Pathophysiology, Prevention, and Treatment of Ebullism

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I have no financial relationships to disclose.

I will discuss the following off-label use and/or investigational use in my presentation:

• High-Flow Percussive Ventilation for ebullism-related pulmonary injury
Introduction

• **Ebullism**
  
  – Effervescent evaporation of body fluids at barometric pressure equal to or below the saturated vapor pressure at body temperature
  
  – Vapor pressure of water at 37°C = 47mmHg
  
  • Equivalent to 63,000ft (19,202m) altitude
Introduction

• Full pressure suits required for flight above 50,000ft (15,240m) – hypoxia and ebullism protection
  – Initially partial pressure suits used in pressurized capsule; replaced by full pressure garments
## Human Exposures

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940s</td>
<td>Dr. Jim Henry places hand in vacuum glove box</td>
</tr>
<tr>
<td>1960s</td>
<td>Captain Joe Kittinger lost right glove pressure on Excelsior III</td>
</tr>
<tr>
<td>1966</td>
<td>NASA vacuum chamber subject exposed to 120,000ft (36,576m) when umbilical disconnected</td>
</tr>
<tr>
<td>1968</td>
<td>F-104 flight; pressure suit from glove came off (fatal aircraft crash)</td>
</tr>
<tr>
<td>1971</td>
<td>Soyuz 11 crew died from capsule pressure leak</td>
</tr>
<tr>
<td>1981</td>
<td>Industrial accident in vacuum chamber</td>
</tr>
<tr>
<td>2003</td>
<td>STS-107 Columbia crew exposed to vacuum during vehicle breakup</td>
</tr>
</tbody>
</table>
Methods

• Literature review
  – Human/animal studies – rapid decompression to vacuum
  – Medline, Web of Science, Scopus, Google Scholar, National Technical Information Service
    • Retrieved 2 documents
  – Search expanded to manual search of available periodicals at medical libraries, military archives
    • Retrieved 12 documents
  – Author first-hand knowledge, unpublished experimentation – most performed >30y ago
Results

• Predictable injury by organ system
  – Cardiovascular: vapor lock
  – Respiratory: emphysematous changes, alveolar destruction, atelectasis, edema, barotrauma
  – GI/GU: projectile emesis/defecation/urination, organ hemorrhage
  – Nervous: LOC, spinal cord hemorrhage, bubble infarctions
  – Body Cavities: barotrauma
  – Fluid Evaporation: hypothermia, dehydration, tissue freezing
## Sequence of Ebullism

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>+0 sec</td>
<td>Anxiety, agitation</td>
</tr>
<tr>
<td></td>
<td>Abdominal distension</td>
</tr>
<tr>
<td>+10 sec</td>
<td>Loss of consciousness</td>
</tr>
<tr>
<td></td>
<td>Circulatory vapor lock</td>
</tr>
<tr>
<td>+30 sec</td>
<td>Seizure/paralysis</td>
</tr>
<tr>
<td></td>
<td>Vapothorax</td>
</tr>
<tr>
<td></td>
<td>Vapoperitoneum</td>
</tr>
<tr>
<td></td>
<td>Hypothermia</td>
</tr>
<tr>
<td></td>
<td>Dysrhythmia</td>
</tr>
<tr>
<td>+4 min</td>
<td>Irreversible brain injury</td>
</tr>
<tr>
<td></td>
<td>Death</td>
</tr>
</tbody>
</table>
## Factors Influencing Morbidity and Mortality

<table>
<thead>
<tr>
<th>Factor</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anoxia</td>
<td>&lt;90 sec survival in animal models</td>
</tr>
<tr>
<td></td>
<td>Death within 5 min if uncorrected</td>
</tr>
<tr>
<td>Bubbles, Trapped Gas</td>
<td>Absolute/relative pressure change</td>
</tr>
<tr>
<td></td>
<td>Rate of pressure change</td>
</tr>
<tr>
<td></td>
<td>Altitude</td>
</tr>
<tr>
<td></td>
<td>Prebreathe/Denitrogenation</td>
</tr>
<tr>
<td></td>
<td>Atmospheric components</td>
</tr>
<tr>
<td>Fluid loss</td>
<td>Hypothermia</td>
</tr>
</tbody>
</table>
High-Frequency Percussive Ventilation

• Commonly used for ARDS
  – Improves oxygenation without increasing lung damage
  – Damage to ebullized lungs similar to ARDS

• Provides oxygenation at low pressures
  – Damaged lung tissue: considerably decreased compliance
  – Must guard against providing too much peak and expiratory pressure during ventilation
  – Must guard against inadvertent circuit break (no visible chest rise)
Decompression above 63,000 feet

Pre-Landing
- Ensure immediate transport is available
- Prep for RSI, high-frequency percussive ventilation
- Obtain exposure characteristics

Upon Landing
- Breach suit for access if applicable
- Give 100% O₂ by face mask
- Maintain stable C-spine as appropriate

Conscious? Yes

Talk test? Good

No

Pulse? Yes

Evidence of tension PTX?

No

Adequate ventilation?

No

- Check/adjust equipment
- Reassess

Yes

Needle thoracostomy

- Continue 100% O₂
- Monitor*
- Frequent assessment
- Transport as necessary

- Ensure IV access (fluids TKO)
- Treat other injuries
- Conduct secondary assessment
- Continue transport and monitoring
- Be aware of hypothermia

* Monitoring to include:
  Vital signs
  Cardiac monitoring
  SpO₂
  End-tidal CO₂
  Temperature
Discussion

• Research (human/animal) extremely limited
• Protocol put into place but untested
• Literature suggest survival is possible
  – Animals: 90-120 second exposures survivable
  – Humans: survival based on exposure duration, but likely can withstand more than animals
    • JSC Vacuum Chamber test, industrial vacuum chamber accident
Discussion

• Lung damage primary factor in survival
  – Use of HFPV can oxygenate through damaged tissues, allows time for recovery of other insults

• Prebreathing oxygen improves survival
  – Denitrogenation reduces incidence and severity of lung damage

• Rate of decompression/recompression factors into survival
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