Aircraft Fundamentals & Flight Physiology
Intro

• Many conditions can be exacerbated by changes in barometric pressure that occurs at altitude

• Forces experienced during flight may have substantial impact on disease pathophysiology
Conditions of Concern for Aeromedical Transport

• Severe anemia
• Hemoglobinopathy
• Myocardial infarction within 10 days or complications in the 5 days before flight (flight to PCI center is not contraindicated)
• Uncontrolled dysrhythmia
• Pregnancy past 24 weeks
• Recent eye surgery
• Nonacute hypovolemia
The Atmosphere

• Oxygen
  • 21% of the atmosphere

• Nitrogen
  • 78% of the atmosphere
  • Can be responsible for evolved gas disorders
Zones of the Atmosphere

• **Physiologic zone**
  • Sea level to 10,000 feet
  • Barometric pressure falls from 760 mm Hg to 523 mm Hg
  • Many healthy people can experience symptoms of hypoxia at 10,000 ft

• **Physiologically Deficient Zone**
  • 10,000 to 50,000 feet
  • Barometric pressure drops from 523 mm Hg to 87 mm Hg
  • Effects of trapped gases becomes more pronounced
  • Protective equipment is required
Barometric Pressure

• Direct result of weight of air
  • Varies with time and location
  • Related to density of air from temperature and height above the surface

• Measured in mm Mercury (mmHg), millibars (mb), or atmospheres (atm)
Gas Laws

• Boyles Law
• Charles’s Law
• Dalton’s Law
• Fick’s Law
• Henry’s Law
• Universal Gas Law
• Gay-Lussac’s Law
• Graham’s Law
Boyle's Law

• Changes in gas volume with changes in ambient pressure
  • Increased pressure leads to decreased volume
  • Decreased pressure leads to increase volume

• Clinical Significance:
  • Gases trapped in body cavities will expand with increase in altitude and contract with decrease in altitude

\[ P_1 \times V_1 = P_2 \times V_2 \quad \text{or} \quad \frac{P_1}{P_2} = \frac{V_2}{V_1} \]
Charles’s Law

• Volume of a gas is proportional to its absolute temperature
  • Increase temperature – increased volume
  • Decrease temperature – decreased volume

\[
\frac{V_1}{V_2} = \frac{T_1}{T_2} \quad \text{or} \quad \frac{V_1}{T_1} = \frac{V_2}{T_2}
\]
Gay-Lussac’s Law

- Pressure of a gas is directly proportional to the absolute temperature when volume is maintained.
  - Increased pressure – increased temperature
  - Decreased pressure – decreased temperature

Standard lapse rate: -2 C (-3.5 F) per 1,000 feet of altitude
Universal Gas Law

• Relationship of temperature, pressure, and volume for a gas

\[
\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}
\]
Dalton’s Law

• Total pressure of a gas mixture is the sum of individual or partial pressures of the gases in the mixture

• Multiplying % of a gas by the total pressure of the mixture yields the partial pressure of that gas
Fick’s Law

- Diffusion rate of a gas across a fluid membrane is proportional to the difference in partial pressure, proportional to the area of the membrane, and inversely proportional to the thickness of the membrane.
Henry’s Law

- Amount of gas dissolved in solution is directly proportional to the pressure of the gas over the solution.

- Dissolved nitrogen transitions to a gas phase in blood and tissues during decompressions sufficient to result in supersaturation.

\[
\text{Initial FIO2} \times \text{Initial Barometric Pressure} = \text{Adjusted FIO2}
\]

\[
\frac{70\% \times \text{FIO2} \times 760 \text{ mm Hg}}{600 \text{ mm Hg}} = 88.7\% \text{ Adjusted FIO2}
\]
Graham’s Law

• Rate at which gases diffuse is inversely related to the square root of their densities
  • Less dense – greater diffusion

• Large difference in concentration produces greater diffusion

• Fundamental process of lung and cellular respiration

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**Graham’s Law: Diffusion and Effusion**

• **Diffusion** is the mixing of different gases by random molecular motion and collision.

• **Effusion** is when gas molecules escape without collision, through a tiny hole into a vacuum.
Pressurized vs Nonpressurized Aircraft

• Most effective way to protect from physiologic effects of reduced barometric pressure
• Increase pressure inside of aircraft > ambient pressure
  • Isobaric pressure – pressure constant at altitudes
  • Differential control – pressure fluctuates with altitude
• Rapid decompression
  • Load explosion, immediate exposure to dangers of hypoxia, decompression sickness, GI expansion, and hypothermia
• Slow decompression
  • Small leak with insidious onset leading to hypoxia and death if uncorrected

A descent must be immediately made to a level at or below 10,000 feet and all occupants use oxygen if there is a loss of cabin pressure!!
Stressors of Flight

- Decreased levels of O2
- Barometric pressure changes
- Thermal changes
- Vibration
- Decreased humidity
- Noise
- Fatigue
- Gravitational forces

- Spatial Disorientation
- Third Spacing
- Flicker Vertigo
- Fuel Vapors
- Weather
- Anxiety
Decreased levels of $O_2$

- Percentage of oxygen is constant at higher altitudes
  - Barometric pressure is lower, oxygen molecules are fewer
  - 15,000 feet barometric pressure = 429 mm Hg
    - Oxygen sat 80% with $PaO_2$ of 44 mm Hg
Barometric pressure changes

- Greatest pressure change from sea level to 5,000 feet

<table>
<thead>
<tr>
<th>Altitude</th>
<th>Atmospheric Pressure (mm Hg)</th>
<th>PaO2</th>
<th>Blood Saturation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Level</td>
<td>760</td>
<td>100</td>
<td>98</td>
</tr>
<tr>
<td>5,000 feet</td>
<td>630</td>
<td>80</td>
<td>95</td>
</tr>
<tr>
<td>8,000 feet</td>
<td>562</td>
<td>70</td>
<td>93</td>
</tr>
<tr>
<td>10,000 feet</td>
<td>524</td>
<td>61</td>
<td>90</td>
</tr>
<tr>
<td>18,000 feet</td>
<td>380</td>
<td>38</td>
<td>75</td>
</tr>
<tr>
<td>22,000 feet</td>
<td>321</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>25,000</td>
<td>282</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>
Thermal changes

- Temperature declines with altitude

- Radiant solar heat
  - Enclosed cockpit heat can increase by up to 50 degrees
Vibration

• Low frequency vibrations
  • Fatigue
  • Abdomen / chest discomfort
  • Decreased vision
  • May increase temperature as body fights vibrations/movements

• Can be reduced by seat cushions and use of shoulder & lap belts
Decreased humidity

• Relative humidity decreases with altitude

• Pressurized aircraft is recirculated through filters and moisture is drawn off
  • < 5% remains after 2 hours of flight
  • 1% remains after 4 hours of flight

• Can lead to
  • Fatigue
  • Dehydration
  • Sore throat
  • Cracked mucous membranes
Noise

• Subtle symptoms of hearing loss
• Impedes communication
• Difficulty in patient assessment by auscultation
• Provide hearing protection to all patients
Gravitational forces

- Rapid acceleration and deceleration
  - 1 g = body weight
  - 2 g = 2 X body weight
  - 10 g = 10X body weight

- Positive G forces
  - Acceleration, climbs, turns
  - Push blood away from the brain

- Negative G forces
  - Steep dives
  - Push blood away from the brain

Healthy crewmembers may sustain hypoxia at 5-6 G’s & loss of consciousness at 6-8 G’s. Tolerance may be greatly reduced by age, illness,
Spatial Disorientation

• Type I - not noticed by crew
• Type II – spatial disorientation not noticed, but knows that something is wrong
• Type III – illusion of intense movement and unable to orient
Third Spacing

• Centrifugal force associated with acceleration / deceleration
• Pushes fluid from intravascular space to extravascular space
Flicker Vertigo

• Imbalance in brain cell activity caused by exposure to low-frequency flickering or flashing of relative bright light
• Bright light flickering at frequency of 4-20 cycles per second
• Natura light or anticollision strobe lights distorted by rotor blades
• May cause:
  • Nausea
  • Vomiting
  • Seizures
Fuel Vapors

• Noxious odors
• Associated with nausea & headaches
Anxiety

• May effects crew and patients
• Catecholamine release during rotary wing operations shown in studies
• Patients may require anxiolysis
Hypoxia

• May effect patients with impaired pulmonary function at lower altitudes

• Impaired judgement is an early sign
  • Limits ability to take immediate action
  • May mimic fatigue and hypoglycemia

• Effective performance time
  • 30 minutes to 10 minutes

• Time of useful consciousness
  • Varies from 5 minutes to 1 minute

A rapid decompression can reduce time of useful consciousness by > 50%
Hypoxic Hypoxia

• Altitude hypoxia
  • Inadequate respiration or reduction in oxygen pressure
  • Lack of oxygen entering the blood

• Medical causes
  • Lung disease
  • Right-to-left shunt
  • Airway obstruction

Recovery can be rapid with high-flow oxygen. Prevention is the key to safety. Pilots must use oxygen from 10,000 – 12,000 feet if > 30 minutes and at all times when > 12,000 feet in nonpressurized aircraft. All occupants must have oxygen at cabin altitudes above 15,000 feet.
Histotoxic Hypoxia

• Inability of cells to adequately use oxygen because of substances in the blood
  • Narcotics
  • Alcohol
  • Tobacco

Oxygen is available, but can’t be utilized
Stagnant Hypoxia

• Failure to transport oxygenate blood
  • Heart failure
  • Venous pooling
Hypemic Hypoxia

- Anemic hypoxia
- Too few functional hemoglobin molecules present
  - Anemia
  - Hemorrhage
  - Carbon monoxide
Stages of Hypoxia

- Indifferent stage
- Compensatory stage
- Disturbance stage
- Critical stage

<table>
<thead>
<tr>
<th>Stage of Hypoxia</th>
<th>Cabin Altitude</th>
<th>PaO2 (mmHg) and percentage saturation of Hemoglobin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Breathing Air</td>
<td>Breathing 100% O2</td>
</tr>
<tr>
<td>Indifferent</td>
<td>0-3,30m 0-10,000 ft</td>
<td>10,300-12,000m 33,000-40,000 ft</td>
</tr>
<tr>
<td>Compensatory</td>
<td>3,030-4,500m 10,000-15,000 ft</td>
<td>12,000-13,000m 40,000-42,500 ft</td>
</tr>
<tr>
<td>Disturbance</td>
<td>4,500-6,000m 15,000-20,000 ft</td>
<td>13,000-13,500m 42,500-45,000 ft</td>
</tr>
<tr>
<td>Critical</td>
<td>6,000-7,000m 20,000-23,000 ft</td>
<td>13,500-13,800m 45,000-46,000 ft</td>
</tr>
</tbody>
</table>
Hyperventilation vs Hypoxia

• Hyperventilation can mimic hypoxia

• Both can result in:
  • Confusion
  • Poor judgement
  • Inappropriate corrective maneuvers

• Hyperventilation may also cause
  • Drowsiness
  • Muscle spasms
  • Ataxia
Dysbarism and Evolved Gas Disorders

• Barotitis Media
• Barosinusitis
• Barodontalgia
Dysbarism and Evolved Gas Disorders

• Decompression Sickness
  • Explained by Henry’s Law
  • Inert nitrogen gas bubbles form in the body
  • Body tissues may contain 1 – 1.5 L of nitrogen
  • Fat dissolves nitrogen 5-6 times faster than blood
  • When supersaturated, nitrogen forms a gas
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