BREATH-HOLD DIVING WITH A CLINICAL PERSPECTIVE

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Depth? Duration?

Any MEDICAL dangers?

OUTLINE OF LECTURE

- Compression
- Decompression
- Loss of consciousness
- Glossopharyngeal insufflation, lungpacking
- Diving response and arrhythmias
- Fitness to breath-hold dive

Come up conscious?

Or

Come up in full health?

Breath-hold diving (apnea)

Recreation

Spearfishing

Competition

Military training

Records: male 124m / female 96m

Compression

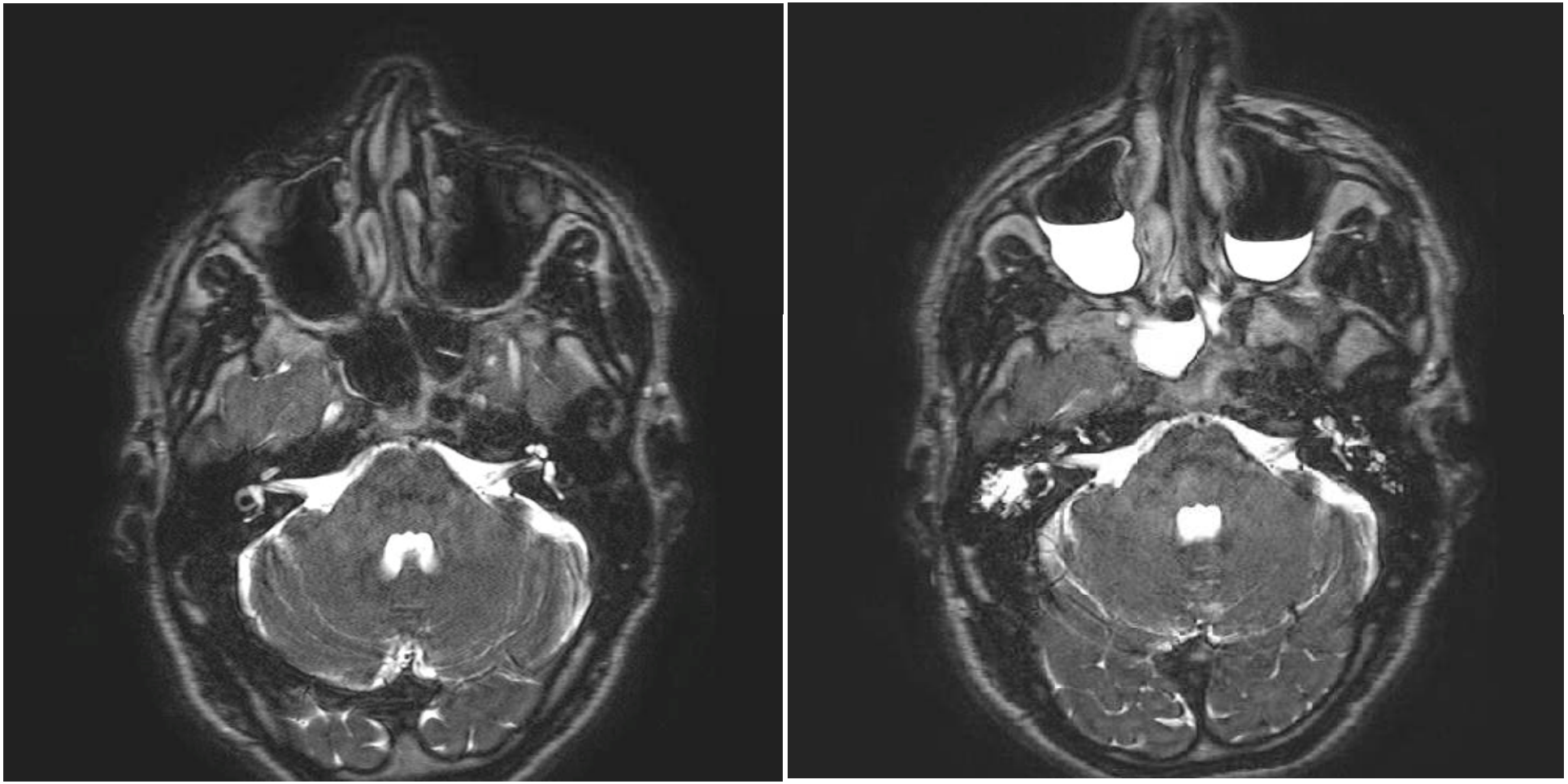
- Boyle's law $V_{surface}*P_{surface}=V_{depth}*P_{depth}$
- Ear
- Lung
- Gas compression-partial pressure changes

EAR

- Ruptured ear drum, no diving 6? weeks, dive anyway (competition)?
- External otitis “swimmers ear” and exostoses from cold water exposure “surfers ear”

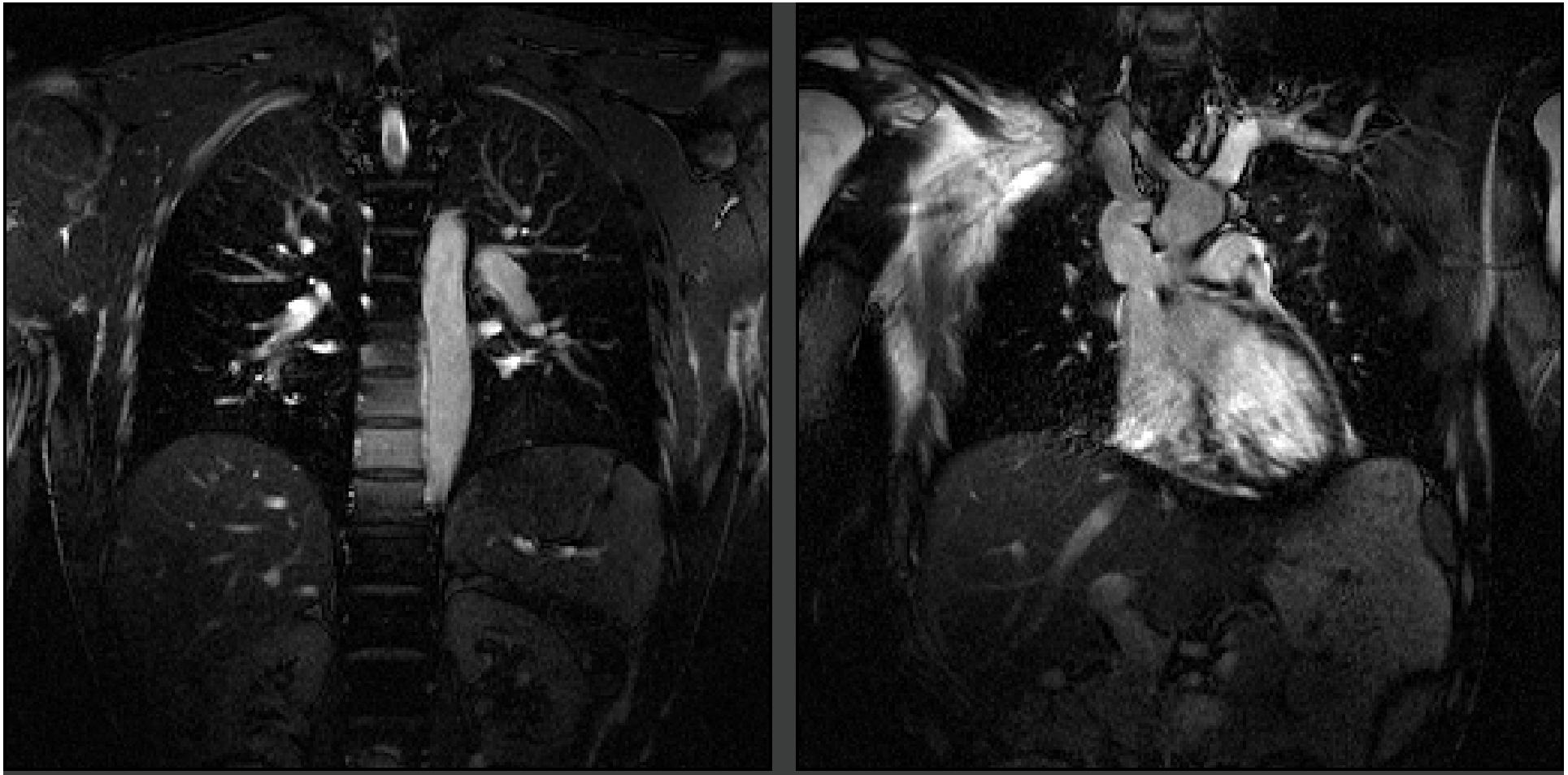
- Voluntary opening of the eustachian tubes
- Valsalva (not recommended)
- Frenzel (pressure with the tongue, not using thoracic muscles)
- Water filling

Passive flooding of paranasal sinuses and middle ears as a method of equalisation in extreme breath-hold diving
Germonpré P, Balestra C, and P Musimu, Br J Sports Med. 2008



PULMONARY

- Compression of gas cause:
- Blood shift (centralization of blood)
- Schaefer et al Science 1968, and Craig JAP 1968



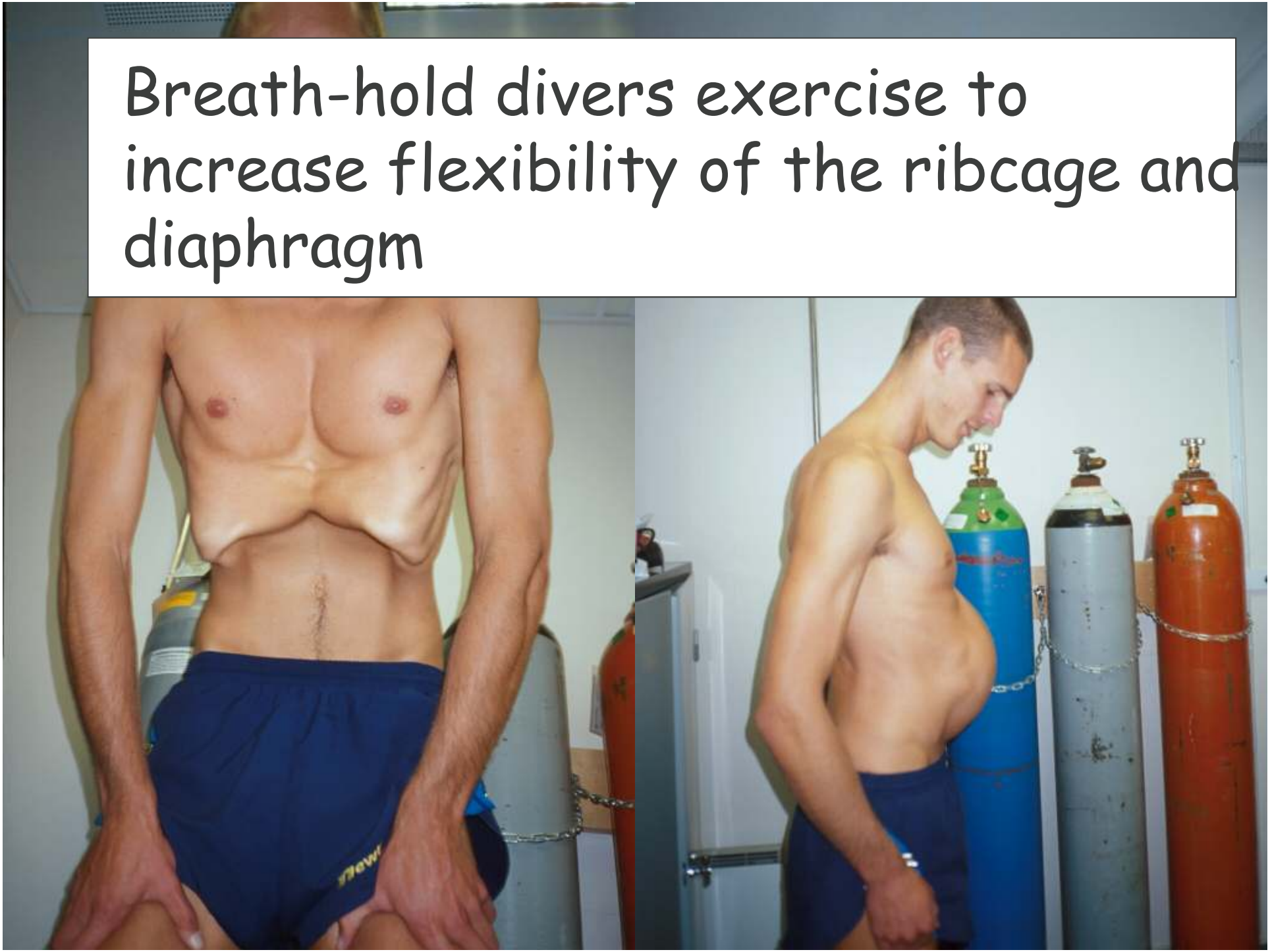
SIMULATION OF DEPTH IN AN MRI: exhalation to Residual Volume and glossopharyngeal exsufflation Lindholm Nyren 2005 EJAP

PULMONARY

- Compression of gas cause:
- Blood shift (centralization of blood)
- Schaefer et al Science 1968 and Craig JAP 1968

- At a certain depth the chest will be maximally compressed
- Increased flexibility of chest and diaphragm

Breath-hold divers exercise to increase flexibility of the ribcage and diaphragm



Squeeze

- Diving deeper…Squeeze (Barotrauma of descent)

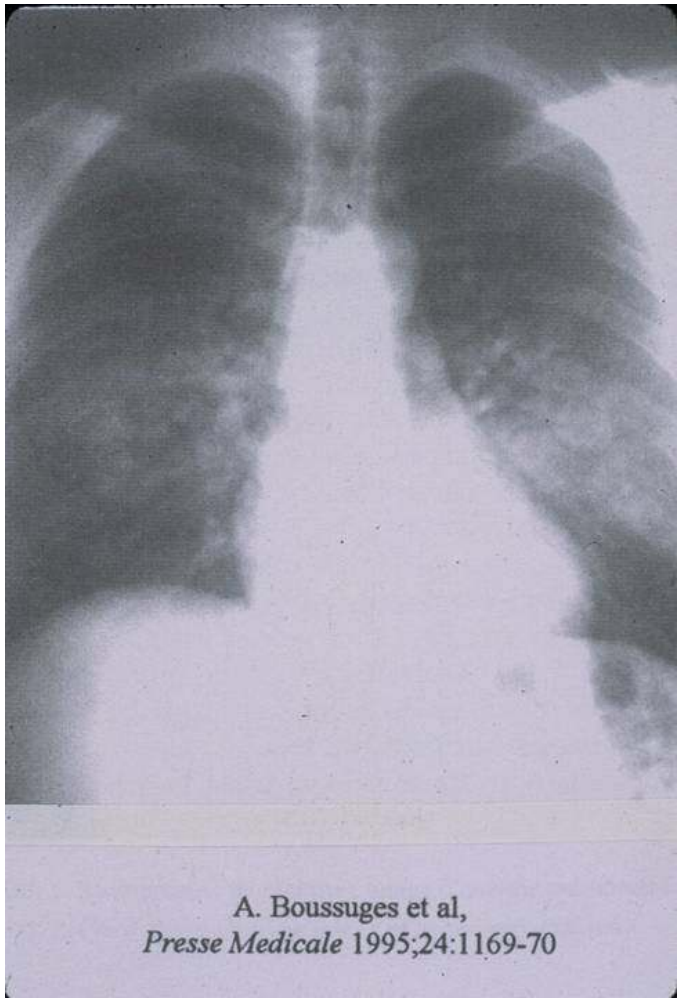
- Pulmonary edema with or without bleeding
- Hemoptysis without edema, from upper airways ?Pulmonary edema (Lindholm et al JAP 2008)
- Partial collapse? of lungs, of trachea? (Lindholm and Nyrén EJAP 2005)

How to avoid Squeeze

- Practice makes you able to dive deeper?
- Avoid strain on pulmonary tissue at depth (swimming technique, contractions etc).
- Adaptation of pulmonary vessels?
- Glossopharyngeal insufflation ”lung packing” to increase gas stores

Immersion pulmonary edema

- Presentation: dyspnea, cough, hypoxemia, and occasionally hemoptysis
- Physical examination and chest radiograph usually reveal evidence of pulmonary edema
- Treatment is symptomatic and conservative: dry patient, warm environment, oxygen, Beta-2 agonists
- X-ray usually normalized within 24-48 hrs.



The clinical question: when can I dive again after a squeeze? (immersion pulmonary edema)

No scientific data available (yet?)

Gas Compression…Nitrogen Narcosis

- Nitrogen partial pressure during breath-hold diving is enough to cause narcosis.
- Duration is long enough to nitrogen uptake to affect the brain
- Deepest scuba dive on air 155m (incapacitated but survived)
- Deepest breath-hold dive on air 214 m
- Streeter 2006 UHMS/DAN workshop

How can breath-hold divers dive deeper than scuba divers on air?

- Short duration of dive, ”only” 4-5 minutes
- Delay of symptoms…peak during early ascent
- Gas uptake may be limited (atelectasis increasing pulmonary shunts)
- Practise maneuvers many times? Tolerance and natural selection?
- Possible that divers reach the surface still under some narcosis

Decompression

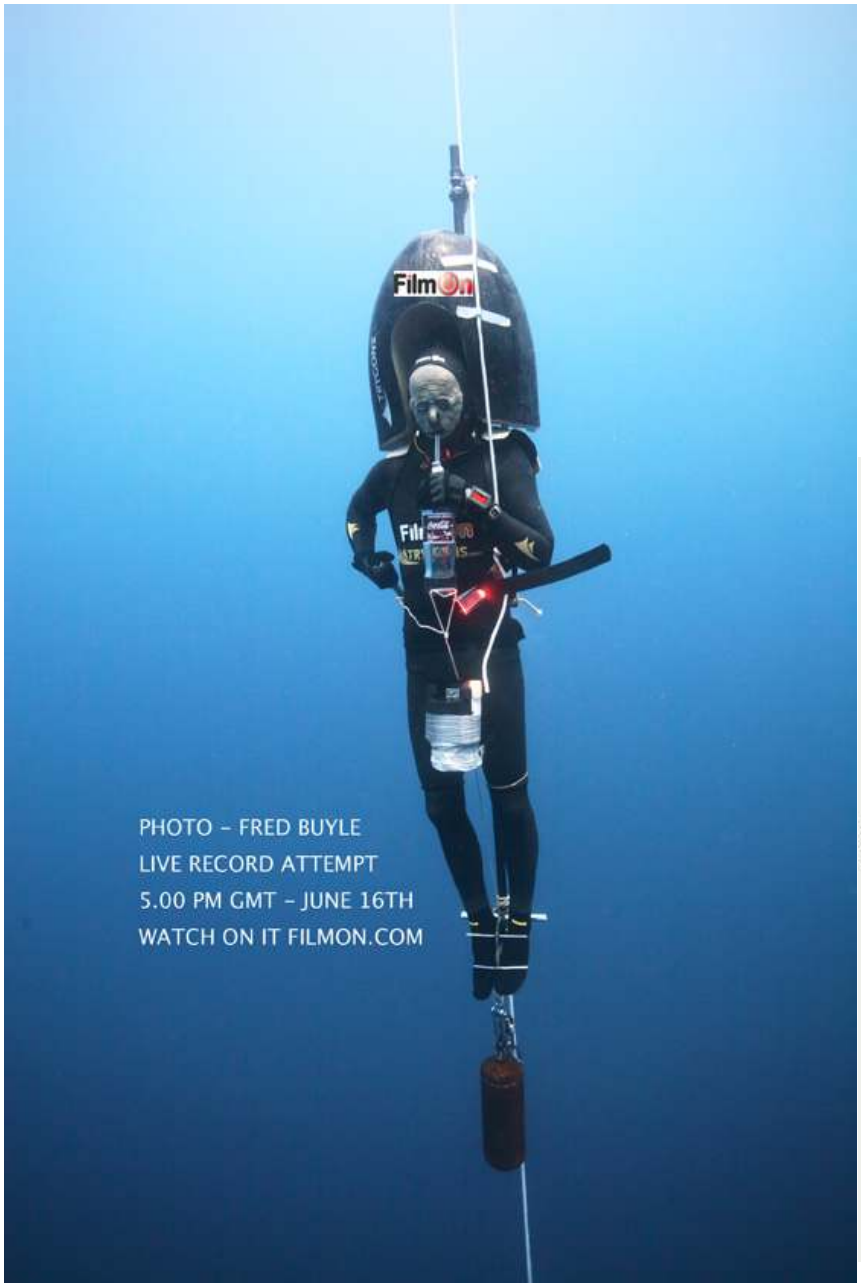
- DCS
- DCI
- Hypoxia of ascent

Decompression sickness

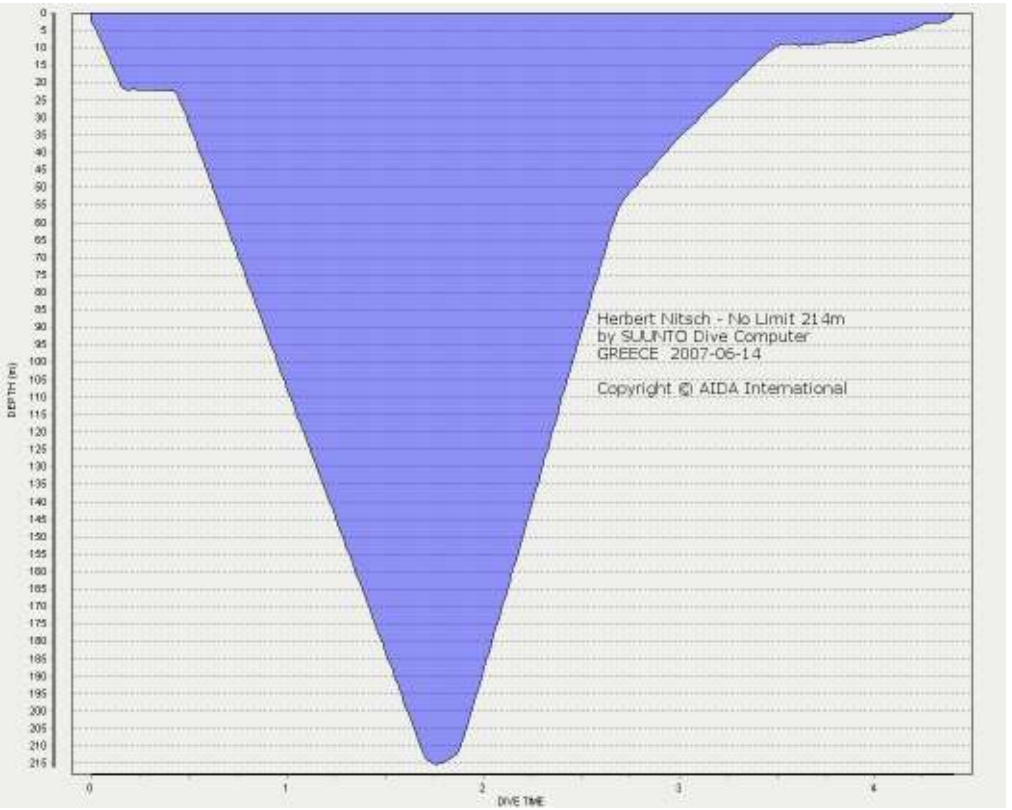
- Multiple reports available about neurological DCS?
- DCS is possible from repetitive breath-hold dives
- Decompression sickness… dive depth and duration enable tissue supersaturation and DCS according to conventional decompression calculations. (Lanphier 1965)
- N_2 uptake during a single deep dive is not well explored
- DCS? After a single dive (182m and 5.02 min) treated with recompression

Decompression illness?

- Barotrauma of ascent…
- Blood shift and collapse of lung reduce space available for gas expansion?..
- Glossopharyngeal insufflation enable starting with 3-4 liters of extra air insufflated to 100+ cmH_2O (11kPa).
- Air trapping on ascent? (we don't allow divers with pulmonary disease to dive to avoid DCI?)



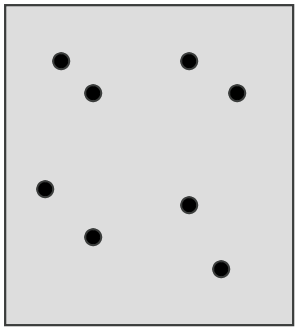
– 214 m record ”no limits”

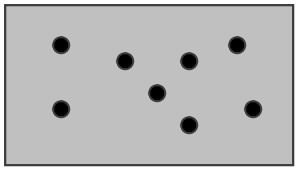


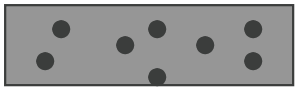
Treating decompression sickness or illness?

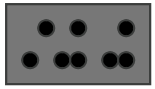
- Neurological symptoms in someone who has dived…
- Recompression chamber, hyperbaric oxygen
- I would try a test of pressure and a standard table B6

Hypoxia of ascent

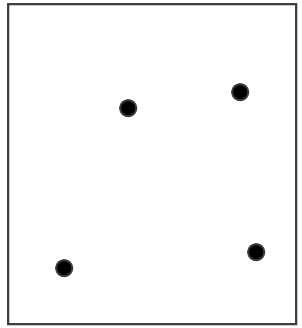


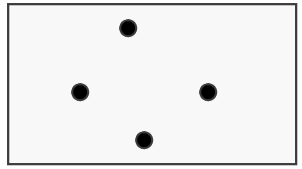


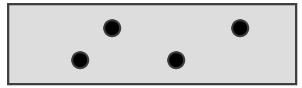


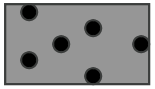


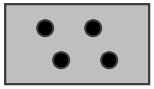
- Reduction of pressure during ascent will reduce partial pressure of oxygen even if the fraction is unchanged, ie regardless of duration or metabolism
- A pulmonary fraction of 2% O_2 will give enough pO_2 at 20meters 6 kPa (45mmHg) to sustain consciousness
- A 2% fraction will only give 2kPa (15mmHg) at surface---LOC on ascent



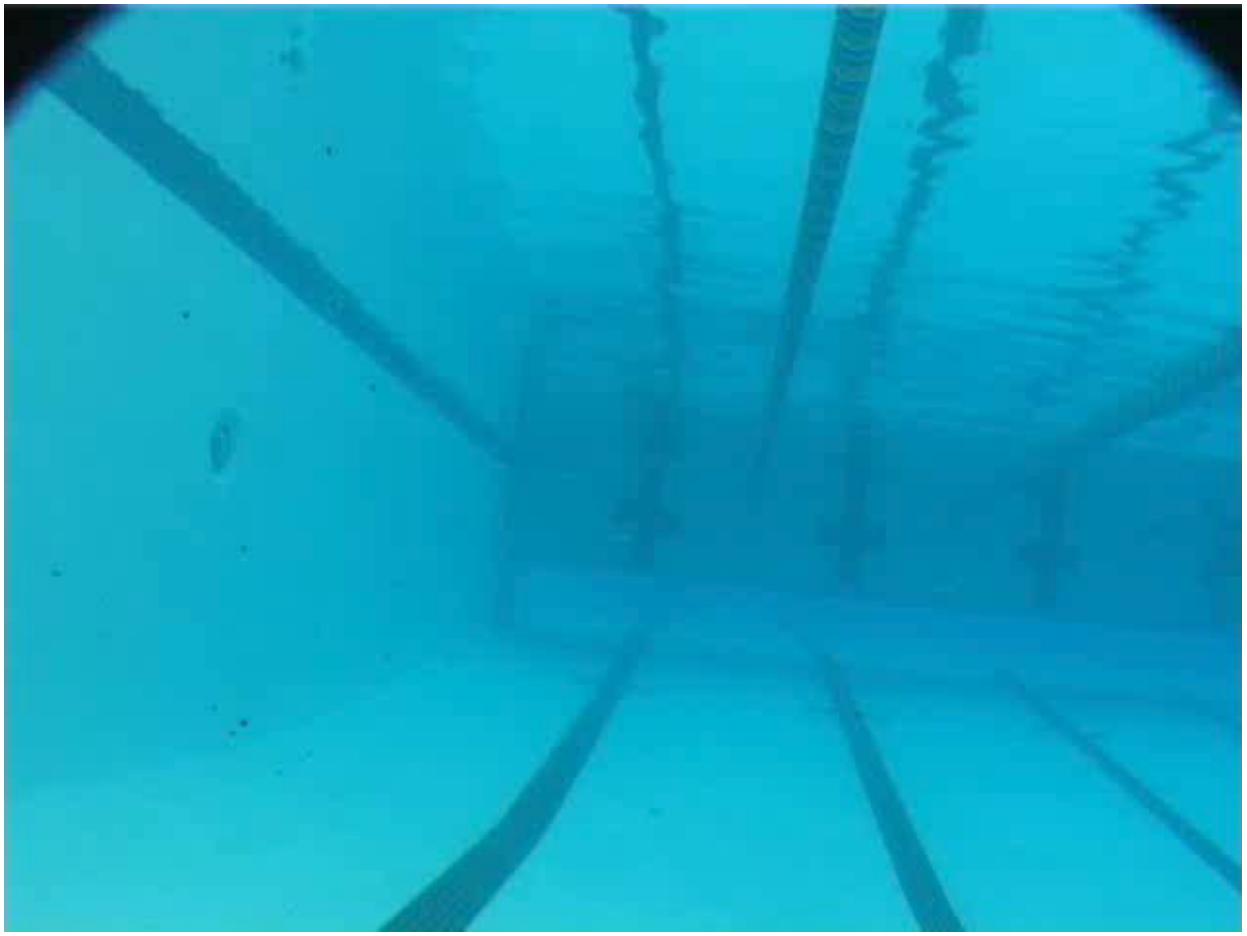








Breath-hold underwater swimming



- Swimming
- Military training
- SCUBA training
- UW-rugby

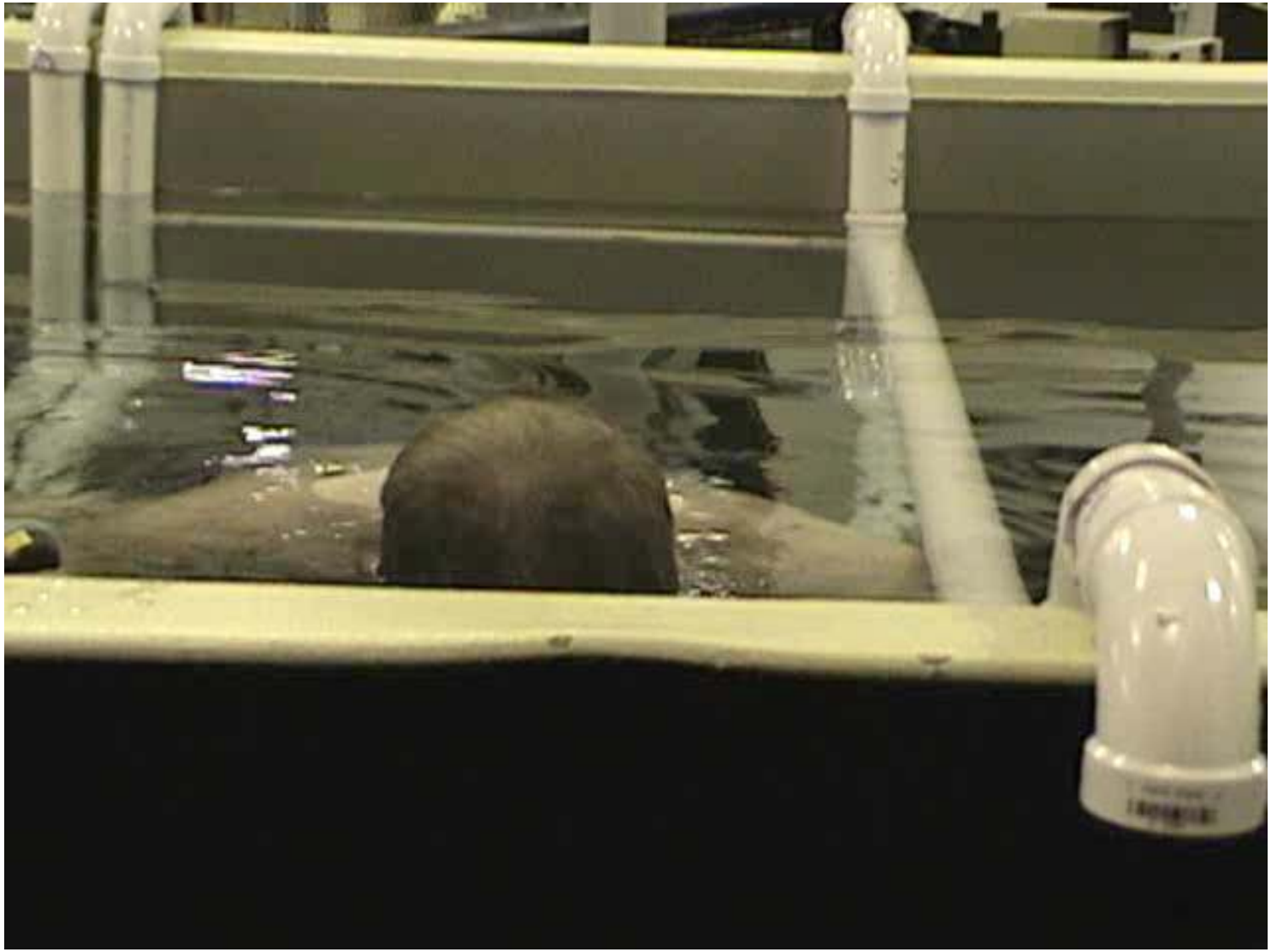
Records: Male 213 m/ Female 160m

Duration or distance in pool diving

- Gas stores (lungs, blood, tissue)
- Gas consumption (basal metabolic rate) (exercise)
- Breakpoint? Dyspnea?
- Loss of consciousness?

Symptoms of hypoxia

- Loss of consciousness
- Loss of motor control
- Affected speech, loss of memory, loss of muscle tension
- A collection of failures in competitions in Static Apnea in a pool



20 mmHg ET P_{O_2} and 39 mmHg ET P_{CO_2}

Lindholm and Lundgren UHM 2006; 33(6):463-467

Does apnea cause brain damage?

- Clinically 3-4 minutes of cardiac arrest
- Ischemia not hypoxia
- Fighter pilots are not considered to suffer brain damage from a G-LOC
- Syncope is common in the population about 1% of ER visits

- Sleep apnea

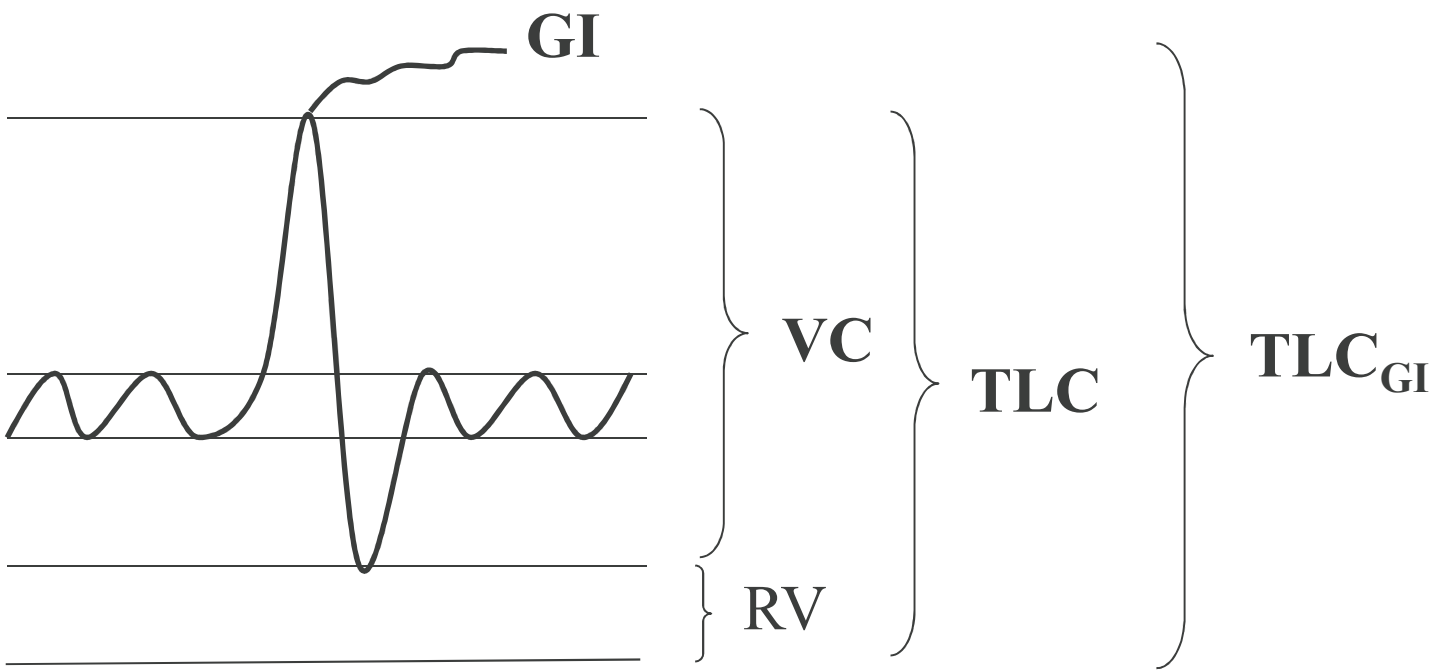
Drowning in breath-hold diving

- Hypoxic syncope (duration and/or hypoxia of ascent)
- Shallow water blackout “old terminology”
- Hyperventilation

Another way to avoid barotrauma of descent and extend duration:

- To increase gas stores by glossopharyngeal insufflation

Glossopharyngeal Insufflation (GI)



- **TLC : Total Lung Capacity**
- **VC : Vital Capacity**
- **RV : Residual Volume**

Glossopharyngeal insufflation GI
Glossopharyngeal exsufflation GE

Lindholm et al Resp Phys Neurobiol 2009

Where does the extra air go?

- Increased circumference of the thorax and a downward shift of the diaphragm enable a larger filling of the lungs (the chest expands).

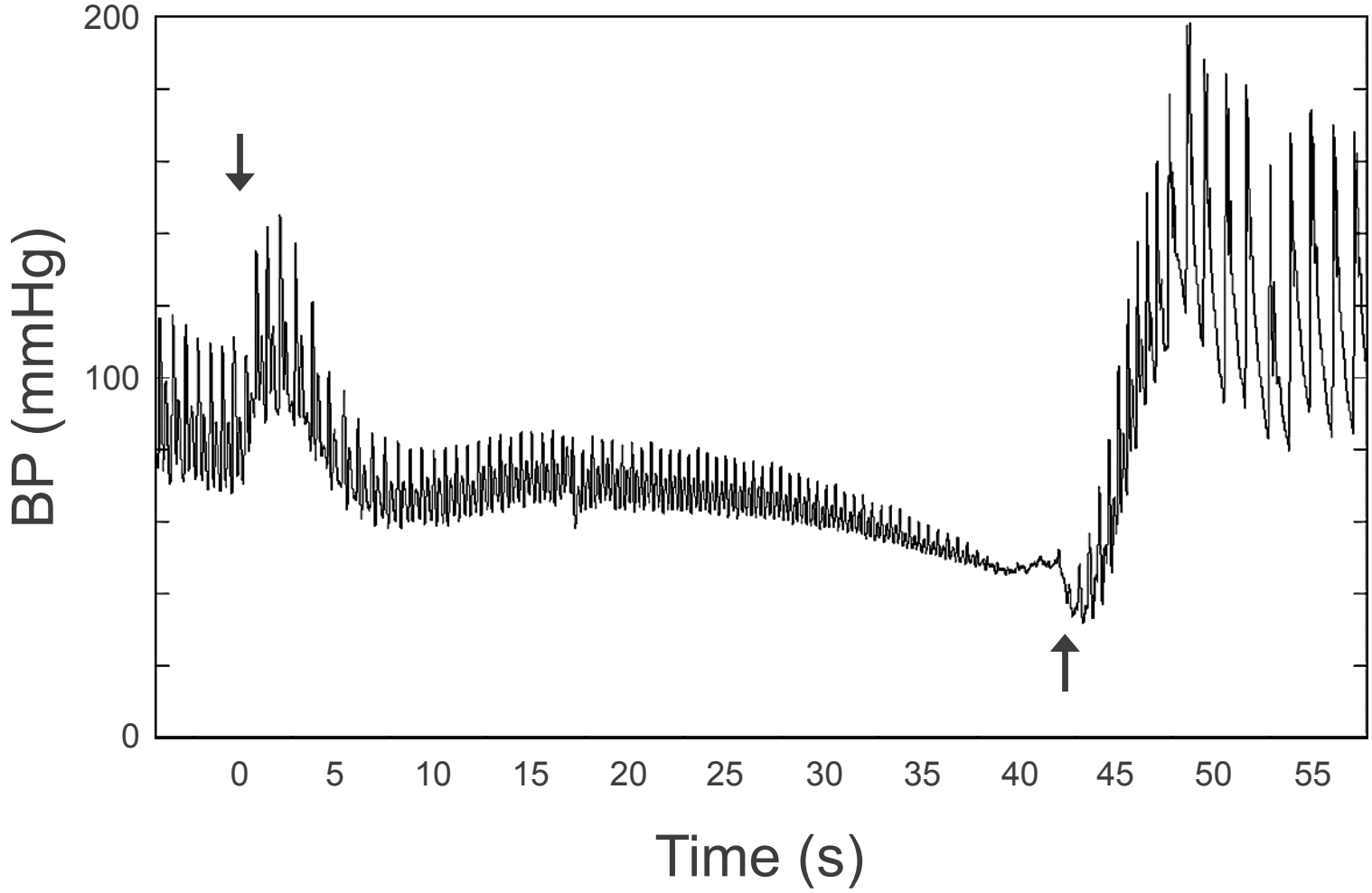
- High intrathoracic pressure reduces blood volume in the chest with a resulting larger space for air

- High intrapulmonary pressure (extremes about 109 cm H_2O) compress gas in the lungs 100 cmH_2O = 10 kPa =>10% extra air compared to 0 kPa.

Loring et al, JAP 2007

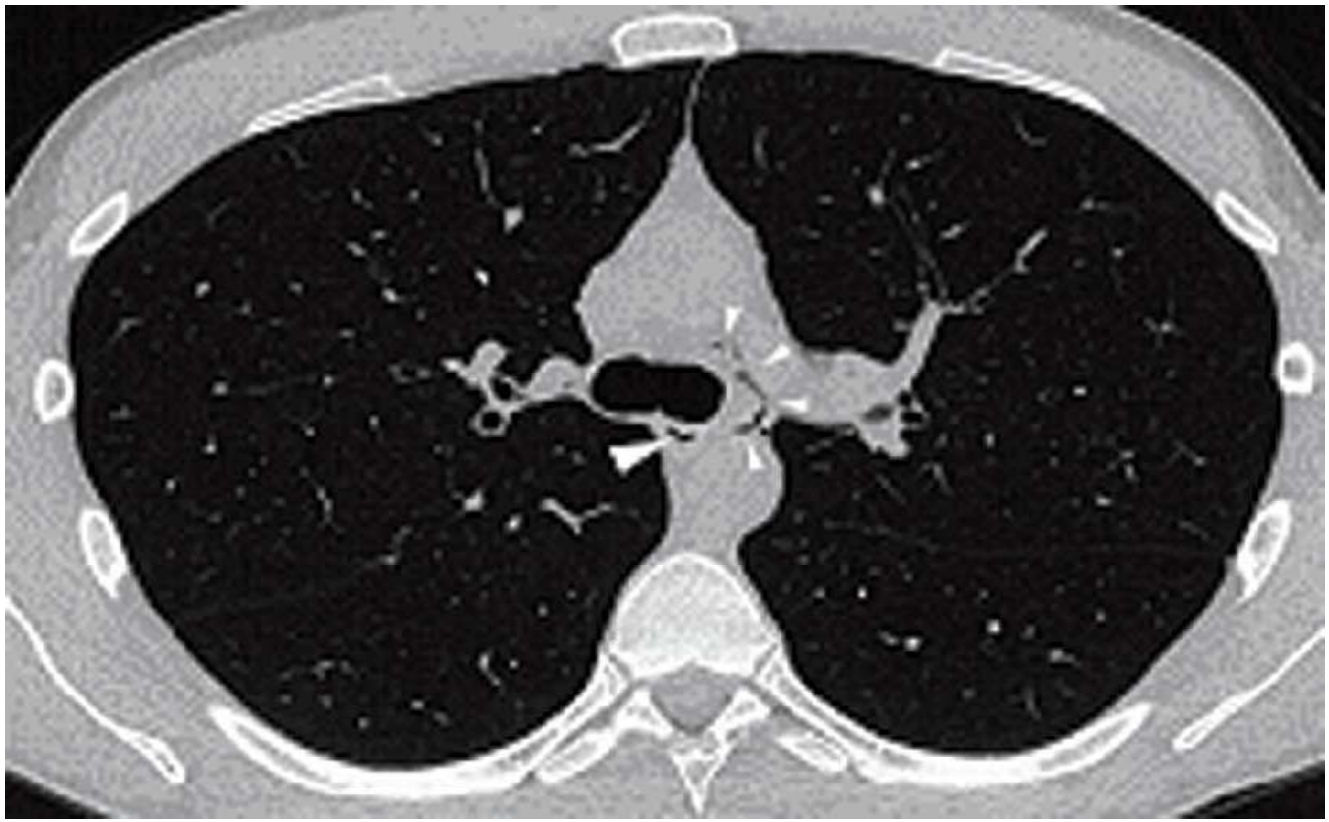
Glossopharyngeal insufflation

Reduction in cardiac output…syncope not uncommon



Novalija et al UHM 2007

Pneumomediastinum after GI, Gas in the mediastinum
Jacobson, Loring, Ferrigno UHM 2006, Vol. 33, No. 5



Glossopharyngeal insufflation

- Overextension and overpressurization of the lung may cause barotrauma
- Pneumomediastinum.
- Arterial gas emboli, reports of neurological symptoms (not lasting) that suggest arterial gas emboli (total 7 cases known, e.g. Lindholm et al 2007, Andersson et al 2010).
- No permanent adverse effects reported in 50 years of use by patients
- AGE in water may cause drowning (Schiffer et al 2010)


I’m an expert in glossopharyngeal breathing

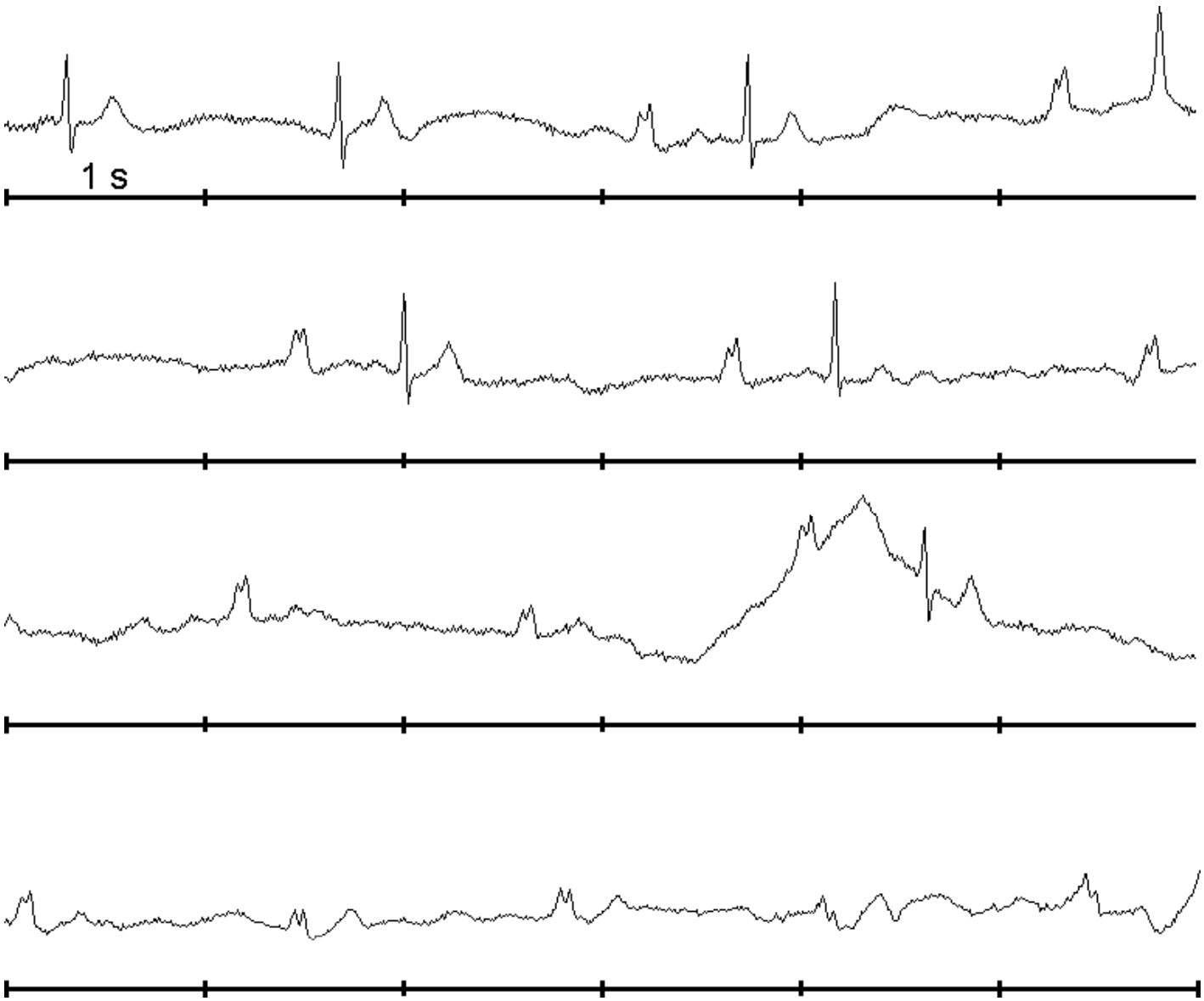
Diving response and arrhythmia

- Apnea induce vasoconstriction and bradycardia
- These responses are augmented by e.g. hypoxia, cold stimuli in the face (via trigeminal nerve).
- Hypertension
- Very strong in diving mammals

Diving response

- The diving response is highly variable among individuals, and it is strong enough to affect oxygen consumption during apnea
- A strong diving response conserve oxygen and increase duration during both resting and exercising apnea
- Lindholm et al JAP 1999, AJP 2002
- Andersson et al JAP 2002, RPNB 2008

ECG at 40m (130 ft) depth, cold water ”Normal!?”



Arrhythmia "normal"

- Arrhythmias are common and normal during breath-hold diving
- Simultaneous increase in output in both sympathetic and parasympathetic effects on the heart
- SCHOLANDER et al JAP 1962

Arrhythmia “pathology”

- Fatal arrhythmias occur in swimming and other sports as well as in normal life, possibly could happen during diving as well
- Not clear whether the brady-arrhythmias of the diving response would increase the risk or trigger a fatal arrhythmia in a predisposed subject
- Spectrum and frequency of cardiac channel defects in swimming-triggered arrhythmia syndromes. Choi G, Kopplin LJ, Tester DJ, Will ML, Haglund CM, Ackerman MJ. Circulation. 2004

Medical examination of competitive divers

- Divers often has to provide medical documents of fitness to dive in breath-hold diving competitions
- Competitive breath-hold diving require higher physical fitness than scuba diving?
- Pool competitions differ from diving, if you give a selective medical pass, since no effects of compression, and pool competitions does not need competent diving/hyperbaric physicians

- If asked to be the medic at a dive site, be prepared for e.g. non-fatal drowning, pulmonary edema and DCS.

Fitness to breath-hold dive competitively

- My basic recommendation is to evaluate such a diver as if fit to scuba dive? **And if in doubt say no**.
- If diver history suggest a diver to be healthy (and not too old), I would only make a physical examination, no imaging, no blood tests.
- Most focus on ear, lungs, neurology and the heart
- Diabetes is an unclear issue, should you be allowed to compete with diabetes? I would prefer not to have such athletes if I was the responsible physician at a competition

Acknowledgments

- Claes Lundgren
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- Sven Nyrén
- Andreas Ekborn
- Steve Loring


Questions?
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World Records

Constant Weight Without Fins (CNF)
95 m: William TRUBRIDGE

62 m: Natalia MOLCHANOVA

Constant Weight (CWT)
124 m: Herbert NITSCH

96 m: Sara Campbell

Dynamic Without Fins (DNF)
213 m: Tom SIETAS/ Dave MULLINS

160 m: Natalia MOLCHANOVA

Dynamic With Fins (DYN)
250 m: Alexey MOLCHANOV

225 m: Natalia MOLCHANOVA

Static Apnea (STA)
11 min 35 sec: Stefane MIFSUD

8 min 23 sec Natalia MOLCHANOVA

Free Immersion (FIM)
110 m: Martin STEPANEK

90 m: Natalia MOLCHANOVA

Variable Weight (VWT)
142 m: Herbert NITSCH

122 m: Tanya STREETER

No Limit (NLT)
214 m: Herbert NITSCH

160 m: Tanya STREETER