Air Medical Services and Flight Physiology

June 30th, 2015
• Vision
  – Community & Academic EMS Physician Education
    • Information Sharing
    • Board Preparation

– Group involvement
  • Meet and see our peers
  • Involve your unique experiences and skills
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Today’s Presenter:

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Air Medical Services & Flight Physiology

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Outline

- Air Medical Services Overview
- Flight Physiology
- Clinical Applications
- Special Considerations
Air Medical Services
Purpose of Air Transport

Provide scene and inter-facility transfers for critically ill / injured patients in a safe, efficient and expert manner within an unpredictable environment at a medical practice standard equivalent to in-hospital care.
History of Air Medical Transport

- Helicopters first used for transport in the Korean Conflict in the early 1950’s.
- Increased use during the Vietnam war
- Vietnam war highlighted need for standardized trauma care in the U.S. along with transport to regionalized Trauma Centers
Development of Trauma Systems

- Accidental Death and Disability: The Neglected Disease of Modern Society (1966)
  - White paper from the National Academy of Sciences, Committee on Trauma and Committee on Shock
  - Highlighted need for standardized care in trauma and EMS

- Trauma systems and air medical transport systems have been under development for the past 45 years with civilian medical helicopter use following after a military model
History of Air Medical Transport

- Trauma only
- Trauma
- Stroke
- STEMI
- Transplant
- Post–Cardiac Arrest
- Shock
- Other Critical Care
Modern Programs:

- Safety culture
  - From individuals to equipment
  - Just Culture
    - Allows for non-punitive error reporting
    - Identification of system errors

- Strong medical direction

- Quality assurance and quality improvement programs

- Protocols and policies based on research
Air Medical Aircraft

- **Rotor:**
  - Require 100 x 100 ft landing zone
  - Can perform door-to-door transport
  - Fly ~120 mph
  - Service area of ~150 miles
  - Lower altitudes (~2,000ft)

- **Fixed Wing:**
  - Require transport to/from an airport
  - Fly 200–500 mph
  - Higher altitudes (6,000–8,000 ft cabin pressure)
Air Medical Aircraft (Single Engine Rotor)

- Least Expensive to operate
- Reduced safety in engine out scenarios
- No Instrument Flight Rules Capability (limits use in bad weather)
- Some advantage at high altitudes or very hot ambient temperatures

Bell 206

EC-130
Air Medical Aircraft (Twin Engine Rotor)

- Increased safety margin
- IFR Capable (Can complete all weather missions)
- Some models with de-icing capability
- May be equipped with Terrain and Collision Avoidance Systems
- Typical range: **150 miles**
- More expensive to operate than single engine aircraft

MD Explorer

EC-135

EC-145
Air Medical Aircraft (Multi-mission Rotor)

Used to perform medical missions plus:

- Search and Rescue
- Fire Suppression
- Hoist Rescue
- Law Enforcement

Dolphin

Bell 412
Air Medical Aircraft (Fixed Wing Medium Range)

- Require short airfields
- Ideal for distances of 150–500 miles
- Fly at ~200–300 mph
- Relatively inexpensive to operate
- Can be configured for all weather flight

King Air 200

Pilatus PC12
Air Medical Aircraft
(Fixed Wing Long Range)

- Most expensive to operate
- Requires longer, more improved runways
- Speeds exceeding 500 mph
- Intercontinental range

Lear 45
Challenger 600
Crew Configuration

- Type I (+/- specialty designation*)
  - Critical Care
  - Minimum of (1) Advanced Provider (MD, PE, RN) + (1) EMTP
  - Minimum levels of training and experience

- Type II
  - Critical Care
  - Minimum (1) AP + (1) EMTP

- Type III
  - ALS
  - Minimum (2) EMTP

*Specialty personnel:
  - Respiratory therapist, LVAD technician
  - Pediatric Intensivist, Neonatologist
Specialty Teams

- Pediatric / neonatal
- High Risk OB
- LVAD or ECMO
- IABP
- Transplant / CORE
Capabilities of Nurses vs. EMTPs

- Varies by state

- Procedures and medications that can be performed by each may be regulated by:
  - State Departments of Health
  - State EMS boards
  - State nursing boards
  - Regional EMS organizations
  - Local EMS agency medical directors
Potential Indications for Air Medical Transport from a Scene

- Need for rapid transport due to time-dependent condition
  - Trauma
  - ST-elevation myocardial infarction
  - Stroke

- Need for critical care interventions
  - Rapid sequence induction
  - Blood product administration

- Local ground resources not available or limited

- Time to hospital by ground considered excessive (due to distance, road conditions, traffic)

- Area inaccessible for ground transport
Potential Indications for Interfacility Air Medical Transport

- Need for rapid transfer for specialty care
- Time to specialty hospital by ground considered excessive
- Specialty care needed not available on ground unit
Contraindications for Transport

- Unsafe transport conditions
  - Weather
  - Size restrictions

- Compromised airway

- CPR without ROSC / DNR orders
  - Poor resource utilization

- Active labor (based on stage)
  - Cervical dilation remains controversial
Limitations of Air Transport

Aircraft by nature are / have:

- Crowded and claustrophobic
- Noisy
- Compromise performance of CPR
- Vibrations
- Poor lighting
- Limit senses of care provider
- Prone to extreme temperatures
Scene Rendezvous & Helistops

- Ground EMS may rendezvous with helicopters at a variety of scene locations
  - Includes hospital helipads (“Helistops”)

- Use of a Helistop does not obligate the hospital to perform a medical screening exam
  - No request for care at the facility
  - No EMTALA obligation
Risks and Costs of Critical Care Transport
The Cost of Critical Care Transport

Air Ambulances Offer a Lifeline, and Then a Sky-High Bill

By PETER EAVIS  MAY 8, 2015

An air ambulance crew from Life Star of Kansas delivers a patient to Stormont Vail Hospital in Topeka. Life Star is a nonprofit, and its fees are not as high as those charged by some services. Craig Hacker for The New York Times
Average Cost for HEMS transport $5–10K

Charges range:
- $10–50K

Cost per life year saved $2227–$12,022

Galvagno, JAMA 2012
- $325K per life saved ($15,476 per QALY)
- Cost of QALY decreases as severity of illness increases
What are the Risks of Transport?

Unacceptable Risk: The Troubling Medical Helicopter Safety Record

Medical helicopters are supposed to save lives. Too often, they put both flight crew and patients in danger instead. Here, in this Popular Mechanics special report, we investigate the crashes and statistics that make medical helicopter an unacceptable risk.

- Fatal accident rate for all general aviation
  - 1.13 per 100,000 flight hours

- Fatal accident rate on HEMS aircraft
  - 1.18 per 100,000 flight hours
“2nd death in Jacksonville crash involving ambulance” (Florida – Dec 3, 2009 – EMSNetwork.org)

Seven injured after ambulance hits two cars in South Londonderry Twp. (Pennsylvania – Dec 8, 2009 – EMSNetwork.org)

“Several injured in crash involving ambulance – Missouri” (Missouri – Dec 11, 2009 – EMSNetwork.org)

Ellicott City man, 47, dies of injuries suffered in collision (Maryland – Dec 7, 2009 – Baltimore Sun Reporter)
PATIENT DIES AFTER AMBULANCE CRASH IN SLEEPY HOLLOW

Tim Fleischer has reaction to the tragic accident from City Island (Photo of victim courtesy Ron Terner, Focal Point Art Gallery, City Island)
What is the Risk to the patient?

- Ground EMS
  - 0.67 injuries per 100,000 miles
  - 3% of injuries are fatal
  - 0.02 deaths per 100,000 miles

- Helicopter EMS
  - 2 deaths per 100,000 flight hours
  - 120 miles per flight hour
  - 0.017 deaths per 100,000 miles
Mitigating Risk of Air Medical Transport
Instrument Flight Rules (IFR)

- The ability to fly through clouds and limited visibility.
GPS Approaches

- FAA certified safe pathways into hospitals and landing zones when clouds are low.
Twin Turbine Engines

- Two engines with redundant hydraulic, electric and fuel supply systems
Information Systems

- Color Weather Radar
- Traffic Collision Avoidance System (TCAS)
- Enhanced Ground Proximity Warning System (EGPWS)
Flight Physiology
Flight Physiology

The atmosphere

- Sea level to 70,000 ft
- Composition:
  - Nitrogen 70.8%
  - Oxygen 20.95%
  - Remaining % – Argon, Carbon dioxide, Hydrogen, Helium, Neon
Changes with Altitude

- Barometric pressure decreases
- Partial pressure of oxygen decreases
- Gases expand

- Temperature falls
  - 59° @ sea level → −5° @ 10,000 ft.
The Gas Laws

- Boyle: The effect of altitude on gas volume
- Dalton: The effect of altitude on oxygen availability
- Henry: Gas equalization due to pressure changes
- Charles: The effect of temperature on gas volume
- Graham: Diffusion of gases from higher to lower concentrations

Physics Alert!
Boyle’s Law (Expansion)

- \( \frac{P_1}{P_2} = \frac{V_2}{V_1} \)
  - The volume of gas is inversely proportional to its pressure (if the temperature remains constant)
  - i.e. a volume of gas increases as pressure decreases

- Considerations:
  - Gas within an enclosed space will expand
  - The reverse occurs on descent

- Body is adaptable up to 10,000 feet above sea level
**Effects on Equipment**

**Endotracheal Tube**

- The cuff (filled with air) may expand and contract with changes in altitude

- **Results in:**
  - Rupture and/or tracheal damage
  - Air leaks and difficulty ventilation

- **Solutions:**
  - Inflate the cuff with water
  - If filled with air, check and adjust in-flight

- Also applies to use in a Hyperbaric chamber
Effects on Equipment

**Intravenous Drips**

- As air expands, pressure in a closed space increases so flow increases
  - The reverse occurs during descent

- **Solution:**
  - Put all lines on mechanical pumps with the ability to always control the rate!
Effects on Equipment

Splints

- Monitor closely any fractures placed in air splints
- The splints may need to be inflated or deflated
Ventilators

- Before flying a ventilated patient make sure it is electronically and not pneumatically controlled and that the ventilator is certified by the manufacturer.
Boyle’s Law in Action

- What happens to a patient with a pneumothorax that we transport in a helicopter?
- How much does the volume of the pneumothorax increase?
Boyle’s Law in Action

- \( P_1 V_1 = P_2 V_2 \)  
  \( V_2 = \frac{(P_1 \times V_1)}{P_2} \)

- Sea Level \( (P_1) = 760 \text{mm Hg} \)
- PTX \( (V_1) = 100 \text{ ml} \)
- Flight Level 6,000 Ft. \( (P_2) = 609 \text{mm Hg} \)

- PTX \( (V_2) = 125 \text{ml} \) (25% increase)

- Note: at <2,000 feet there is <5% increase
Dalton’s Law

- The total pressure of a mixture of gases is equal to the sum of the partial pressures of each gas in that mixture.

\[ P_{Total} = P_1 + P_2 + P_3 + \ldots + P_n \]
Dalton’s Law

- As altitude increases, atmospheric pressure decreases
  - Gas molecules are further apart as altitude increases → the availability of oxygen decreases as altitude increases.
  - Even though FiO₂ does not change the PaO₂ declines
PaO₂ is 20.95% (constant)

- @ Sea Level  \( PO_2 = 20.95\% \times 760 = 159.22 \text{mmHg} \)
- @ 5,000 ft.  \( PO_2 = 20.95\% \times 632 = 132.40 \text{mmHg} \)
- @ 10,000 ft. \( PO_2 = 20.95\% \times 523 = 109.52 \text{mmHg} \)

Therefore flight itself can cause or worsen hypoxia!
Effect on oxygen transfer in the bloodstream:
- A patient that has an oxygen saturation of **98%** at sea level will have an oxygen saturation of **87%** at 10,000 feet.
- At 22,000 feet their oxygen saturation will be **60%**.

How do we increase PaO$_2$?
- Increase FiO$_2$
- Increase atmospheric pressure (descend)
Dalton’s Law

Solving the problem:
- Limited impact for helicopter transport (1,500–2,500 ft)
- In fixed wing aircraft, cabin is pressurized at 8,000 ft
- Routine use of supplemental oxygen
Advantages of Pressurized Cabins

- Gastrointestinal trapped gas pains are reduced
- Cabin temperature, humidity and ventilation can be controlled within desired comfort levels
- Crew unencumbered by oxygen masks
- Minimum of fatigue and discomfort
Disadvantages of Pressurized Cabins

- Increased structural weight
- Additional maintenance
- Possible contamination of the cabin air from smoke, fumes, carbon monoxide, carbon dioxide and odors
- If rapid decompression occurs, exposure to the dangers of hypoxia, decompression sickness, and hypothermia
Dalton’s Law in Action

- **Patient with COPD**
  - Room air O2 Sat at sea level is 95%
  - Flight on commercial aircraft
  - At 8,000 ft, O2 Sat is 86% → patient becomes short of breath

- **Solution:**
  - On commercial aircraft: Use of portable oxygen
  - On medical aircraft: Routine use of oxygen
Altitude Oxygen Requirement Equation

\[
\text{Initial } \text{FiO}_2 \times \text{BP}_1 = \text{FiO}_2 \text{ Required } \text{BP}_2
\]

\[BP=\text{barometric pressure}\]
Henry’s Law

- The amount of gas that will dissolve in a solution and remain in solution is directly proportional to the pressure of the gas over the solution.

\[ P = k_H c \]

- \( P \) is partial pressure of solute in the gas above the solution.
- \( c \) is concentration of the solute.
- \( k_H \) is Henry’s constant (depends on the solute, solvent, and temperature).
Henry’s Law

- Example: carbonated beverages

- No bubbles when the cap is on $\rightarrow$ pressure is equal.

- Bubbles when the cap is off $\rightarrow$ pressure is released that was keeping the gas dissolved
Henry’s Law

- Not related to solubility of gas in solution

- Clinically important in the development of decompression sickness (i.e. dissolved gases in solution vaporize as the ambient pressure decreases)
Henry’s Law in Action

- Scuba diver enjoying himself diving off an island in the Bahamas
  - Normal ascents, no problems

- On day of diving, he is involved in a motor vehicle collision, unrelated to diving
  - Requires air medical transport to a trauma center on the mainland
Henry’s Law in Action

Any problems?

- Patient put in medical fixed wing aircraft
- Plane ascends to altitude
- Nitrogen bubbles form as nitrogen gas comes out of solution in the blood stream → The Bends
  - Bubbles form in the spinal cord and in joints
  - Sudden neurological symptoms and/or joint pain
Recommendations for Diving & Flying

- Single non-decompression dive (<30 feet)
  - Minimum of 12 hours before flying

- Multiple dives per day, multiple days of diving, or dive requiring any stages of ascent
  - Minimum of 24 hours before flying

- If unable to wait due to medical transport emergency, consider
  - Increased pressurization of cabin
  - Flying at lower altitude
Graham’s Law

- Gases diffuse from higher to lower concentrations
  - Impacts normal gas exchange and cellular respiration

- Rate of diffusion of a gas through a medium is:
  - Directly related to the solubility of the gas
  - Inversely proportional to the square root of its density
  - E.g. improved diffusion of oxygen with heliox versus air
Charles’s Law

- If pressure is constant the volume of a gas is proportional to its temperature
  - Gas expands when heated (think explosions of un-vented gas tank) and contracts when cooled
  - Increase in altitude decreases pressure and consequently temperature
  - Changes in temperature increase metabolic rate, heart rate, and oxygen demand with potential decompensation in compromised patient.
Gay–Lussac’s Law

- Pressure and temperature are directly related when volume is constant

- E.g. Pressure in an oxygen tank decreases as the temperature decreases
Take-Home Points

- Air medical transport requires increased attention to operating environment for both crew and patients.

- Air operations, even at low altitudes, present a series of risks which must be proactively anticipated and managed.

- Clinicians must have an understanding of aircraft limitations, operating characteristics, attributes, and safety equipment.

- The effects of altitude physiology may be insidious, especially hypoxia, affecting both patients and air medical crew.

- Crew resource management (CRM) is essential in all operations and especially essential in helicopter operations due to low altitude with limited recovery time.
Questions?