Presentation at the First Plenary Meeting of the Advisory Committee on Acoustic Impacts on Marine Mammals

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Auditory Impacts of Sound on Marine Mammals

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Key Questions

- What do we know so far, with what level of agreement?
- What are the key issues for the future, including mitigation?

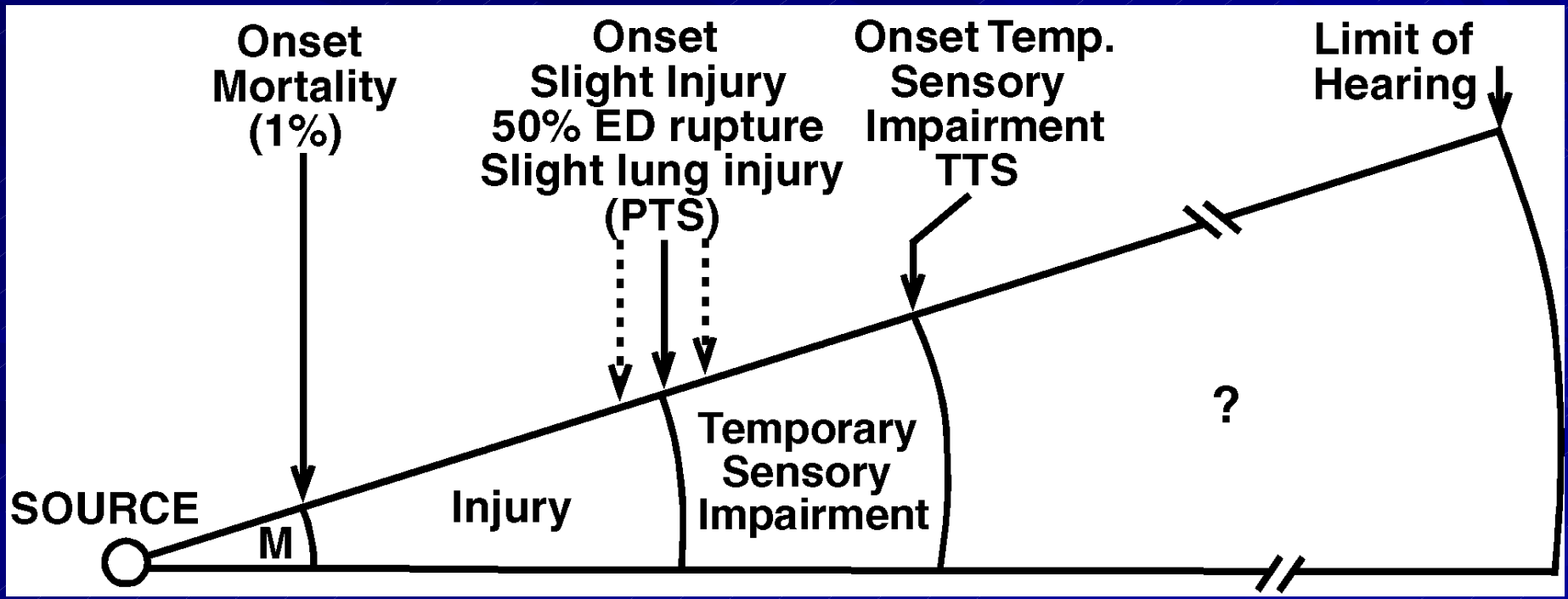
- Hearing loss – normally caused by temporary or permanent damage to inner ear components, (and middle ear, or central nervous system)

Potential Effects of Underwater Sound Exposure

- Physical injury – including mortality
- Permanent hearing loss
- Temporary hearing loss
- Masking – (interfering with the ability to hear) biologically important sounds

Diagram of Exposure Effects

- Generally, effects are less severe as distance to source increases
- But this is an oversimplification considering the complexity of acoustical physics

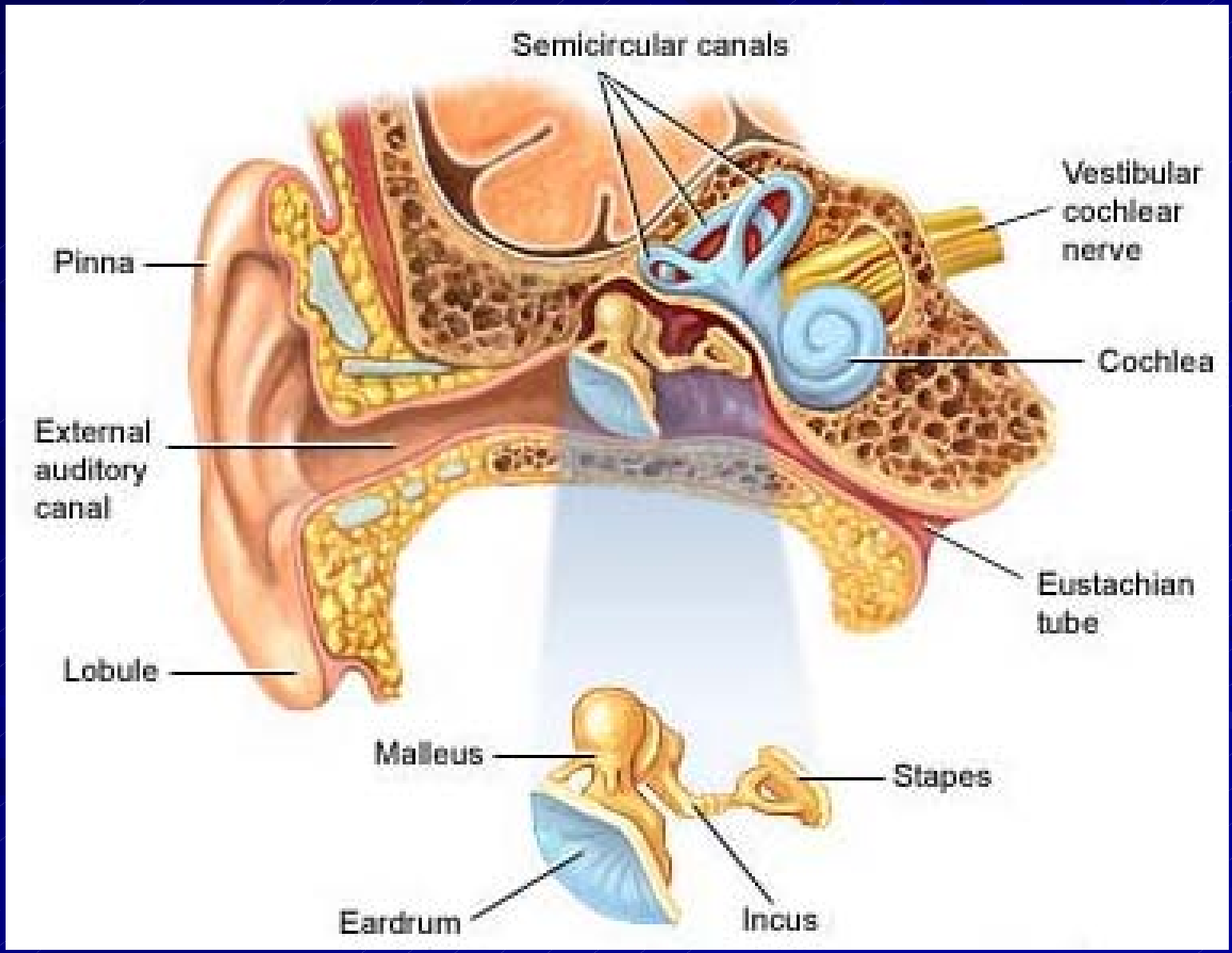


Standard Mammalian Ear Rubric

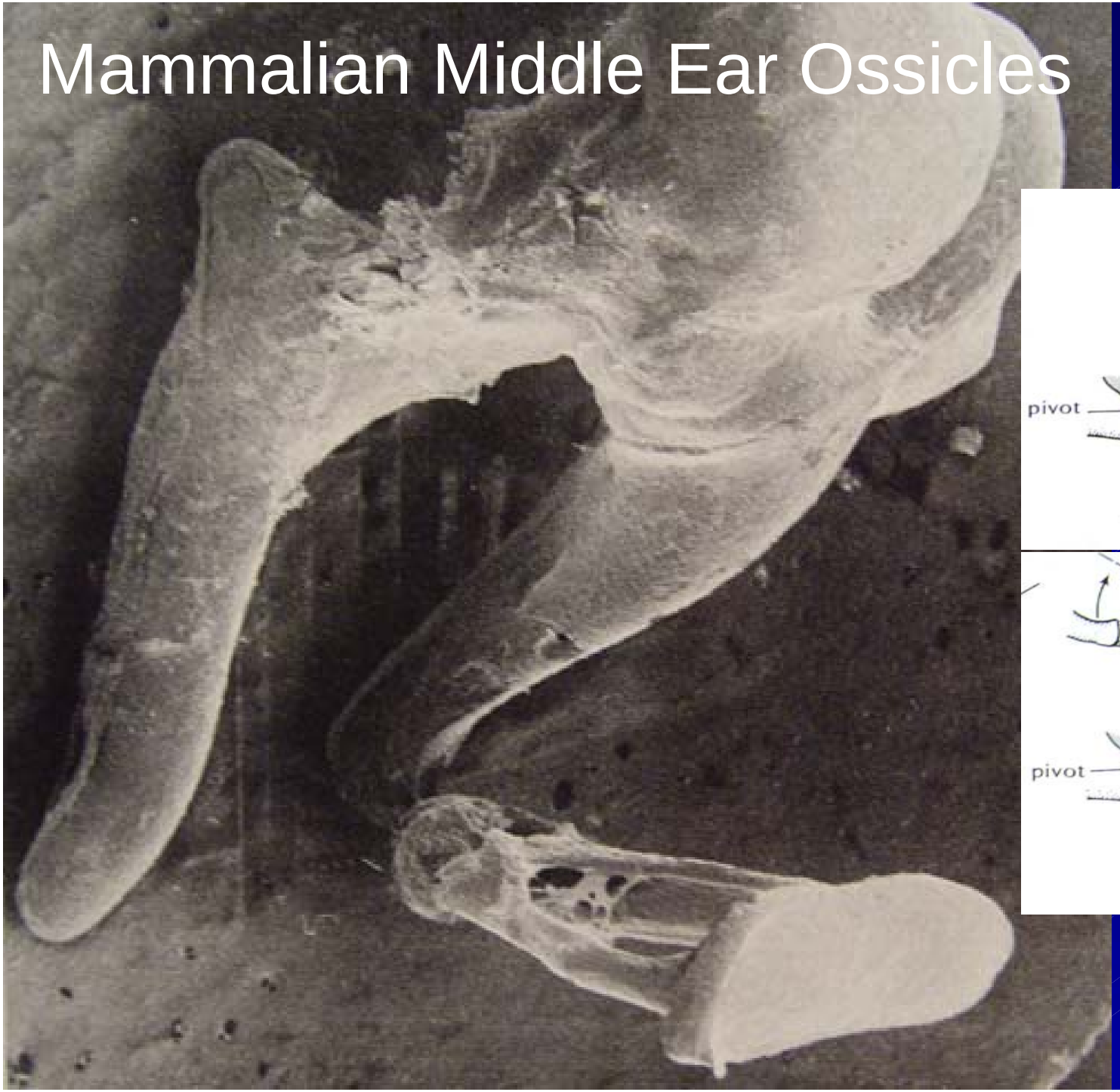
Three Subdivisions

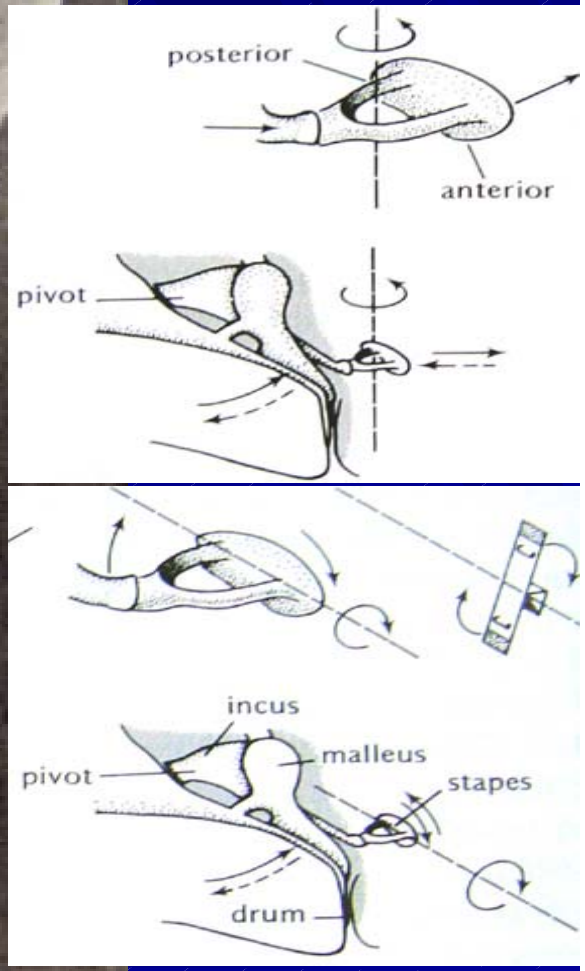
- 1) Outer ear – collects & channels sound
  - Pinnae in most except aquatic mammals
- 2) Middle ear – conducts & amplifies sound
  - 3 bones or ossicules
- 3) Inner ear – transduces
  - contains hair cells (receptors)

Anatomy & Physiology of Hearing

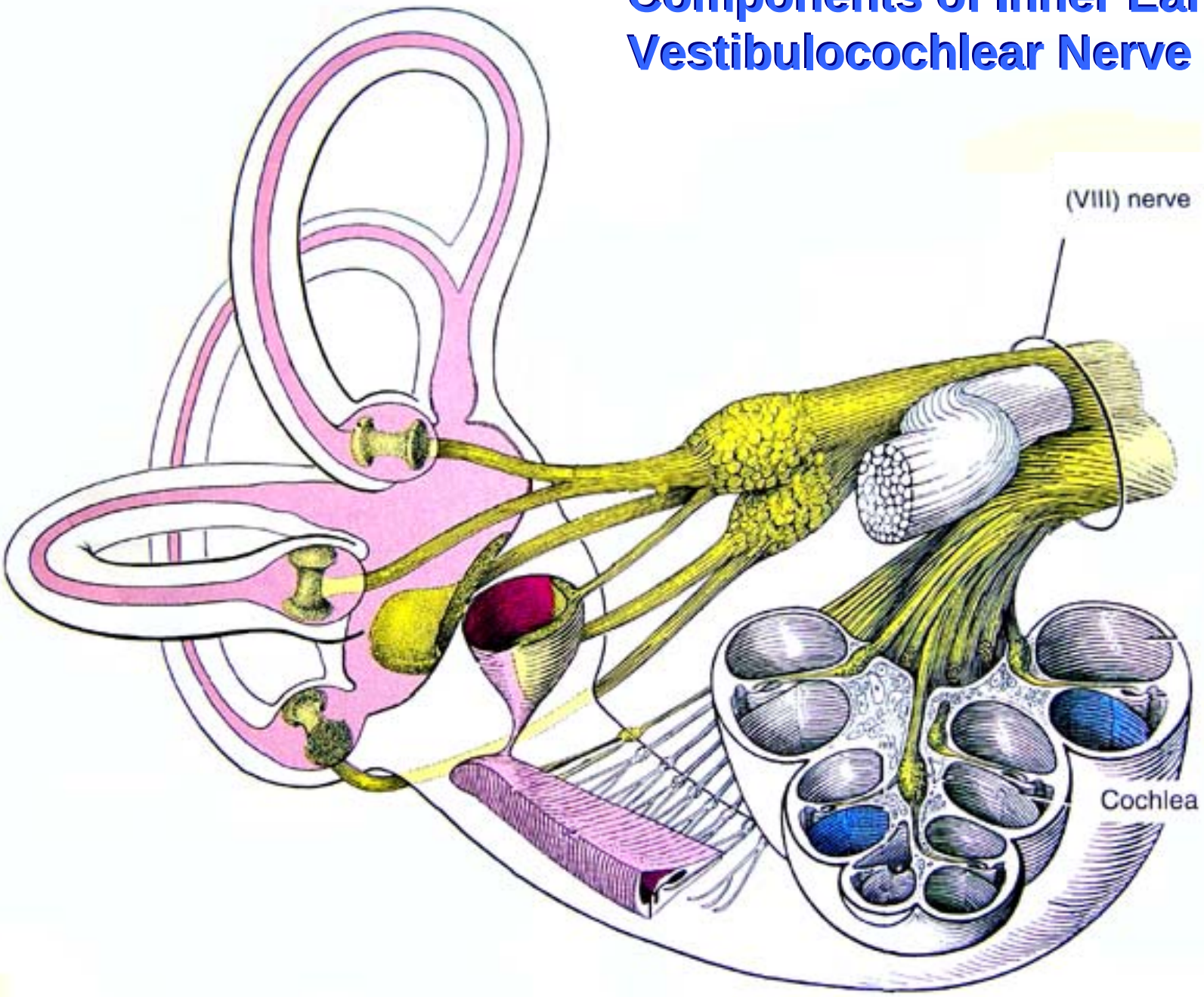


Mammalian Middle Ear Ossicles

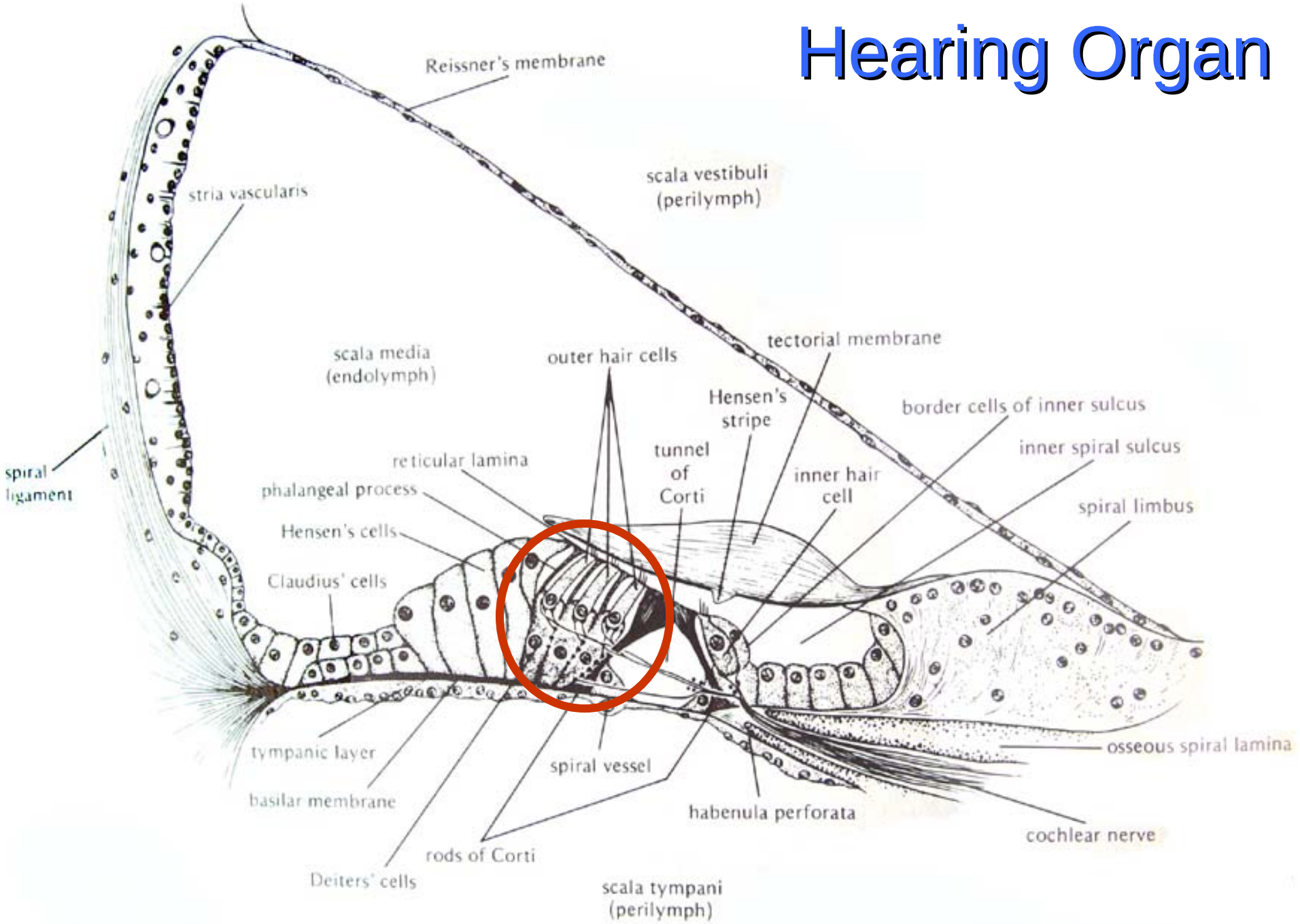


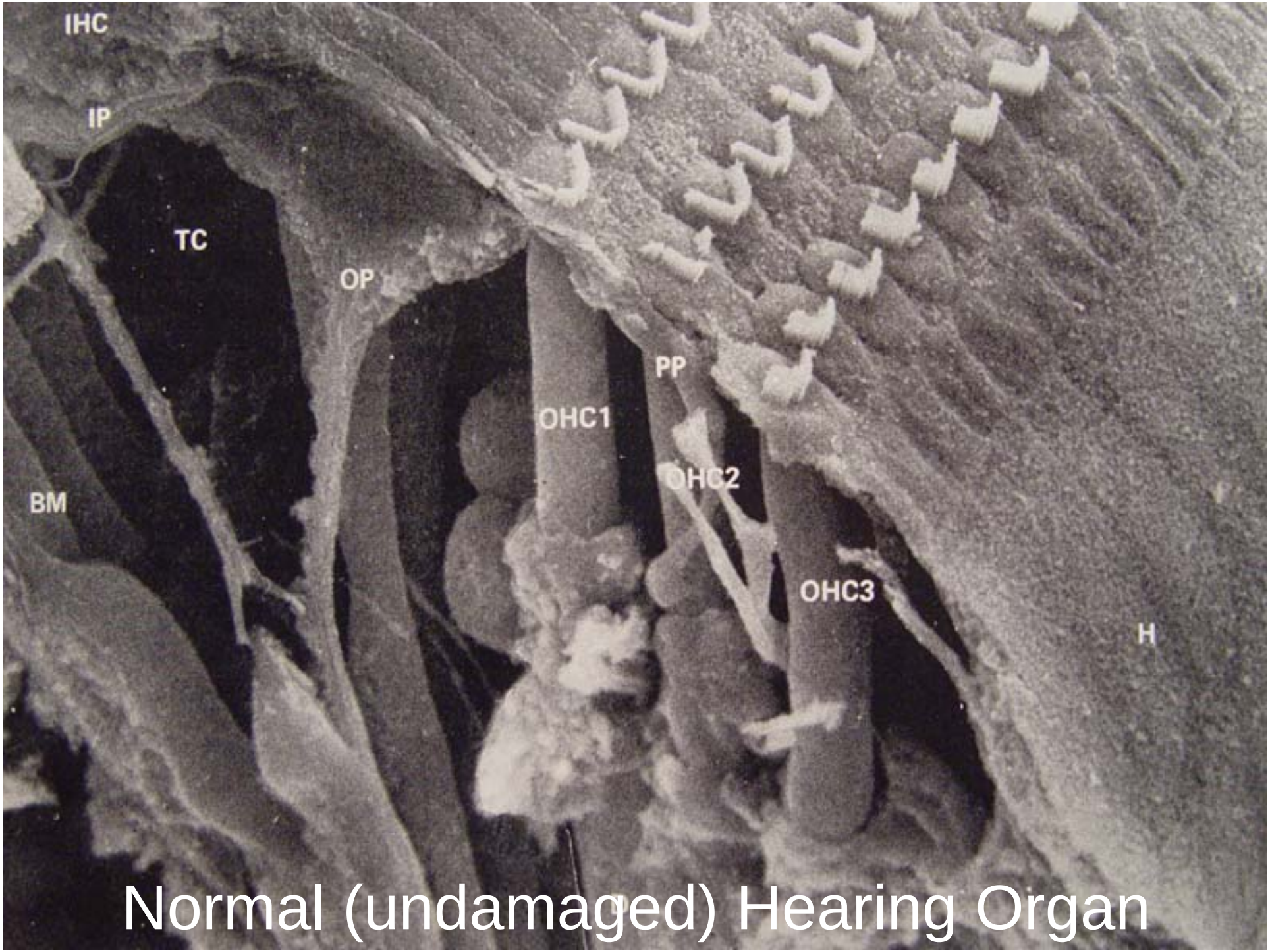


Components of Inner Ear & Vestibulocochlear Nerve (VIII)

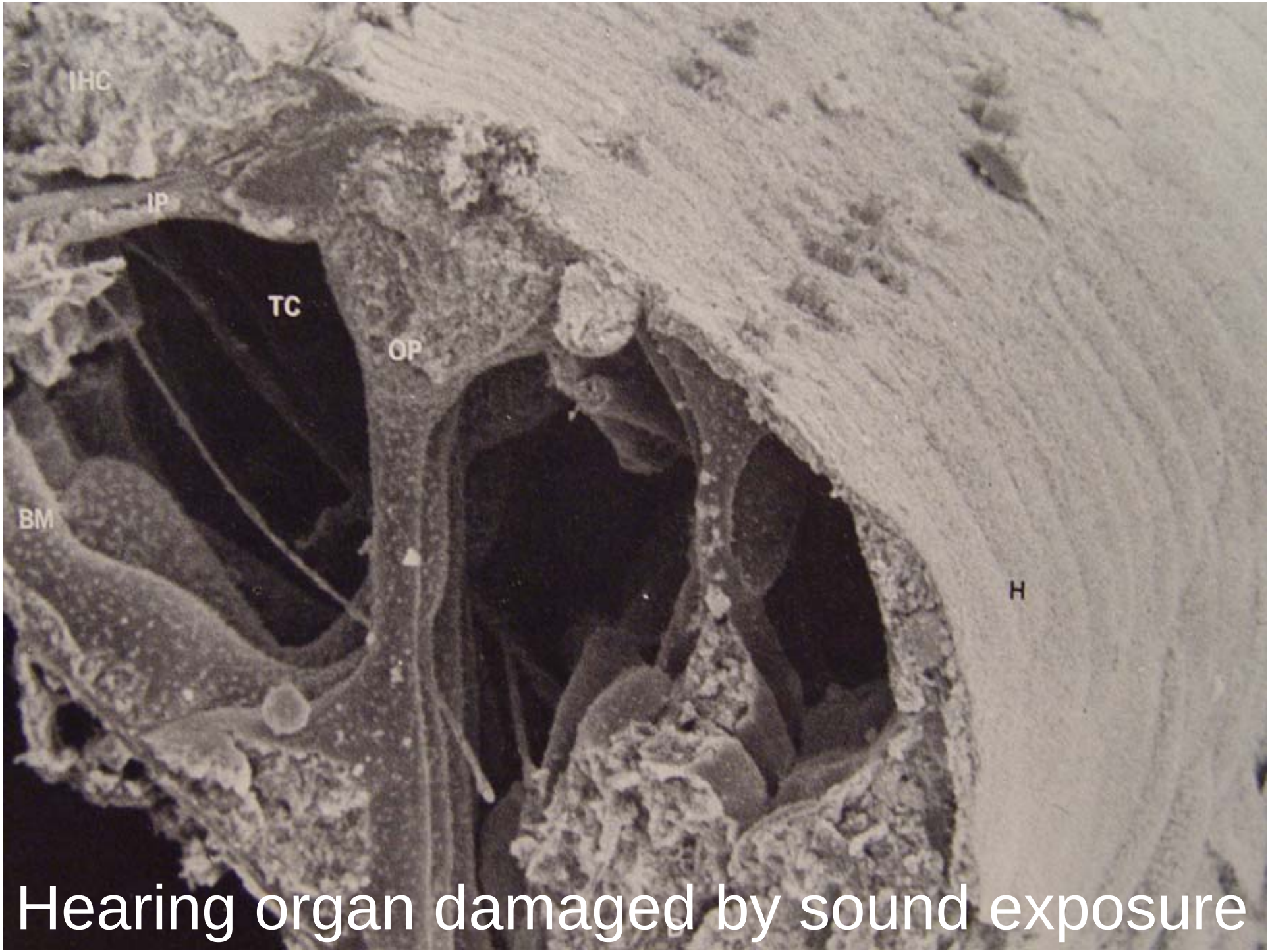


Hearing Organ

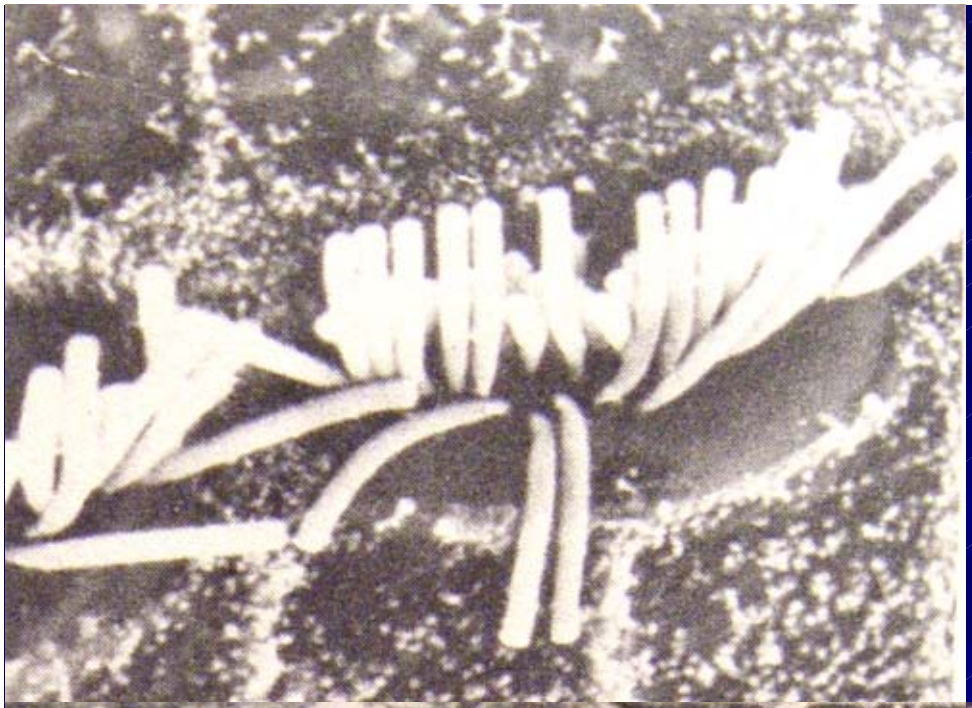




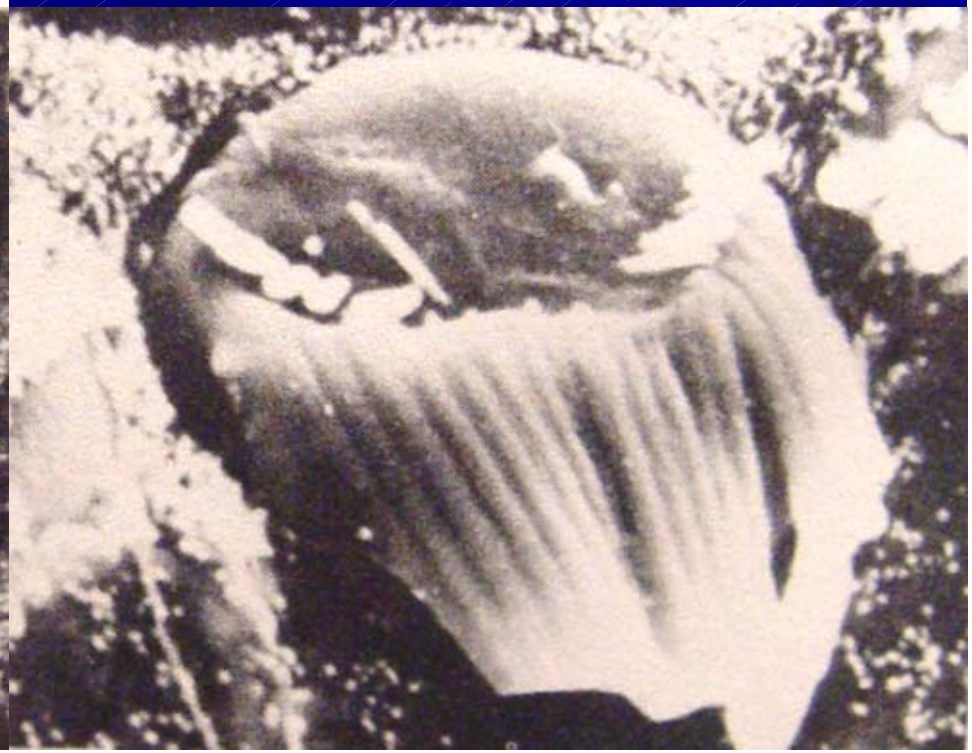
Normal (undamaged) Hearing Organ



Hearing organ damaged by sound exposure



Abnormal stereocilia after exposure



Inner ear

- Hair cells and stereocilia convert or transduce mechanical and hydrodynamic forces within the cochlea into neural impulses within the auditory nerve
- Damage to hair cells would dramatically affect the transduction process and impact hearing ability
- Hair cells are most vulnerable to overstimulation caused by acoustic stimuli

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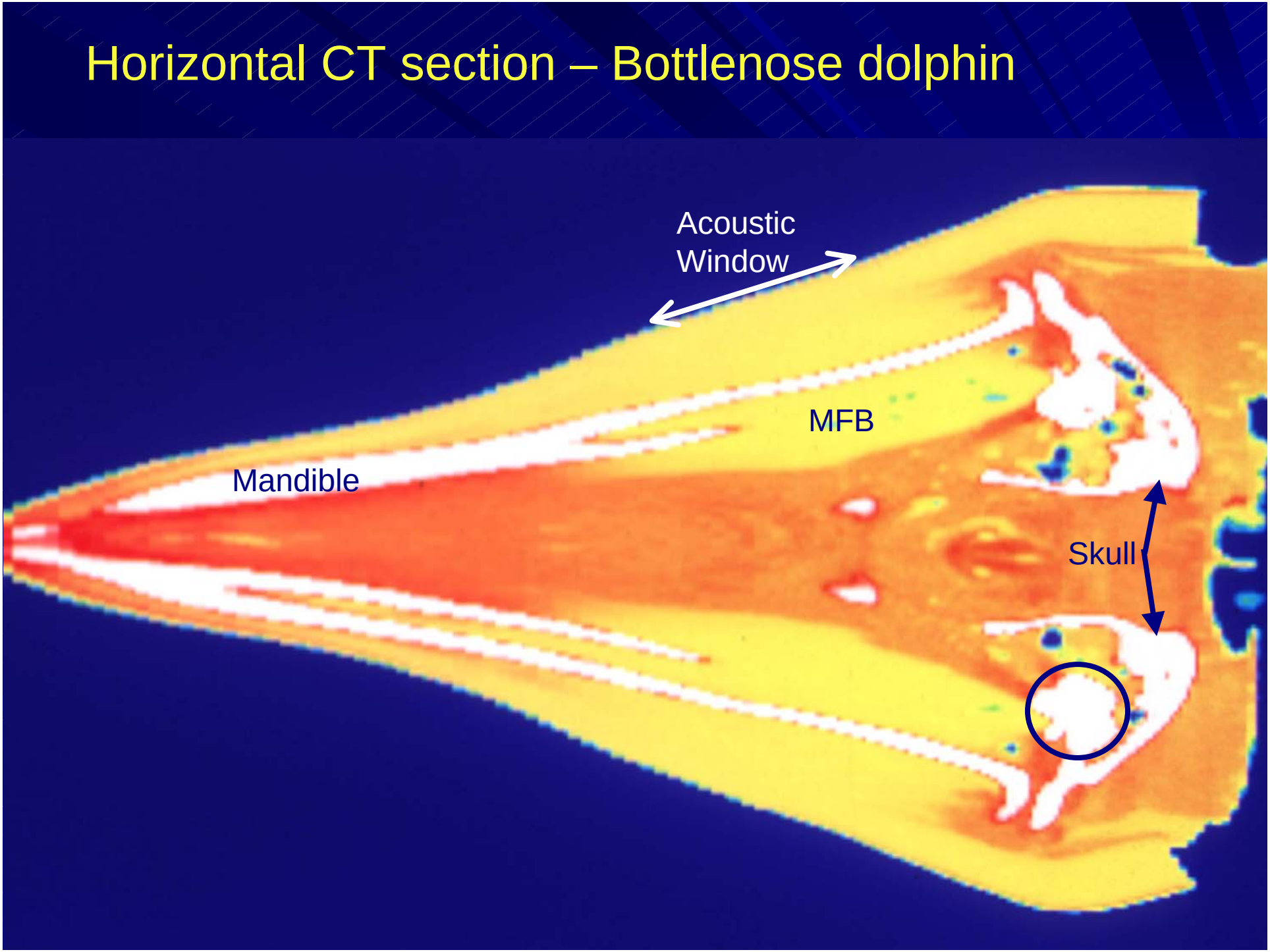
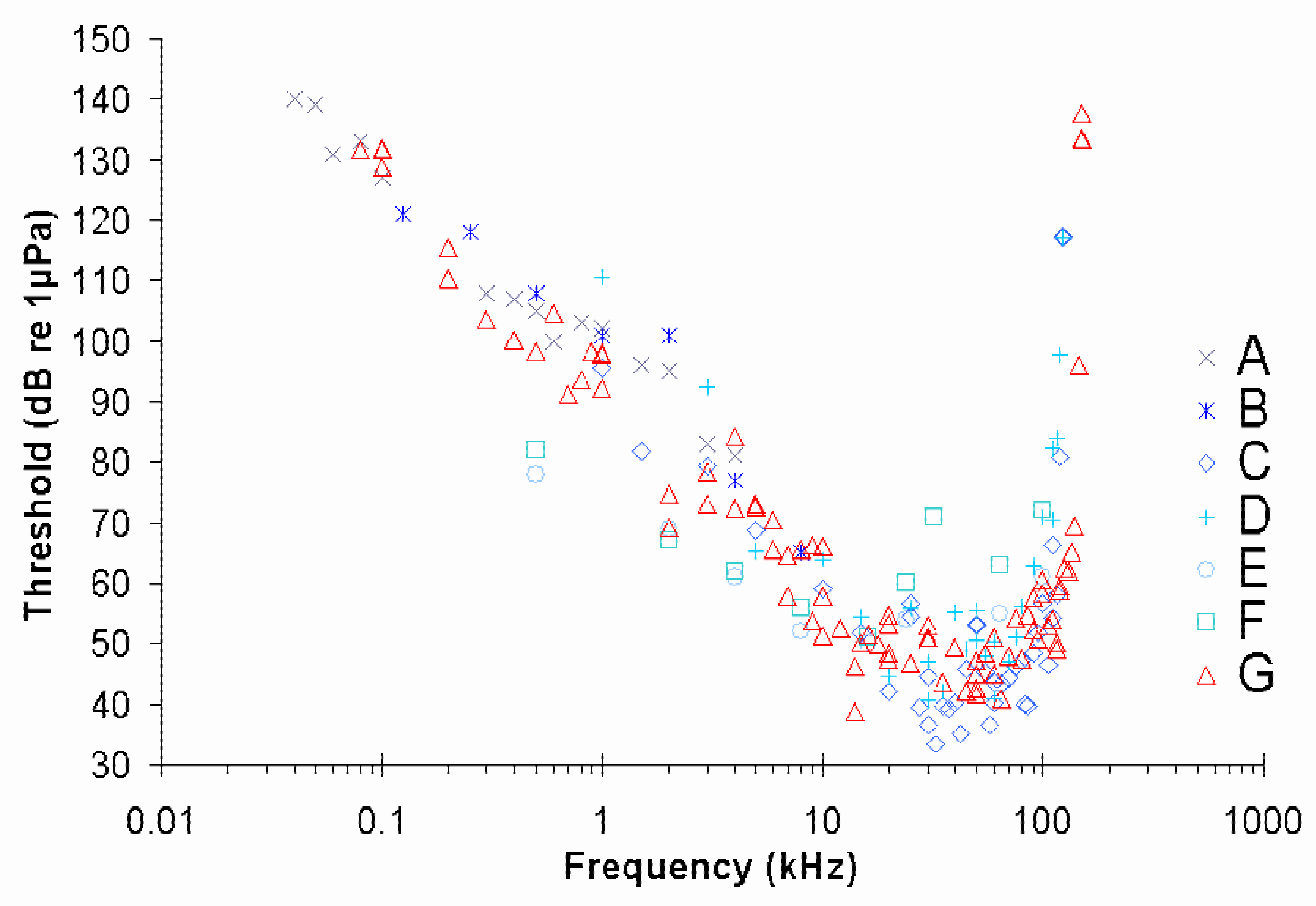
- What are the key issues for the future?
- Mitigation?

Horizontal CT section – Bottlenose dolphin



Hearing Thresholds



(A) White whale from Johnson et al. (1989).
(B) White whale from Awbrey et al. (1988).
(C)&(D) White whale female and male from White et al. (1978).
(E)&(F) White whale female and male from Ridgway et al. (2001).
(G) Bottlenose dolphin from Johnson (1967).

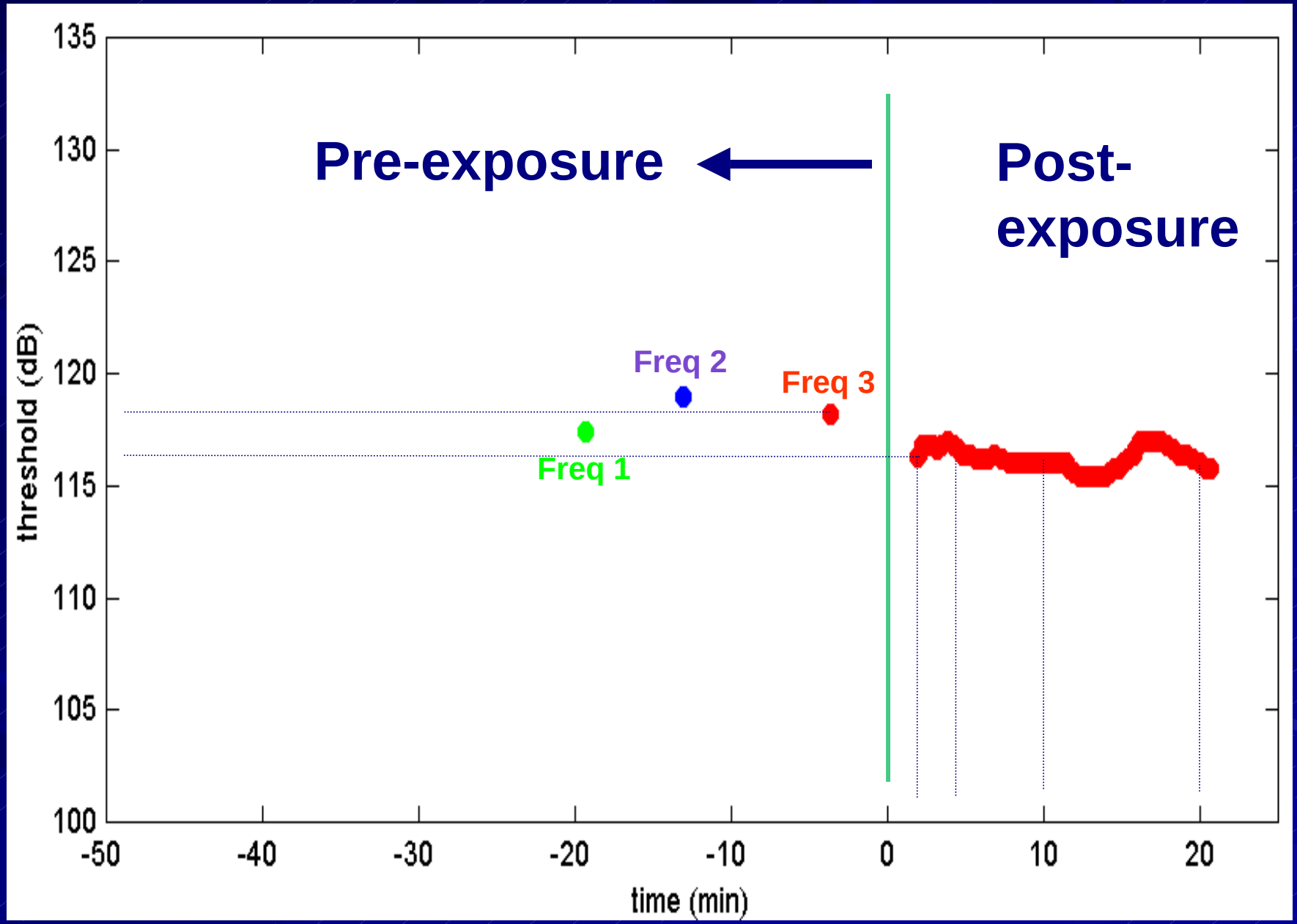
Temporary Threshold Shift

- Threshold shift (TS)
  - Increase in auditory threshold after exposure to sound
  - Threshold increase = hearing loss
- Permanent threshold shift (PTS)
  - Threshold does not return to pre-exposure value
  - PTS is associated with permanent damage to the auditory system and hair cell loss
- Temporary threshold shift (TTS)
  - Temporary loss of hearing ability
  - Threshold returns to pre-exposure value, no permanent injury to the ear
  - Can be tested safely in marine mammals
- Measure hearing thresholds before and immediately after exposure to sounds representative of specific sources

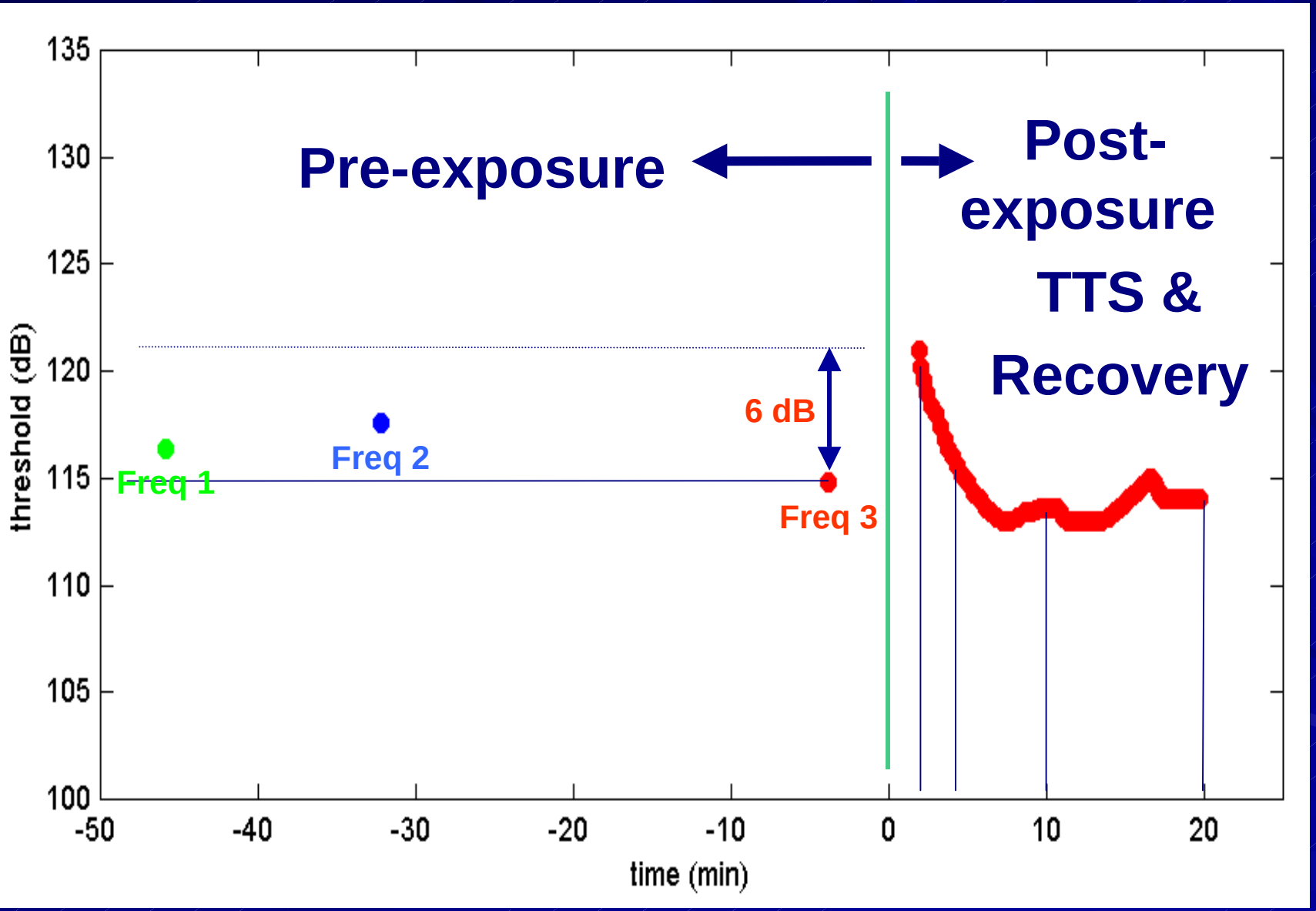
TTS Approach

- Compare hearing thresholds measured before and immediately after exposure to intense underwater sounds
- Subtract pre-exposure threshold from post-exposure threshold to determine amount of TTS
- Majority of tests used a 6-dB criterion
  - TTS must be consistent to be considered significant
  - Larger than the typical session-to-session and day-to-day variability

Control

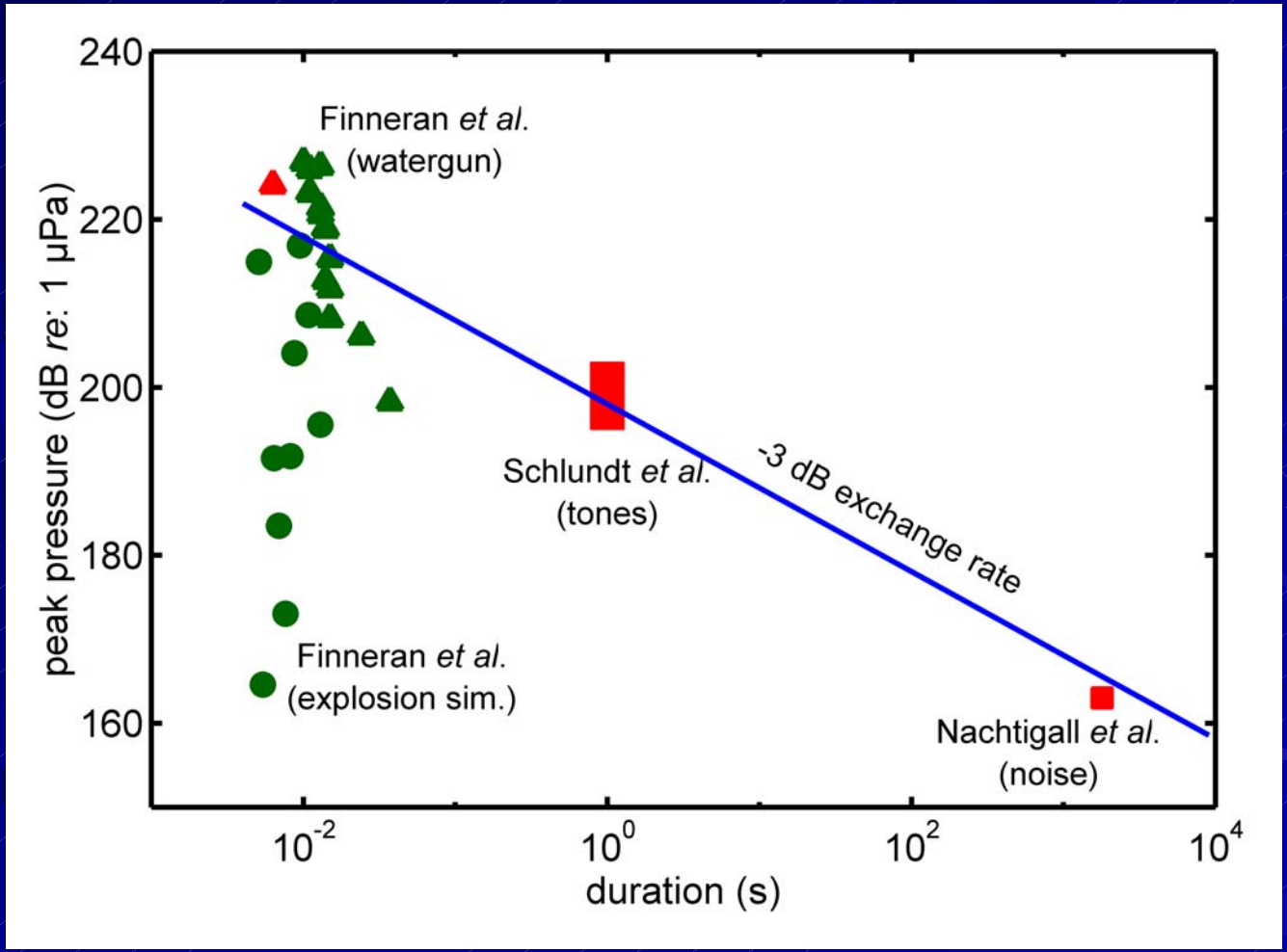

Pre-exposure
Post-exposure
Freq 1
Freq 2
Freq 3
threshold (dB)
time (min)
135
130
125
120
115
110
105
100
-50
-40
-30
-20
-10
0
10
20

Exposure


Pre-exposure
Post-exposure
TTS & Recovery
6 dB
Freq 1
Freq 2
Freq 3
threshold (dB)
time (min)
135
130
125
120
115
110
105
100
-50
-40
-30
-20
-10
0
10
20

Data Summary (dolphins & white whales)

- **Effect is a function of amplitude and duration**
- **Slope of -3 dB per doubling of time fits data reasonably well**
  - **-3 dB exchange rate**
  - **“equal-energy” criterion**

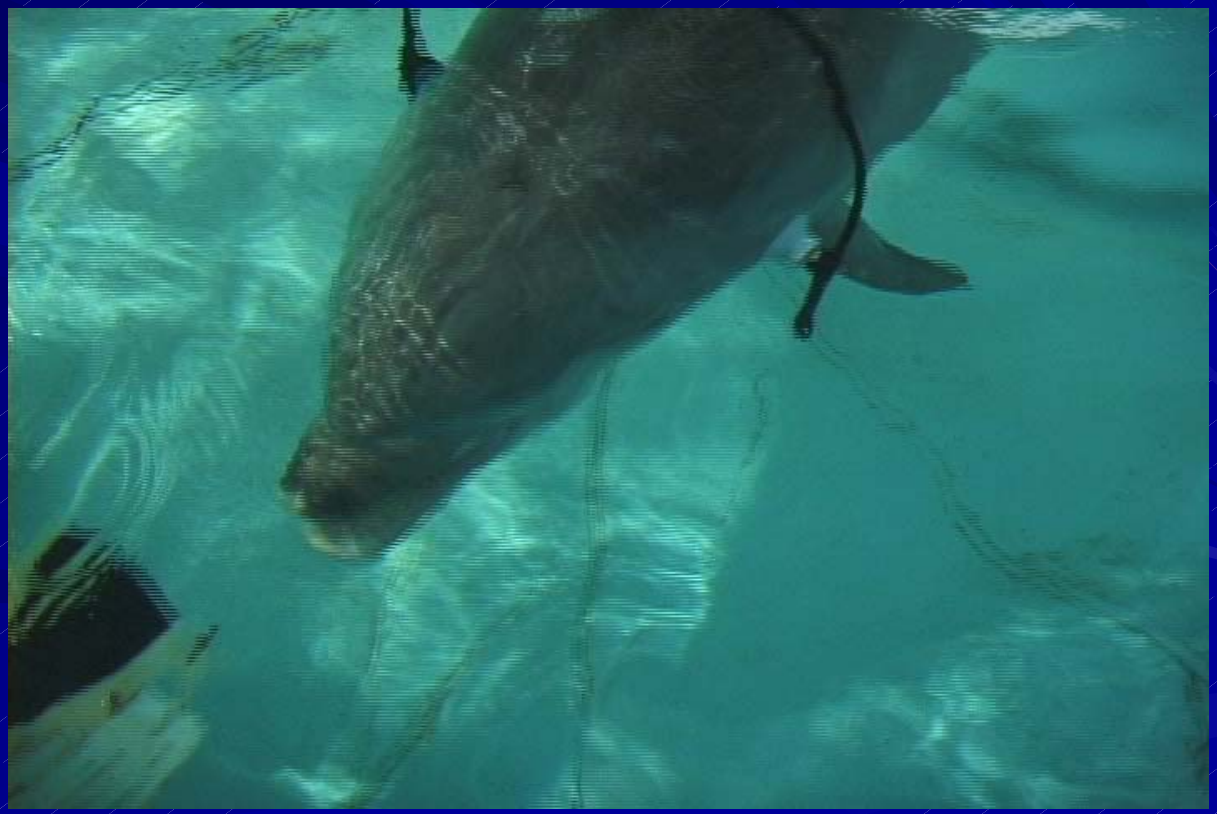


Current data gaps

- Ideal approach – laboratory/open-water setting, repeatable, sophisticated questions
  - Effects of multiple impulses
  - Effects of multiple intermittent tones
  - Frequency dependency of TTS
  - Depth dependant effects
  - Fatigue of protective mechanisms
  - Transition from short tones to impulses
- Imperfect approach – technology modeling and strandings
  - Hearing thresholds, TTS, and effects of high-intensity sounds on large odontocetes and mysticetes
  - Remote imaging and finite element modeling
  - Stranded whale action team
  - Dry-docked whale

- Dolphin trained to wear hydrophones mounted on suction cups
- Allows accurate measurement of sound exposure

hydrophones



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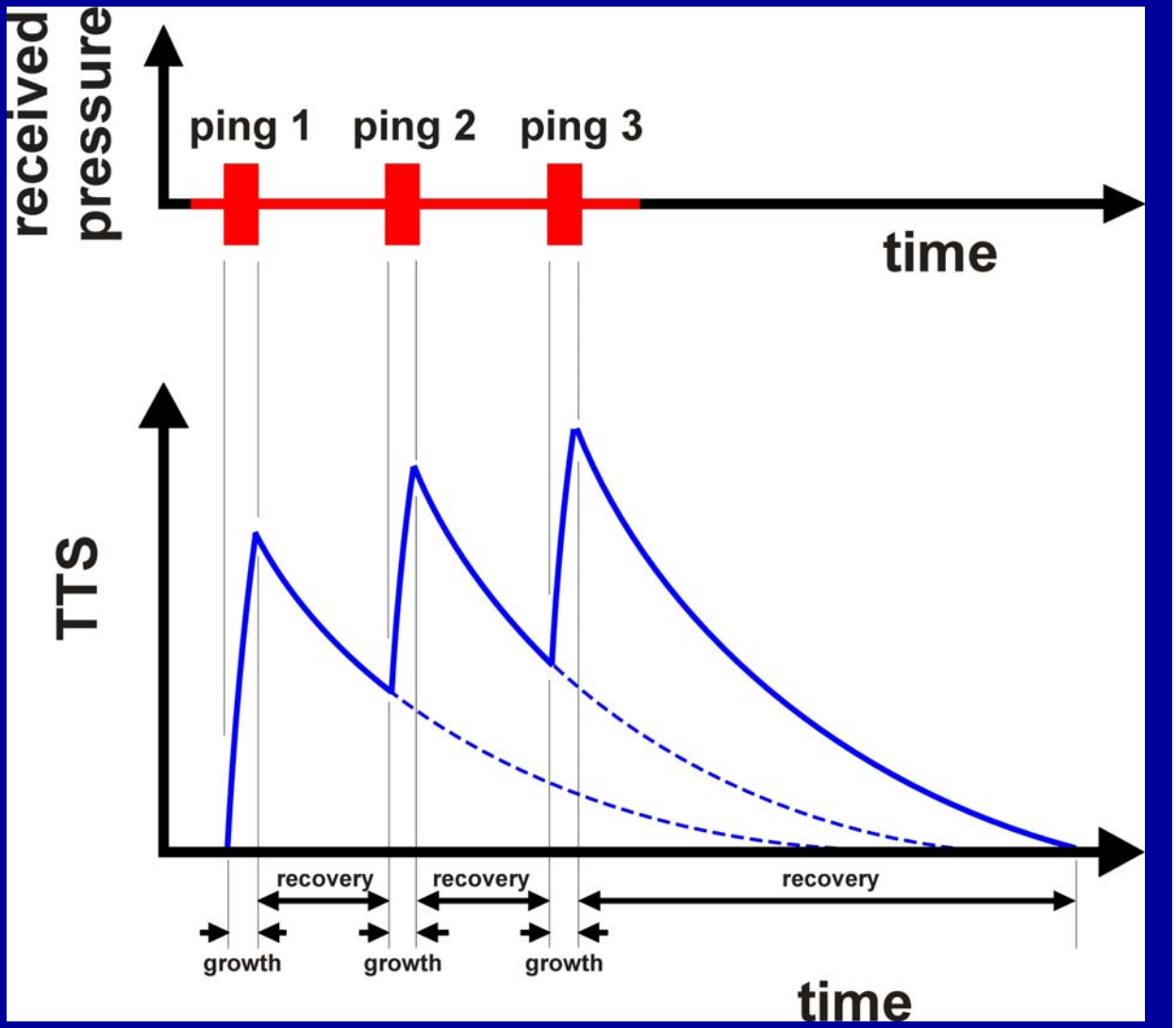
Future work

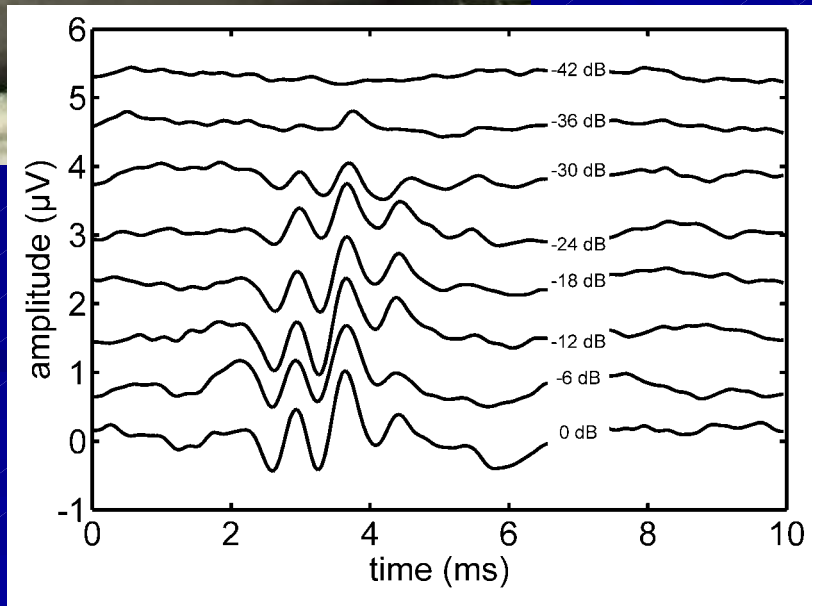
- TTS growth and recovery for longer duration tones
- Effects of intermittent tones



Evoked Potential Measurements

- Some work has been done to develop a system for auditory evoked potential measurements
  - **Assess hearing in subjects not trained for behavioral response paradigm**
  - **Stranded animals**

Dolphin AEP Example Data



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Thank You