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Transport of the critically ill

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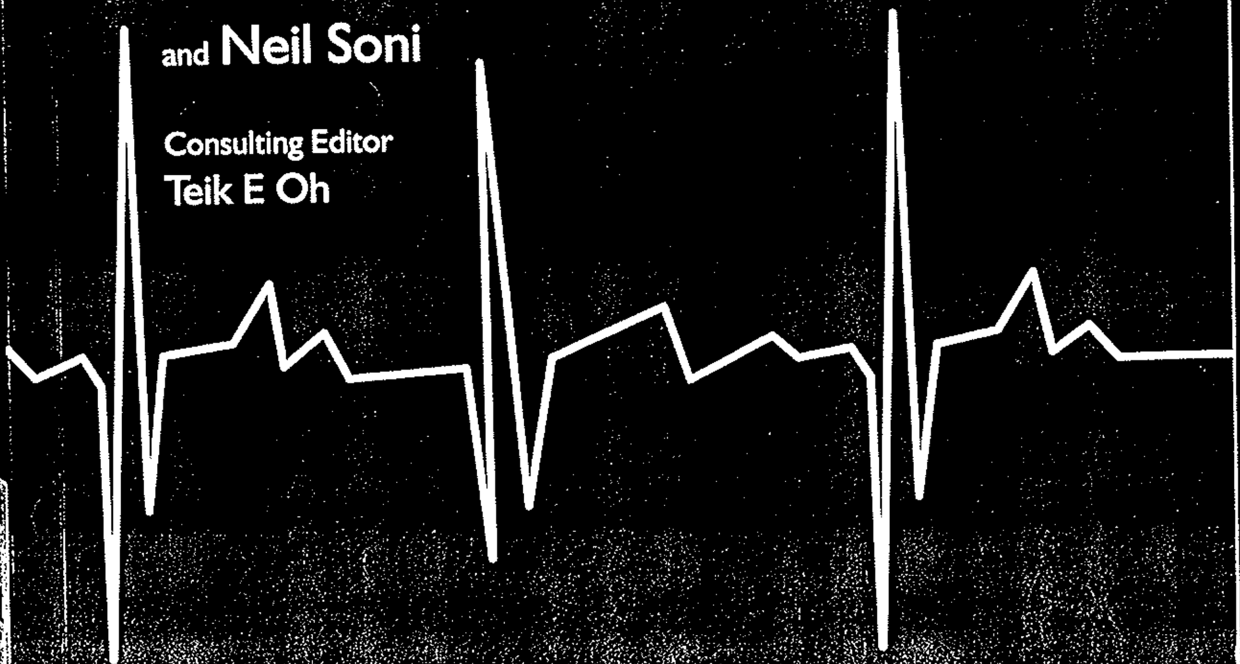

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Transport of the critically ill

E Everest and B Munford

All intensive care units (ICUs) are required to move critically ill patients for investigations or procedures that cannot be performed in the ICU. These patients have reduced or absent physiological reserves and even short trips can result in significant adverse events.[1,2] These events can be reduced by the use of trained personnel.[3,4]

In addition, ICU personnel are frequently involved in the stabilization and transfer of critically ill patients into an ICU,[5] while some units may be involved in the transport of patients from the site of a pre-hospital incident, or between hospitals.[6,7] The inter-hospital transfer could be due to the increasing sophistication of critical care facilities in tertiary hospitals compared with district or rural hospitals, different subspecialty capabilities, local bed shortages[3] or, in certain health systems, for insurance or financial reasons. In some cases, the complexity of these inter-hospital transfers can be further complicated by the need for rapid transport, or the distances involved. All patient movement is associated with an increase in mortality or morbidity, but with an integrated approach using high level clinical personnel who have the correct equipment and undertake sufficient planning, adverse events can be reduced.[3,4,6–8] Regular ambulances or untrained hospital staff should not be expected to manage ICU patients. Compared with specialist transport teams, standard ambulances with junior doctor escorts are associated with more cases of hypotension, acidosis and death.[9]

The hospital of the future has been described as the critical care hub of a dispersed network of facilities linked by information systems and critical care transport services.[10] Critical Care transport should be part of a regional intensive care network and adhere to promulgated minimum standards for transport of the critically ill.[11,12]

INTER-HOSPITAL TRANSPORT

The general principles of patient transport regarding equipment, patient monitoring and checking after movement are identical, whether intra-hospital or inter-hospital. In inter-hospital transport the same problems are encountered but compounded by distance and the vehicular environment.

Patients are moved from the ICU for generally two reasons: (i) diagnostic imaging that cannot be performed in the ICU, and (ii) for procedures, traditionally the operating theatre, but increasingly for radiologically guided procedures including vascular embolization, angioplasty, percutaneous drainage and stent insertion.

Moving an ICU patient is a high-risk procedure but with sufficient planning and preparation there should be little or no compromise to his or her condition. Unfortunately, this is not always achieved, as there are often a number of distractions that will divert staff from monitoring the patient, or disconnection of infusions or ventilation. In up to 70% of ICU patient transports, adverse events occur, of which:

- one-third are equipment related[13]
- acute deterioration of PaO_2/FIO_2 ratio is common
- ventilator associated pneumonia is significantly increased.[14,15]

However management is changed in 40–50% of patients, thus justifying the risk. Sufficient notification will allow the assembly of equipment, monitoring and sufficient staff who are trained and familiar with the equipment and the patient. The more complex the patient, the more capable the team required. In unstable patients the minimum team should consist of a suitably trained doctor (e.g. one capable of re-intubating a ventilated patient and able to manage any changes occurring in the patient's condition), the patient's nurse and two assistants to move the bed and help to lift the patient. For more stable, less complicated patients the patient's nurse and assistants may be sufficient.

CT SCANNING

The most common diagnostic investigations necessitating transport is computerized tomography (CT). On most occasions very little planning and preparation is required for what is almost a routine procedure. The exceptions are patients with head injuries and the administration of nasogastric contrast and the increased aspiration risk in patients with decreased gastric motility. Repeated CT scanning of head injury patients is common.

In those patients with decreased cerebral compliance, movement and changes in body position or $PaCO_2$ can result in marked changes in intracranial pressure (ICP). Prior to transport, $EtCO_2$ should be measured on the transport monitor while the patient remains connected to the ICU ventilator. ICP changes caused by ventilator induced variations in $PaCO_2$ when switching to the transport ventilator can be reduced by adjusting the minute volume to maintain a stable $EtCO_2$ Adequate sedation will also decrease movement induced rises in ICP. Ideally, the ICP should be measured on the transport monitor but this is often not possible. Whether a staff member remains in the scanner room or views the patient and monitor from outside depends on patient stability. Radiation exposure, is small and is not considered a risk, and depends on where personnel stand in relation to the scanner's 'doughnut', from where the radiation is emitted.

MRI SCANNING

The hazards to a patient in MRI are greater due to limitations in the proximity of infusion pumps, ventilators and monitors to the magnet, and at times on catheters and pacemakers inserted in the patient. The need for the MRI needs to be balanced with the information likely to be gained. The three main problems with transport equipment are:

- metal objects becoming projectiles when in close proximity to the magnet
- equipment interfering with the MRI
- the MRI causing failures in transport equipment.

MRI units vary in policy, from prohibiting any equipment in the room to having minimal equipment that is placed as far away from the magnet as possible. The ability of ventilators and infusion pumps to function in the MRI scan room must have been tested prior to any patient being scanned, as some modern transport ventilators have failed in the MRI. Ideally, the equipment should be left outside the room with extensions added to the infusion and ventilator tubing, but this increases the risk of disconnection. There is one reported case of the external part of a pulmonary artery catheter burning through during an MRI scan,[16] probably caused by the development of RF eddy currents. Thermodilution pulmonary artery catheters are probably safe, but although patients with internal defibrillators and permanent pacemakers have been scanned with no consequence, deaths have been reported. Prior discussion with individual MRI units on how ICU patients can be scanned is required.

INTER-HOSPITAL TRANSPORT

ORGANIZATIONAL ASPECTS

Provision of critical care transport services needs to be a part of regional ICU services. The staffing of critical care transport teams will depend on the workload, with around 300 per year, being the threshold for a specific transport roster, depending on transport duration and regulations affecting duty times. Other factors include regional demographics, resources and geography. A team from within that unit, or from another ICU, or an emergency department, or a stand-alone transport service may provide transport of patients to a particular ICU. The merits of each system have been summarized recently.[17] Whatever arrangement is chosen, staff should not be conscripts but selected from those interested in critical care transport, and should be appropriately trained. Use of junior inexperienced staff is associated with increases in preventable mortality and morbidity.[18,19] Rostering of teams needs to be appropriate for the workload and take into account the potential for significant overtime hours when urgent requests occur near shift changeovers. If personnel are also allocated to other clinical duties, they need to be readily relieved when required. Equipment should be prechecked and the team should have a practised routine to enable prompt departure

A co-ordination centre should be used in systems involving multiple requests and transport teams.

PERSONNEL

The aim of the transport team is to at least maintain but preferably enhance the level of care. This requires transport teams to have diagnostic and procedural skills to provide the full complement of care for the full range of patients transported. Ideally, the personnel caring for the patient in transit should be equivalent to the 'front line' clinical team at the destination, implying a physician based team, although transport of well-stabilized patients by non-physician teams has been reported.[20]

The transport team should be a minimum of two people. For multiple patients a formula of $n+1$ personnel for n critical patients has been suggested.[21] Multidisciplinary teams of physicians, nurse and/or ambulance officers offer advantages of a wider range of skills and training than a team from any single profession. In certain circumstances, other specialized staff may need to be taken, for example a surgeon or obstetrician.[6] It is preferable and safer to add a specialist to the standard team because of the latter's familiarity with the practicalities of the transport environment. Other desirable attributes in staff include: good teamwork and communication skills; adaptability; reasonable body habitus and physical condition; and no significant visual or auditory impairment or susceptibility to motion sickness. Travel sickness medications such as hyoscine (scopolamine) are of limited value, needing to be taken up to 4 hours pre-transport and may cause significant side-effects.[22]

Training should encompass:

- principles and practicalities of clinical care in transport
- vehicle familiarization

- relevant communication, safety and emergency procedures.

Staff should have:

- appropriate personal protective equipment
- lightweight fireproof overalls or other clothing
- uniforms for pre-hospital responses, which should be of high visibility and bear identification.

PATIENT SELECTION

The best utilization of a critical care transport system is when it is activated for appropriate patients, which will depend on the levels of care available within the ambulance services. The need for critical care transport may be identified by:

- a diagnosis with the potential to deteriorate
- the requirement for physiological monitoring and acute interventions
- the continuation of treatment already instituted during transport.

Both receiving hospitals and ambulance services need to be alert to possible cases where critical care transport is indicated, but not identified by the referring team. A mechanism that is highly sensitive and specific at identifying patients unsuitable for standard ambulance transport is required. Triage mechanisms and tables to aid in patient selection have been described.[23,24]

COMMUNICATIONS

A systematic approach is necessary to ensure a smooth response when the need for transport of a critically ill patient is identified. A single toll-free telephone number with conference call capability is the ideal. Facsimile and teleradiology capabilities may also be of value. The one call for assistance should result in the provision of clinical advice if required, the dispatch of a transport team, and finding a bed in an appropriate hospital. Concise, simple clinical advice appropriate for the capabilities of the referring hospital by either the receiving hospital or the transport service is paramount. No matter how fast the transport team's response, without some interim care the patient with major airway, breathing or circulatory compromise will not survive.[6,7] Ongoing advice including stabilization and preparation of the patient for transport may be required prior to the arrival of the transport team. The provision to referring hospitals of a checklist for patient management and preparation for transport may assist.

The transport team should communicate with the receiving hospital, especially where changes in the patient's condition change the time of arrival, post-transport management or destination within the hospital or to another centre. Cellular telephones have revolutionized communication in transit, but their use may not be possible in all circumstances. Radio communication between ground and air ambulances and relevant hospitals is a preferred backup.

EQUIPMENT

GENERAL CONSIDERATIONS

Minimum standards for supplies, equipment and monitoring for critical care transport have been developed.[10,17] Equipment selection is a compromise between providing for every conceivable scenario and being mobile. The aim should be to have a core set of equipment plus optional items for specific scenarios plus some backup redundancy for vital supplies and equipment such as oxygen, airway devices, and basic circulatory monitoring. A suggested equipment schedule is appended in Table 3.1. Meticulous checking of equipment after each use and on a regular basis is essential.

Transport monitors, infusion pumps and ventilators must work outside the transport vehicle. This requires equipment to be battery powered and readily portable. Although newer monitors and other devices have rechargeable batteries with improved endurance, problems can still occur. The equipment checking process includes different charging regimes. Nickel cadmium (NiCad) batteries need to be fully discharged before recharging to decrease memory effect, which reduces endurance, whereas sealed lead–acid or lithium batteries perform best when continually charged between uses.[25]

Internal batteries should not be relied upon unless transport duration is less than half the estimated battery life. For longer trips, a supplementary power source from either an external battery pack or the transport vehicle should be available to reduce battery use or even charge the batteries. An external supply combined with a wiring harness to run and recharge internal batteries on all devices is preferable. Spare batteries are not ideal, as many devices are not amenable to rapid 'on the job' battery swaps without interruption of monitoring and therapy.

Portability can be addressed in two ways. Equipment can be vehicle mounted but readily detachable to accompany the patient, either as individual devices or more conveniently as a modular unit.[26] Alternatively, a mobile intensive care module can be incorporated into the stretcher; either in the base[27] or as a 'stretcher bridge' straddling the patient.[28] Such designs are now widely used and allow the patient and equipment to be assembled into one unit at the referral point; this reduces loading and unloading time, ventilator and other device disconnections, and the risk of leaving equipment behind. Minor disadvantages include the increase in weight (25–30 kg), with corresponding reduction in maximum patient weight; and slight top heaviness of the stretcher/patient combination.

MONITORING

Clinical observation by experienced personnel remains the mainstay of monitoring,[10] but some clinical assessments such as auscultation are impossible during transit. Hence monitoring by appropriate equipment should at the same or higher level than what the patient rec in the stationary setting. Referring institutions s

Table 3.1 Suggested equipment schedule for inter-hospital critical care transport

RESPIRATORY EQUIPMENT

- Intubation kit:
  - Endotracheal tubes & connectors – adult & paediatric sizes
  - Introducers, bougies, Magill forceps
  - Laryngoscopes, blades, spare globes & batteries
  - Ancillaries: cuff syringe & manometer, clip forceps, 'gooseneck' tubing, HME/filter(s), securing ties, lubricant
- Alternative airways:
  - Simple: Guedel & nasopharyngeal
  - Supraglottic: laryngeal masks &/or Combitube
  - Infraglottic: cricothyrotomy kit & tubes
- Oxygen masks (including high FiO_2 type), tubing, nebulizers
- Suction equipment:
  - Main suction system – usually vehicle mounted
  - Spare (portable) suction – hand, O_2, or battery powered
  - Suction tubing, handles, catheters & spare reservoir
- Self-inflating hand ventilator, with masks & PEEP valve
- Portable ventilator with disconnect & overpressure alarms
- Ventilator circuit & spares
- Spirometer & cuff manometer
- Capnometer/capnograph.
- Pleural drainage equipment:
  - Intercostal catheters & cannulae
  - Surgical insertion kit & sutures (see below)
  - Heimlich type valves & drainage bags
- Main oxygen system (usually vehicle mounted) of adequate capacity with flowmeters and standard wall outlets
- Portable/reserve oxygen system with flowmeter & std outlet

CIRCULATORY EQUIPMENT

- Defibrillator/monitor/external pacemaker, with leads, electrodes & pads
- i.v. fluid administration equipment:
  - Range of fluids: isotonic crystalloid, dextrose, colloids
  - High flow & metered flow giving sets
  - i.v. cannulae in range of sizes: peripheral & central/long lines
  - i.v. extension sets, 3 way taps & needle free injection system
  - Syringes, needles & drawing up cannulae
  - Skin preparation wipes, i.v. dressings & bandaids
  - Pressure infusion bags (for arterial line also)
- Blood pressure monitoring equipment:
  - Arterial cannulae with arterial tubing & transducers
  - Invasive & non-invasive (automated) BP pressure monitors
  - Aneroid (non-mercury) sphygmomanometer & range of cuffs (preferably compatible with NIBP also)
- Pulse oximeter, with finger & multi-site probes
- Syringe/infusion pumps (minimum 2) & appropriate tubing

MISCELLANOUS EQUIPMENT

- Urinary catheters & drainage/measurement bag
- Gastric tubes & drainage bag
- Minor surgical kit (for ICC, CV lines, cricothyrotomy, etc):
  - Sterile instruments: scalpels, scissors, forceps, needle holders
  - Suture material & needles
  - Antiseptics, skin preparation packs & dressings
  - Sterile gloves (various sizes); drapes +/– gowns
- Cervical collars, spinal immobilization kit, splints
- Pneumatic anti-shock garment (MAST suit)
- Thermometer (non-mercury) &/or temperature probe/monitor
- Reflective (space) blanket & thermal insulation drapes
- Bandages, tapes, heavy duty scissors (shears)
- Gloves and eye protection
- Sharps & contaminated waste receptacles
- Pen & folder for paperwork
- Torch +/– head light.
- Drug/additive labels & marker pen
- Nasal decongestant (for barotitis prophylaxis)

PHARMACOLOGICAL AGENTS

- CNS drugs:
  - Narcotics +/– non narcotic analgesics
  - Anxiolytics/sedatives
  - Major tranquillizers
  - Anticonvulsants
  - i.v. Hypnotics/anaesthetic agents
  - Antiemetics
  - Local anaesthetics
- Cardiovascular drugs:
  - Antiarrhythmics
  - Anticholinergics
  - Inotropes/vasoconstrictors
  - Nitrates
  - α & β blockers; other hypotensives
- Electrolytes & renal agents:
  - Sodium bicarbonate
  - Calcium (chloride)
  - Magnesium
  - Potassium
  - Loop diuretics
  - Osmotic diuretics
- Endocrine & metabolic agents:
  - Glucose (concentrate) +/– glucagon
  - Insulin
  - Steroids
- Other agents:
  - Neuromuscular blockers: depolarizing & non-depolarizing
  - Anticholinesterases (neuromuscular block reversal)
  - Narcotic & benzodiazepine antagonists.
  - Bronchodilators
  - Antihistamines
  - H_2 blockers/proton pump inhibitors
  - Anticoagulants
  - Thrombolytics
  - Vitamin K

Table 3.1 *(cont'd)*

PHARMACOLOGICAL AGENTS *(cont'd)*	
Antibiotics	Tocolytics
Oxytocics	Diluents (saline & sterile water)
ADDITIONAL/OPTIONAL EQUIPMENT	
Transvenous temporary pacing kit & pacemaker	Additional paediatric equipment (depending on capability of basic kit)
Blood (usually O negative) &/or blood products	Antivenene (polyvalent or specific)
Additonal infusion pumps & associated i.v. sets	Specific drugs or antagonists
Obstetrics kit	

Intercostal catheter (ICC). Central venous (CV). Heat moisture exchanger (HME). For other abbreviations, see text.

not allow patients to be transported by teams with inferior monitoring capability. Compact transport monitors offering ECG, SpO_2, non-invasive and multi-channel invasive pressures, capnography and temperature monitoring have largely superseded older techniques, such as systolic pressure estimation by palpation and mean arterial pressure monitoring via an aneroid interface and gauge. These older techniques can still be used for backup, as can defibrillators for ECG, while small hand-held pulse oximeters and $Etco_2$ detector are also available. Non-invasive blood pressure and pulse oximetry devices are susceptible to artefact[29,30] and the use of invasive arterial monitoring or shielding pulse oximetry probes may be required. Mercury-containing devices are unsuitable especially in aircraft. For longer transports, or patients with major biochemical or respiratory disturbances, compact biochemical and blood gas analysers may be valuable.[31]

VENTILATION AND RESPIRATORY SUPPORT

A mechanical ventilator should be used on all ventilated patients during transport. Manual ventilation occupies one team member fully and cannot reliably deliver constant tidal volumes and stable $Etco_2$.[32] Transport ventilators are a compromise between portability and features.

Table 3.2 Features of an ideal transport ventilator[a]

- Small, light, robust, and cheap.
- Not dependent on external power source.
- Easy to use and clean, with foolproof assembly.
- Economical on gas consumption.
- Suitable for patients from neonates to large adults.
- FiO_2 continuously variable from ambient air to 100% oxygen.
- Able to deliver PEEP, CPAP, SIMV & pressure support.
- Variable I:E ratios
- Flow or pressure generator modes
- Integrated monitoring & alarm functions with audio & visual signals
- Altitude compensated

[a] For abbreviations, see text.

The characteristics of an ideal transport ventilator are outlined in Table 3.2. No currently available transport ventilator meets all of these, and different models are optimized for different scenarios, so selection of a transport ventilator should take into account likely clinical and operational requirements. Backup manual ventilation equipment must be available. In some cases of severe respiratory disease, a standard ICU ventilator may be needed. This may require medical air and AC power although newer hybrid ICU/transport ventilators can provide enhanced ventilation capability without supply of these.[33] Similar requirements will apply to transport of patients on extracorporeal membrane oxygenation.

The provision of continuous positive airways pressure (CPAP) in transport remains problematic. 'Clapper board' type systems are economical on gas consumption, but being gravity driven perform poorly during movement. Conventional CPAP systems have extremely high gas consumption, rendering them impractical except for short road transports. Electronically triggered CPAP is a feature of some newer transport ventilators; however, though they have been successfully used on occasions, poor performance with mask CPAP has been reported,[34] and some patients may need to be converted to SIMV or intermittent positive pressure ventilation (IPPV) for transport.

Maintenance of humidification of inspired gases is important during transport. In most cases, heat and moisture exchangers should provide adequate protection for intubated patients.[35] In special circumstances, for example, in neonates and cystic fibrosis patients, it may be necessary to use active humidification.

A suction system and preferably a reserve are needed during all phases of transport. These may be venturi systems, electrical powered pumps or manual aspirators. Oxygen venturi systems are lighter than electrical systems and outperform manual aspirators, but have high oxygen consumption, >40 l/min.[36]

INFUSIONS

Critically ill patients often have multiple drug infusions which need to be continued during transport.

A reduction in pumps may be obtained by combining sedation infusions or by suspending some infusions for transport and giving them as intermittent boluses.

During the referral process it is important to ascertain the number of infusions running to ensure sufficient pumps are taken. Modern lightweight syringe drivers are preferable for most infusions but a volumetric pump is superior if an infusion of large volumes of fluid is required. Older 'drop counting' type infusion pumps are susceptible to disruption by movement and ambient pressure change and should not be used. Infusion pressure bags should also be available to maintain i.v. flow rates, as only minimal elevation of fluid bags is possible in most transport vehicles.

MISCELLANEOUS EQUIPMENT

Transcutaneous pacing is adequate in an emergency, or during very short transports, but in other circumstances elective trans-venous pacing should be instituted. Equipment to institute or maintain other specialized therapy en route should be carried if required. In some cases situations such as with an intra-aortic balloon pump, the equipment may be bulky and can influence the selection of the transport vehicle.[37]

Heimlich or similar one-way flap valves for pleural drainage are essential, as underwater seal drainage systems are not suitable for transport, owing to the likelihood of tipping and/or syphoning. Equipment to maintain nasogastric, urinary, and wound drainage is also required.

MODE OF TRANSPORT

Three types of transport vehicles are commonly employed: road, aeroplane (fixed wing), and helicopter (rotary wing). Basic requirements for critical care transport vehicles are listed in Table 3.3. Ideally, dedicated vehicles for all transport modes should be used, but the workload may not justify this and often vehicles that can be readily converted for mobile ICU use are seconded as required. The mode of transport depends on distances involved between referring and receiving hospitals and transport team locations; also the urgency of the case, which is often influenced by the clinical capability of the referring centre. Guidelines for vehicle utilization should be developed but should have some flexibility for special circumstances e.g. workload, traffic congestion, weather. Features and limitations of different modes of transport are summarized in Table 3.4.

ROAD TRANSPORT

The ground ambulance remains the most commonly used critical care vehicle. With patients for whom time is not critical and level of care in transit is more important than speed, road transport over considerable distances is feasible and may be safer in some patient groups.[38]

Table 3.3 Essential features of transport vehicles

- Readily available
- Adequate operational safety
- Capable of carrying (at least one) stretcher and mobile intensive care equipment set
- Safe seating for full medical team, including at head and side of patient
- Adequate space and patient access for observation & procedures
- Equipped with adequate supply of oxygen/other gases for duration of transport
- Fitted with medical power supply of appropriate voltage and current capacity
- Appropriate speed (coupled with) comfortable ride, without undue exposure to accelerations in any axis
- Acceptable noise and vibration levels
- Adequate cabin lighting, ventilation and climate control.
- Fitted with overhead i.v. hooks, and sharps/biohazard waste receptacles
- Straightforward embarkation & disembarkation of patient and team
- Fitted with appropriate radios and mobile telephone

FIXED WING TRANSPORT

Conventional aircraft are the most suitable for long-range transport. Their faster speed is offset by the secondary ambulance transport at both ends. Advantages over helicopters include pressurized cabins (in most models), decreased cabin noise compared with helicopters and the ability to fly in icing conditions.

ROTARY WING TRANSPORT

Helicopters remain the most controversial, high profile and expensive vehicles which require significant internal adaptations by clinical teams to enable them to perform patient care. Smaller helicopters are relatively or totally unsuitable as air ambulances. Appropriate helicopters are versatile vehicles, with the ability to perform transport both inside and beyond their 50–300 km optimum range 'doughnut'. Maximum value is obtained with a high workload, ensuring efficient clinical team utilization and between hospitals with on-site helipads to avoid secondary transport.

SAFETY AND TRAINING

Transport by any mode involves risk to staff and patients, and also imposes limitations on the delivery of care. In the aeromedical environment unfamiliar personnel perform clinical tasks poorly,[39] so teams must be appropriately trained and equipped to function effectively and safely in each mode of transport. They need to be familiar with use of the various transport vehicles' oxygen, suction, medical power, communications systems, and other equipment and stores. A senior member of their own professional group should train and accompany new personnel for several missions. Other specialist staff added to a team should receive a thorough safety brief

Table 3.4 Properties of transport vehicles

	Road	Helicopter	Fixed wing
Launch time	3–5 min	5–10 min (more if IFR)	30–60 min
Speed	10–120 km/h dependent on roads & traffic	120–150 knots (220–290 km/h), straight line	140–180 knots (piston) 230–270 knots (turboprop) 375–460 knots (jet)
Secondary transport	Not applicable	Sometimes	Inevitable
Effective range	0–100 km (longer if required)	50–300 km (longer or shorter in special cases)	200–2000 km
Noise	Low, except at high speed	Moderate to high (headsets required)	Low to moderate (cruise). Higher on takeoff/landing
Vibrations	Variable with speed & road surface	Moderate in most phases (varies with rotor type)	Low in cruise, moderate or high on takeoff/landing
Accelerations	Variable and sometimes unpredictable in all axes	Minimal & usually vertical only	Significant (fore/aft) on takeoff & landing
Special features	Base vehicles readily available	Versatility; point to point capability	Cabin pressurization & all weather capability (most)
Acquisition cost	Lowest	High (US$1–4.5 million new) depending on capabilities	Moderate (piston) to very high (jet)
Operating costs (per km)	Intermediate	Intermediate to high	Low to intermediate

and work under the direction of regular transport team members. Aeromedical crew training should encompass safety equipment, crash response, emergency egress and survival. Safety should be a foremost consideration in any transport. Activities that compromise road and air safety such as hazardous driving or flying below safe minima are not acceptable, and clinical teams must avoid attempting to coerce drivers or pilots to take risks. This has been recognized as a contributor to air ambulance accidents.[40]

ALTITUDE AND TRANSPORT PHYSIOLOGY

All transport modes result in increased noise, vibration, turbulence and accelerations in various or all axes (see Table 3.4). Personnel need to be aware of altitude-related complications that can occur with air transport. Increasing altitude results in decreasing oxygen partial pressure in accordance with Dalton's Law; while gas volumes increase or where volume change is restricted relative increases in pressure occur in accordance with Boyle's Law (see Table 3.5). Good introductory[41,42] and more detailed[43,44] aviation physiology texts are available.

OXYGENATION AND HYPOXIA

Critical patients who are already dependent on an increased FIO_2 will be compromised by reduction in atmospheric pressure. Further oxygen supplementation will be required to maintain arterial PaO_2. Only in special or unexpected circumstances, for example, alpine helicopter operations or cabin decompression, would hypoxia be expected to affect the medical crew; however, they should be aware of the risk and alert to symptoms. The manifestations of hypoxia are well described elsewhere.[37–40]

GAS EXPANSION

Expansion of trapped gases can manifest in (a) physiological air spaces, (b) pathological air spaces, and (c) air-containing equipment.

The first category includes the middle ear, nasal sinuses, and the gastrointestinal tract. These manifestations can affect crew as well as patients; consequently staff with upper respiratory tract infections or gastrointestinal disturbances should not fly.

The second category includes pneumothoraces, emphysematous lung cysts or bullae, intraocular or intracranial air from open injuries, bowel obstruction or rupture, and gas emboli. Such patients should be transported at the lowest possible cabin or ambient altitude, with close monitoring and extreme care, especially on the ascent phase. The effect of trapped gas expansion can be reduced with denitrogenation by breathing 100% O_2 before and during flight.

Air-containing equipment includes: endotracheal and tracheostomy tube cuffs; Sengstaken–Blakemore tubes; pulmonary artery catheter balloons; air splints, pneumatic antishock garments (MAST suit) and pleural, gastric and some wound drainage bags. Endotracheal cuff pressures need to be adjusted during flight, or filled

Table 3.5 Changes with altitude

Altitude (feet)	Pressure (mmHg)	Alveolar Po_2 (on air)	Alveolar Po_2 (100% O_2)	Gas space expansion	Std Temp (°Celcius)	Notes
Sea Level	760	103	663	–	15	15°C is 'reference' average temp – actual obviously varies.
1000	733	98	636	+3.6%	13	Minimum altitude above ground level for helicopter transports
2000	706	94	609	+8%	11	Likely altitude for most (VFR) helicopter flights over sea level terrain
3000	681	89	584	+12%	9	Likely range of cabin altitude for standard flights in most turboprop air ambulance craft (e.g. Raytheon–Beech King Air series)
4000	656	85	559	+16%	7	
7000	586	73	489	+29%	1	Standard cabin altitude for airliners & most jet air ambulances (e.g. Lear 35)
10 000	523	61	426	+45%	−5	Likely ceiling of helicopter operations & hypoxic threshold in normal individuals
15 000	429	45	332	+77	−14.5	Threshold for hypoxic decompensation in non acclimatized individuals
20 000	349	34	252	+117	−24.5	Likely upper range of cruise altitude for turboprop aircraft. Decompression at these altitudes causes rapid loss of consciousness & death without O_2
25 000	282	30	185	+170	−34	
40 000	141	<10	61	+439	−56	Cruise ceiling for airliners & jets. Limit for survivable decompression, even with 100% O_2 for flight crew

with water. Increases in tidal volume in pneumatically controlled ventilators can occur with altitude, necessitating setting changes.[45]

CABIN PRESSURIZATION

Most fixed wing air ambulances have pressurized cabins, which decreases hypoxia and gas expansion. The pressurization creates a cabin pressure equivalent to flying at a lower altitude, hence the term 'cabin altitude'. The maximum pressure differential that can be generated depends on the aircraft model. Most turboprop air ambulances can provide around 350 mmHg (46.7 kPa) differential, or cabin altitude of 1000 m (3000 ft) while flying at 6500 m (20 000 ft). Once maximum differential has been achieved lower cabin altitude can only be provided by lower flight, which may be relatively or absolutely contraindicated – for example, a slower more turbulent flight or beneath lowest safe altitude, respectively. The medical team should not request a lower cabin altitude than what is required, with the final decision resting with the pilot. Failure of cabin pressurization is rare, but if sudden can have dramatic consequences, and teams should be aware of procedures to follow.

OTHER CONSIDERATIONS

Temperature falls by 2°C for every 300 m (1000 ft) altitude increase. Water partial pressure also falls and is not corrected by cabin pressurization. Respiratory and other exposed mucosa can become dehydrated and could eventually lead to systemic hypovolaemia. All intubated patients should have at least passive humidification. On prolonged journeys, staff may also be affected. Staff rostered for air transport should refrain from compressed gas diving for at least 24 hours prior to the shift.[46]

PATIENT PREPARATION FOR TRANSPORT

The preparation phase for transport will depend on the patient's diagnosis and condition. If possible, the patient should be stable; and efforts, which may include surgery, should be undertaken to obtain stability. The exception would be a patient requiring time-critical intervention at the receiving hospital. These transports are riskier, but are likely to be less futile than attempting to stabilize an inevitably deteriorating patient. All patients prior to any transport must have a secure airway, either self-maintained or intubated and ventilated, and intravenous access. Any external bleeding should be controlled.

Table 3.6 Suggested pre-departure checklists

A. BEFORE LEAVING HOSPITAL	
Patient identity & next of kin	Recorded
Consent for transport	Obtained & documented
Paperwork & X-rays	Collected
Drugs for transport	Present & sufficient
Emergency drugs/equipment	Available
Medical equipment	Collected & repacked
Monitors, ventilator & infusions	Connected & on
Tubes, lines, drains & catheters	Secured
Altitude request (if applicable)	Passed to pilot
Receiving unit	Contacted & updated
B. IN VEHICLE & PRE-DEPARTURE	
Stretcher & patient restraints	Secured & checked
Oxygen supply	On & sufficient
Monitors, ventilator & infusions	Working & secure
Emergency drugs/equipment	Stowed & accessible
Other medical packs	Stowed
i.v. fluids	Hung & running
i.v. injection port	Accessible
Medical power	On & connected
Communications	Checked as applicable
Seatbelts	On & checked
Staff/patient headsets	On/checked (if applicable)

Urgent investigations (e.g. X-rays, arterial blood gases) should be obtained where indicated, and possible in the time available. The patient should be secured on the stretcher and connected to ventilators and monitoring commensurate to the degree of stability and time constraints. Infusions should be rationalized and sedation may need to be increased during the trip.

Intercostal drains, if present or placed, should be connected to Heimlich type valves. If parenteral nutrition is discontinued, an appropriate dextrose infusion should be substituted, with interval blood glucose estimation.

Appropriate documentation including a referral letter, results of investigations and hospital and ambulance observations needs to accompany the patient. The team should ensure that any relevant legal requirements have been complied with and, where possible, consent for transport obtained.[47] The final step prior to transport should be a series of checks as listed in Table 3.6.

PATIENT CARE DURING TRANSPORT

If the patient is adequately prepared this phase should be uneventful. Special vigilance should be employed in the initial stages of movement, as this is the most likely time for either physiological decompensation, or technical problems such as disconnections to occur. Once in the transport vehicle, a further set of checks is advisable (see Table 3.6). Therapy, monitoring and documentation should continue during transport. Transported patients are vulnerable to hypothermia, especially if intubated and/or paralysed and/or receiving multiple infusions.[2,48] Active heating in-transit may be possible using the vehicle heating, while passive heat conservation should be practised during loading and unloading. Transport crews should be restrained during transport. If a critical event occurs necessitating the crew leaving their seats, the driver or pilot should be informed.

Death in transport should be a rare occurrence.[6,7] If it does occur, distance and the expectations and location of relatives should be taken into account in making the decision whether or not to continue transport to the destination. Carriage of relatives remains a controversial issue. For conscious patients, especially children, the presence of family members may have a beneficial effect. For unconscious patients it is less clear and needs to be balanced against space constraints in the mobile ICU vehicle, and the potential reaction of relatives in case of a critical event. Transport services should have policies in place both for carriage of relatives and for death in transit.

QUALITY ASSURANCE IN EDUCATION AND RESEARCH

Critical care transport is a recent development where accepted standards and guidelines are still evolving.[49] This means there is still considerable likelihood of problems, errors and critical incidents; with corresponding scope for research and quality improvement. This requires good clinical and operational data collection and patient outcomes. The process should be sensitive to the existence of system errors as well as individual patient, equipment or staff incidents. Preliminary results from the use of a critical incident monitoring system have been reported.[13] Users of the service must be informed of recommendations and system changes resulting from this process. Innovation and research by staff involved in this area should be encouraged.

SPECIAL TRANSPORT SITUATIONS

PERINATAL TRANSPORT

This encompasses both *in utero* and extrauterine transport of the neonate. Specialized neonatal teams normally perform neonatal transport.[50] Alternatively, part or all of the regular transport team may accompany specialist neonatal personnel. Neonatal transport stretchers are bulky and heavy, and require a vehicular power output of up to 250 W for the incubator and active humidifier as well as monitors, ventilator and infusion pumps. They also require a supply of medical air to allow precise regulation of FIO_2.[51] Transport of the pregnant patient carries the risk of precipitating labour, and in rare cases, delivery in transit.[52] This is suboptimal, especially where the baby is premature or otherwise at risk. Where labour cannot be suppressed, consideration should be given to delivery at the referring hospital, with subsequent neonatal and maternal transport.

TRANSPORT OF DIVING INJURY PATIENTS

Patients with decompression sickness or arterial gas embolus require expeditious transport to a recompression facility. This must be balanced against the risk of even small decreases in ambient pressure; even a 100 m (300 ft) increase in altitude can exacerbate pathogenesis.[42] Divers with other problems such as marine animal envenomation, or other medical conditions will still have increased total body nitrogen stores and can be at risk of developing evolved gas disorders during air transport. The use of transportable hyperbaric chambers has been reported[53] but their use severely compromises speed of response, and therapy possible in transit. Transport at or very near sea level cabin pressure on 100% oxygen is the usual procedure.

INTERNATIONAL AND LONG DISTANCE TRANSPORTS

International transport of critically ill patients is becoming increasingly common. There are often complex medical, social and economic factors to return a patient to their own medical system. These must be balanced against the immigration, visa, and logistic requirements, and medical problems of ultra-long distance transport.[54] A physician based team is less likely to have problems relating to drug carriage and status compared with a paramedical team. Logistic problems include carriage of sufficient supplies, and clinical staff to work shifts for prolonged transports. Pressure may be exerted to utilize cheaper regular passenger transport services instead of much more expensive air ambulances. Most international airlines will accept a stable seated patient; but there is considerable variation among airlines willing to carry stretcher patients and associated equipment. Such transports require considerable planning to arrange stretcher fitment and sufficient supplies of oxygen and electric power. A separate oxygen system for critical care transports is required as the aircraft's emergency oxygen system is not permitted for patient care and the oxygen systems for inflight use by passengers with medical conditions can only deliver up to 4 l/min.[50] Airline engineering clearance of medical equipment is often required. Aircraft power needs to be negotiated or sufficient batteries carried. An air ambulance may be indicated for cases that are urgent, infective or require low cabin altitude; whereas stable post myocardial patients can be safely transported in commercial aircraft with appropriate escorts.[55]

CRITICAL CARE SCENE RESPONSES

Critical care teams offer a wide range of measures to complement standard pre-hospital providers, especially for major trauma; including: sedative/relaxant assisted intubation; cricothyrotomy; tube thoracostomy; intravenous cutdown or central line insertion; and blood administration; as well as triage to an appropriate hospital.[56] These teams are useful only for trapped patients in the urban setting,[57] but combined with helicopter transport can improve outcomes in rural patients with blunt trauma.[56,58,59] In these situations the team should include an experienced pre-hospital provider. With appropriate activation the team may reach the patient at the scene or supplement management at the local hospital.

Critical care teams may also be of value in disaster situations.[60] Disaster medicine involves a change in emphasis to performing a small number of basic life-saving procedures on a large number of patients. Personnel with transport/pre-hospital experience are likely to be better trained and equipped to work at disaster scenes than traditional hospital disaster teams.[61] The order of priority remains the same as traditional critical care transport: triage, treatment, and then transport.

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