Physiology of patient transfer by land and air

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Abstract

Patient transfer is an important part of many patients' journeys through the healthcare system. In the UK, the majority of transfers are undertaken by land ambulance but some are by air utilizing helicopters or fixed wing aircraft. The transfer of patients is challenging often involving unstable critically ill patients, trainee staff, time pressure, out of hours work and unfamiliar transfer equipment. Patients are exposed to a number of physical factors including acceleration and deceleration, decreased barometric pressure, noise, vibration, reduced humidity and altered ambient temperatures. These factors have a significant effect on patient physiology and it is important that clinicians understand these effects and integrate them with planning and decision making. Other challenges include staff fatigue, communication difficulties, the effects of transfer on medical equipment and the hazards of caring for patients in confined spaces for prolonged periods of time.

Keywords Acceleration; aerospace medicine; air ambulances; ambulances; atmospheric pressure; patient transfer

Royal College of Anaesthetists CPD Matrix: 1A01, 1A03, 2A11, 3A11

Learning objectives

After reading this article, you should be able to:

- describe the common forms of transport utilized for patient transfer in the United Kingdom
- explain the physiological effects of acceleration, decreased barometric pressure, noise, vibration, reduced humidity and altered ambient temperature
- integrate patient diagnosis with the physiological effects of transport to allow appropriate planning and safe patient transfer
- identify the effects of transfer on medical staff and equipment
- recognize the hazards associated with prolonged transfer

Introduction

Safe patient transfer is an integral part of patient care and can be classified as primary or secondary.[1] Primary transfer is the initial movement of the patient from the scene of injury or illness to hospital and is commonly undertaken by paramedics and other pre-hospital specialists using land ambulance or helicopter. Secondary transfers occur between hospitals either for access to specialist care, repatriation or due to lack of bed space. The majority of secondary transfers are carried out by land ambulance but some occur by air, particularly for longer distances. Critically unwell patients are often accompanied by an anaesthetic or intensive care escort and transfer competencies are included in both the ICM and Anaesthesia curriculums in the United Kingdom.

It is estimated that around 11,000 critical care transfers occur annually in the UK.[1] These are challenging for a multitude of reasons including the following:

- They often involve unstable patients awaiting definitive treatment (e.g. neurosurgery).
- They are often carried out by trainee doctors, out of normal hours and under time-pressure.
- They rely on portable equipment including transfer ventilators and monitors, which staff are less familiar with and are sometimes less capable than their non-portable equivalents.
- They expose the patient to physical factors (e.g. acceleration) which adversely affect physiology and can lead to patient deterioration.

Considering their challenging nature, it is not surprising that in a prospective study in the Netherlands, adverse events occurred in 34% of secondary transfers and 70% of these were thought to be preventable.[2] It is therefore essential that staff undertaking transfers have appropriate knowledge, training and equipment to undertake them safely and this is highlighted in national guidelines by the ICS and AAGBI.[1,3] The transfer of patients by air can occur by helicopter or fixed wing aircraft, both of which present different problems. The transfer of patients by air is more challenging than land and should only be carried out by staff with appropriate aeromedical training, usually a dedicated specialist team.[1]

The following sections discuss in detail the physical factors associated with land and air transfer, the physiological effects they have on the patient and how anticipating these effects must be integrated with decision making.

Acceleration

Newton's laws of motion describe the interplay between an object's velocity, external forces and mass (Table 1). The second law of motion states that the acceleration of an object is proportional to the force applied. Transport by vehicle is associated

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Newton's laws of motion

Laws	Description
First	An object either remains at rest or continues to move at a constant velocity, unless acted upon by a force
Second	The vector sum of the forces on an object is equal to the mass of that object multiplied by the acceleration of the object
Third	When one body exerts a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction on the first body

Table 1

with significantly greater acceleration than a patient experiences in hospital and therefore the forces applied and the effects they will have are greater. When a vehicle accelerates, an external force is transferred to the patient via the trolley and any straps used to secure the patient. This is then transferred to the visceral organs via the skeletal and ligamentous structures. Newton's third law states that when an external force is applied to the body it experiences an equal and opposite reactionary force, also termed inertial force. The inertial force leads to the displacement of mobile structures and fluid within the body to dependent areas. For instance, when an ambulance accelerates forwards with a patient loaded head first, the organs and blood are pulled towards the feet.

The effect force has on the body is determined by the direction and magnitude of the force and the physiological status of the body. Force can be applied in all directions but commonly road transfer involves forwards/backwards and lateral forces. In air transfers forces can also be applied vertically, termed Gz forces. The greatest effect is when force is applied in a caudal or cephalad direction as is commonly encountered when vehicles accelerate or decelerate and the patient is loaded head or feet first. A healthy person sitting upright with forces applied in an anterior, posterior or lateral direction will compensate well, whereas a sick patient loaded supine with force applied in a cephalad or caudal direction will not.

The effect of these dynamic forces can be amplified or reduced by placing the patient head up or down where the force of gravity summates with the external force (Figure 1).

Effects of caudal forces (e.g. an aircraft taking off with a patient loaded head first)

- Cardiovascular – blood is pulled caudally, pooling in the lower body, reducing venous return and decreasing cardiac output. Healthy individuals compensate via the baroreceptor reflex but in the critically ill these mechanisms are often obtunded causing hypotension. Hypovolaemia and positive pressure ventilation also reduce venous return and worsen hypotension. It is important that unstable patients are fluid resuscitated prior to transfer and inotropes and vasopressors are available during transfer. Periods of instability (e.g. takeoff) should also be anticipated and preemptive actions taken (e.g. increasing vasopressors).
- Neurological – an uncompensated reduction in cardiac output will lead to reduced arterial pressure and reduced cerebral perfusion pressure. This may worsen secondary brain injury.

Effects of cephalad forces (e.g. an ambulance decelerating with a patient loaded head first)

- Cardiovascular – blood is pulled upwards from the lower body increasing venous return. This can cause volume overload, particularly in patients with pre-existing cardiac disease leading to cardiac failure, pulmonary oedema and arrhythmia.
- Neurological – blood and CSF are pulled into the cranial cavity leading to a rise in ICP and reduction in cerebral

Diagram of the forces experienced by a patient loaded supine and head first onto a fixed wing aircraft during takeoff

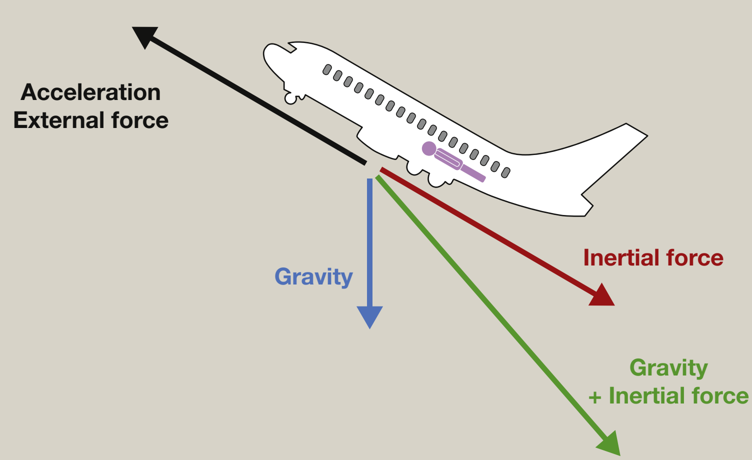

Figure 1

perfusion pressure which may worsen secondary brain injury.

- Respiratory – upwards displacement of the abdominal organs leads to splinting of the diaphragm, decreased tidal volumes, increased airway pressures and worsening gas exchange.
- Gastrointestinal – the stomach and gastric content are displaced upwards leading to regurgitation of gastric content, especially if there is lower oesophageal junction incompetence as is common in the sedated unwell patient. There should be a low threshold for insertion of an NG tube prior to transfer.[1]
- Musculoskeletal – axial loading of the spine occurs, potentially worsening unstable spinal injuries. It is essential that patients with suspected unstable spinal injuries are immobilized with an appropriate technique. The Faculty of Pre-hospital Care have released consensus statements for the primary transfer of patients requiring spinal immobilization.[4,5] They would advise the use of vacuum mattresses for transfers over 45 minutes.

Acceleration also effects equipment and medical personnel. Equipment can move and fall causing harm to the patient or staff. Lines and tubes can become displaced and staff can fall or be thrown. Transfer trolleys should be compliant with the appropriate regulatory requirements and the patient should be secured appropriately (e.g. a five-point strap). Equipment should be securely stowed in lockers or on the floor against a bulkhead.[1] Staff should remain seated and strapped in at all times and if emergency interventions are required the vehicle should be stopped. During air transfers staff should remain strapped in during takeoff and landing, as well as during other periods of high risk (e.g. turbulence or low-level flying).

The best strategy to minimize the effects of acceleration is prevention. A smooth, steady transfer avoiding rapid changes in speed will be more beneficial to most patients than the time saved by a high speed transfer.[1] This should be discussed with the ambulance crew prior to commencing the transfer.

Temperature

Most ambulances are unable to regulate internal temperature tightly, and in hot or cold climates patients are at risk of hypothermia or hyperthermia. For aircraft, as altitude increases the air temperature decreases by roughly 2°C per 1000 ft. Modern day passenger jets are well insulated and avoid large changes in temperature as they climb. Small aircraft such as helicopters and less well insulated transport aircraft expose the patient to the cold environment as they climb. The likely temperature a patient will be exposed to should be considered and planned for prior to transfer with extra blankets and heating devices to compensate for cold environments. The patient temperature should be monitored regularly, especially during prolonged transfers.[1,6] The effects of temperature on staff should also be considered with appropriate PPE and fluids available for warmer climates.

Noise

Land based ambulances are associated with moderately increased noise which can create communication difficulties, cause patient distress and limit examination, for example the use of a stethoscope. Aircraft are associated with extreme noise which in addition to the above can cause hearing damage. It is essential that staff and patients, even when sedated, have appropriate hearing protection. The excessive noise in aircraft can also make audible alarms imperceptible and unaided verbal communication all but impossible so appropriate communication equipment is required in order to allow communication amongst the medical team and aircrew.

Vibration

A vibration is an oscillation around an equilibrium point and is associated with all forms of motorized vehicles. Helicopters in particular are associated with significant vibration which can have a significant effect on the patient and staff.

- Vibrations in all vehicles cause interference with monitoring devices, particularly automated NIBP cuffs and ECGs. For primary transfers the blood pressure is commonly estimated by pulse strength and for secondary transfers there should be a low threshold for insertion of an arterial line prior to transfer.[1,6] Automatic NIBP cuffs also consume large amounts of electricity so greatly shorten the battery life of monitors.
- Vibrations transferred to the patient cause the displacement of hard and soft tissues. This can be distressing for the patient and can increase pain, especially due to musculoskeletal injuries. It can also worsen bleeding by dislodging clots and preventing haemostasis.
- The vibrations caused by helicopters and other aircraft have a significant fatiguing effect on crew. This is due to the increased muscle tone required to maintain posture. This is compounded by increased noise, reduced temperature, reduced humidity and reduced atmospheric pressure. Fatigue is known to have an effect on non-technical skills and task success.[6] It is therefore essential that staff undertaking regular or prolonged transfers are well rested, with appropriate shift plans and breaks.

Barometric pressure

As altitude increases, pressure drops and gas expands (Figure 2). The pressure changes during land transfer in the UK are normally insignificant as the changes in altitude are small.

Helicopters and unpressurized fixed wing aircraft operate up to 10,000 feet. The cabin pressure in these aircraft is equal to outside pressure and above this altitude cabin pressurization or supplementary oxygen is required to prevent the crew becoming hypoxic. Helicopter air ambulances in the UK routinely operate

Boyle's law

$$P = \frac{1}{V}$$

P, pressure; V, volume

Figure 2

below 2000 feet and the pressure changes associated with this are relatively small and hence the effects small.

Larger aircraft normally have pressurized cabins and can operate at heights of up to 50,000 feet. They routinely pressurize their cabin to an altitude of 5000–8000 feet, therefore the pressure within the cabin is significantly higher than outside the aircraft. Some fixed-wing aircraft used for aeromedical transfer are able to pressurize their cabin to ground level, meaning that the patient and crew experience no pressure changes throughout the transfer. This does, however, decrease the speed and height which the aircraft can fly at, increasing the duration of transfer.

A reduction in barometric pressure can affect the patient and crew in a number of ways:

- There is a reduction in alveolar oxygen tension. Table 2 gives an estimation of the P_AO_2 at different altitudes and F_iO_2. Healthy crew can compensate up to 10,000 feet without supplementary oxygen but a patient with impaired gas exchange will require an increased F_iO_2 below this altitude. It is essential when pressure reduces to increase F_iO_2 and continually monitor SpO_2. A higher oxygen requirement should also be taken into account when calculating the total oxygen requirement for the transfer.
- As height increases gas within the body expands, and on descent it contracts. This is commonly observed as flatulence on climbing as bowel gas escapes and as a sensation of pressure changes within the ear on climbing and descending. Column 5 of Table 1 indicates how much 1 L of gas at sea level will expand to at different altitudes. The expansion is generally small unless there are large alterations in pressure but there is a theoretical risk of complications in a number of body systems.
  - Pneumothorax – pneumothoraces will expand as height increases, worsening gas exchange and potentially causing a tension pneumothorax. National guidelines state that in patients with a proven or suspected pneumothorax a chest tube or thoracostomy should be performed prior to air transfer and a skilled practitioner with appropriate equipment should accompany the patient in case the procedure needs repeating in flight.[1,7] Chest tubes should not be clamped during flight.
  - Bowel gas – patients with illeus, bowel obstruction or following bowel surgery have increased bowel gas and the expansion of this gas can distend the bowel leading to perforation or anastomotic breakdown. Due to this theoretical risk, guidelines suggest inserting an NG which should be left on free drainage, or flying patients with cabin pressurization to ground level where possible.[7] Patients following laparoscopic surgery with residual pneumoperitoneum should also be flown with ground level pressurization.
  - Head injuries – air within the skull may expand, potentially causing a rise in ICP. The significance of this remains uncertain but guidelines advise to transfer patients with pneumocephalus and open skull fractures with cabin pressurization to ground level.[7] Recently there has been evidence that reduced barometric pressure and aeromedical transfers have a negative effect on traumatic brain injuries.[8,9] This may be due to hypoxia, hypotension or due to a direct effect of reduced pressure secondary brain injury. It may therefore be advisable to fly all patients at risk of secondary brain injury at ground level pressurization.
  - Musculoskeletal injuries – inflamed tissues can swell so casts should be split and bandages loose enough to allow expansion prior to transfer.
  - Medical equipment – the volume of gas in endotracheal tube cuffs will vary with altitude. On climbing it will increase causing mucosal ischaemia, and on descent it will decrease leading to a cuff leak.[10] Cuff pressure should be measured regularly especially following changes in altitude or the cuff should be filled with saline.[1] Other gas-filled equipment (e.g. pressure bags) should also be monitored as they are at risk of rupture. Some electromedical equipment (e.g. ventilators) can fail or become inaccurate at higher altitude. All equipment used must be validated and approved for use in the air environment.[1]

Effects of increasing altitude/decreasing barometric pressure

Altitude (feet)	Barometric pressure (kPa)	P_AO_2 with F_iO_2 0.21[a] (kPa)	P_AO_2 with F_iO_2 1.0[a] (kPa)	Volume expansion[b] (litres)
0	103	13.7	90.1	1.00
5000	84	9.7	71.1	1.23
10,000	70	6.7	57.1	1.47
20,000	47	1.9	34.1	2.19
40,000	19		6.1	5.42

[a] P_AO_2 estimated using the alveolar gas equation assuming a P_aCO_2 of 5.33kPa and an RQ of 0.8.
[b] Volume that 1L of gas at 0 feet will expand to with increasing altitude assuming a constant temperature. Calculated using Boyle's law.

Table 2

Humidity

Ambulance and aircraft are unable to tightly regulate humidity. For aircraft, as altitude increases humidity decreases. Reduced humidity leads to increased heat loss by evaporation and increased drying of mucous membranes such as the respiratory mucosa and eyes. The use of heating devices, HME filters and routine eye care with artificial tears is important especially during prolonged air transfers.

Limited space

Most vehicles used for transfer have limited space with poor patient access. Often there is only access from one side with limited airway access. This has implications for emergency interventions and routine patient care during prolonged transfers.

During prolonged transfers the confined space limits routine nursing care including rolling, washing, changing position, pressure area care, oral care and eye care. The pooling of fluids is common and this can worsen pressure areas leading to skin maceration. It is essential that patients are appropriately loaded with special care of pressure areas with adequate padding.[1,3] For other routine care, as much as is feasible should be continued throughout transfer.

Emergencies can be difficult to manage with limited patient access. This is especially relevant during air transfers where landing to allow increased access can take significant time. It is also an inherently isolated environment so there are decreased resources and backup. It is therefore crucial that patients are stabilized as much as possible prior to transfer and any potential risks are mitigated (e.g. Securing an airway prior to transfer in a moderate head injury).[3] If deterioration requiring intervention during transfer is likely then land transfer may be preferable to air transfer.

Conclusion

The transfer of critically ill patients by land poses a number of unique hazards which anaesthetists and intensivists should be familiar with. Understanding these hazards and integrating them with planning and decision making will reduce adverse events and increase safety. The transfer of patients by air is associated with even more challenges and where possible should be carried out by staff with specialist aeromedical training. ◆

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