, changing sedation or ventilation settings.

Patient History (SAMPLES mnemonic)

This should be as thorough and detailed as possible and include the following details:

- Signs/symptoms; history of presenting condition
- Allergies
- Medications (normal meds and any additions whilst in hospital)
- Past medical and surgical history
- Last meal/drink
- Events leading up to hospital/event presentation
- Social and family history (including smoking and alcohol history)
Patient Assessment

This begins as soon as the telephone handover occurs and clinical details are taken. A telephone handover may reveal important information regarding the patient’s current state, but often skilled questioning is needed to elicit specific and more detailed information, especially where contingency planning is concerned. For example, will the neurosurgical patient require intubation? How likely is it that the cardiac patient will have dysrhythmias and require defibrillation during transfer?

Planning is the key to a seamless transport

“More is missed by not looking than not knowing”

Once in the referring area, the flight nurse is able to assess the patient utilising assessment skills such as inspection, palpation, percussion and auscultation. A thorough patient history however is undeniably one of the most crucial steps in the assessment of the patient.

Other factors to consider:

• Blood test results including ABG
• Vital signs
• Current treatments and drug infusions

Depending on the patient’s condition and results of phone assessment recommendations may need to be made such as:

• Preparing specific medications
• Additional drug infusions to help stabilize the patient
• Intubation pre-arrival of the transport team if able

The following tables describe patient assessment and considerations for management.
### Airway

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Management</th>
</tr>
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<tbody>
<tr>
<td>Is the airway compromised</td>
<td>• Intubate if GCS&lt;10 or suspicion of airway compromise</td>
</tr>
<tr>
<td>Is GCS &lt; 12</td>
<td></td>
</tr>
<tr>
<td>If intubated, is the ETT secure</td>
<td>• Secure ETT and document size and depth</td>
</tr>
<tr>
<td>Cuff pressure</td>
<td>• Document cuff pressure, ensure not overinflated</td>
</tr>
<tr>
<td>C-SPINE – is there a hard collar?</td>
<td>• Use vacuum mattress and log rolling for all spinal injuries</td>
</tr>
<tr>
<td>Has the C-spine been cleared?</td>
<td>• Have suction available at all times in case of vomiting; ensure NG insitu and on free drainage</td>
</tr>
</tbody>
</table>

### Breathing

<p>| How does the work of breathing appear?         | Assess the patient’s lungs – Inspect, palpate, percuss, and auscultate                                                                  |
| Chest rising and falling evenly?              | • Suction prior to transport if indicated                                                                                              |
| Colour of patient?                            | • Ensure nasogastric/orogastric tube placed for gastric decompression                                                                 |
| Oxygen saturations                            |                                                                                                                                 |
| Are they ventilated?                          | • Ensure close monitoring of respiratory and cardiac parameters once placed onto transport ventilator                                    |
| What mode?                                    | • May need to change modes if not ventilating appropriately (e.g. use PCV if high airway pressures)                                          |
| How much PEEP and FiO2 do the need?           | • Provide additional sedation, analgesia or paralysis as needed                                                                           |
| Spontaneous or only mandatory ventilator breaths? |                                                                                                                                         |
| Is there patient-ventilator synchrony?        |                                                                                                                                          |
| EtCO₂ monitoring                               | • Ensure continuous close monitoring of end tidal CO₂, consider an arterial blood gas on transport ventilator before leaving the referring area (if possible) |
| How does it correlate with the CO₂ on ABG     |                                                                                                                                 |
| Is there a pneumothorax/haemothorax?          | • Ensure chest drain is inserted prior to transport and a check CXR performed                                                            |
| Chest drains                                  | • Attach Heimlich valves/pneumostat and drainage bags to all chest drains. May be necessary to perform another chest x ray to ensure correct drainage and re-inflation of lung |
| CRX review                                    | • Check for the presence of haemo/pneumothorax, general status of lungs, ETT / TT position and CVC position                           |</p>
<table>
<thead>
<tr>
<th>Assessment</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the patient adequately hydrated? Urine Output?</td>
<td>• Ensure IDC draining and patent</td>
</tr>
<tr>
<td>Capillary refill</td>
<td>• Continue fluids and monitor hydration status</td>
</tr>
<tr>
<td>Are they warm to touch? Is the skin dry, moist or clammy?</td>
<td>• Consider continuous temperature monitoring for brain injured patients, spinal patients, burns and paediatrics</td>
</tr>
<tr>
<td>What IV access does the patient have?</td>
<td>• Ensure adequate intravenous access, at least two large bore peripheral IV access for ICU patients or ideally central line insitu</td>
</tr>
<tr>
<td></td>
<td>• Secure all lines and tubes</td>
</tr>
<tr>
<td>Is the haemoglobin adequate?</td>
<td>Does the patient need blood products for the transfer due to potential for bleeding? Ensure correct packaging of products</td>
</tr>
<tr>
<td>Is the patient actively bleeding?</td>
<td></td>
</tr>
<tr>
<td>What blood products and other fluids have they received?</td>
<td></td>
</tr>
<tr>
<td>What infusions are running?</td>
<td>• Think about what can be given in bolus form, to reduce need for infusions e.g. analgesia</td>
</tr>
<tr>
<td>Inotropes?</td>
<td>• Swap infusions to syringe drivers</td>
</tr>
<tr>
<td></td>
<td>• Discontinue any non-essential fluids or infusions if possible</td>
</tr>
<tr>
<td></td>
<td>• Have inotropes ready if particularly unstable patient</td>
</tr>
<tr>
<td>What monitoring does the patient have?</td>
<td>• Ensure minimum of haemodynamic monitoring, BP (cuff and/or arterial), continuous ECG monitoring, monitor colour and perfusion of patient, capillary refill if able to in flight</td>
</tr>
<tr>
<td>Arterial line in situ?</td>
<td>• Swap arterial pressure bags</td>
</tr>
<tr>
<td>If not in SR is it ST because of hypovolaemia or some other medical condition?</td>
<td>• Consider what extra medications may be needed for arrhythmias?</td>
</tr>
<tr>
<td>If in SB are they fit or beta blocked – can they compensate for hypovolaemia?</td>
<td>• Consider attaching defib pads if the patient is high risk for arresting or having a shockable rhythm or may need external pacing</td>
</tr>
</tbody>
</table>
### Disability / Neurological

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>What is the GCS?</strong>&lt;br&gt;Break down GCS to find out specifics of E V M ICP monitoring required?</td>
<td>• Close monitoring of neurological state and pupillary reaction&lt;br&gt;• Continue ICP monitoring and continuous monitoring of cerebral perfusion pressure</td>
</tr>
<tr>
<td>Pupils equal and reactive? If pupils unequal then why and what treatment have they had for this?</td>
<td>• Consider carrying additional medications for raised ICP management including concentrated salt or mannitol</td>
</tr>
<tr>
<td>Pain relief required</td>
<td>• Always anticipate pain and discomfort&lt;br&gt;• Appropriate analgesics to hand</td>
</tr>
<tr>
<td>Sedated or non-sedated? Paralysis given?</td>
<td>• Ensure sufficient sedation and paralysis for entire transfer&lt;br&gt;• Protect patient’s ears with ear defenders and/or ear plugs whilst in the aircraft</td>
</tr>
<tr>
<td>Any nausea</td>
<td>• Administer anti-emetics</td>
</tr>
<tr>
<td>What is the BSL</td>
<td>• Monitor BSL as required</td>
</tr>
<tr>
<td>Are they going to put others at risk, e.g. agitated, combative, pulling at lines. Can the safety of the patient and crew be maintained at all times?</td>
<td>• Provide reassurance and good communication with patient. Consider anxiolytics for particularly anxious patients&lt;br&gt;• Consider intubation if no other way to safely transport patient&lt;br&gt;• Explain all procedures and what to expect during the flight</td>
</tr>
</tbody>
</table>

### Exposure - Pieces of Plastic

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Nasogastric or orogastric tube&lt;br&gt;• 2x IVCs in situ or CVL if inotropes required&lt;br&gt;• Arterial line&lt;br&gt;• IDC&lt;br&gt;• Stoma with ostomy bag&lt;br&gt;• Intercostal/chest under water seal drains&lt;br&gt;• Surgical drains&lt;br&gt;• Plaster of Paris</td>
<td>• Aspirate NG, place on free drainage&lt;br&gt;• Empty all IDC, NG and drain bags prior to transport&lt;br&gt;• Attach Heimlich valve drain/pnumostat&lt;br&gt;• Bi-valve POP if &lt; 48 hours</td>
</tr>
</tbody>
</table>
Other considerations:

- Ensure medications given and administered according to C&CDHB medicines and standing orders policy for flight
- Think about extra equipment you might need, for example if a patient has a difficult airway and may need intubating, do you need to take other airway adjuncts that are not in your equipment bag?
- Ensure good communication between receiving and referring area, keep in close contact
- Paperwork – Ensure all paperwork present to accompany patient.
  - All notes
  - Investigations (bloods, x-rays, scans)
  - Medication chart
  - Discharge summary
  - Stickie labels

  Note - Most hospitals are now digital with PACS, if not, ask the staff in the referring area to ensure they are put onto disc early to reduce waiting at the referring area for this to be done.
In-Flight Patient Care

The flight nurse must ensure:

- Safe loading and unloading from aircraft
- Adequately securing the patient and stretcher to prevent undue movement
- Safe, secure stowage of all loose equipment
- Safety from extremes of pressure and temperature changes
- Adequate oxygenation and ventilation
- Circulatory efficiency
- Accurate fluid and drug administration

After loading, but prior to take-off, the following checks should be completed:

- Recheck ETT placement and secured
- Oxygen supply opened and accessible
- Ventilator parameters re-assessed
- Monitors secure and provide good visual access
- IV access patent. Arterial lines secured and accessible
- IV bags secured and infusion rates checked
- Suction readily available
- Receiving facility has been notified of estimated time of arrival and patient status
- Ground arrangements confirmed

The flight nurse must anticipate potential complications and be prepared to intervene as necessary.

- Frequent observations of vital signs and patient condition documented throughout transportation. Ideally every 15 minutes if ventilated or unstable.
- Documentation of flight and cabin altitude
- Communicate frequently to alleviate patient anxiety
- Ensure comfort and warmth
- Monitor ventilator and cuff pressure fluctuations carefully
Post flight Care

- Thorough handover to receiving area along with accompanying paperwork, X-rays, investigation results, referral letters etc.
- No tarmac handovers. The patient is the responsibility of the flight nurse until handed over to the staff in the receiving area.
- Complete post flight assessment of the patient including vital signs to highlight any potential complications though the flight period.
- Document the name of the person taking over responsibility for the patient.
- Complete flight documentation and photocopy
Section Six: Considerations for Specific Patient Groups
Cardiac Considerations

- Chest pain: PQRST assessment
  ➢ Provoking and relieving factors
  ➢ Quality of the pain
  ➢ Region and radiation
  ➢ Severity, signs and symptoms
  ➢ Time of onset and how long each episode lasts
- Recent scans/tests and results (including CXR, Trop T, CKMB, full bloods, electrolytes, CT if querying dissection).
- If for angiography, they will want to know coag results (INR, APTT), haemoglobin, creatinine level and medications administered (drug, dose, route, time)
- Treatment thus far – thrombolysis, aspirin, oxygen, anti-platelet, fibrinolytic agents, beta blockers, GTN etc. Normal medications.
- Dysrhythmias and rhythm, 12 lead ECGs.
- Vital signs – blood pressure (both arms), perfusion, colour, GCS, urine output.
- Respiratory status – any accompanying shortness of breath, oxygen requirements, SpO₂, respiratory rate, lung fields on auscultation.
- O₂ therapy, all patients are hypoxic if there is poor cardiac function, failure or pulmonary oedema
- Have available GTN spray, morphine, anti-emetics

Aortic Dissection/Abdominal aneurysm Considerations:

- Essential communication needed between flight nurse, cardiothoracic team and operating theatres to ensure timely transfer of patient.
- Perform full assessment, especially assessment of haemodynamics and cardiac status.
- Assess level of pain and ensure plentiful analgesia.
- Anti-emetic essential to prevent straining and vomiting.
- Ensure that 2 large bore cannulae are insitu.
- Ensure at least 6 units of blood boxed up and ready to go with the patient.
- Arterial monitoring is the gold standard, aiming to keep SBP < 100 mmHg.
- However, timely transport is of the utmost importance.
- It is essential to discuss potential outcomes with the family and patient prior to transport, that resuscitation efforts may be futile in the face of a ruptured aneurysm.
Trauma Considerations

- Time of injury.
- Mechanism of injury.
- Passenger/driver front or back seat.
- Restrained or unrestrained.
- Glasgow coma score at the scene and extrication time.
- Injuries sustained spine and immobilization, chest, pelvis, heart, bones and treatment thus far. CT scans and X rays.
- Haemodynamic status (stable or not? bleeding).
- Barometric pressure – any air in the skull, sinuses or eyes, will cause pain. Any exudate of brain matter or vitreous.
- Lacerations sutured or bandaged.
- Where possible, cabin altitude of sea level.
- Avoid Valsalva.
- Stabilise bleeding
- IV access – large bore cannulae x 2, fluid resuscitation

Limb/Fracture Considerations:

- Mechanism and time of injury.
- Colour, warmth, movement, sensitivity of limb.
- Perfusion and capillary refill of digits.
- Plaster cast – time of application (plaster of paris splints need to be bi-valved if less than 48 hours in situ to allow for air bubble expansion in the cast and swelling of the limb.)
- Any evidence of rhabdomyolysis or compartment syndrome needs to be considered prior to transport.
- Ensure recent bloods available, myoglobin, urea and creatinine especially if muscle damage.
- If multi-trauma suspected, full primary and secondary survey is essential to ensure other injuries are assessed and treated promptly.
- Elevate and pain relief.
- Splint.
- No weights, as counter traction unable to be maintained due to lack of space, G-force and weights become a flying hazard.
Maxillofacial Injuries:

- Protect airway. Can it be maintained? If there is a risk of airway compromise other airway adjuncts and intubation will need to be considered
- Wired jaw – wire cutter
- NBM and anti-emetics
- Pain relief

Amputation Requiring Replantation:

- Transport of the completely amputated part: this should accompany the patient. It should be retrieved and, with no interference, the exposed or torn muscle should be wrapped in gauze dressing moistened with saline and placed in a double plastic bag and sealed. Then place in a container of iced water to keep the amputated part from freezing. Revascularisation should be within four hours.
- Transport of the incomplete amputated part. Place in a normal position, dress lightly and splint. Cool area. Take care not to complete the amputation
- Oxygen therapy
- Haemostasis
- IV cannula
- Pain relief

Burns Considerations:

- Time and mechanism of injury, any loss of consciousness
- Involvement of face and neck & singed facial hair, consider early intubation
- Other injuries sustained
- Status of airway (think early intubation)
- Degree of burn and body surface area involved
- Any escharotomy performed
- Fluid replacement and calculation of requirements needed for transfer
- Urine output and haemodynamic status and vital signs (any evidence of shock). Any arrhythmias or myocardial ischaemia
- Analgesia, sedation and treatments
- Body temperature, temp probe insertion
- All blood results, especially electrolytes, myoglobin
Head/Brain Considerations:

- Current GCS – eye opening, motor score, verbal score.
- Any drops in GCS – when and how often, what does it drop to.
- Limb movement and strength bilaterally, any other focal changes.
- Pupil size, reaction and equality
- Seizure activity, anti seizure medications given when and how often.
- Any neck pain/ stiffness.
- Photophobia.
- Nausea and vomiting.
- Any ECG changes related specifically to SAH.
- Current therapies and treatments initiated.
- Blood results, specifically serum sodium and electrolytes.
- Think – noise and vibration – turbulence
  - Strobe lights – if epileptic may cause seizures
  - Hypoxia
  - BP increases with altitude
  - Decreased humidity
  - G-force – take off and landing. Long roll outs.
  - Head up on pillows.

Interventions to consider:
- Adequate sedation and analgesia
- Mannitol and/or conc. Saline 23%
- Hypertension
- Inotropes to maintain cerebral perfusion pressure >60mmHg
- Intubate orally and orogastric tube
- Anti-emetics, vomiting increases ICP by 100mmHg
- IV access
- Monitoring, ETCO₂

Ocular considerations:

- Mechanism of injury, type, penetrating or blunt.
- Extent of injury, loss of vision, any other complications and other injuries to face.
- Normal eye history, any past surgery or current medications/eye drops.
- Pad both the eyes to maintain cleanliness and to restrict movements of eyes.
- Orientation and patient reassurance very important.
- Analgesics – try to avoid meds that cause pupillary constriction.
- Anti-emetics and naso/orogastric tube to avoid vomiting and straining hypertension.
- Be aware of long flights will cause dryness and irritation of the eyes. Consider saline soaked pads over the eyes and changing regularly during the flight.
- Always administer oxygen – retina requires a high level of Oxygen to maintain normal processes.
Spinal Considerations:

- Stabilise and immobilise spine
- Mechanism of injury (any loss of consciousness at the scene).
- Timing of injury.
- Other injuries (head, bones, pelvis).
- Full assessment of ABC and neurological state
- Assess level of sensation, dermatome level and any limb movement.
- Full examination to ensure respiratory status stable (think early Bipap)
- Full skin assessment – log roll to ensure back and sacrum free of any tubes, leads and caps, etc before sliding onto the stretcher.
- Ensure haemodynamics stable prior to transfer especially HR and blood pressure.
- Ensure IDC is patent and free of kinks.
- Ensure NGT on free drainage and anti-emetics. Prone to paralytic ileus. Maintain NBM. Ensure suction easy to access and available at all times.
- Vacuum mattress – decrease in barometric pressure causes the air to expand, depressurising the mattress on ascent then causes it to tighten on descent. Constant readjustment is required.
- Long transfers in the bean bag can be uncomfortable for the patient, ensure analgesia prescribed and give as often as needed.
- Monitor temperature also as the bean bag can get hot as well as vibrations of the aircraft. (Rectal/central temp).
- Note initial amount in bladder on insertion of IDC as important for rehabilitation.
- Always anticipate fluid replacement. Ensure full assessment of haemodynamics, renal parameters and fluid status is performed prior to transfer.
- Colostomy or drainage bags watch for air expansion – air vent – empty.

Abdominal Considerations:

- Comprehensive history and abdominal examination prior to transfer.
- Mode of transport important to consider early – perforation of small bowel, ileus and acute appendicitis all produce gas, sea level cabin will help to reduce the risk of rupture where gas expansion may occur.
- Ensure anti-emetics given pre-transfer unless contraindicated.
- Analgesia for abdominal pain.
- Recent bloods especially HB, Coags, Urea and electrolytes, and LFT’s. If an arterial line is insitu an ABG and lactate level may be of some use.
- If bleeding is suspected think about taking blood and products and volume replacement.
- Orogastric/nasogastric output. Ensure bag is emptied prior to transfer and tube is not kinked.
Paediatric Considerations:

- Weight and Height.
- AVPU and GCS.
- Last feed (bottle or breast).
- Last nappy change, last wet or dirty nappy.
- Respiratory rate, drooling, coughing, sternal retractions, in-drawing etc
- Colour, perfusion, heart rate and capillary refill.
- General state e.g. crying, somnolent, difficult to console, interaction with family.
- Immunisations and vaccination history.
- Maternal and pregnancy history, delivery problems, neonatal history.
- Sibling and family history.
- Social history from staff is important, especially in cases of Non accidental injury.
- Ensure the appropriate MDTs are notified and communicated with (including social work, CYFS etc). This will need to be communicated to the accepting area on handover of the patient.
Obstetric Considerations:

- Take an experienced midwife.
- Thorough examination of the patient including vaginal exam before transfer if not contraindicated (i.e. ante-partum hemorrhage & placental abruption). Note PV losses and contractions, how long and how far apart.
- Details of past pregnancies and problems, especially previous rapid deliveries and premature labours.
- Nifedipine and bethamethasone (steroids) pre transfer – dose and time and regime followed for premature labour. Antibiotics if SROM.
- Discuss with neonatal team if transfer going to be a long process and delivery is imminent. May be better to deliver baby in the referring area and utilize the neonatal transfer team afterwards.

**Caution if >6cm dilated with regular contractions**

- If history of ante partum hemorrhages think about taking extra fluids, blood and colloid and close monitoring of haemodynamic status.
- If foetal heart rate monitoring insitu, continue if able through flight (although often this is difficult due to noise and vibration of the aircraft). The midwife should carry a handheld doppler in her kit.
- Essential to monitor oxygen saturations closely and continue with oxygen therapy through the transfer to avoid foetal hypoxia.
- Be aware that turbulence, G-Forces during take off and landing may increase uterine contractions and spontaneous rupture of membranes if cervix is already dilated.

Pre Eclampsia:

- Ascertain severity of pre-eclampsia (mild, severe).
- Bloods pre transfer, especially creatinine, proteins, Coags, LFT’s.
- Full systems assessment, may be evidence of respiratory distress, hypertension, fluid overload, pulmonary oedema and oliguria. Note fluid balance also & assessment of foetus and FHR.
- Hospital history, any seizures, visual disturbances, headache, clonus etc
- Magnesium therapy thus far & medications for hypertension, dosage and frequency.
- Establish targets for blood pressure – discuss with obstetric and ICU team.

Ante-partum Haemorrhage:

- Large bore IVs
- Blood and products
- Stable vital signs
- NBM
Decompression Sickness Considerations:

- Full assessment of cardiac, respiratory and neurological status.
- Time and mechanism – Details of dive, previous experience, previous diving accidents, number of dives, max depth, number of ascents, time of onset of symptoms and nature of symptoms.
- Treatment given and response to treatment.
- Think rapid and continuous intravenous fluid replacement (take extras), need to know fluid replacement already given.
- Consider ways of giving 100 % FiO₂, tight fitting non-rebreather, CPAP, etc. May need to take extra equipment.
- Will need the appropriate mode of transport, if fixed wing maintain cabin pressure at sea level and always less than 1000 feet.
- Ensure patient remains lying flat at all times, no standing transfers.
- Ensure patient is catheterised for transfer to monitor fluid balance status, aiming to keep urine output > 1ml/kg/hour.
- Ensure good communication between receiving area and the hyperbaric chamber staff. Notify if anything changes with the patient’s status.

Carbon Monoxide Poisoning Considerations:

- 100% oxygen at all times, particularly when transferring from ambulance to plane as the fumes for the vehicles will lead to a further increase in the level of carboxyhaemoglobin.
- Sea level cabin
- Consider Met Hb level prior to transport as a baseline.

Head Colds, Sinus, Throat and/or Ear Infections:

- Patients/staff with head colds, sinus, throat and/or ear infection should not be transported by Air Ambulance unless they are able to perform a Valsalva manoeuvre (voluntary equalising of the pressure either side of eardrum).

Psychiatric Patients:

- History of violence
- Fear of flying
- Use another means of transport
- IV access
- If necessary, sedate well +/- intubate and ventilate.
- Consider safety of all staff and crew
- Are there any accompanying personnel – police, mental health workers?
References


(Compiled by Lynsey Sutton, 2009)
Section Seven: Further Resources
Aneurysms

Aneurysms & why they are bad for you

Alex Psirides
Wellington Hospital

What is an aneurysm?

- Localised dilation of a blood vessel
- Caused by disease or weakening of vessel wall
- Most commonly occur in arteries
- Weakening progresses to
- Dissection
- Rupture

*(by definition, aneurysm if 50% greater in diameter than normal size of artery)*

Who gets them?

- Male: female 3:1
- 3-4% incidence at autopsy in people older>65.
- Aetiology is multifactorial
- Atherosclerosis and smoking = high risk
- Hypertension associated with 70% of cases
- Family history
- Rarer causes include: Bicuspid aortic valve, CABG surgery, Cardiac catheterisation, High-intensity weight lifting, Connective tissue disorders, Inflammatory disease causing vasculitis, Crack cocaine

Pathology

- Aorta normally 2.5-3.5cm diameter
- 3 layers in aortic wall Intima, media, adventitia
- Dissection occurs when tear of intima (inner lining) allows blood to leak into media (middle layer) - two passages for blood are created:
  - True lumen - normal passage
  - False lumen - newly created passage

Presentation:

- Sudden death
- Severe cardiovascular collapse
- Abdominal, chest or back pain
- Asymptomatic pulsatile abdominal swelling
- Stroke
- Incidental radiological finding
- Distended neck veins, cough, dysphagia,
  - haematemesis, paraplegia, distal emboli
Dissection

- Blood flow into false lumen causes it to enlarge - may block flow in true lumen
- Blood diverted away from organs supplied by true lumen as dissection progresses
- Dissection spread may involve other organs
- Dissection may spread:
  - brain (carotids)
  - kidneys (renals)
  - GI tract (superior & inferior mesenteric arteries)
  - arms (brachiocephalic trunk)
  - legs (iliacs)

Types of aortic Aneurysm

- Classified by where they originate & which part of the aorta is involved
  - DeBakey I: originated in ascending; II: originated in & confined to ascending; III: originated in descending
  - Stanford A: originated & involves ascending aorta; B: originated & involves descending aorta

Transfer concerns

- High risk patients who may deteriorate during transfer
- Good preparation is essential
- Symptoms may change during transfer
- Blood pressure control
- Degree of urgency
- may deteriorate requiring intubation, dissect up carotids causing CVA, back to coronary sinus causing arrest
- do not delay transfer waiting for blood results, blood products or X-rays

Communication

- Good communication needed between multiple groups
- Type & location of aneurysm
- How diagnosed
- Cardiovascular state & co-morbidities
- Deterioration en route
- Surgical team and/or theatres aware: Have they been accepted by the cardiothoracic or vascular team? Do theatres need to be on standby?
- Resuscitation status
- Is it dissecting? Ruptured but contained?
- Have they been anticoagulated? (beware of thrombolysed patients)
- Resus status discussed with family & patient if able
**Recommended minimum**
- Arterial line
- Large bore intravenous access (multiple if possible)
- Relevant radiology
- Blood, fluid & clotting products (if indicated)
- Drugs
- Positive inotropes
- Negative inotropes & vasodilators & beta Blockers if hypertensive.
- Beta blockers help to reduce sheer stresses on the vessel walls.

**Blood pressure control**
- Goal-directed
- “Enough to keep them conscious”
- Systolic 90-100mmHg ‘maximum’ acceptable
- Be wary of over-resuscitation
- ‘Normal’ BP for that patient
- Infusion vs bolus
- Which drug(s) to use
- Which fluid to use

**Aims of drug therapy**
- Halting progression of dissecting force
- Lowering BP
- Decreasing left ventricular contractility
- Decreasing heart rate
- Stabilise pending definitive surgical (or medical)
- management

**Drugs**
- Beta-blockade: Esmolol, Labetalolol, Metoprolol
- Vasodilators: Sodium Nitroprusside, Hydralazine
  - SNP - rapid onset, short duration. Reflex tachycardia so give in conjunction with beta-blockade. Arterial & venous dilation; light sensitive, cyanide toxicity
- Esmolol - ultra-short beta; elimination half-life 9mins. Load then bolus
- Labetalolol - alpha, beta-1, beta-2
- Metoprolol - oral & iv; longer acting
- Pain & anxiety will contribute - analgesia important: Morphine, Fentanyl
Conclusions

- May be difficult patients to transfer
- Preparation is key
- Anticipate difficulties
- Rapid but safe transfer is optimal
- Blood pressure control & analgesia important
- Good communication between teams before, during
- & after transfer is essential
Trauma & Spinal Injuries

Trauma & Spinal Injuries
Alex Psirides
Wellington Hospital

Trauma
- Physical injury from mechanical energy
- Blunt
- Penetrating
- Motor vehicles, falls, assault (stabbing, shooting), explosions, burns
- Systematic approach to assessment
- Repeat assessment

Timing of Deaths from Injuries
- First peak: Overwhelming primary injury. Seconds to minutes
- Second peak: Hours Avoidance of Secondary Injury from hypoxia, hypotension.
- Third peak: Days to weeks Sepsis, multiorgan failure, head injuries

Assessment & Priorities
Early Markers of the Severely Injured
- Depressed Consciousness Brain injury, hypoxaemia, shock, alcohol, drugs
- Breathing difficulties Airway obstruction, laryngeal injury, pulmonary aspiration, lung or
- Chest wall injury
- Shock & Hypovolaemia

Initial Treatment & Investigation
- Oxygen & Ventilatory Support
- Blood Cross-Match & TestsHigh flow O2 to all trauma patients, intubate if GCS<8 or agitated/unco-operative
- 6u X-match urgently
- Fluid resuscitation via 2-3 large (14 or 16G cannulas) - upper limb, ext jug, femoral veins
- Analgesia - opioids i/v
- Urinary cath unless ruptured urethra present (blood at urinary meatus, abnormal prostate on PR, severe pelvic #) -
- Urine output good guide to resuscitation

Secondary Survey
- Clinical evaluation of injuries
- Front & back of patient
- Special attention to regions with lacerations, contusions & abrasions
- All regions examined systematically
- May need to return to Primary Survey at any point
Priorities

- Support life
- Resuscitation
- Locate & control bleeding
- Prevent brainstem compression
- & spinal cord damage
- Diagnose & treat all other injuries & complications

Basic Treatment Principles
Primary & Secondary Surveys

- Primary Survey
  - Airway obstruction
    Noisy (or silent) breathing, paradoxical chest movements, inadequate airway protection.
  - Breathing difficulty
tachypnoea, cyanosis, confusion, abnormal pattern
  - Circulatory shock
cold peripheries with delayed capillary refill, weak rapid pulse, low BP.

Secondary survey: Systematic

- Head - neuro obs, ears & nose for CSF leak & blood, scalp for injury
- Face - airway bleeding, tested for abnormal mobility
- Spine - C-spine #/dislocation assumed in ALL patient with decreased GCS
- Signs of spinal cord injury - warm dilated peripheries (loss vasmotor tone), diaphragmatic breathing, paralysis, priapism, loss of anal tone. Inspection & palpation thoracic & lumbar spine
- Thorax - haemo, pneumo, lung contusion, flail chest, heart/great vessel injuries
- Pelvis - massive blood loss esp post # with sacroiliac dislocation. Ruptured bladder/urethra with ant #
- Extremities - >1l blood loss into # femur. Long bone # serious if open, comminuted, displaced. Also associated
  nerve/arterial/venous damage
- External - contusions extensive, serious if fall from height, on back. Burns - fluid loss
Secondary Injury
And how to avoid it

- Main Pitfalls:
  - Hypotension
  - Hypoxia
  - Late detection of injuries
  - Sepsis
  - Multi-organ failure

Basic Principle of Trauma Transfers
TRUST NO ONE
Re-evaluate

- Handover of complex patient by someone who’s already had the patient handed over to them
- Assume nothing
- ‘Dump and run’ principle
- Which drugs have been given - antibiotics, ADT, fluids & how much

Retrieval team assessment

- Issues: DAI, cerebroprotection, hypotension, hypoxia, inadequate resuscitation, definitive surgical plan
- A, B, C
- Check tube, ventilation - ?ET moved in-transit
  - ?ventilator delivering 100% ?obstruction
- Check breathing - chest injury, tension pneumo, collapse, haemothorax
- Check pulse - accurate BP, HR, SpO2
- iv access, fluid resuscitation, maintain MAP
  - inotropes ?CV access required

Cerebral Circulation

- Cerebral Perfusion Pressure
- CPP=MAP-ICP
- Normally 70-90mmHg
- Cerebral ischaemia below 40mmHg
- Maintained by Autoregulation - little change in CPP if healthy.

Management

- Bad Things
  - High ICP, Low MAP, Poor oxygenation
- Good Things
  - Low ICP, Adequate MAP, Good oxygenation

Cerebroprotection

- Normocapnia/avoid hypercapnia
- Normoxia/avoid hypoxia
- Hypothermia/avoid hyperthermia
- Maintain CPP>70 with inotropes/filling
- Head up
- Neck straight
- Analgesia +/- Sedation +/- Paralysis
- Mannitol +/- Concentrated NaCl
Monro-Kellie doctrine

- Incompressible contents
- Skull has fixed volume
- Rise in volume causes rise in pressure
- Pressure beyond certain point causes brain-stem herniation.

Signs of Cerebral Ischaemia

- Headache
- Nausea & vomiting
- Confusion
- Papilloedema
- Impaired consciousness
- Hypertension & bradycardia
- Hypotension
- Coma, apnoea, fixed dilated pupils

Possible Undiagnosed Injuries

- Repeating head-to-toe trauma assessment within 24 hours has been shown to reduce frequency of missed injuries
- Assess adequacy of imaging & quality of reporting
- Second opinion if indicated
  - Intracranial haemorrhage
  - Traumatic aortic disruption
  - Intra-abdominal injuries
  - Pulmonary contusion
  - Rhabdomyolysis

Aortic Rupture

- 80% die at scene
  - Of those that survive, 50% die within first 24hrs unless repaired
- 50% patients have no external chest signs
  - Widening mediastinum on CXR has 90% sensitivity for rupture or dissection.
- Symptoms include midscapular pain, SOB and dysphagia, hoarse voice.

Intra-abdominal Injury

- Study of 607 abdominal trauma patients showed
  - Missed injuries subsequently requiring repair in 12 cases (2%)
  - Missed due to inexperience, atypical radiography, unclear history.
  - Suspect in patients with blunt or penetrating trauma, evidence ongoing blood loss
  - Tests include diagnostic peritoneal lavage, CT, ultrasound, bladder pressures, FAST SCAN.
  - FAST (Focused Assessment with Sonography for Trauma) - replaced DPL. Rapid, non-invasive, bedside. Operator dependent, unable to detect source of bleed, non-invasive. 80-100% sensitive.
Pulmonary Contusion

- Pulmonary Contusion
- Oedema, blood, atelectasis
- 17% of multiple trauma patients
- Most common injury in blunt chest trauma
- Mortality 6-25%
- Symptoms include SOB, haemoptysis, wheeze, hypoxaemia, hypercarbia
- Radiological changes delayed up to 6hrs after injury
- Treatment is supportive
- Rapid deceleration in MVA, falls, explosive blasts
- Mortality due to superimposed pneumonia, ARDS
- Rib #s may or may not be present
- Avoid overloading to minimise oedema
- Analgesia important if not intubated
- If intubated, consider double-lumen tube with selective PEEP for each lung - minimise barotrauma risk in unaffected lung.

References:


Spinal Cord Injury

Epidemiology
- Incidence TSCI USA 40 per millions persons per year
- 250,000 living survivors
- Major causes MVA (47%), Falls (23%), Violence (14%), Sports (9%)
- Male (80%), median age 22, alcohol involved in 25% cases
- NZ incidence 'one of highest in Western world'
- Highest rates for young Maori males
- NZ children 4 times risk of SCI than US equivalents

Mechanism SCI
- Most cord injuries in association with vertebral column injury
- Fracture of bony elements
- Dislocation at one or more joints
- Tearing of ligaments
- Disruption/herniation of intervertebral disc
- Primary injury vs secondary injury (may evolve from minutes to hours after initial injury)
- Cord edema maximal days 3-6, receding after 9th day & replaced by central haemorrhagic necrosis
- SCI also from bullet that does not enter spinal canal (advance wave of kinetic energy?)

Transfer Principles
- Airway, Breathing, Circulation
- Assess spinal level prior to mobilisation
- Close monitoring given potential for deterioration
- Don’t assume hypotension is of spinal origin
- Assume all trauma patients have a spinal injury
- Transfer supine on firm surface with spine in good alignment

Complications
- Cardiovascular: CV - Interruption of autonomic pathways - decreased vascular resistance. Beware blood loss - don’t assume hypotension due to sympathectomy. Recommend MAP 80-90 to avoid secondary ischaemic injury - vasopressors. Also atropine +/- pacing.
- Neurogenic shock - hypotension & bradycardia
- Respiratory: Respiratory failure, pulmonary oedema, pneumonia weakened cough, atelectasis,
- Venous thromboembolism
- Urinary catheterisation
- Temperature control: Temp control - can’t sweat below lesion so temp varies with environmental temp
- Pressures sores
Outcomes

- Early death rates range from 4-20%
- Age & level predict mortality
  C1-3 6x increased risk death
  C4-5 2.5x increased risk death
  C6-8 1.5x increased risk death
- Most recovery of incomplete SCI takes places within first six months

Transfer Practicalities

- Urinary catheter (retention)
- NG tube (paralytic ileus)
- Temperature probe (unable to autoregulate)
- Large bore intravenous access (fluid resuscitation +/-)
- Stabilise & immobilise - Beanbag
- Cervical spine traction if available
- Consider other injuries - rarely isolated spinal lesion

Summary

- Primary Survey - ABC
- Secondary Survey - everything else
- Beware missed injuries & secondary injury
- Assume nothing
- Be prepared for deterioration in transit
Premature labour and threatened premature are the most common reasons for transfer. Usually these mothers are being transferred into Wellington, so that the babies can be cared for by the Neonatal team, and admitted to the Neonatal Unit. Occasionally they are transferred out of Wellington, as there are no beds in the Wellington NNU.

Pre-eclampsia may necessitate the mother needing advanced obstetric care. May also need NNU care depending on the gestation of the baby. Careful thought needs to be given before transporting the mother with vaginal bleeding. Particularly with placental abruptions, the baby may perish quickly and of course a caesarean section cannot be performed in the air. The obstetric team must decide whether to deliver the baby first and then get the neonatal retrieval team to transport the baby.
Premature labour can be difficult to diagnose. Some women have very little cervical change, and contractions that do not appear to be very strong, but go on to deliver quickly. Other women have a “niggly” uterus with some cervical effacement but do not establish in premature labour. As there is some difficulty sometimes diagnosing premature labour, some women may end up being transferred unnecessarily. Premature delivery is a major course of perinatal morbidity and mortality.

This picture shows the cervix at the end of the vagina. You can see that it looks like a tunnel when the woman is not in labour. When the cervix gets shorter then the cervix is effacing. It may be partially or fully effaced. The cervix is assessed by either speculum or digital examination. As labour progresses the cervix will also dilate.
Breech presentation is more common with premature birth than a full term birth. A premature breech presentation is said to be more dangerous than that of a full term infant. The largest part of any baby is the head. With a full term infant the diameter of the buttocks is similar to that of a well flexed head.

With a premature baby, the diameter of the buttocks is smaller than a well flexed head. This means that there is a greater risk of the premature baby’s body slipping through the cervix with the head still trapped inside the uterus. To add to the risks associated with this, the cervix does not always need to be completely dilated to allow a premature infant’s body to slip through the cervix. If the cervix is not fully dilated the head is more likely to become trapped. The consequences are even worse as the baby is fragile. Premature babies are more delicate, more likely to have a cerebral bleed. If a decision is made to transfer, do it early and get on with it.
Watch for the woman pushing involuntarily. Look under the blanket, part the woman’s legs, and see if you can see the head. Watch the perineal area if she starts pushing as the baby can come quickly.

**Vaginal Bleeding**
- Placenta Previa
- Placental Abruption
- Ruptured Uterus
- Ruptured membranes
- Cervical erosion
- Vaginal trauma
- "show"

**Placenta Previa**


**Pre-eclampsia**
- A multiorgan disease process characterised by Hypertension, Proteinuria, and sometimes oedema
- May be mild, moderate or severe

**Severe Pre-eclampsia**
- Blood pressure increases
- Proteinuria becomes more significant
- Elevated serum creatinine
- Oliguria
- Pulmonary Oedema
- Grand mal Seizures
- Microangiopathic hemolysis
- Thrombocytopenia
- Elevated liver enzymes
- IUGR
- Headache, Visual Disturbances, epigastric pain RUQ P

**Treatment of Premature Labour**
- Nifedipine - aim to delay delivery until steroids given
- Steroids – Betamethasone 2 doses 12hrs apart to mature baby’s lungs
- IV antibiotics for infection or prolonged or prelabour rupture of membranes.
- Transport to hospital with appropriate neonatal care if necessary.
The obstetric team should ensure that the steroids have been given. Even with the best of intentions, several hours have often passed before the woman arrives at the receiving hospital. Every hour that passes once the steroid injection has been given to the mother improves the baby’s chance of survival.

An independent midwife in Wanaka ventilated a baby of 24 weeks gestation for four hours until help arrived from Dunedin. The help was slow due to adverse weather conditions. The baby survived. This demonstrates that keeping even a premature baby warm and ventilating with a bag and mask will often keep that baby alive.

If ventilation is adequate, then the heart rate should be good

Women with severe pre-eclampsia need to be transferred to larger centres for intensive care. The onset of severe PET may be sudden or gradual with multiple organ systems involved:

- Nervous system – Headache, and visual disturbances, hyperreflexia, can be signs of a convulsion.
- Severe Vasospasm and increased peripheral resistance stress the cardiovascular system, and pulmonary oedema may occur.
- Haematological derangements include decreased vascular volume, increased blood viscosity and haemoconcentration. Coagulopathies including HELP and DIC may occur.
- Renal manifestations include a decreased glomerular filtration rate, which may progress to oliguria and acute renal failure.
- Liver damage causes raised ALT. Sub capsular haemorrhage may cause right upper quadrant pain to occur.
Women with severe pre-eclampsia should be transferred with magnesium sulphate infusing. If the woman does seize, protect from injury, maintain airway, ensure magnesium sulphate is infusing, and seek advice about giving a further dose. Listen to foetal heart. Look for signs of abruption. The uterus should be soft to palpate between contractions. The baby should be delivered at the earliest opportunity.

References


Section Eight: Neonates
As a member of a neonatal air transport team, whether fixed-wing or rotary-wing, you must have a basic understanding of flight physiology. The negative effects of altitude on the human body can be very detrimental, if not fatal, for the compromised neonate. This article looks at the physiologic stressors of air transport such as hypoxia and gas expansion. It also discusses environmental stressors such as noise, vibration, motion, temperature and humidity. The key to successful neonatal air transport is the transport team knowing what physiologic changes to expect, properly assessing the infant, preventing stressors if able, and properly intervening as necessary.

Many babies born prematurely are in critical condition and simply cannot remain at their home hospital due to lack of specialised equipment and adequately trained medical staff. Transfer to a neonatal intensive care unit (NICU) may be necessary. Traditional ground transport by ambulance is often used, but is rather slow. Air transport via rotary-wing (helicopter) or fixed-wing (aeroplane) aircraft seems to be the transport mode of choice for covering long distances quickly, but it is not without problems. Team members involved in neonatal air transport must have a basic understanding of the physiologic changes that occur within the human body during air transport. The most frequently seen problems are altitude induced; others simply relate to the aircraft itself. Hypoxia; expanding of the entrapped gases; and stress from noise, vibration, motion and decreases in temperature are common. All of these physiologic changes must be considered and dealt with during air transport of the neonate.

Physiologic Stressors

During air transport, the predominant factor affecting normal human physiology is altitude. As altitude increases, barometric or atmospheric pressure falls. This eventually causes oxygenation problems. Hypoxia or oxygen deficiency can be fatal if not treated and is a major concern when transporting infants with poor cardiopulmonary status and vulnerability to hypoxia. The types of hypoxia most often seen during air transport are hypoxaemic hypoxia and stagnant hypoxia.

Hypoxaemic Hypoxia

In flight, the percentage of inspired gases, such as oxygen (O₂), remain the same, but the partial pressures they exert change. At higher altitudes, there is less pressure to push the O₂ from the alveoli in the lungs to the capillaries. Inadequate blood oxygen tensions cause an insufficient amount of O₂ to cross the alveolar-capillary membrane, resulting in hypoxaemic hypoxia. Although the effects of altitude-induced hypoxia are well studied in adults, there are few current data specific to neonates. However, the adult values, demonstrates the obvious physiologic changes that take place in any human being. In a normal adult, the pressure of oxygen (PO₂) is about 159mmHg at atmospheric pressure of 760mmHg.

The resulting pressure at the arterial level (PaO₂) is about 110mmHg and the resulting pressure at the alveolar level (PAO₂) is around 100mmHg. However, at 10,000 feet of altitude, the atmospheric pressure falls to about 524mmHg and the PO₂ also drops to about 110mmHg. The PaO₂ also drops to about 100mmHg. The PaO₂ in turn drops to about 61mmHg and the PAO₂ decreases to 52mmHg (see Table 1).
Consequently, if the arterial oxygen saturation (SaO₂) is 98 percent at sea level, it is reduced to 87 percent at 10,000 feet and to 60 percent at 22,000 feet. Oxygenation decreases with a decrease in PO₂, which in turn produces a smaller diffusion gradient at the alveolar level. At sea level, the healthy adult has an alveolar-arterial O₂ gradient of about 5mmHg. However, the newborn has an alveolar-arterial gradient of five times that (25mmHg) at the same atmospheric pressure. The arterial oxygen tensions in infants will be even lower at certain altitudes and hypoxia will result. The term threshold altitude has been used to describe the altitude above which harmful effects like hypoxia can be noticed and measured. The exact numbers have not been specified because each patient differs physiologically. For healthy adults, the threshold altitude is estimated to be between 8,000 and 10,000 feet. Early signs of hypoxia in the infant may include hyperventilation, irritability and muscle incoordination. Late signs may include lethargy, bradycardia, desaturation and cyanosis. If the infant has cardiopulmonary problems, the threshold altitude becomes even lower; hypoxia could possibly occur as low as 1,000 feet above take off altitude.

If the infant is on supplemental oxygen, but not 100 percent, an increase in the fractional inspired oxygen concentration or FiO₂ may compensate for altitude changes. If the infant is already on 100 percent oxygen, continuous positive airway pressure (CPAP) or if the infant is artificially ventilated, positive end-expiratory pressure (PEEP) may be the only means for increasing oxygenation in the face of altitude. An altimeter and a barometer should be kept in the cabin of all aircraft and oxygen concentration varied according to altitude. If an altimeter is not located in the cabin, the altitude levels can be obtained from the pilot. Some researchers believe that if the infant’s hematocrit level is less than 35 percent supplemental oxygen should be given during air transport.

Others recommend that all air-transported neonates receive additional oxygen. Supplemental oxygen seems to be the best treatment for hypoxaemic hypoxia and is often used as a prophylactic measure for neonates prone to this type of hypoxia.

**Stagnant Hypoxia**

Stagnant hypoxia is also seen during air transport of the neonate. It is a result of sluggish peripheral capillary blood flow (pooling of blood) that is inadequate to meet the cellular demands for oxygen. Stagnant hypoxia can occur due to gravitational forces (acceleration and deceleration) during takeoff and landing in a fixed-wing aircraft. Depending on patient position during ascent and descent, blood may pool in the head and upper chest or in the lower extremities. According to Hubner and Dunn, “if the neonate’s head is toward the front of the aircraft during take-off, the positive gravity (G) forces will result in

### Table 1: Effect of Altitude on Oxygen Tensions

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<th>Altitude (ft)</th>
<th>P&lt;sub&gt;ATM&lt;/sub&gt;</th>
<th>PO&lt;sub&gt;2&lt;/sub&gt;</th>
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temporary displacement of blood in the lower extremities and abdomen; this would be contraindicated in shock. With the position reversed, the infant’s head toward the tail of the aircraft, the positive (G) forces will result in blood being forced upward into the cranial blood vessels; this would be contraindicated in pulmonary disease, cerebral oedema and intracranial haemorrhage.³

Infants mechanically ventilated with PEEP or CPAP or those who have venous disorders will show more response to aircraft manoeuvres like acceleration and deceleration. To decrease the chances of stagnant hypoxia, it is recommended that the infant be placed parallel with the wings of the aircraft instead of nose to tail.¹ Most transport teams will find this recommendation impractical, however, due to the use of small-bodied, fixed-wing aircraft like the Lear jet. Nevertheless, the effects of altitude-induced hypoxias must be considered during transport of critically ill neonates. Many altitude-induced problems, can be prevented by adequate training and simple understanding of flight physiology.

Gas Expansion

Another aspect of flight physiology that must be considered is gas expansion. According to Boyle’s Law, as altitude increases, the volume of air in enclosed areas also increases. For example, 100ml of gas at sea level expands to 130ml at 6,000 feet and to 400ml at 34,000 feet.² Artificially pressurised cabins reduce but do not eliminate the effects of altitude on gas expansion. Rapid decompression may cause gas expansion in such areas as the inner ear, the gastrointestinal tract and the pleural spaces. The entrapped gases in these areas expand with increased altitude, causing pressure. Unrelieved pressure will cause discomfort, pain and stress in neonate.

Pressure-induced gas expansion is a very important consideration when transporting the neonate with bowel obstruction, necrotizing enterocolitis, peritonitis, and diaphragmatic hernia or pneumotosis intestinalis. Gases trapped in the GI tract will cause discomfort and compromise lung expansion.

To relieve pressure on the GI tract from altitude-induced gas expansion, place an orogastric or nasogastric tube prior to transport. Leaving this tube open to atmospheric pressure or attaching it to low suction will cause gastric decompression to occur, reducing the stress on the neonate.

Gases may also be trapped in the alveoli of the lung, interstitial pulmonary spaces, mediastinal spaces, pericardial spaces and subcutaneous spaces. Should gas expansion become a problem the chances of pneumothorax, pneumomediastinum, pneumopericardium and pulmonary interstitial emphysema are greatly increased.² These effects can be devastating to an already compromised mechanical ventilation, CPAP and PEEP – further increases the risk of barotrauma. Parameters should be kept no higher than necessary to provide adequate blood gas values.⁶

All pneumothoraces regardless of size, should be evacuated prior to transport.¹ The confined quarters of a small aircraft are not the ideal place to perform needle aspiration or a thoracostomy procedure. The chest tubes must be positioned correctly, secured and attached to a closed-system device like the Heimlich valve. A portable transilluminating device is recommended as part of the transport kit. The status of extrapulmonary air should be assessed frequently and the infant should be monitored closely. It should also be noted that free air in the pleural cavity decreases electrical conduction across the chest wall, reducing the waveform size displayed on the continuous oscilloscope.⁷

Most rotary-wing aircraft have a non-pressurised cabin, limiting the altitude at which a critical neonate can be transported safely. If pulmonary air leak is a problem, request that the pilot flies at altitudes within 500 feet of the take-off altitude.¹ It may be necessary to find an alternative to unpressurised air transport if gas expansion is a concern. Using aircraft with pressurised cabins will eliminate most pressure-reduced problems. Request that the cabin be pressurised to the take-off altitude.

Environmental Stressors

Others factors may produce negative physiologic responses or stress in the neonate during air transport. Environmental changes, such as noise, vibration, motion and temperature fluctuations within an ambient
space that result in infant hypothermia, have been proven to cause bradycardia, apnea and metabolic acidosis, eventually leading to persistent pulmonary hypertension of the newborn (TPHN). Stressed infants may revert to fetal circulatory routes and poorly oxygenated blood may be circulated throughout the entire body.\textsuperscript{8} Other reactions may include pallor and decreased SaO\textsubscript{2}.

**Noise**

Excessive noise is believed to contribute to neonatal stress. Although studies of noise-induced stress during air transport have been limited, noise certainly plays an important role as a cause of irritability, fatigue and general discomfort in the neonate. It is, however, an uncontrollable factor. The intensity (in decibels [dBi]) and the pitch (frequency in cycles per second) of the noise in relation to the infant’s condition determine the level of stress produced.\textsuperscript{9} In general, lower frequencies, such as those found in fixed-wing aircraft, noise levels inside the cabin can reach about 95dB and noise levels outside can reach around 110dB. Noise levels above 95dB are considered dangerous and ear protection devices should be worn.\textsuperscript{9} Duration of exposure to noise levels in this range is also a consideration. The use of transport incubators does help to decrease the noise level. Please note that a short flight will not result in sensorineural hearing loss in the neonate, but prolonged exposure will cause added stress.\textsuperscript{10}

**Vibration and Motion**

Vibration and motion are two uncontrollable environmental changes that cause stress in the neonate during air transport. The aircraft engine is the main source of vibration. Because helicopters have considerably more vibration than fixed-wing aircraft, vibration is a greater problem with rotary-wing aircraft. This rational and linear movement simulates the semicircular canals of the inner ear, causing fatigue and irritability. Excessive vibration and motion, especially during acceleration and deceleration, can cause stress in the neonate resulting in bradycardia and apnea. This is seen particularly on descent or landing. Further study of the effects of motion and vibration in the neonate is needed.\textsuperscript{4}

**Temperature**

Heat conservation and thermoregulation are critical during air transport of the neonate. According to Charles’ Law, if the volume of gas remains constant, the temperature of the gas varies directly with pressure. As the aircraft ascends, its frame cools; as a result, the inside cabin temperature may drop as much as 2\textdegree C or 3.5\textdegree F for every 1,000 feet of altitude.\textsuperscript{2} Hypothermia and shivering increase oxygen consumption and can cause bradycardia. The increased metabolic requirements eventually cause metabolic acidosis and hypoglycaemia. Heat retention is crucial to the already compromised neonate.
Humidity

As altitude increases, air becomes drier. Because the air vented to the cabin of the aircraft is atmospheric, passengers are exposed to lower humidity levels. The humidity level in a rotary-wing aircraft may be as low as 10-20 percent and in fixed-wing aircraft, less than five percent. This humidity defect may pose a threat to the critically ill newborn with pulmonary problems and tenacious secretions. Insensible water loss can be as much as 250ml/24-hours (about 10ml/hour) from the lungs and 750ml/24-hours (about 31ml/hour) from the skin. This will vary, depending on the infant’s weight and gestational age.

Hypothermia and humidity deficit may cause stress in the neonate during air transport and should be monitored closely. The use of supplemental humidity and humidified oxygen will decrease the loss of body heat from evaporation, thereby reducing the risk of hypothermia. All aircraft should have heated cabins to increase the temperature during flight, particularly during ascent. The use of prewarmed incubators and such other heating devices as chemical incubators and chemical warming mattresses is also important. Although helicopter emergency unloads with the blades turning (“hot”) are infrequent, be aware that outside a helicopter there are downdraft winds of 15-45mph that cause wind chill in already low outside temperatures.

Summary

The speed of air transport has saved the lives of thousands of critically ill neonates. It is a practice that is becoming more available each day. The benefits of air transport are spectacular, but its disadvantages make it challenging. An understanding of flight physiology is essential to proper management of the infant with a life-threatening illness.

These fascinating aspects of human physiology are understood by few and need to be emphasised in NICU transport team training. Knowledge of the physiology of oxygenation, ventilation and respiration is essential; application of that knowledge in a transport setting is the challenge.

References

Section Nine: References & Recommended Reading
Articles of Interest


Introduction to Aeromedical Transport Course

Your evaluation of this study day would be greatly appreciated. It will be valuable in the planning of future courses.

(June, 2017)

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<td>Were there topics not covered that you think should be included in the future?</td>
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Please return to: Karyn Hathaway, CCDHB ICU and Flight Service, Wellington Regional Hospital.

Thank you for taking the time to complete this evaluation form