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Physiological effects of transfer for critically ill patients

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INTRODUCTION

The transfer of critically ill patients either from the prehospital setting or between hospitals is frequently performed to enable patient access to specialist care or repatriation to a hospital nearer to home. It's estimated that over 11,000 inter-hospital transfers of critically ill patients are undertaken in the UK each year.

The transfer of critically ill patients is not without risk and protocols to guide the transfer of critically ill patients from the Intensive Care Society (ICS)[1] and the Association of Anaesthetists of Great Britain and Ireland (AAGBI)[2] exist.

Adverse events commonly occur during inter-hospital transfer of critically ill patients. A prospective audit from the Netherlands reported adverse events occurred in 34% of transfers, of these adverse events 70% were felt to be avoidable. Many of these adverse events related to equipment failure, inadequate preparation, and poor documentation/communication. A recent ATOTW article on inter-hospital transfers looks at many of these aspects in more detail [3].

Critically ill patients can be exposed to significant physiological changes during transfer that can lead to significant instability with hypoxia, hypotension, arrhythmias and changes in intracranial pressure (ICP). This tutorial will explore the physiological effects that land and air transfer have on critically ill patients and describe how these adverse physiological sequelae can be avoided or reduced.

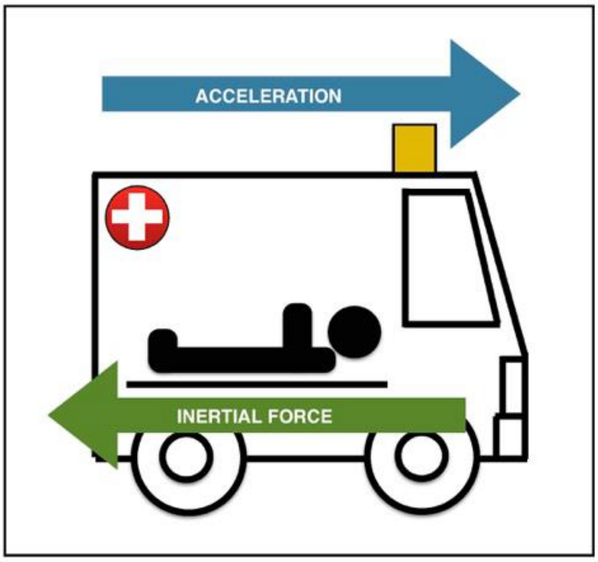
PHYSIOLOGICAL EFFECTS OF LAND TRANSFER

Patients are commonly transported from the pre-hospital setting and between hospitals via land ambulance. The effects of deceleration and acceleration can be significant in critically ill patients due to their reduced ability to compensate. Acceleration and deceleration have an impact on a patient's physiology because of Newton's laws of motion (Figure 1).

First Law	Every object in a state of uniform motion tends to remain in that state of motion unless an external force is applied to it.
Second Law	The sum of the external forces (F) on an object is equal to the mass *m* of that object multiplied by the acceleration vector a of the object: F = *m*a.
Third Law	For every action there is an equal and opposite reaction.

Figure 1: Newton's three laws of motion

Newton's third law states that for every action there is an equal and opposite reaction. When a patient is accelerated due to the application of an external force there will be and equal and opposite force enacted termed inertia (Figure 2a/b)



For example, as a patient accelerates in an ambulance (figure 2a) the external force causing acceleration is towards the patient's head. The inertia force is in the opposite direction i.e. towards the patient's feet. This inertial force causes the displacement of non-tethered organs and fluids such as blood towards the patients feet. The amount of displacement depends on the rate, magnitude and direction of acceleration. The direction of acceleration can be in the anterior-posterior, lateral or cephalo-caudal axis. Commonly in ambulance transport the axis of acceleration is in the cephalic-caudal direction, which has the most significant effect on physiology.[4]

Figure 2a: Acceleration

Deceleration (figure 2b) would have the opposite effect, this time the external force causing deceleration is towards the patient's feet and displacement of blood would be towards the head. The breaking force of an ambulance is much greater than its acceleration force and as such deceleration has a greater impact on a patient than acceleration. [4]

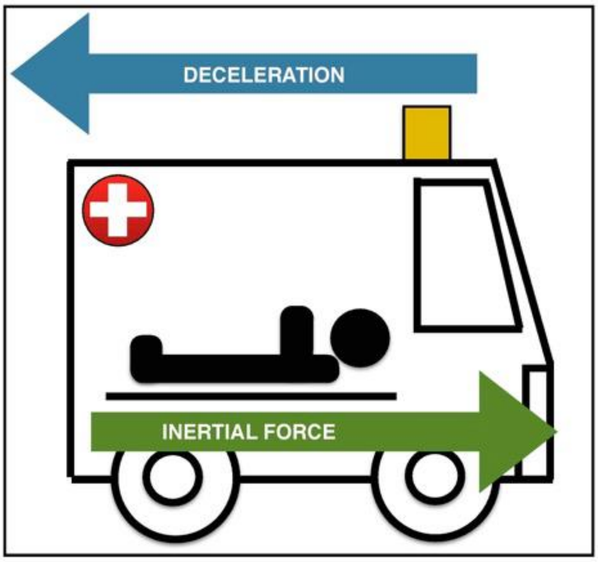


Figure 2b: Deceleration

Physiological consequences of acceleration

Cardiovascular system:

- Blood will pool in the feet resulting in decreased venous return and cardiac output causing hypotension. In health the baroreceptor receptor reflex would compensate for this by an increase in vascular tone, however, in critical illness this reflex can be significantly reduced or absent either due to the critical illness eg sepsis or secondary to drug therapy. Profound hypotension can occur requiring increased inotropic and vasopressor support. Hypotension is exacerbated by hypovolaemia and positive pressure ventilation, both of which reduce preload.[4]

Neurological system:

- Hypotension can lead to reduced cerebral perfusion which can affect a patient's conscious level and is significant in those with head injuries where cerebral perfusion pressure needs to be maintained.
- Cerebral perfusion pressure (CPP) = Mean Arterial Pressure (MAP) – Intracranial pressure (ICP)

Physiological consequences of deceleration:

Cardiovascular system:

- Venous return will be increased due to inertial forces 'pushing' blood in a cephalic direction (towards the head). In patients with cardiac impairment the increased volume in the right ventricle can lead to cardiac failure, pulmonary oedema, and arrhythmias.

Neurological system:

- Due to the displacement of venous blood and CSF the ICP is increased. This is important in patients who already have a raised ICP as their cerebral perfusion may be further compromised during deceleration.

Gastrointestinal system:

- Inertial force displaces the stomach towards the patient's head; this can increase the risk of aspiration.
- This upwards displacement of viscera can also increase trans-diaphragmatic pressure and cause either smaller tidal volumes or higher intrathoracic pressure depending on the mode of ventilation in use.

Musculoskeletal system:

- In patients with significant spinal injuries the inertial force acting during deceleration results in axial loading which can cause displacement of unstable spinal fractures.

It is important to note that these forces also apply to equipment and medical personnel. For this reason equipment should be secured and all medical personnel should be sat down and secured with a seat belt during ambulance movement to reduce the risk of injury. Medical staff are less affected physiologically due to having intact compensatory mechanisms and the direction of inertia acting in the anterior posterior direction because of their seated position. Acceleration and deceleration are dynamic hazards however, there are also static hazards that have a significant effect on patients including:

Noise

- This can affect communication between medical staff as well as patients and cause distress.

Temperature

- Ambulances are not able to regulate their temperature as effectively as hospitals, therefore in extreme heat and cold the patient is exposed to the risk of hypo and hyperthermia. It is therefore, important to monitor a patient's temperature closely during transfer and prepare for cold temperatures with additional blankets and fluid warmers.

Duration

- Pressure areas need to be protected and monitored especially during long journeys. Space is often limited during transfer and meticulous attention needs to be paid to the position of lines and the temptation to rest equipment on the patient must be avoided.
- During prolonged transfer, blood and other bodily fluids can pool in dependent parts of the body and in addition to pressure over bony prominences, this may contribute to tissue maceration and the development of pressure sores. On hard extrication boards (spinal boards) the early stages of pressure sore development can be seen after only 20 minutes in healthy volunteers with normal skin perfusion. In critically ill patients receiving vasopressor therapy these changes can happen more quickly. For this reason, extrication boards should not be used for prolonged transfers, and the Royal College of Surgeons of Edinburgh have released a position statement in 2013 on pre-hospital spinal immobilisation to this effect [5]. A vacuum mattress should be used wherever possible during transfers.

PHYSIOLOGICAL EFFECTS OF AIR TRANSFER

Air transfer either by helicopter or fixed wing aircraft is commonly carried out by the military and other specially trained personnel following additional training. It is however, important to understand the physiological effects of air transport because ICU patients may be transported by air and this will affect how the patient is prepared prior to transfer.

Physiological effects of altitude

Atmospheric pressure

- Atmospheric pressure decreases in a non linear fashion with altitude. The fractional concentration of oxygen remains constant at 0.21 however the partial pressure of oxygen falls. A fall in atmospheric pressure results in a reduction in the alveolar partial pressure of oxygen, which can lead to hypoxia unless supplemental oxygen (increased F_iO_2) is given.
- Hypoxia can cause tachycardia, bradycardia, arrhythmias, hypotension, tachypnoea behavioural changes and altered conscious level in all people. Oxygen supplementation in healthy individuals is usually not required until above 10,000ft.

- At sea level the atmospheric pressure is 101Kpa, at 10,000ft the atmospheric pressure falls to 70kpa. This drop in atmospheric pressure has a significant effect on the partial pressure of oxygen as demonstrated by the alveolar gas equation figure 3.

Alveolar gas equation

$$P_AO_2 = [FiO_2 \times (P_{atm} - P_{H20})] - (P_{ACO2}/R)$$

(P_AO_2 = Alveolar partial pressure of oxygen, FiO_2 = fractional inspired concentration of air (0.21), P_{atm} = atmospheric pressure, P_{H20} = saturated vapour pressure of water at 37oC (6.3kpa), P_{ACO2} = Alveolar pressure of carbon dioxide (typically 5.3kpa) , R = respiratory quotient (typically 0.8 depending on diet.)

For example:

P_AO_2 at Sea Level	**P_AO_2 at 10,000ft**
P_AO_2 = [0.21 x (101kpa – 6.3kpa) – (5.3kpa/0.8)	P_AO_2 = [0.21 x (70kpa – 6.3kpa) – (5.3kpa/0.8)
= 19.8kpa – 6.6kpa	= 13.3kpa – 6.6kpa
= 13.2kpa (99mmHg)	= 6.7kpa (50mmHg)

Figure 3: Alveolar gas equation

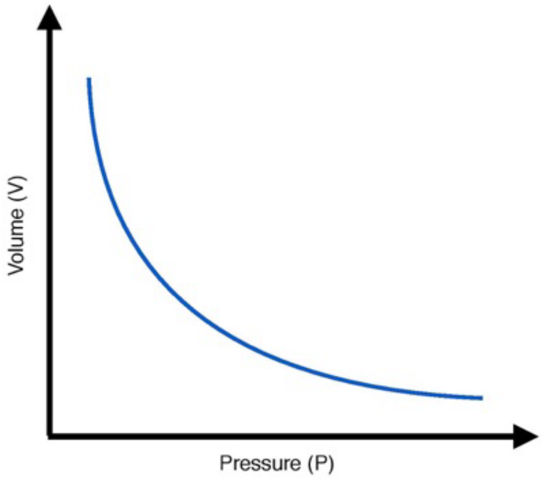
If a critically ill patient becomes hypoxic during flight this can be treated with either an increase in the inspired oxygen concentration (f_iO_2) or by increasing the partial pressure of oxygen by reducing the altitude of flight or pressuring the cabin to a lower altitude.

Consideration should be given to patients with significant alveolar:arterial gradient mismatches such as advanced COPD, pulmonary contusions or pulmonary fibrosis as the relative hypoxia at altitude will result in a lower P_aO_2 in this patient group. It is therefore important to discuss the flying altitude with the pilot prior to takeoff so that a risk assessment of the potential impact of altitude on the patient can be made.

Volume expansion

- Boyles law states that at a constant temperature the volume of a given mass of gas varies inversely with the absolute pressure (Figure 4). Therefore, as you ascend the volume of any gas filled spaces will increase. This will affect any gas filled body cavities and equipment because the volume of gas in enclosed spaces will increase with the drop in atmospheric pressure.

Figure 4: Boyles law



- Physiological effects of volume expansion:
  - Pneumothoraces should be vented and a chest drain inserted prior to air transfer to avoid an increase in the size of a pneumothorax and risk of tensioning.
  - Patients with bowel obstruction or recent bowel surgery requiring anastamosis should be flown at lower altitude or land transfer considered. Fixed wing aircraft may be considered as they are able to pressurise their cabins to sea level or a lesser altitude.
  - Expansion of air in the eustachian tubes can cause pain and discomfort during ascent and descent if patients are not able to equilibrate. This also applies to medical staff.

- Pneumoperiteum and intracranial air are relative contraindications to air transport. In a patient with intracranial air the volume expansion may worsen ICP and reduce cerebral perfusion.
- Equipment with air filled cuffs such as endotracheal tubes, Sengstaken–Blakemore tubes, stoma bags and inflatable pressure bags should have their pressures monitored. On ascent the volume expansion of air in the endotracheal cuff causes a rise in cuff pressure, the volume of air in the cuff will need to be reduced to maintain an appropriate pressure. On descent additional air will need to be added to the cuffs. Another option is to fill the endotracheal cuff with saline. Liquid expands much less than air.

Temperature

- As altitude increases the air temperature falls by 2°C for every 1000ft increase in altitude. Patients being transported at high altitude in aircraft without isolated cabins able to be pressurised and/or for long periods are at risk of hypothermia. As for land transfer appropriate measures to reduce heat loss should be used.

Humidity

- Dehydration occurs faster at higher altitudes due to lower air pressure and humidity, which causes more rapid evaporation of moisture from the skin and lungs. The significance of this is greatest for patients undergoing long transfers and these patients should have their input and output closely monitored to avoid hypovolaemia and dehydration.
  - Reduced humidity can lead to thickened secretions and risk of mucous plugging, a heat moisture exchange filter (HMEF) or humidified oxygen via a facemask should be used.
  - For extended transfers patient's eyes should be lubricated with artificial tears and frequent mouth care is important.

Other considerations for air transport

Acceleration and deceleration

- Patients being transported by air be it helicopter or airplane will still be exposed to the same acceleration and deceleration forces as discussed above for land transfer. The only consideration is that the forces may be acting in a different axis due to the direction of travel and how the patient is orientated. The same considerations as mentioned above still apply.

Noise and vibration

- The noise and vibrations in a helicopter can be distressing for conscious patients especially if there is an element of delirium and this should be considered.
- The increased noise makes communication between the team difficult and is achieved via specialised headsets. The patient should also be provided with ear protection/headset.
- Vibration is the commonest cause of fatigue in medical personnel during helicopter flight and all team members should be alert to this risk. Air crews are subject to strict hours limitations to mitigate the risk of fatigue, and in the event of prolonged transfer the same degree of planning should be extended to accompanying medical staff.
- Vibration also affects monitoring equipment in particular non-invasive blood pressure cuffs that function via the oscillometric method. Patients who require accurate blood pressure monitoring should therefore have an arterial line inserted prior to transfer to allow more accurate blood pressure monitoring during flight.

Limited space

- Space is even more limited in helicopters than land ambulances. Intubation is extremely difficult if not impossible in a helicopter once in flight and so all patients at risk of deterioration should be intubated prior to transfer.

Summary of how to minimise the physiological effects of transfer in the critically ill	
Land Transport	**Air Transport**
• Patients should be appropriately resuscitated and stabilised prior to transfer to reduce the physiological disturbance associated with movement and reduce the risk of deterioration during transfer. (ICS guidelines). • A head up tilt of 15 degrees will reduce the influence of inertial forces on ICP. • During acceleration legs can be raised to help increase venous return and preload. • The intubation of patients will reduce aspiration risk. In those who do not meet criteria for intubation an antiemetic can be given. Insertion of nasogastric tube will also reduce aspiration risk in high risk individuals. • Monitoring of patients temperature regularly during transfer and appropriate use of blankets and fluid warmers. • Monitoring of pressure areas. • Most importantly even in emergency 'blue light' transfers there is little to be gained by rapid acceleration and deceleration. A steady pace with controlled deceleration and acceleration is safest not only for the patient but also medical staff and the public.	• As for land transport patients should be prepared and stabilized prior to transfer to minimise the effects of acceleration and deceleration. Considerations mentioned for land transfer apply. In addition to this: • Pneumothoraces should be drained prior to transfer to prevent the risk of tension pneumothorax during ascent. • Supplemental oxygen and/or reduced flying altitude is required for patients with hypoxia. • If a patient is likely to deteriorate they should be intubated prior to transfer due to the limited space and access to the patient during flight. • If there is concern about pressure changes in the endotracheal cuff during transport it can be filled with saline instead of air. • Patient temperature and pressure areas should be closely monitored. • An arterial line may need to be inserted prior to transfer due to vibration affecting the functioning of oscillometric non-invasive blood pressure cuffs. • Careful consideration is needed as to whether air transport is the best choice for the patient especially in patients at high risk of complications such as those with intracranial air. In these cases avoiding air transport, flying at lower altitude or in a pressurised cabin may be necessary.

Mode of Transport

As detailed above the different modes of transport can have very significant physiological effects on the body, especially in critically ill patients who are not able to compensate for these changes. The decision as to which mode of transport is used will be determined by location, urgency of transfer, availability of transport modes, weather and also patient factors.

	Land Ambulance	Helicopter	Fixed wing aircraft
Positives	• Familiar • Lower overall cost • Rapid mobilisation • Not as affected by weather conditions • Easier patient monitoring.	• Good in remote or inaccessible locations. • Faster than ambulance in some instances. • No need for land transfer at either end if hospital has helipad	• Long journeys where road access is difficult. • Able to pressurise cabin
Negatives	• Slower • Affected by traffic • Better suited for shorter distances • Unable to access patients in some locations eg mountainous regions	• Costly • Unable to fly in bad weather. • Delays in mobilisaton. • Unfamiliar and additional training required. • Very limited space • Unpressurised cabin.	• Costly • Organisation difficulties • Delays in take off • Need for land transfer before and after. • Further training of medicalstaff required.

Figure 5: The positives and negatives for the different modes of transfer

Summary

Patient transfer can have significant physiological effects that influence critically ill patients because critically ill patients are less able to compensate either due to their acute pathology or secondary to drug therapy.

Understanding the physiological impact that both land and air transfer has on the patient enables the patient to be prepared appropriately for transfer and will reduce risk of patient instability and deterioration during transfer.

It is vital to remember that the above principles not only apply to the patient but also to medical staff and equipment. Medical staff should ensure that they remain hydrated and aware to the risk of fatigue especially on long journeys. Monitoring equipment can be effected by vibration and indwelling devices filled with air such as endotracheal cuffs need to have their pressures monitored or be filled with saline during flight. All equipment is subjected to the force of inertia that can cause significant injury to staff if not secured properly.

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