Environmental Injuries Continued

Diving Injuries
Near Drowning

Lecture 21

D. Trigg

Outcomes

- At this lecture's completion, the learner will be able to:
- Describe the incidence, morbidity and mortality associated with drowning and associated with dysbarism: diving injuries that are pressure-related and injuries that are N2 – "bends" - related
- Identify risk factors predisposing to drowning , dysbarism, as well as N2 (and O2) toxicity
- Discuss the physiology of and the physics principles involved in dysbarism, N2 (and O2) toxicity
- Discuss the assessment findings associated with the above
- Correlate abnormal findings with their clinical significance
- Integrate pathophysiology, physical findings, and treatment for the above, in particular the life-threatening pressure-related diving injuries

Diving

Historically

- free diving (with breath-holding), at depths of 100 ft or more, has reportedly occurred since 4500 BC [1]

Dysbarism

- Pressure related injuries
- N_2 - "bends;" DCS
- N_2 (and O2) toxicity

[1] http://www.emedicine.com/emerg/topic154.htm

Diving Injuries

Diving mortality
- Drowning
- Dysbarism

Other Morbidity
- Lacerations
- Bites / Stings

Dysbarism
- Pressure related
  - ie., barotrauma
- N2 – "bends;" DCS
  - decompression sickness
- N_2 and O_2 toxicity

Mortality
- Data for drowning vs dysbarism (barotrauma vs DCS) are difficult to sort.
- One US military report found fatalities at 1.3 / 100,000 dives
- Unofficial data from Catalina Island: M+M: 1/3 ; 1/3 ; 1/3

Laws of Dysbarism
- Boyle's law
- Henry's law
- Dalton's law
- Charles law – no

Laws of Dysbarism

Boyle's law
- Vol of gas varies inversely with pressure
- eg., as balloon ascends, because the atm. pressure decreases, the gas inside ***expands***
- "Squeeze" syndromes

Henry's law
- ***Amt*** of gas ***dissolved*** in a liquid is proportional to the pressure of the gas surrounding that liquid
- Pressure can dissolve, force, a gas into a liquid.
- eg., CO2 escaping from champagne bottle when the cork (pressure) removed.
- Decompression sickness (DCS)

Dalton's law
- As atm. pressure increases the partial pressure of a gas increases - ***moving more easily*** into tissue
- N_2 narcosis; O_2 toxicity

- **B**oyle's (Burst lung)

B
A
L
L
O
O
N

- **H**en$_2$ry's (Hours later)

H
U
R
T

- **D**alton$_2$'s (Drunk)

D
E
E
P

Contraindications to Diving

Contraindications to Diving
- Vertigo
- Panic disorder
- Asthma / COPD
- Syncope disorder
- Seizure disorder

Relative contraindications
- Sinus disorder
- Ear disease
- Poor conditioning

Diving mortality
- Drowning
- Dysbarism

Dysbarism(3)

1. Pressure (barotrauma)
- Descent
  - Non-life threatening
    - except by drowning
- Ascent
  - air-trapping: ↑ risk of barotrauma and arterial gas embolism (AGE)

Dysbarism: Pressure-Related

Pressure-related or barotrauma injuries

- Descent
  - More common
  - Non-life threatening, usually
    - except by drowning
- Ascension
  - Less common
  - More serious

Air-trapping - lung

- Altered Forced Vital Capacity and Forced Expiratory Volume can lead to air-trapping
- Panic disorder (aerophagia)
- Asthma / COPD

Air-trapping - sinus / ear

- Sinus disorder
- Ear disease

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Descent Injury : Squeeze

Ear : the most common injury

- External ear canal
  - Blocked (cerumen or ear plug) creates suction
  - Canal suction pulls TM out
- Middle ear (barotitis)
  - esp if Eustachian tube is small or blocked
  - Middle ear suction pulls TM in.
  - signaled by bubble in outer ear
  - Cold water rush into middle ear → ***vertigo*** (+/- vomiting)
  - Pain commonly precedes rupture and should signal diver to abort descent
  - Death may occur as result of :
    - Vertigo
    - Panic
    - Drowning

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Squeeze Injuries

Ear injuries

- Inner ear
  - Round window implosion
  - Hemorrhage or rupture of round window
  - Vertigo (not from rush of cold water but from direct inner ear trauma) +/- vomiting
  - Tinnitus
  - Ataxia
  - Deafness

Tooth Injuries

- Fillings containing "air gaps"
- Implosion due to ↑ pressure on outside of tooth

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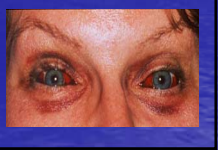
Other Types of Descent or " Squeeze " Injury

Squeeze or suction of:

- Mask
  - Subconjunctival hemorrhages
  - Conjuctival edema
  - Facial petechiae
  - Prevention: exhale into mask on descent
- Sinus
- Suit
- Lung (free diving)



Page 1: www.bsac.com/medical.htm
Page 2: page: www.blue-zoodivers.ch/index.php?page=10.50.10

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Reverse Squeeze or Ascension Injury

- Middle ear : rupture
- Teeth : pain / explosion
- Bowel: worse in diver with aerophagia +/or gum chewing
- Lung : the most serious

Pulmonary Over Pressurization Syndrome (POPS)

- Expanding of unvented lung-gas
- Boyle's Burst lung
- Prevention: must exhale on ascent
- Rapid uncontrolled ascent
  - Panic
  - Loss of weight belt

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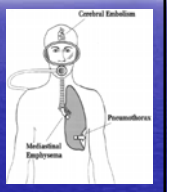
Pulmonary Barotrauma
Pulmonary Over Pressurization Syndrome (POPS) and AGE

Clinical

- Pneumothorax
- Pneumomediastinum (crunch)
- -pericardium; -peritoneum
- AGE (Arterial Air Embolism)
  - High mortality and morbidity
  - Rapid ascent; "last 10 ft."
  - Sudden, dramatic, catastrophic
    - ALOC; seizures are common
  - Alveolar gas enters systemic circulation
    - Air emboli to coronary and cerebral arteries
  - Upon surfacing or within 10 min (unlike DCS)



- Picture http://scuba-doc.com/painbt.gif

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Ascent Injury - Air Embolism

AGE (Arterial Air Embolism)

- Common cause of death in divers
- Mechanism: ruptured pulmonary veins, air enters left heart, and then into the arterial circulation
  - Brain / heart / viscera
- Onset: immediate
  - Immediately after surfacing, air escapes into left heart
  - ***Sudden LOC*** or neurological symptoms ***upon surfacing***
    - ALWAYS an air embolism until proven otherwise
- Not a DCS injury
- Is ***not*** "the bends"
- Not "caisson disease," "cutis marmorata," "go back down"

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Air Embolism Treatment

- 1) A
- 2) B: high flow O2
- 3) C
  - Monitor
  - Large bore IV, NS ; support BP
- 4) D own - head down - no. Air transport: down-low
  - Transport in supine position
    - Trendelenburg and LLD positions are no longer recommended
      - Breathing interference ; ↑ cerebral edema
  - Transport to recompression chamber
    - Air transport at less than 1000 ft

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Other POPS Injuries

Pneumothorax:

- Hx. : ascension followed by immediately by :
  - Hoarseness, neck fullness
  - Chest pain, dyspnea
  - Syncope
- PEx.: JVD; absent BS; shock
- Tx.
  - D ecompress
    - Tension pnthx: immediate needle decompression

Pneumoperitoneum

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Decompression Sickness

- N_2 injury and **Dec**ompression **s**ickness or DCS
- Disorder of gas coming out of solution upon ascent
- Commonly referred to as "the bends"
- Dissolved N_2 builds up in the blood and tissues during compression and then a rapid ascent causes the N_2 to expand in the tissues

- Types
  - Minor (DCS I)
    - Musculoskeletal. (joints) ; skin ; lymphatics (Henry's law Hurts)
  - Major (DCS II)
    - CNS (cord, cerebellum) ; lungs

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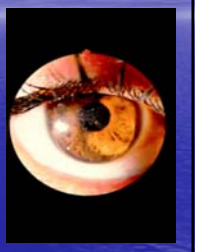
DCS - N_2 Injury

- DCS is clinically concerned with dissolved - N_2 - **expansion** - injury

FYI

- Bubbles formed on decompression are visible in tear fluid beneath contact lens [1]
- Decompression sickness following breath-hold diving does occur [2].
- Injury from repetitive free diving was described as long ago as 1553[3]



[1] BMJ 1998; 317(7164):996 (10 October) at http://www.bmj.com/cgi/content/full/317/7164/996

[2] Research in Sports Medicine: An International Journal Volume 14, Number 3 / July-Sept 2006

[3] Bartolomé de Las Casas, *The Devastation of the Indies: A Brief Account*, 1553

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Decompression Injury

Nitrogen gas build up in tissues and blood

- Decreased time of ascent (rapid ascent) = decreased time for decompression = N_2 still in the blood and tissues
- Increased depth → increased N_2
- Increased time (dive duration) → increased N_2
- Increased weight → increased N_2
  - N_2 is lipid soluble: Obesity is a risk

Spectrum of DCS injury

- Anatomic location and severity of N_2 injury
- Symptoms typically present in 1-6 hrs after surfacing
  - Not within the first 10 minutes !
  - May present much later than 1-6 hr

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History and Risk factors for DCS

Risk factors for DCS
- Cold water
- Arduous dive
- Older diver
- Obesity
- Dehydration
- Alcohol use
- Pain/panic
- Repetitive dives

Important Hx.
- Predive (alcohol…)
- Descent
- Bottom (trauma,…)
- Ascent
- Post dive
  - < 10 min. = air embolism
  - > 10 min. = decompression

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Decompression Injury - DCS I

- Muscles
  - "the bends"
  - "caisson disease"
- Joints
  - Elbows
  - Shoulders
- Skin
  - Itch ; redness
  - Cutis marmorata (skin marbling, or mottling)
    - From venous stasis
    - Not from cord N_2 injury, resulting in vasomotor-instability
      - But how would you know?

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Decompression Injury - DCS II

- CNS
  - N_2 is concentrated in CNS
  - Cortex
  - Midbrain -- CN
  - Cerebellum
  - Cord
- Lungs

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DCS II Clinical Presentation

- Symptoms: gradual; hours and hours after surfacing
  [unlike arterial gas embolism AGE]
- HA, inappropriate behavior (Cortex)
  - LOC is rare in DCS
    [LOC is common in AGE-cerebral air embolism]
- Diplopia; dysarthria (Midbrain / CN)
- "The staggers" (Cerebellum)
- Priapism ; incontinence ; urinary retention (Cord)
- Limb weakness and prickly paresthesias (Cord)
- Dermatome sensory loss (Cord)
- "The chokes" (Lungs)

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DCS II Lung Injury

"The chokes"
- Caused by microemboli (N_2) to the lungs
  - Unlike POPS
- Gradual, not sudden onset
  - Unlike AGE
- Dyspnea
- Cough
- Chest pain
- Rarely, cyanosis
- Rarely, RVCHF Sx and signs
  - With hypotension

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Recompression Therapy

- Recompression : not just for DCS, but also for AGE
- AGE
  - patient is non-elective ; CPR in progress,…
- DCS
  - May recompress up to 14 days after symptom onset
  - Delayed onset of symptoms is common
  - Minor symptoms may progress
  - Symptoms associated with flying
    - Divers with minor or no initial symptoms
  - Flying
    - No flying for 3-7 days after DCS I
    - No flying for 1 month after DCS II

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N_2 Narcosis and O_2 Toxicity

N_2 narcosis (alcohol like)
- Sx: Euphoria, confusion, disorientation
  Poor judgment; poor coordination
- Injury due to Depth
  - ↑ depth = ↑ N_2 partial pressure
    [Dalton's -- Depth -- Drunk]
- Occurs at
- > 200 ft: delirium 120
- > 300 ft: LOC 200
- Tx: controlled ascent

O_2 toxicity
- O_2 can be neurotoxic[1] at extremely high partial pressures
- Injury at depth > 200 ft

[1] Seizures - see: *BMJ* 1998;317:996-999

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Drowning

Definitions
- Drowning : suffocation from submersion
- Near drowning : recovery from submersion
- Dry drowning : laryngospasm then asphyxia
- Wet drowning : aspiration (more common)
- Secondary drowning : recovery +/- ; then ARDS
- Dunker : child looking perfectly stable [deceptively] after recovery from submersion
- Immersion syndrome : sudden death in cold water

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Drowning Epidemiology

- Young children
- 2nd leading cause of accidental death
- Pools
- Bathtubs ; buckets
- Surveillance
- Fencing
- Curious ; following sibs
- Inability to swim

- Teens and adults
- 3rd leading cause of accidental death
- Alcohol
- Trauma
- Seizures
- Judgment
  - Exhaustion
  - Overwhelmed / Lack of ability
  - Hypothermia
- Inability to swim
- Scuba

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Drowning Survival

- Primarily determined by:
  - Duration of submersion
- Low core temperature:
  - Correlates with a poor outcome
  - Mammalian diving reflex may be somewhat protective in sudden cold water immersion in children
- Shock (rare in drowning)
  - Poor prognostic sign (C/Spine, multi-trauma; drugs)
- Salt water vs fresh water: no effect on survival
- Water contamination
- Bystander CPR

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Drowning Pathophysiolgy

- Death by:
  - Respiratory
    - Submersion hypoxia → ischemic injury
- Fresh water
- Loss of surface tension properties of surfactant → ventilation-perfusion mismatch
- Hypoxia
  - Can occur after minimal vol of aspiration (2.2 mL/kg; toddler: 3 tbsp)
- Pulmonary edema
  - Direct injury ; loss of surfactant
  - Cerebral injury
- Dilutional hemolysis and electrolyte abn : rarely significant
- Metabolic acidosis is common

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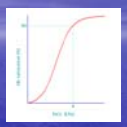
Drowning Treatment

Standard CABCDE ; COMEBIG
- O2 100%
- Continuous monitoring, esp O2 sat
  - Maintain sat above 90%
- Intubation if:
  - Persistent hypoxia on 60-100% FiO2
    - Child: pO2 < 80 [O2 sat : <90-91%]
    - Adult: pO2 < 60 [O2 sat : <<80%]
      (O2 sat : 80% corresponds to a PaO2 of 50)



Treat bronchospasm, hypoglycemia, hypothermia, seizures, arrhythmias in the usual fashion
- Support of BP: may require pressors
- No steroids, hypertonic saline, mannitol, antibiotics

CPR
- CPR, ACLS drugs; non-reactive pupils = poor prognostic sign
- However, up to 24% of children with outright cardiac arrest can survive with intact neurological function

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Summary

- Diving mortality; dysbarism ; the laws of dysbarism ("Boyle had a balloon that burst; Henry hurt hours later; and Dalton went too deep and got drunk")
- Dysbarism can result in either barotrauma AGE or N2-related – "bends;" or decompression sickness DCS
- POPS (Pulm Over Press Syn) and ***AGE*** can occur in the last 10 ft resulting in: life-threatening event within ***10 min*** of surfacing
- Physical findings associated with and treatment of AGE, +/or a POPed lung. Difference between POPed and "the chokes" ("***a popped lung is not a bent [DCS] lung***")
- Hx and physical findings associated DCS I + II and hyperbaric treatment for both AGE and DCS
- Drowning : prevention and treatment; early aggressive treatment in a child may be associated with a favorable outcome

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