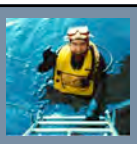
Middle and inner ear lesions in divers

Relevant anatomy.
Diagnosis and practical conduct.
Considerations on "fitness to dive"

J. Claes MD PhD
Univ.Dienst NKO & Hoofd- Hals heelkunde U.Z. Antwerpen

Knowledge / Experience / Care

The diving patient

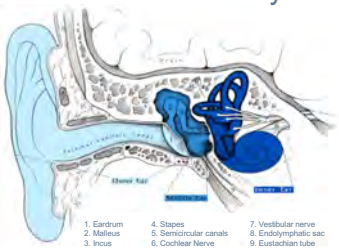


Well informed — medically
diving technology

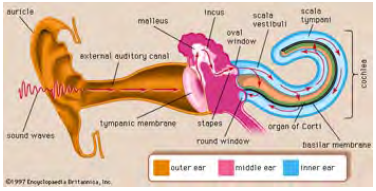
Strongly motivated — professionnal
recreative
hobby…..obsession

"special" doctor- patiënt relation
making our notions on diving obvious

An Ear's Anatomy



Sound travels through the whole system



Issues in middle and inner ear damage
Barotrauma

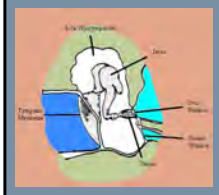
Vulnerable: tissues in proximity to gas containing spaces

Middle ear: drum; mucosal lining; (dehiscent) facial nerve canal; mastoid cavity; oval & round window; Eustachian tube

Inner ear; oval & round window; "third window"; cochlear & vestibular aqueduct; inner ear membranes

(Other ENT: external ear canal; nose & sinuses; larynx; teeth)

Anatomy & function



Middle ear — transducer function

Eustachian tube — active & passive

"breathing" middle ear mucosa

Barotrauma : mucosal tears – blood

tympanic membrane rupture

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Modified Teed's Classification of Middle Ear Barotrauma

- Grade Findings on otoscopy
- 0 Normal examination
- 1 Tympanic membrane injection or retraction
- 2 Slightly hemorrhagic tympanic membrane
- 3 Grossly hemorrhagic tympanic membrane
- 4 Hemotympanum
- 5 Tympanic membrane perforation

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Middle ear barotrauma (MEBT)

Occurs during descent

Clearing problems

Conductive hearing loss

Otoscopic abnormalities

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Clearing of the middle ear

- Active and passive Eustachian tube function
- Different methods of active clearing:
  Valsalva, Toynbee, Frenzel
- Influence of: age
  posture
  speed of descent
- Middle ear barotrauma and drum rupture can occur at Δp 60 mmHg (80 cmH^2O)

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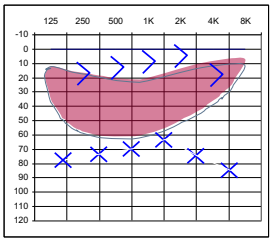
Sound proof room

Audiogram

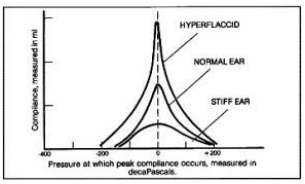


ex : conductive hearing loss

Physiopathology of tubal function

- Muscular deficit cleft palate
  infantile deglutition
- Luminal deficit mucosal pathology
  extrinsic compression

Tympanometry



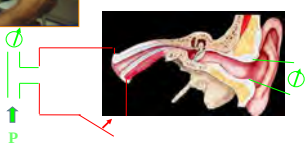
Measuring the middle ear's "pressure condition"

- Tympanometry: gas diffusion
  (tubal function)
- Tubomanometry: active tubal function
  (gas diffusion)

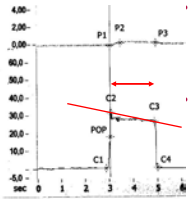
Tubomanometry as a measure of active tubal function

- Measure pressure changes in time:
  - at the level of
    - nasopharynx
    - external ear canal
  - during deglutition
  - while additional pressure is applied to the nasopharynx

Tubomanometry schematic principle

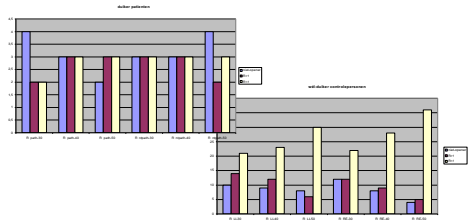


Parameters in tubomanometry

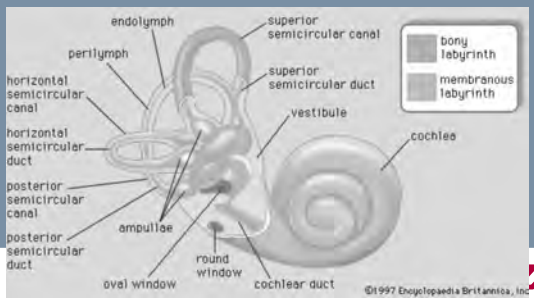


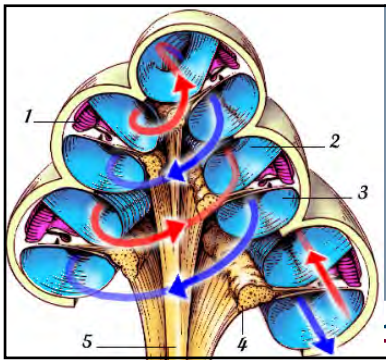
- Pressure pattern in rhinopharynx
  - C3-C2 (mbar)/C3-C2 (sec)
  - C2 (mbar) as a function of pressure load (consigne)
- Time of tubal opening
  - before C2
  - after C2
  - R= (P1-C1)/(C2-C1) (sec) corrected latency for tubal opening
  - no opening (NO)

TMM: study of divers after IEBT vs diver controls



Anatomy & Function: Inner ear





Cochlear microstructure

Endolymph (cochlear duct) and perilymph (scala vestibuli & scala tympani)

Traveling wave

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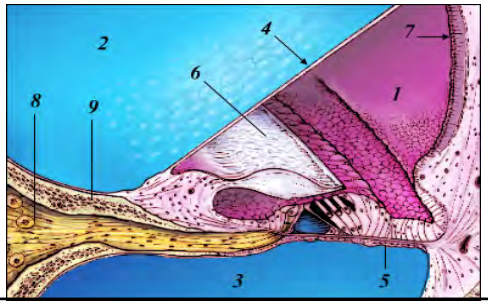
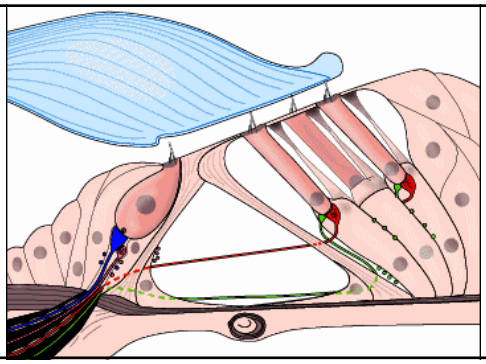
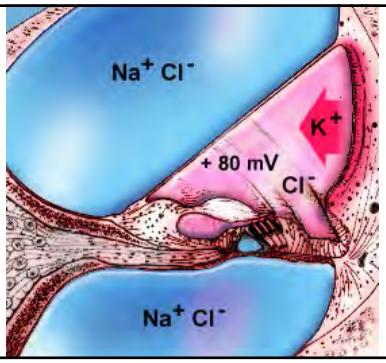
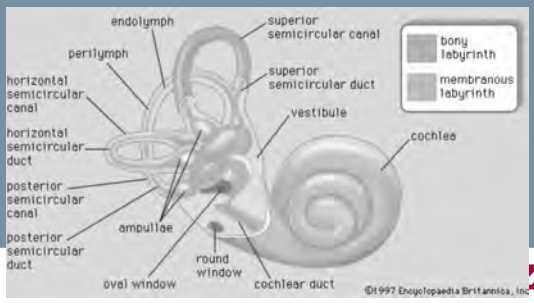
Corti's sensory organ



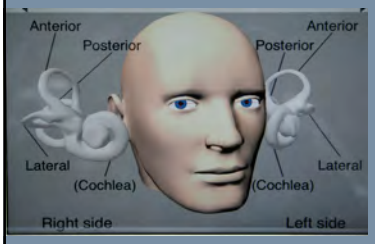




Anatomy & Function: inner ear



Vestibular system



Semicircular canals with ampullae

Sacculus and utriculus with maculae

Endolymph and perilymph shared with cochlear system

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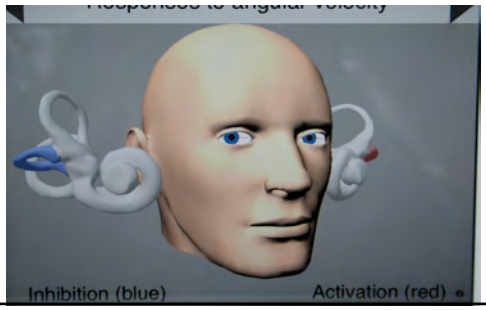
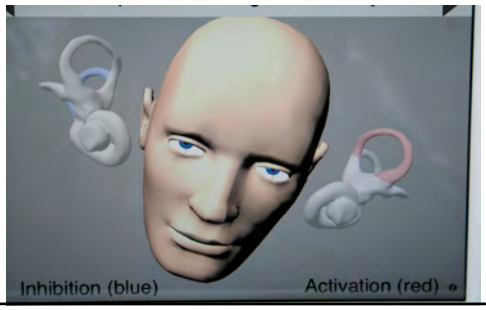
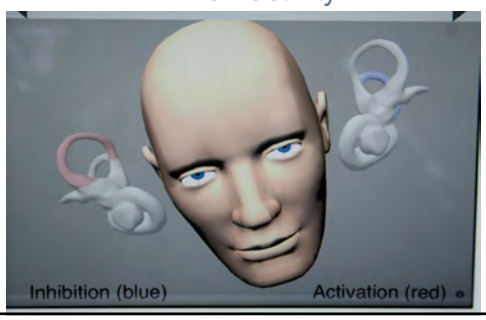
"mirror" activity



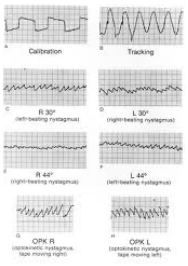
"mirror" activity



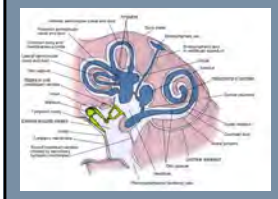
"mirror" activity



Electronystagmography



Anatomy & Function



Inner ear:
- vestibular organ → equilibrium & gaze stabilization
- cochlea → hearing

Barotrauma:
- Round / oval window rupture
- Cochlear/vestibular membrane tearing
- Possible role for cochlear & vestibular aqueduct (and third windows)

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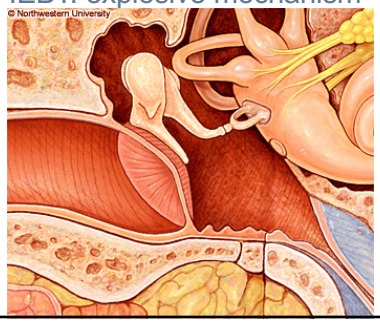
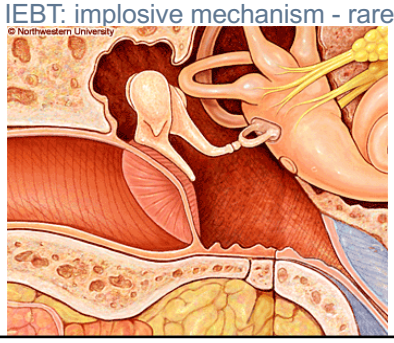
IEBT: explosive mechanism



IEBT: implosive mechanism - rare



Inner ear barotrauma (IEBT)

- Symptoms occur during descent
- Hearing loss and vertigo
- Often but not always associated with MEBT
- Clearing problems
- Differentiation with IEDT can be difficult

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Arguments in IEBT

Elliott EJ, Smart DR. Diving & Hyperbaric Medicine, 44, 4: 208-222. Dec 2014. Review of literature on IEBT.

Clinical presentation NOT always typical: ex.:
- only hearing loss, only vertigo
- symptoms develop during ascent or even later
- no clearing problems noted
- spontaneous recovery may occur

Challenge of precise pathophysiological diagnosis
Lack of pre-existing hearing data
Limited benefit from technical investigations

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Issues in inner ear damage Decompression trauma

Vulnerable: cochlear & vestibular sensory organs
- Vascularization (PFO)
- Tissue characteristics

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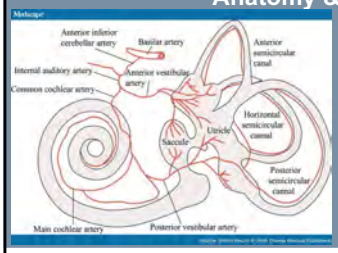
Anatomy & Function



Inner ear:
"end type" vascularization
increased susceptibility of inner ear tissues for IEDCS

Decompression trauma:
Vascular occlusion by bubbles
Slow nitrogen washout ➡ bubbles in tissues

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Inner ear decompression trauma (IEDCS)

Deep dive

Associated with other signs of DCS

Several dives in one day

Symptoms occur at the end of the dive or later

Recent literature: IEDCS is not rare

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Arguments in IEDCS

Mitchell SJ, Doolette DJ. Diving and Hyperbaric Medicine. Vol 45; 2: 105-110, 2015.
Review of literature on IEDCS

IEDCS can occur
- relatively early
- after shallow dives
- as isolated target organ
- mostly with vestibular function loss
- but also with isolated cochlear function loss
- mostly related to PFO causing arterial bubbles

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Table 1
Numbers of inner-ear DCS cases presenting with isolated inner ear symptoms and within the latency categories specified in those series reporting compatible data; only one diver (in the Ignatescu study[8]) developed symptoms during ascent
* % out of 211; † combined numbers and % for latency >30 min

Study	*n*	'Pure' inner ear DCS	Latency of symptoms after surfacing (min)		
			0–30	31–60	>60
Ignatescu[8]	33	16	22	7	3
Klingmann[4]	34	28	20	9	5
Nachum[5]	29	15	18	6	5
Smerz[18]	28	Unknown	21	3	4
Gempp[9]	115	98	98	17†	
Totals (%)	239	157 (74)*	179 (75)	59 (25 †)	

Arguments in IEDCS

Isolated IE symptoms

Short latency

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Table 2
Numbers of inner-ear DCS cases presenting with vestibular only, cochlear only and combined presentations in those series reporting compatible data

Study	*n*	Vestibular	Cochlea	Vestibular and cochlear
Klingmann[5]	34	19	0	15
Nachum[4]	29	10	4	15
Smerz[18]	28	19	0	9
Gempp[9]	115	88	7	20
Totals (%)	206	136 (66)	11 (5)	59 (29)

Arguments in IEDCS

Mostly vestibular symptoms

Isolated vestibular, cochlear, or mixed symptoms

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Table 3
Methods and outcomes of testing for right-to-left shunt (RLS) in inner-ear DCS cases from those series reporting compatible data; all four studies used bubble contrast; TTE – transthoracic echocardiology; TCD – transcranial Doppler; * % out of 179

Study	*n*	Test	RLS +ve	Large RLS
Ignatescu[8]	30	TTE	24	24
Klingmann[4]	34	TCD	25	Not specified
Cantais[10]	34	TCD	28	24
Gempp[9]	115	TCD	95	89
Totals (%)	213		172 (81)	137 (77*)

Arguments in IEDCS

Over-representation of PFO

Control groups: approx 25%

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Diagnosis of ear damage in divers

Anamnesis – history of what happened: dive profile
time course of symptoms

Clinical exam – micro-otoscopy – clinical vestibular examination

Technical examinations - Audiometry
(nystagmography)
(medical imaging – ex. HRCT)

➡ Document the loss of function
the extent of damage
middle and/or inner ear function loss

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Challenging: inner ear damage & no clear diagnosis IEDCS><IEBT

Sensorineural hearing loss +/- vestibular symptoms

No typical/ suggestive circumstances

No middle ear damage, no signs of DCS in other organs

Patient consulting late

Patient "colours" the story

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Pragmatic conduct in inner ear damage after diving

Diagnostic factor

Time factor

In daily practice: different patient groups:

IEBT
IEDT
IE damage with unclear diagnosis

presenting early
late

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Therapeutic options in IE damage

IEDT early: recompression (HBO)
late: none

(investigation for PFO)

IEBT early: supportive, symptomatic treatment
late: consider middle ear exploration

a place for HBO?

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ME exploration for Ruptured window repair

- When conservative treatment of IEBT proves ineffective after d10
- ?Value of fistula test
  positional PTA
- Several reports of >50% success
- Chances of success decline with time