IMMERSION PULMONARY OEDEMA IN DIVERS

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Thank you Carl Edmonds

Huge contribution to diving medicine
Wise man, mentor and inspiration
Generous sharing of publications
Have not always agreed with his conclusions but time has usually shown him to be correct
Also Steve Wills & Martin Sage for permission to use the cases & Mike Davis & John Lippmann
Immersion Pulmonary oedema in divers

1. Several well documented deaths in scuba divers due to immersion pulmonary oedema (IPE) where there was a preceding episode of shortness of breath or syncope.

2. It is hard to distinguish between immersion pulmonary oedema in divers and drowning at autopsy but we are starting to recognise the condition.

3. DAN Asia-Pacific dive fatality reporting project - immersion pulmonary oedema often raised in;

   1. > 50 year old women
   2. 50% narrowing of coronary arteries
   3. Left ventricular hypertrophy
   4. Cold water conditions
Pulmonary oedema

Non-specific accumulation of fluid in the lungs

1. Cardiogenic
   1. Congestive cardiac failure
   2. Myocardial infarction
   3. Cardiac arrhythmia

2. Non-cardiogenic pulmonary oedema
   1. Obstruction
   2. Infections,
   3. Allergies,
   4. Trauma,
   5. Toxins and
   6. Restriction of inspiration. Negative inspiratory pressure seems to induce pulmonary oedema

3. Neurogenic Pulmonary oedema-head injury

4. Altitude Sickness &

5. Exercise induced P O
Immersion Pulmonary oedema

1. Immersion in water to the neck results in a shift of 600-700ml of blood centrally
2. Cold and wet suit amplify this effect
3. Dive reflex - Bradycardia & increased venous return
4. Normal heart will compensate
5. Some individuals with normal ventricular function develop pulmonary oedema.
   1. Lungs: High inspiratory resistance causes “over-breathing” creating higher negative pressures and pulling fluid into the alveoli.
   2. Heart: Impairment of left ventricular relaxation causes elevation of left ventricular end diastolic pressure elevating pulmonary wedge pressure during exercise
Edmonds classification of IPE

1. Swimming induced pulmonary oedema (SIPE)
2. Free Diving/Pulmonary Barotrauma of descent
3. Scuba divers Pulmonary Oedema (SDPE)

or are they all

Immersion Pulmonary oedema (IPE)

Lumpers & Splitters- philosophical or will data show they are separate?
Swimming induced pulmonary oedema

1. Extreme exercise & immersion
2. +/- Cold
3. Hypertension
4. Swimming longer distances
5. Female
6. 1. 4% of Triathletes

Increased pulmonary vascular pooling
Free diving/ Barotrauma of descent

Pulmonary oedema due to excessive pressure gradient that develops between pulmonary capillaries and alveoli after reduction of residual lung volume
Risk factors for IPED

1. Older divers- mean age of 49-52 y
2. Females
3. Hypertension
4. B Blockers
5. Pre-existing cardiac disease, in water ischaemic heart disease tends to manifest as shortness of breath not chest pain
6. Stressor
   1. Cold water < 16° C
   2. Exertion or
   3. Anxiety
7. Recurrent 30% ? Predisposition
8. Increased partial pressure of O₂ (0.99bar) deeper dives
9. SOB at start of ascent ? Decompression sickness ?
Differential diagnosis of IPE

1. Saltwater aspiration syndrome /Drowning
2. Gas induced pulmonary toxicity
3. Dysbaric lung syndrome
4. Pulmonary decompression sickness
5. Envenomation
6. Cold urticaria
7. Asthma
Scuba Divers Pulmonary Oedema

1. Is it Uncommon or Rare?
2. 2015 Duke review 292 cases of IPE
3. Survey (Pons 1995)
   1. 1250 divers,
   2. 460 responses,
   3. 4 events of pulmonary oedema
   4. 1 recurrent
4. Actual frequency in living may help working out how common it is in the dead
5. Fatalities 6 SCUBA divers & 1 snorkeler
Case 1

52 year old female
Experienced diver, 900+ logged dives
**Event 1** (one year before death);
30m swim on snorkel
struck by wave, may have swallowed water
short of breath (SOB)
12 m dive aborted due to SOB
Cough, pink sputum
Case 1

Hospital (Event 1)
No fever, 100 beats /min, 130/80,
Cough and wheeze
Chest x-ray right basal density ?pulmonary oedema
Mild reduction in FEV1 and FVC
Normal ECG & Echo
Stress test no inducible ischaemia
Case 1, Event 1

Diagnosis- Immersion Pulmonary oedema
unfit to dive
Review – more likely Saltwater aspiration
50 further uneventful dives
Case 1 Event 2

19.7m dive for 36 min
25 min into dive
Hand signal to return to exit point
Ascended to 7 m (no rapid ascent)
indicated not feeling well
Surfaced - cough, wheeze & vomited
Could not breathe
Towed 100m to shore, not breathing
Unable to resuscitate
Case 1 Autopsy

Forensic Pathologist experienced diver
Discussion about SDPE
X ray not CT scan, 2 days after death
increased opacification of both lung fields and pulmonary oedema, no gas.
Case 1 Autopsy

1. 1.67 m, 88.5kg BMI 31.7kg/m²
2. Extensive pulmonary oedema in airways
3. R lung 835 grams (N=304-817g) L lung 579 grams (N=287-695g).
4. Markedly oedematous and crepitant but not over-expanded.
5. Histology rupture of some subpleural bullae no changes of asthma
Case 1 Autopsy

6. Heart normal 310g
7. Diffuse haemorrhages
8. No L ventricular hypertrophy
9. Coronary arteries <25% narrowing
10. Myocardial bridging (not significant)
11. Histology contraction band necrosis and interstitial haemorrhage? CPR
Case 1 Autopsy

12. Cause of death:
“Immersion/scuba divers pulmonary oedema”.

unable to confirm or exclude an underlying cardiac Channelopathy although the normal cardiac study makes this seem unlikely.
Significant features Case 1

1. Previous episode of pulmonary oedema.
2. Pulmonary oedema in airways and lungs
3. No apparent history of inhalation of water
4. Lungs crepitant but not over-expanded
5. Contraction band necrosis in the heart
6. No evidence of left ventricular hypertrophy
7. The best documented case we are likely to see
Case 2

51 year old Female
20 dives over 2 years
Two previous events
**Event 1** 5 months before death
found semi-conscious between two rocks and took 60-90 minutes to recover.
**Event 2** 8 days before death
inexplicably wanted to go to shore and took the most direct route possible.
No medical attention or cardiac follow-up
Case 2

Event 3
15 min dive to 11 m
2 ascents from 6-8m
one faster than recommended
On 3rd ascent signalled not OK
controlled ascent
On surface short of breath, dizzy, condition deteriorating
Towed to shore unconscious for last 5 min
Could not resuscitate
Case 2 CT scan

Small amount of air in the falx cerebri, brain, heart, large vessels and liver.

Probably post-mortem gas formation but the possibility of early barotrauma was not excluded.
Case 2 Autopsy

1. 1.71 m, 71.1 kg and BMI 24.3 kg/m$^2$.
2. Pulmonary oedema in airways
3. R lung 890 g (N=344-750g)
5. Lungs oedematous but not over-expanded
6. Histology sarcoidosis in lymph nodes
Case 2 Autopsy

7. Heart 372g (N=240-376g)
8. Mild mitral valve prolapse (incidental)
9. Ca++ near AV node but no sarcoidosis
10. Histology – normal some contraction bands on review but not prominent
11. Equipment spare regulator leaked but not used. Tank increased water
Case 2 Cause of death

Pathologist
Most likely “Drowning”
Could not exclude cardiac arrhythmia
Diving physician
“Scuba divers pulmonary oedema”
regulator not out of the mouth so inhalation of water unlikely
Case 2 significant features

1. Severe pulmonary oedema
2. Two previous episodes.
3. The lungs not particularly over-expanded,
4. Heart showed mitral valve prolapse but no LVH
5. Sarcoidosis in hilar lymph nodes
   1. Fibrosis increases risk of pulmonary barotrauma,
   2. Can affect conduction system some calcification near the AV node.
6. There was no Cardiology review. Rhythm strip which looked normal
Case 3

56 year Female
Snorkelling with dolphins

Event 1 (10 months before death)
Chest tightness and shortness of breath following strenuous exercise
Normal ECG

Event 2 - 4  SOB after strenuous exercise
Case 3

Event 5
Some snorkelling experience
~10 min indicated distress with raised fist
Responded to call
Rolled on back, snorkel in mouth
Coughing, again raised fist
“I can’t breath”
assisted into boat
Coughing up foam
Possible Oesophageal intubation
to Hospital - cardiac arrest
Case 3 Autopsy

1. 1.68 m, 71kg, BMI 25.2kg/m².
2. Pulmonary oedema
3. R lung 954 g (N=305-817g),
4. L lung 869 grams (N=287-695g).
5. Lungs not particularly crepitant or over-expanded.
Case 3

1. Heart heavy 443 grams (N=285-439g).
2. Left ventricular hypertrophy 19mm (N=<14mm.)
3. Coronary arteries normal.
4. Histology- extensive contraction band necrosis and some haemorrhage
5. Kidney changes suggest hypertension
Case 3 significant features

1. Severe pulmonary oedema
2. Previous episodes
3. Snorkeller not SCUBA
4. Lungs heavy not crepitant or over-expanded
5. Left ventricular hypertrophy 19mm
6. Contraction band necrosis and haemorrhage but vigorous resuscitation
Case 4

51 year Female experienced diver
Short shallow dive
On return to surface short of breath
BC inflated, head above water
Unconscious not resuscitated
Autopsy no barotrauma or AGE
Pulmonary oedema
50% stenosis of coronary artery
Diagnosis - Acute pulmonary oedema
Case 5

46 year Female inexperienced
26 m dive 16 min
Gave low air signal (120 bar)
Regulator checked
Signalled low air and started to ascend
Ascent controlled by instructor
Short rapid breaths
Felt unwell on surface,
Foam coming from mouth
Case 5 X ray (48h PM)

Generalised gas in the chambers of the heart and large vessels including the cerebral arteries.

Pulmonary barotrauma/ arterial gas embolism, really post mortem decomposition artefact and post mortem resuscitation artefact.
Case 5 Autopsy

1. 1.76 m, 84kg, BMI 27kg/m2
2. Food in upper airway
3. Pulmonary oedema in lungs
4. R Lung heavy 915 g (N=305-817g)
5. L lung heavy 740 g (N=287-695g)
6. Lungs well expended not over expanded
Case 5 Autopsy

1. Heart normal 360 grams (N=285-439g)
2. 20% narrowing right coronary artery
3. Histology Fine replacement fibrosis
4. Large amounts of gas in the cerebral vessels and ventricles.
Case 5 Cause of death

1. Original Pathologist - Cerebral artery gas embolism (CAGE)

2. ? post-mortem decomposition, decompression or resuscitation artefact

3. apparent distress and shortness of breath under water is not typical of Pulmonary barotrauma/ AGE
Case 5

1. Pulmonary oedema in lungs not airway
2. No previous episodes
3. Possible AGE?
4. Normal heart
5. Distress and shortness of breath before ascent
6. I have an open mind on this case
Case 6 & 7

2 French cases (Cochard) not much detail

1. Male 53
   a) Hypertension
   b) Shortness of breath & cardiorespiratory arrest
   c) Pulmonary oedema and scarred kidneys

2. Male 56 recurrent event
   a) Hypertension, hyperlipidaemia & “arteriopathy”
   b) Smoker
   c) Cardiorespiratory arrest
   d) Haemoptysis & pulmonary oedema
IPED Fatalities

1. 5 Females 2 Males
2. Average age 52 y (46-56y)
3. Water Temp 10-19°C
4. 4 previous episode
5. Lungs heavy but not overexpanded
6. Mean heart weight 371g (N=285-439g) one heavy 443g
7. 3 Hypertension, 1 Left Ventricular hypertrophy
8. 2 sub-lethal coronary artery disease
9. None on B Blockers
Diagnosis of IPED

1. 50y Female
2. Lungs heavy but not over-expanded
3. Left ventricular hypertrophy or coronary artery disease
4. Contraction band necrosis
5. Previous events
6. Cold water? anxiety? exercise?
7. History excludes inhalation of water
   i.e. regulator not out of mouth
7. Edmonds- “drowning tend to sink”
Contraction band necrosis

1. Shock
2. Cardiac ischaemia
3. Reversible cardiac ischaemic/ stress cardiomyopathy,
4. Takotsubo cardiomyopathy,
5. Head injury patients given catecholamines
6. Stimulants such as methamphetamine & cocaine
7. Direct trauma around injuries or cardiac rupture
8. Reperfusion/Resuscitation
Cochard & Edmonds

The explanation for IPED is probably multifactorial, a combination of immersion, cold, exercise and compressed air breathing stresses imposed on the heart and lungs.

“Stress mediated reaction” to immersion, cold, exercise, anxiety, deeper dives, individual predisposition and pre-existing cardiac disease “Reversible cardiac dysfunction”.

IPED
Takotsubo cardiomyopathy

1. Reversible left ventricular dysfunction that simulates acute coronary syndrome
2. Chest pain or dyspnoea
3. ST, T wave or QTc interval changes on ECG
4. Raised cardiac enzymes
5. Apical hypokinesis
6. Menopausal women
7. Trigger is physical or psychological stress
8. Contraction band necrosis & focal necrosis.
9. Not diagnosable at autopsy?
Takotsubo cardiomyopathy

1. Four cases have been described in divers
2. Gempp (2013) 15 divers with reversible myocardial dysfunction
3. Tests for reversible cardiac dysfunction
   1. Creatinine kinase MB (CPK-MB)
   2. Troponin I & T,
   3. Brain Natriuretic Peptide or NT-proBNT
4. Is Takotsubo cardiomyopathy the cause of immersion pulmonary oedema in divers?
Prophylactic sildenafil appears to prevent the rise in pulmonary wedge pressure?