Arterial Gas Embolism & pulmonary barotrauma

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Case

- Jill 35 yrs, OWC 22 dives
- Dives with the much more experienced Robert (UW photographer)
- Jill runs out of air at @ 35 msw, panics and shoots for the surface
- Robert is focused on taking pictures of a lionfish 15 meter away from Jill
Case

- Jill makes a ‘ballistic’ ascent.
- On surfacing she makes a high pitched noise and loses consciousness within 1 min.
- It took 10 minutes before she was finally on deck of the boat.
- BLS by the divemaster.
- SAR evacuation.
- Declared dead after 90 min of CPR.
Arterial Gas Embolus (AGE)

Most feared and serious dive injury!
• pulmonary barotrauma
• arterial gas embolism (AGE)
• cerebral gas embolism (CAGE)
• venous vs arterial gas embolism (VAGE)
• pathophysiology
• signs & symptoms
• clinical VGE
• HBOT for AGE
• adjuncts
• take home
Divers AGE: sudden death

- immediately after surfacing rare
- 4% will die on the scene
  - sudden loss of consciousness, PEA
  - no effect of CPR
  - die on surfacing
  - complete filling of central veins and arteries
- 5% will die in hospital
Pulmonary barotrauma

- usually: uncontrolled ascent (panic) without exhalation
- ascent from 1 m depth with total lung volume!
- airway obstruction in asthma
- presence of blebs and bullae
Predisposing factors

- blebs/ bullea
- asthma
- sarcoidosis
- tumors
- pleural adhesions
- pulmonary fibrosis
- infection
Pulmonary barotrauma

- high pitched cry on surfacing
- dyspnoea
- cough
- haemoptysis
Pneumomediastinum

- ruptured alveoli > perivascular sheaths > bronchi > mediastinum
- no pain or substernal chest pain
- ascending air to the neck > subcutaneous emphysema
- chest x-ray: look along the edge of the heart, aorta
- pneumothorax is not necessary
- HBO is not needed (unless AGE)
- conservative treatment, 100% O₂
- no flying for 1 week after resolution.
Pneumomediastinum
Pneumothorax

- rupture of alveoli adjacent to visceral pleura
- less common
- occurs in 5-10% of AGE
- very relevant for the chamber!
- symptoms:
  - pleuritic chest pain
  - SOB, dyspnea
- CT scan is more sensitive
- echo: absence of sliding sign
- usually small pneumothorax:
  - 100% oxygen
  - observation

Pleural tear
Arterial gas embolus (AGE)

- organs at risk:
  - flow: heart and brain
  - not gravity!
- ischemia due to arteriolar occlusion
- endothelial damage
  - platelet adhesion
  - vasodilation
  - loss of auto-regulation
  - loss of blood-brain barrier > edema

Pathophysiology cerebral AGE

- most bubbles pass through the cerebral circulation
- occlusion at diameter 30-60 µm
- junction white/grey matter
Cerebral symptoms, not spinal!

- loss of consciousness
- stupor, confusion
- cortical blindness
- monoplegia
- asymmetric multiplegia
- paresthesias
- convulsions
- aphasia, visual field defects
- vertigo, dizzyness
- less frequent:
  - complete hemiplegia
  - paraparesis
• spontaneous improvement due to breaking up and redistributing
• deterioration due to microthrombus and edema formation!
• combination with DCS!
• CK (mm) is correlated to severity and neurological outcome

Smith RM, Neuman TS. Elevation of serum creatine kinase in divers with arterial gas embolism. NEJM 1994;33:19-24
CAGE bubble

- Gas bubble
- Artery
- Cell injury and edema
  - Na⁺, H₂O
- Affected neuron
- Flow
- Endothelial irritation
- Inflammation and vasogenic edema
  - Affected neurons
AGE

• pulmonary barotrauma
  – emergency ascent without exhaling!
  – blebs and bullae
  – arterial gas embolism

• iatrogenic or DCS:
  – direct intra arterial injection
  – $VGE + R > L$ shunt (PFO)
  – $VGE +$ pulmonary pass through (massive gas load)
HBO for AGE

- high ambient pressure:
  - modest bubble reduction!
  - T6a (6 bar) vs T6 (2.8 bar)
- high O$_2$ partial pressure
  - to speed up N$_2$ washout (N$_2$ gradient)
  - to increase plasma O$_2$ content (oxygenation)
  - to decrease cerebral edema (vasoconstriction)
  - to antagonize $\beta_2$ integrin mediated capillary blockage
  - to reduce I/R injury
Mechanical effects of HBO

From 1 > 2.8 bar
volume reduction 73%
diameter reduction 35%

Modest effect from compressing to 6 bar
Total elapsed time:
285 min
4 h 45 min
(not including descent time)
Case series

• Trytko & Bennet AGE review 1996-2006
  • 18 diving related AGE
  • 12 rapid ascent
  • 4 PFO (TEE confirmed)
  • 2 suspected PFO (not confirmed TEE)
  • average treatments 3.6
  • treatment delay 4 - 44H
  • complete resolution 15/18 = 83%
  • minor residual symptoms 3/18
Adjuncts to treatment

- 100% $O_2$ by mask (class I, level C)
- normal saline (class IIb, level C)
- lidocaine 1.0 mg/kg, 2-4 mg/min iv. (class IIb, level C) = obsolete…..
- thrombosis prophylaxis (class I, level A)
Chest drain

- diver with pneumothorax
  - before air evacuation
  - before recompression
- inside chamber
  - problems arise during ascent!
  - stop ascent, descent 2 meter
  - insert chest drain with Heimlich valve
  - or emergency needle thorococentese
TTE: absence of sliding sign
Return to diving

• return to diving?
  – if symptom free
  – no pulmonary contraindication
  – HRCT lung
  – after 1 month
  – If spontaneous pneumothorax or bronchial rupture due to blebs and bullae > no more diving!!
problems arise during ascent
or shortly after surfacing (minutes)
  – altered consciousness
  – confusion
  – focal cortical signs
  – seizure

• treatment the same as DCS
• 100% O₂
• supine flat or recovery position
• evac < 1000ft to HBOT
• deterioration after improvement is possible, always evacuate for HBOT
Clinical iatrogenic gas embolism

- sudden unexplained neurological, pulmonary or cardiac abnormality during or shortly after an invasive procedure
- such as:
  - central line insertion, removal or manipulation
  - delivery
  - neurosurgery

- doppler ultra sound of heart
- Echocardiography
- CT scanning
- Or straight to HBOT
Venous gas embolism

venous air entry:
- diving DCS
- clinical:
  - central venous catheter
  - neurosurgery (sitting)
  - CABG
  - prostatectomy
  - hip/spine surgery
  - Cesarean section
  - et al.

- low volume > no symptoms
- large volume > vapour lock/ chokes

lung filter! (bubble > 22 µm)
- pulmonary pass through:
  - dose
  - injection speed
  - pressure gradient

Arterial Gas Embolus (AGE)

• pulmonary filter overwhelmed above:
  – 0.4 ml/kg/min (dog)
  – 0.17 ml/kg/min (sheep)

• lethal bolus of intravenous air (air lock)
  – rabbits 0.55 ml/kg
  – dogs 7.5 ml/kg
  – human (case reports) 3-5 ml/kg = 200-300 ml
Hemiplegia after CVC insertion

- only air in
  - ophthalmic vein
  - central venous sinus
  - brachiocephalic vein
Therapy AGE & VGE

- VGE massive:
  - cardiac massage dislodges the vapour lock!
  - HBO (no data, risk/ benefit of transport)
- VGE mild:
  - supportive, 100% $\text{O}_2$
  - pulmonary edema $>$ HBOT
- + neurological or cardiovascular signs: HBOT
  - up to 24 hours after incident (3-48 h)
  - table 6 $= 2.8$ ATA

Wondwossen G, case series 1990-2012

- 36 patients iatrogenic CAGE
- neurologic signs: global > focal
- 26/36 = 72% favourable outcome
- + younger patients (< 44 yr)
- + time to HBO < 6 h
- - presence of infarct or edema before HBOT
Thank you for listening.

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Slides available @
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