ENT Issues in Diving

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Dr. Claes Lundgren, MD, PhD (1931-2022)

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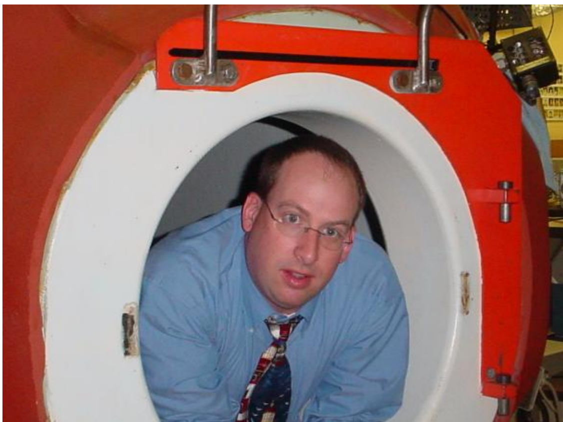

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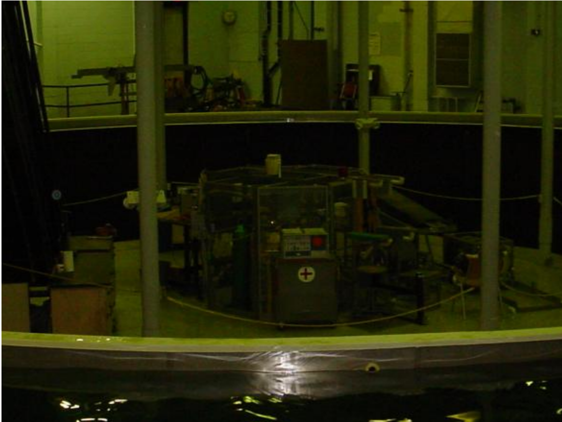

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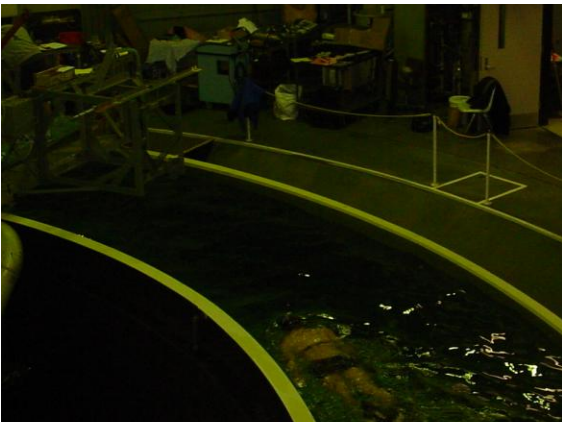

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Disclosure Statement

- I have no financial relationships or conflicts related to this talk, or others I am providing within this course, to disclose

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Objectives

- Understand and describe techniques for prevention and treatment of:
  - Middle ear barotrauma
  - Otitis externa
- Describe signs and symptoms of sinus barotrauma
- Intelligently discuss the differential diagnosis of vertigo in a diver
- Describe the basic ENT evaluation of a diver with otological symptoms

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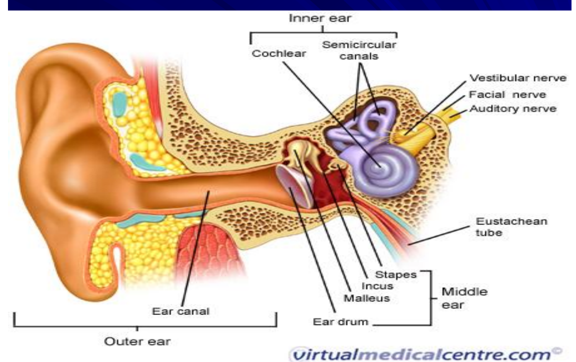
The Ear



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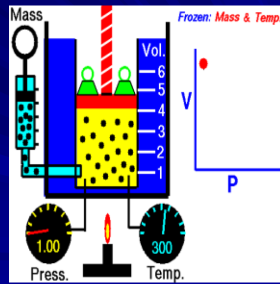
Boyles Law

- Assume constant T
- $P_1V_1 = P_2V_2$
- Pressure and volume are inversely proportional
- Relationship not linear
  - 1 ATA = 100%
  - 2 ATA = 50%
  - 3 ATA = 33%
  - 4 ATA = 25%
  - 6 ATA = 17%



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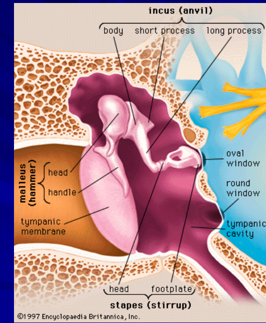
The Middle Ear

- The middle ear is a gas filled space
- There is only one normal anatomical pathway for movement of gas in and out
- Eustachian tube function is important when pressure changes are incurred



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The Eustachian Tube

- It arises from the anterior-inferior wall of the middle ear cavity
- Connects to an opening in the lateral wall of the nasopharynx
- It is surrounded by bone (near the middle ear) and cartilage (closer to the nasopharynx) and is lined by mucosal epithelium
- There are four muscles that are involved with ET function

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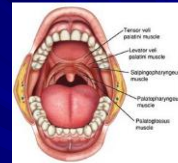
Muscles that Assist ET Function



- Levator veli palatini
  - Helps with swallowing
- Salpingopharyngeus
  - Helps with swallowing
  - Helps to open the ET
- Tensor tympani
  - Stabilizes the malleus and dampens noises
- Tensor veli palatini
  - Tenses the palate
  - Helps to open the ET

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Middle Ear Barotrauma

- The most common diving (hyperbaric) medical problem
- Most commonly occurs during descent
- Small pressure differences between ambient and middle ear pressures can cause significant problems
- Can occur upon ascent if the middle ear cannot properly decompress after having been equalized at elevated pressures (reverse block)

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Middle Ear Barotrauma

- A pressure difference of only 60 mmHg (2.6 fsw) can cause mucosal congestion of the ET and make equalization difficult
- 90 mmHg (3.9 fsw) can induce the nasopharyngeal valve effect (“locked ET”) making equalization nearly impossible without decompressing first
- 100–500 mmHg (4.3–21 fsw) can be sufficient to cause TM rupture

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Middle Ear Barotrauma

- If the middle ear cannot be equalized as ambient pressure increases, the volume of gas in the middle ear tries to contract due to Boyle's Law
- The TM will retract towards the middle ear space and cannot function properly
  - Diminished or muffled hearing can be noted
- The mucosal lining of the middle ear can become congested and inflamed

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Middle Ear Barotrauma

- As the pressure differential increases, the TM can become damaged
  - Visual changes can be seen on otoscopy
  - TM rupture can occur
- The mucosal lining of the middle ear can undergo cellular damage with increased vascular leakiness
  - Middle ear effusion (with or without blood can occur)

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Middle Ear Barotrauma

- Symptoms
  - Blocked sensation
  - Decreased hearing
  - Otalgia
  - Tinnitus
  - Vertigo
- Signs
  - Change in appearance of TM
  - Middle ear effusion
  - TM rupture

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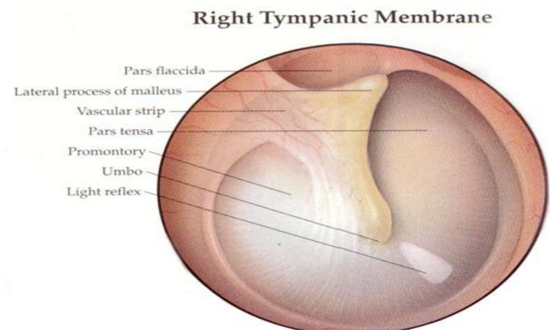
The Tympanic Membrane



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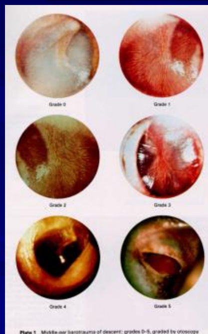
Middle Ear Barotrauma

TEED Classification of TM Barotrauma



- **Teed 0 -** No visible damage, normal ear
- **Teed 1 -** Congestion around the umbo, occurs with a pressure differential of 2 pounds per square inch (psi)
- **Teed 2 -** Congestion of entire TM, occurs with a pressure differential of 2-3 psi
- **Teed 3 -** Hemorrhage into the middle ear
- **Teed 4 -** Extensive middle ear hemorrhage with blood bubbles visible behind TM; TM may rupture
- **Teed 5 -** Entire middle ear filled with dark (deoxygenated) blood

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Prevention of Middle Ear Barotrauma

- Don't dive with an URI or inflammation from seasonal allergies
  - Try to avoid the use of pre-dive nasal decongestants
  - Oral pseudophedrine is preferred for prevention
  - Topical nasal oxymetazoline no better than placebo for prevention (Jones et al., Amer J Emerg Med, 1998)
  - Intranasal topical steroids (fluticasone propionate) may be helpful, but need to begin using 4-7 days prior to diving
- Utilize middle ear equalization techniques early and often throughout descent
- Slow, feet first descent
- Train your ET muscles
  - Anecdotal improvement in ET function with gum chewing regimen

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Middle Ear Equalization Techniques

- Valsalva is not the preferred method!!
- Modified yawn and swallow
  - Yawn and swallow with mouth and nose closed
- Frenzel maneuver
  - Pinch nose, make “K' or “guh” sound
  - Drives tongue backwards (like a piston) to compress air in the posterior pharynx with mouth, nose and glottis closed
- Voluntary contraction of the soft palate
- Toynbee maneuver
  - Pinch nose and swallow with the mouth closed

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Treatment of Middle Ear Barotrauma

- Avoid further pressure changes (diving)
  - Until symptoms have resolved and adequate ET function has returned
  - DO NOT refer for hyperbaric oxygen treatment
- Oral and topical nasal decongestants
- Systemic antibiotics
  - If infection is suspected
- Antibiotic ear drops
  - Can be used with TM rupture

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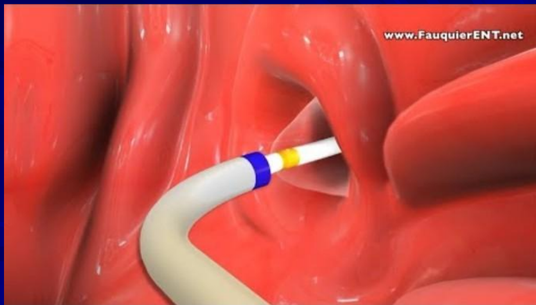
Eustachian Tube Dilation?



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The External Auditory Canal

- Lined with keratinized squamous epithelium that is continuous with the outer layer of the TM
- The cells migrate from the TM outward
- Proximal EAC is surrounded by bone
- Distal EAC is surrounded by cartilage
- Cerumen is produced by the outer cartilaginous portion of the EAC

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The External Auditory Canal

- Cerumen
  - Contains water-soluble bacteriostatic fatty acids
  - Contains oil-soluble fatty acids
  - Makes EAC pH slighty acidic (bacteriostatic)
  - Is clear when made but becomes brown when oxidized

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Otitis Externa

- The second most common diving related medical problem
- Caused by excessive moisture and humidity in the external auditory canal (EAC)
- Maceration of the squamous epithelium and changes in pH increase susceptibility to infection
- The presence of exostosis can increase risk
- Certain invasive bacteria can be involved
- Can become more serious if invasion of the mastoid occurs (mastoiditis)

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Otitis Externa

- Organisms
  - Pseudomonas
  - Proteus
  - Staphylococcus
  - E. Coli
  - Aerobacter
  - Aspergillus
  - Candida

Dibb, Undersea Biomed Res, 1992

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Otitis Externa

- Symptoms
  - Itching
  - Burning
  - Pain
  - Discharge
  - Decreased hearing
  - Fever
- Signs
  - Inflamed EAC
  - Tender to palpation
  - Discharge
  - Peri-auricular erythema
  - Cervical and posterior auricular lymphadenopathy
  - Hearing loss

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Otitis Externa Prevention

- Avoid prolonged exposure to moist environments
- Keep ears clean
- Preventative otic solution after water exposure
  - 2% Acetic acid (or vinegar)
    - Keeps pH slightly acidic (bacteriostatic)
  - Isopropyl alcohol
    - Drying agent

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Otitis Externa Treatment

- Cleaning out the EAC
  - Irrigation with warm water or hydrogen peroxide (unless TM perforation)
  - Dry EAC afterwards
  - Placement of wick if swelling is severe
- Topical antibiotics +/- topical steroids
  - Cipro HC is approved for use with TM perforation
- Normalize the pH
  - Acetic acid (or vinegar)

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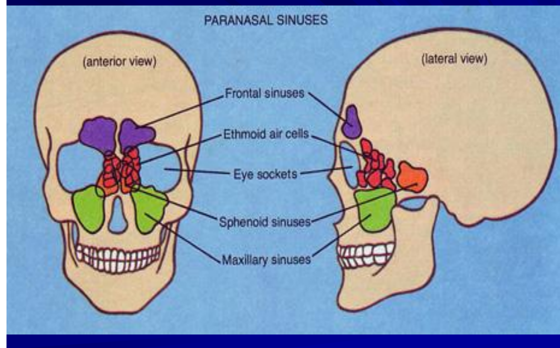
The Paranasal Sinuses



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Paranasal Sinus Barotrauma

- Gas filled sinus cavities in the bones of the skull
- Open to the nasopharynx via ostia
- Barotrauma results from inadequate pressure equalization of these spaces
- In a case series of 50 cases of sinus barotrauma in divers
  - 68% occurred during descent
  - 32% during ascent
  - 50% reported a recent history of URI

Fagan et al, Otol Rhino Laryngol, 1976

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Paranasal Sinus Barotrauma

- Pain is the most common symptom
  - Frontal – Forehead location
  - Maxillary – Below the eyes or maxillary teeth
  - Sphenoid – Vertex of skull or occiput
  - Ethmoid – Behind the eyes
- Epistaxis is second most common symptom
  - Sinuses are lined with delicate respiratory epithelium

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Paranasal Sinus Barotrauma

- Prevention
  - Avoid diving with an URI or acute/chronic sinusitis
  - Proper equalization techniques
- Treatment
  - Nasal decongestants
  - Antibiotics if infection is suspected

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Consequences of Boyles Law: "The Squeezes"

- Middle Ear Squeeze
- Sinus Squeeze
- Outer Ear Squeeze
- Mask Squeeze
- Tooth Squeeze
- Goggle Squeeze
- Reverse Block
- Inner Ear Barotrauma
- Alternobaric Vertigo

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Diving and the Inner Ear

- Deafness and vertigo were described in association with caissons diseases by Smith in 1873 (Brooklyn Bridge) and Alt and Heller in 1897 (Germany)
- In 1929, Vail described barotrauma of the inner ear and inner ear decompression illness (animal studies)
- The 1970s saw renewed interest in the role of the inner ear in the pathophysiology of diving related diseases

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The Dizzy Diver?

- What is vertigo?
- What are non-diving related medical conditions that cause vertigo?
- Vertigo is a common symptom in divers
- A careful and detailed history is very important
- The physical exam (ENT and Neuro) is important
- The differential diagnosis is broad
- Making the correct diagnosis is important

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What is Vertigo?

- Dizziness is an overused and often confusing term
  - Lightheaded?
  - Near-syncope?
  - Vertigo?
- Vertigo is a symptom not a disease
- Defined as the sensation of movement when someone is really stationary

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What is vertigo?

- Pathophysiology
  - Peripheral
    - A problem that localizes to the inner ear
    - Semi-circular canals and the otoliths
  - Central
    - A problem in the CNS
    - Brainstem or cerebellum

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Peripheral vs Central Vertigo?

- Peripheral
  - Motion sickness
  - Meniere's disease
  - Benign positional vertigo
  - Labrynthitis
  - Perilymph fistula
  - Vestibulotoxic medications
    - Aminoglycosides
    - Macrolides
    - Lasix
    - Aspirin
    - Quinine
- Central
  - Vertebrobasilar insufficiency
  - Multiple sclerosis
  - Seizure disorder
  - Vertebrobasilar migraine
  - Cerebellar CVA
  - CNS tumor

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Evaluation of Vertigo in a Diver

- The history will be your most important diagnostic tool!
- Medical history
- Diving history
- History of the present illness is most important
- Physical Exam

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Medical History

- Any diseases that could precipitate vertigo as a symptom?
- Any new medications that could cause vertigo?
- Recent URI or other illness?
- History of diving related ear problems?

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Diving History

- Level of Certification
- Years diving, # of dives, # of dives within the last year?
- Historical problems with middle ear pressure equalization or barotrauma?
- Frequent use of nasal decongestants while diving?

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History of the Present Illness

- When did the vertigo begin?
  - Before the dive
  - During descent
  - While on the bottom
  - During ascent
  - After the dive

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History of the Present Illness

- The Diving HPI
  - Buoyancy problems?
  - Equipment problems?
  - Difficulty with equalization?
  - Dive profile(s)
  - Uncontrolled ascent?
  - Omitted decompression?

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History of the Present Illness

- Associated signs and symptoms
  - Tinnitus
  - Nausea and vomiting
  - Inability to stand or walk
  - Nystagmus
  - Epistaxis
  - Joint or muscle pains
  - Chest pain or shortness of breath
  - Difficulty with speech
  - Unilateral or focal numbness or weakness

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The ENT Exam

- Otoscopy with insufflation must be performed
  - Signs of TM injury?
  - Adequate movement of TM with insufflation?
  - Symptoms worsen with insufflation?
- Assessment of hearing
  - Tuning forks (256, 512 and/or 1024Hz)
  - Weber
  - Rinne
  - Schwabach

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The ENT/Neuro Exam

- Careful evaluation of extra-ocular movements and nystagmus
- Vestibular and cerebellar function
  - Gait
  - Romberg (sharpened)*
  - Unterberger
  - Finger-nose-finger, heel-shin

*Fitzgerald, SPUMS 1996, Sept; 26(3): 142-146

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Formal Testing

- Pure tone audiometry
- Tympanogram
- Nystagmography
  - Electronystagmogram (ENG)
  - Videonystagmogram (VNG)
- Imaging (CT or MRI)

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Vertigo in Divers
Differential Diagnosis

- Middle ear barotrauma
- Sensory deprivation
- Nitrogen narcosis
- Hypercarbia/Hypocarbia
- Unilateral cold caloric stimulation
- Alternobaric vertigo
- Inner ear barotrauma
- Inner ear DCS

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Alternobaric Vertigo

- First described by Lundgren in 1965
- Unequal middle ear pressures leads to temporary confusion of the vestibular input to the brain
- Commonly occurs during ascent
- Frequently occurs in the setting of an URI or with forced Valsalva
- Is usually mild, benign and short-lived

Lundgren, CE *Brit Med J*. 1965; 2(5460): 511-3.

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Inner Ear Barotrauma

- Frequently occurs during descent in a diver who is having difficulty with middle ear equalization
- A forceful Valsalva maneuver with a "locked" ET can lead to inability to equalize the middle ear (negative pressure) + increased intracranial pressure
- Can result in explosive rupture of round or oval window in the direction of the middle ear space
- Alternatively, middle ear over-pressurization (sudden equalization or reverse block) can lead to implosive injury with rupture towards the intra-labyrinthine space

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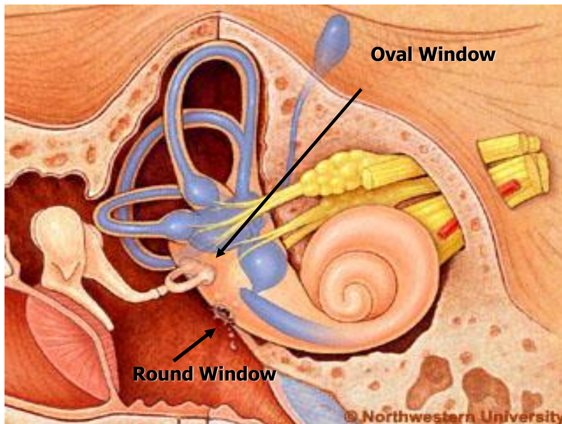

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Inner Ear Barotrauma

- Symptoms
  - Acute onset profound vertigo usually during descent
  - Sustained/Persistent symptoms
  - Usually roaring tinnitus
  - Sensorineural hearing loss almost always present
  - Only definitive way to diagnose is by surgical exploration
- Must have ENT referral and likely will require surgical repair

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Inner Ear DCI

- The cause is most likely bubble formation in the inner ear
  - Labyrinthine vessels
  - Endo- or perilymph
- Commonly occurs in association with deep diving operations using helium or from isobaric counterdiffusion (gas switching)
- Recent literature suggests that it occurs more frequently than previously thought in recreational diving (Nachum et al., Laryng, 2001)
- Association with PFO has been suggested in the literature (Cantais et al., Crit Care Med, 2003)

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What the heck is Isobaric Counterdiffusion?

- It only happens with gas switching
- Isobaric (constant pressure)
- Switch the breathing gas
  - Off-gassing of one inert gas
  - On-gassing of another inert gas
  - The gases diffuse at different rates based on their properties

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Isobaric Counterdiffusion

- Can be a problem when switching abruptly from N_2 containing gas → He containing gas
- Helium diffuses in very rapidly
- N_2 diffuses out slowly
- You have excess total inert gas
- You can get DCS without decompressing, simply from a gas switch at depth
- Inner ear DCS almost exclusively caused by this phenomenon

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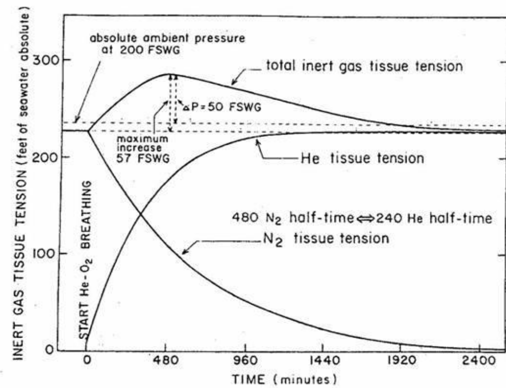

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Inner Ear DCI

- Occurs with significant decompression stress (usually provocative dive profiles)
- Symptoms
  - Vertigo
  - Tinnitus
  - Occasional sensorineural hearing loss
  - Look carefully for other signs/symptoms of DCI
    - Joint or muscle pain
    - Focal paresthesia or weakness
    - Rash

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Differential Diagnosis Dilemma IEBT vs IEDCI

- IEBT
  - Onset during descent
  - Can happen on shallow non-provocative dives
  - Difficulty with ear clearing
  - Abnormal otoscopy
- IEDCI
  - Onset after surfacing
  - Occurs after dives with significant decompression stress
  - Not associated with equalization problems
  - Would expect normal otoscopy (if no MEBT)

These are generalizations that are not always true!

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Treatment?

- IEBT
  - Bed rest
  - Keep CSF pressures low (no straining)
  - Surgical exploration and/or repair may be necessary
  - DO NOT RECOMPRESS!!
- IEDCI
  - Oxygen
  - Hydration
  - Recompression and HBOT are URGENT and NECESSARY!!

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Common questions?

- Can I dive if I have had a perforated TM in the past? After tympanoplasty? PE tubes in the past?
  - TM must be intact
  - Must have adequate ET function
  - Another diving related TM perforation is likely to be disqualifying

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Common questions?

- Can I dive after ear or sinus surgery? PORP or TORP? Round window repair?
  - Always discuss with ENT specialist
  - PORP/TORP → NO GO
  - Round window repair → controversial
  - Sinus surgery → possibly after adequate convalescence and can equalize sinuses

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Summary

- Middle ear barotrauma is the most common diving related medical problem
- Otitis externa is the second most common problem
- Vertigo is a common symptom associated with diving
- The differential diagnosis of vertigo in diving is broad and complex
- Making the diagnosis can be difficult and is very important for management of the patient

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