Aerospace Physiology

- Cardiopulmonary Physiology
  - Respiratory
  - Cardiovascular
- Musculoskeletal
- Vestibular
- Neurological
The Human Circulatory System

Arterial Network:
- Innominate artery
- Subclavian artery
- Left subclavian artery
- Common carotid artery
- Right iliac artery
- Hepatic artery
- Celiac artery
- Splenic artery
- Renal arteries
- Medial collateral arteries
- Femoral arteries
- Popliteal artery
- Tibial arteries

Heart:
- Aorta
- Left atrium
- Right atrium
- Left ventricle
- Right ventricle
- Pulmonary arteries
- Systemic arteries

Vein Network:
- Internal jugular vein
- Subclavian veins
- Right subclavian vein
- Femoral veins
- Popliteal veins
- Tibial veins

Pulmonary circuit:
- Pulmonary arteries
- Pulmonary veins
- Heart
- Capillaries

Systemic circuit:
- Arteries
- Veins
- Capillaries

Muscle contracts
Valve closed
Muscle relaxes
Valve open
Blood propelled forward by muscle contractions and, possibly, by gravity
Back pressure due to contractions of atria, contractions of muscles, and, possibly, gravity

Valve open
Valve closed

UNIVERSITY OF MARYLAND
Aerospace Physiology
Principles of Space Systems Design
Lung Measurements

Blood Pressure in Circulatory System

- Artery
- Arterioles
- Capillaries
- Venules
- Vein

Blood pressure (mm Hg)

Total area (cm²)

Velocity (cm/sec)

Large arteries
Small arteries
Arterioles
Capillaries
Venules
Veins
Gas Exchange in the Lungs

Gas Exchange in the Tissues

Metabolic Processes

- Respiratory Quotient ("RQ")

\[ RQ = \frac{\text{Exhaled volume of } CO_2}{\text{Inhaled volume of } O_2} \]

- Function of activity and dietary balance
  - Sugar:  \( C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \)  \( \text{(RQ} = 1.0) \)
  - Protein:  \( 2C_3H_7O_2N + 6O_2 \rightarrow 5CO_2 + 5H_2O \)  \( \text{(RQ} = 0.83) \)
  - Fat:  \( C_{57}H_{104}O_6 + 80O_2 \rightarrow 57CO_2 + 52H_2O \)  \( \text{(RQ} = 0.71) \)

- For well-balance diet RQ~0.85
Respiratory Problems

• Hypoxia
  - Hypoxic
  - Hypemic
  - Stagnant
  - Histotoxic
• Hyperoxia
• Hypocapnia
• Hypercapnia
Types of Hypoxia

• Hypoxic (insufficient $O_2$ present)
  - Decompression
  - Pneumonia

• Hypemic (insufficient blood capacity)
  - Hemorrhage
  - Anemia

• Stagnant (insufficient blood transport)
  - Excessive acceleration
  - Heart failure

• Histotoxic (insufficient tissue absorption)
  - Poisoning
Alveolar Pressures

Effects of Supplemental Oxygen


Aerospace Physiology
Principles of Space Systems Design
Hypoxia Effective Performance Time

Oxygen Toxicity

The Human Circulatory System, Revisited

Muscle contracts
Valve closed

Muscle relaxes
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Cardiovascular Effects of Microgravity

- Cardiovascular deconditioning
- Upper body blood pooling
- Changes in blood volume
- Increased calcium content
Acceleration Effects on Arterial Pressure

120/80 mmHg

25/-- mmHg

320 mm

1200 mm

475/435 mmHg

At 4 g’s longitudinal:
1000 mmH₂O = 296 mmHg
Decompression Sickness

• Release of dissolved gases in blood following pressure drop
• “DCS”, “Caisson Disease”, “The Bends”
• J. B. S. Haldane modeled DCS as supersaturation of dissolved nitrogen in blood:
  \[ R = \frac{P_{N_2}}{P_{ambient}} = 0.79 \text{ (nominally)} \]
• Experience indicates symptomatic DCS onset at levels of 1.6-1.8
Haldane Tissue Model

- Hypothesized that tissues absorb and release dissolved gases at exponential rates

\[
\frac{dP_{tissue}}{dt} = k(P_{alveoli} - P_{tissue})
\]

- Response to a step change in alveolar pressure

\[
P_{tissue}(t) = P_{tissue,0} + (P_{alveoli} - P_{tissue})(1 - e^{-kt})
\]
Tissue Models, continued

• Rate coefficient frequently given as time to evolve half of dissolved gases:

\[ T_{1/2} = \frac{\ln(2)}{k} \]

• Workman added concept of “M-values” - critical saturation limits for tissues

• Continued refinement of tissue models for predicting onset of DCS
# PADUA (Univ of Pennsylvania) Tissue Model

<table>
<thead>
<tr>
<th>Tissue</th>
<th>$T_{1/2}$ (minutes)</th>
<th>$M_0$ (bar)</th>
</tr>
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<tr>
<td>1</td>
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<td>8</td>
<td>240</td>
<td>1.490</td>
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<tr>
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<td>1.490</td>
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<tr>
<td>10</td>
<td>480</td>
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</tbody>
</table>
Tissue Saturation following Descent

![Graph showing partial nitrogen pressure in tissue over time. The graph plots partial pressure (bar) against time (minutes) from 0 to 50 minutes. Two lines are shown, one for 4 bar and another for 30 bar, indicating the saturation levels.]
Tissue Saturation after Ascent

![Graph showing partial nitrogen pressure in tissue over time.](image-url)
In equilibrium, external pressure balanced by internal gas pressure and surface tension.

Surface tension forces inversely proportional to radius.
Vestibular System

Vestibular Sense Organs

Otolith Responses

Artificial Gravity

\[ g_{\text{rotation}} = \left( \frac{w}{r} \right)^2 \]

- Lunar gravity
- Mars gravity
- 0.5*Earth gravity
- 0.75*Earth gravity
- Earth gravity

Rotation Rate (rpm)

Radius (m)
Allowable Rotation Rates

- Select groups (highly trained, physically fit) can become acclimated to 7 rpm
- 95% of population can tolerate 3 rpm
- Sensitive groups (elderly, young, pregnant women) may have tolerance levels as low as 1 rpm
Short-Term Dose Radiation Effects

- 10-50 rem - minor blood changes
- 50-100 rem
  - 5-10% minor nausea and vomiting
- 100-200 rem
  - 25-50% nausea and vomiting
  - 50% reduction in lymphocytes
- 200-350 rem
  - Nausea, vomiting, diarrhea, minor hemorrhage
  - 75% reduction in all blood cells
  - 5-50% incidence of death
Short-Term Dose Radiation Effects

- 350-550 rem
  - Nausea, vomiting, diarrhea, hemorrhage, emaciation
  - 75% reduction in all blood cells
  - 50-90% mortality within 6 weeks
  - 6 month convalescence
- 550-750 rem
  - Nausea and vomiting within four hours
  - Mortality approaching 100%
- 750-2000 - survival time <2 weeks
- 2000+ - incapacitation within hours
NASA Radiation Dose Limits

NCRP-132 (2000)

10 Year Career Exposure Limits ($\text{S}_\text{v}$)

- NCRP-132 (Male)
- NCRP-132 (Female)

Age (yrs.)

0 0.5 1 1.5 2 2.5 3 3.5 4

25 35 45 55
References