Histological Study of Synergistic Protective Effects of Helmet and Earplugs on Blast-Induced Auditory Injuries in Chinchilla

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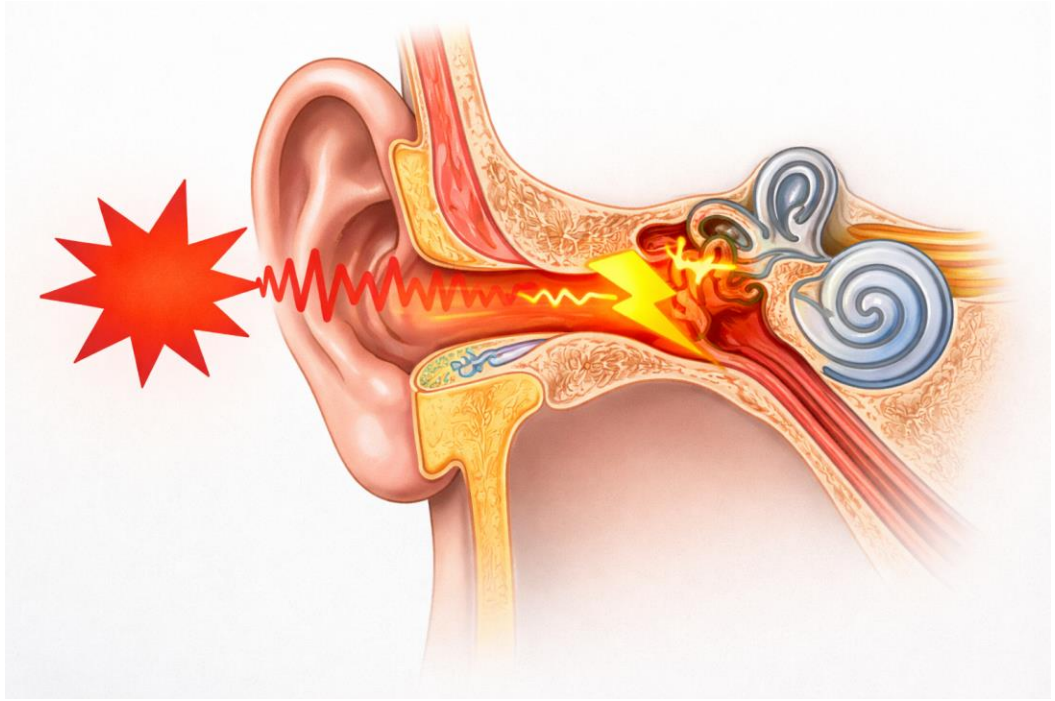
BIOMEDICAL
Engineering Laboratory

Non-Disclosure

- Qunfeng Cai, PhD, MD, has no conflict to report
- Roshan Sharma, MS, has no conflict to report
- Shangyuan Jiang, PhD, has no conflict to report
- Rong Z. Gan, PhD, has no conflict to report
- Yijie Jiang, PhD, has no conflict to report

Introduction



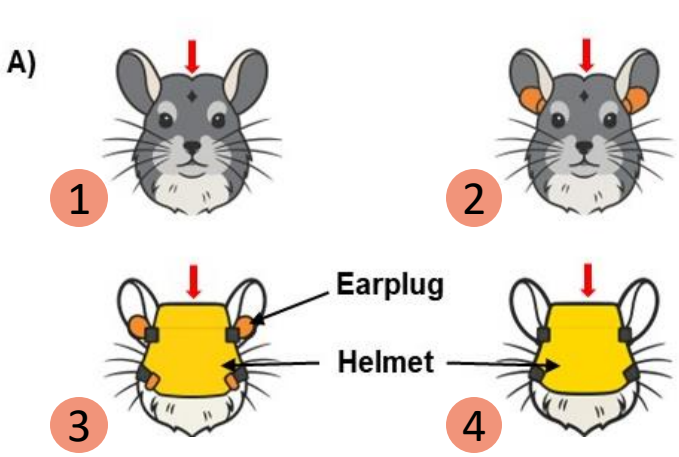
Source: AI generated

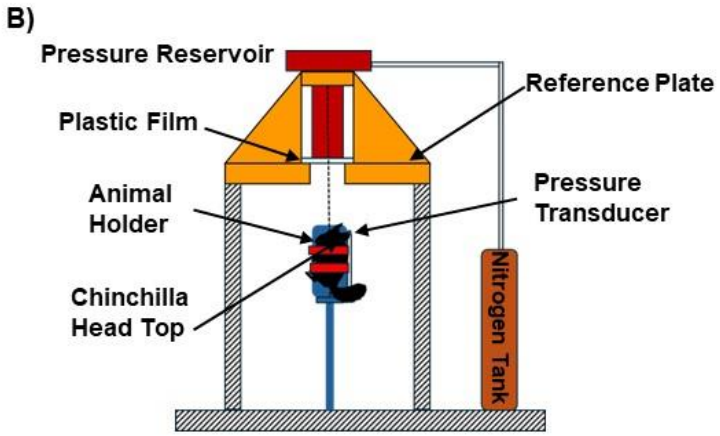
Blast-induced auditory injuries:

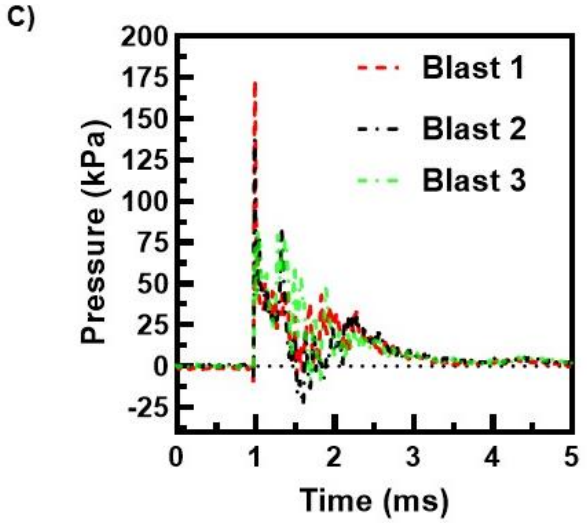
- Severe hearing damage can be caused by intense blast overpressure (BOP) in training and battlefield.
- Hearing loss is one of the leading occupational health concerns in military settings and high-risk industries.
- Injuries include tympanic membrane rupture, ossicular chain disruption, and sensorineural hearing loss.
- This study investigates a 3D-printed chinchilla helmet and earplug protection against blast-induced auditory injuries.

Elsayed, Nabil M. "Toxicology of blast overpressure." *Toxicology* 121.1 (1997): 1-15.
Meng, Dejing, and Jichuan Chen. "Hearing Damage Through Blast." *Explosive Blast Injuries: Principles and Practices*. Singapore: Springer Nature Singapore, 2023. 301-317.

Animal model – Chinchillas in 4 cases

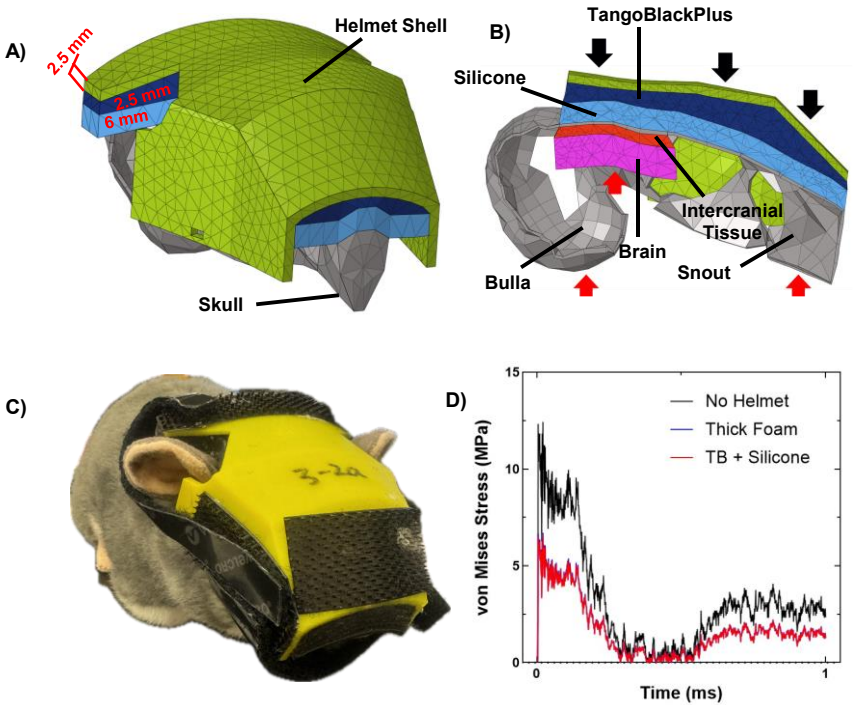


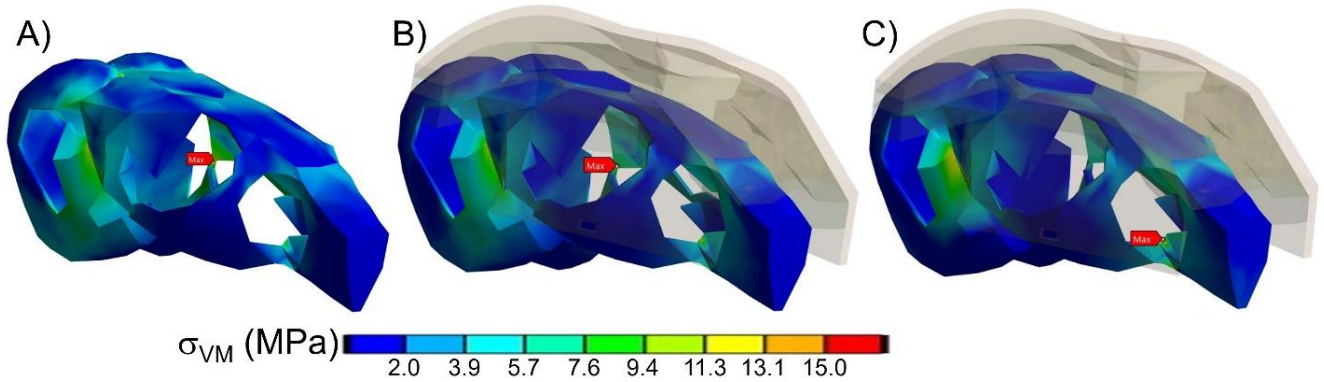




- Illustration of four experimental cases in chinchillas used in this study, red arrow indicates blast direction.
- A schematic of animal experimental setup with blast apparatus.
- Repeated BOPs measured at the entrance of the ear canal.

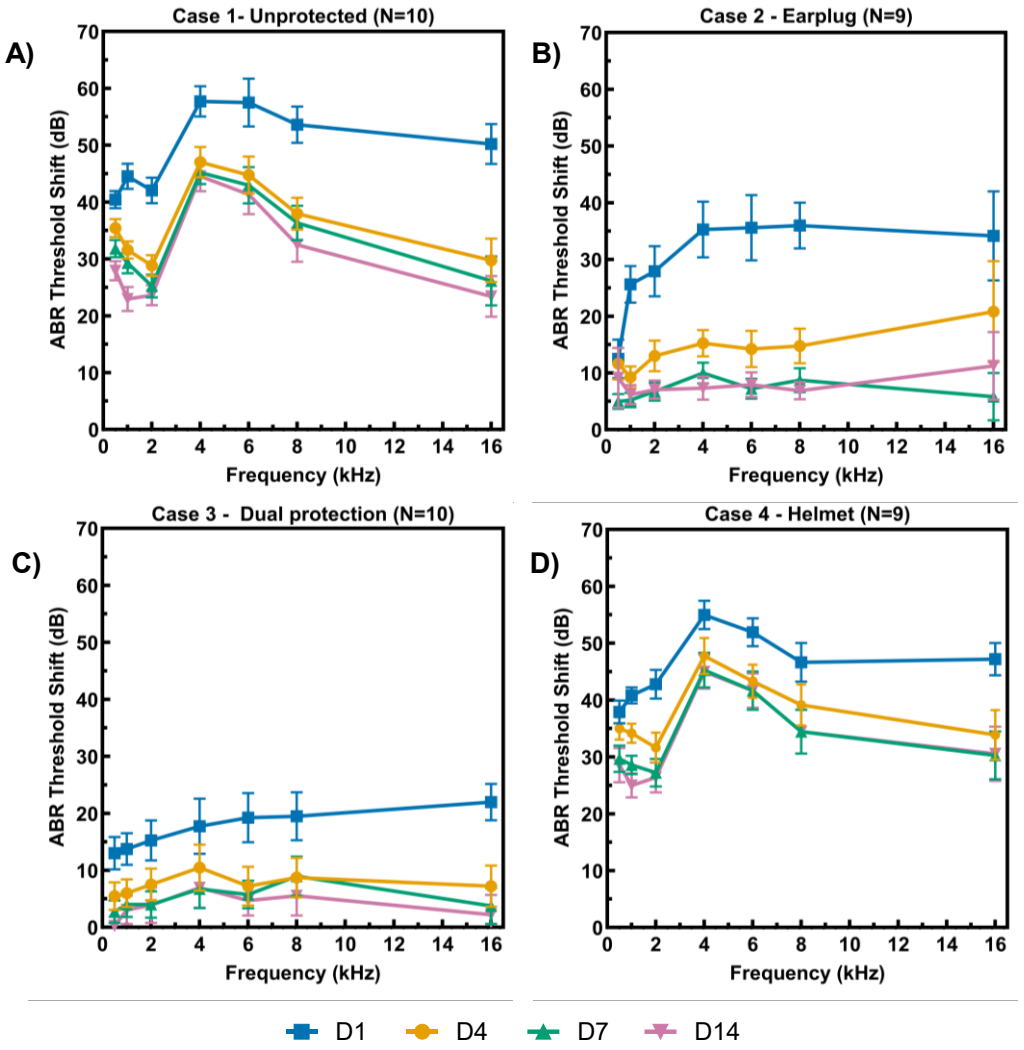
Finite element modeling of helmet protection

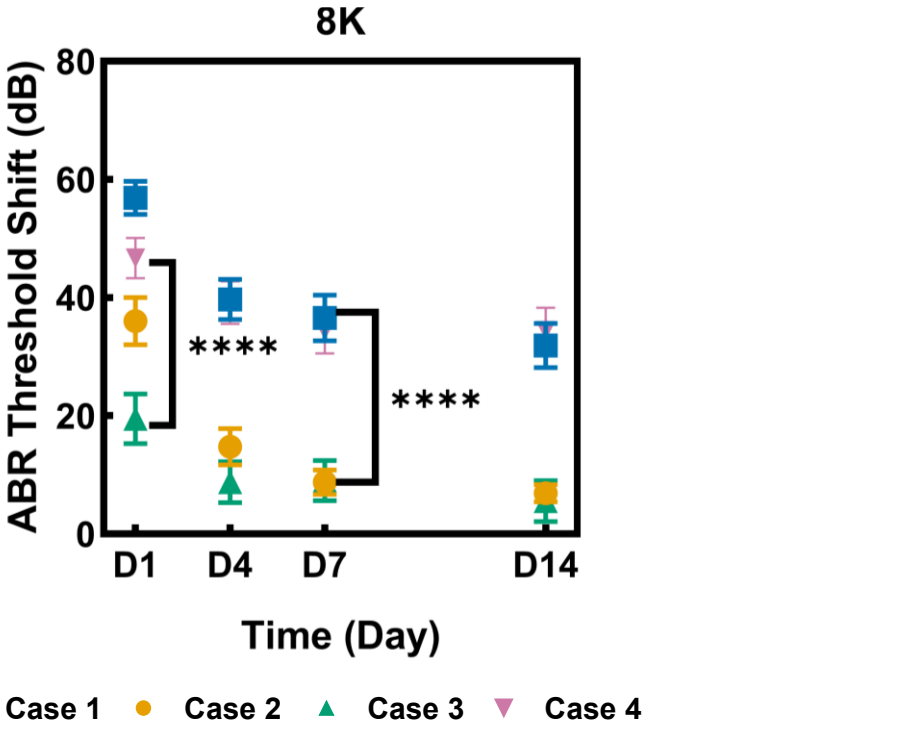




- FE model of the helmet–skull system showing the three-layer helmet structure
- Cross-sectional view of the FE model illustrating helmet materials, skull anatomy, intracranial tissue, supporting boundaries (red arrows), and regions of blast loading (black arrows)
- Simulation results demonstrating reduced blast-induced maximum von Mises stress on top of the skull with no helmet and with helmets
- FE simulation of stress distributions in the chinchilla skull at the time of peak loading following blast exposure

ABR tests



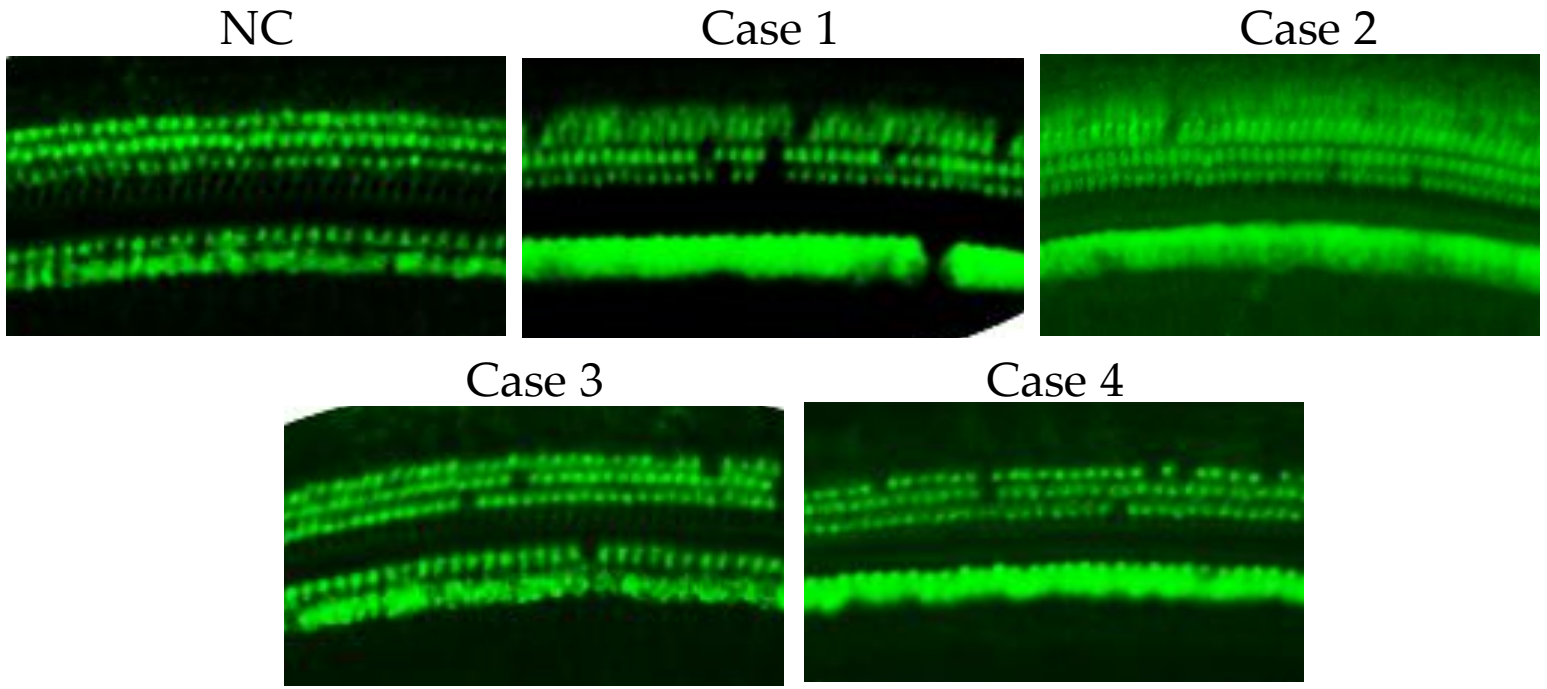


- ABR threshold shifts for four post-blast time points, Day 1 (post blast) to Day 14 across four experimental groups.
- Significant differences are observed among cases, highlighting the efficiency of dual-protection case (Case 3)

Histological study of cochleae

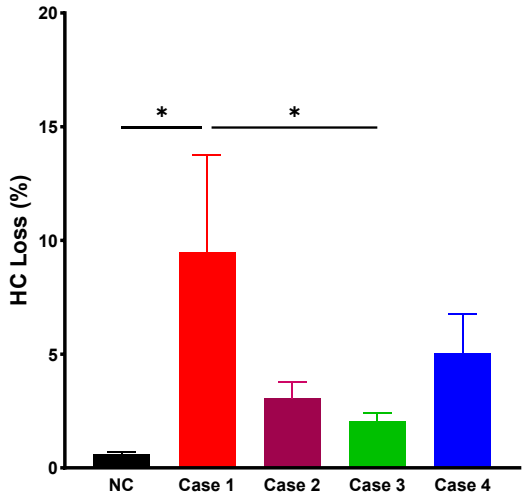
- All specimens are collected at Day 14
  - Naive control (NC) and the 4 cases
- Hair cells (both inner and outer hair cells)
  - Immunolabeled with Myosin VIIa
- Ribbon synapses
  - Immunolabeled with CtBP2
- Spiral ganglion neurons (SGNs)
  - Toluidine blue staining

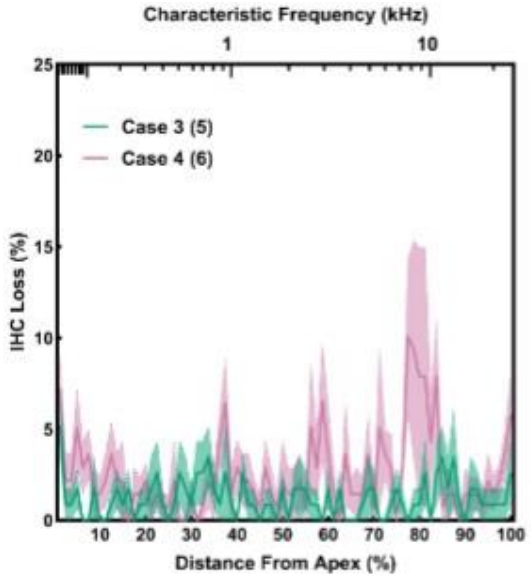
Hair cells loss

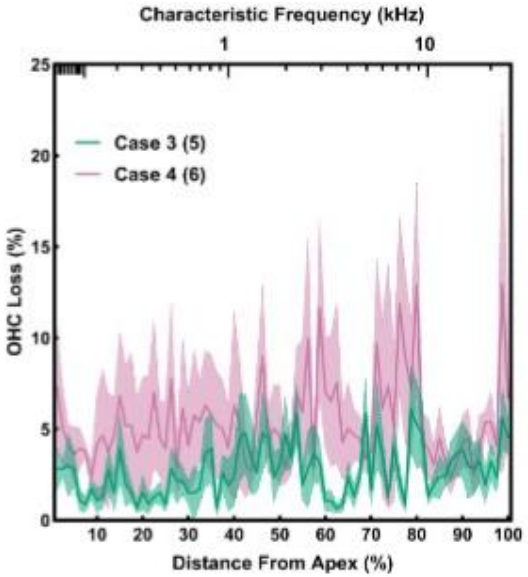


- Representative images of immunolabeled cochlear hair cells (survived at Day 14)
- Missing hair cells are observed in all four cases and for both inner and outer hair cells
- Cochleogram depicts the percentation of missing hair cells along the basilar membrane

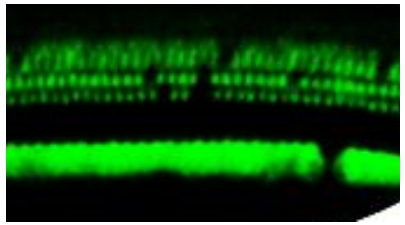
Hair cells loss



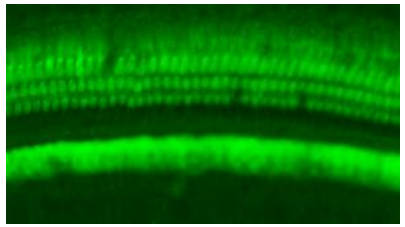




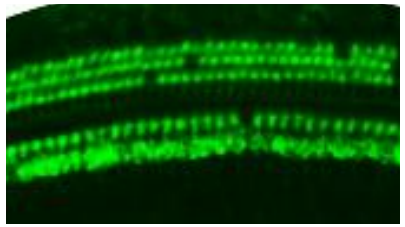
Case 1



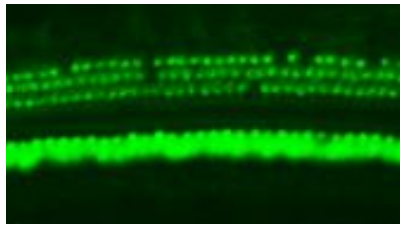
Case 2



Case 3



Case 4



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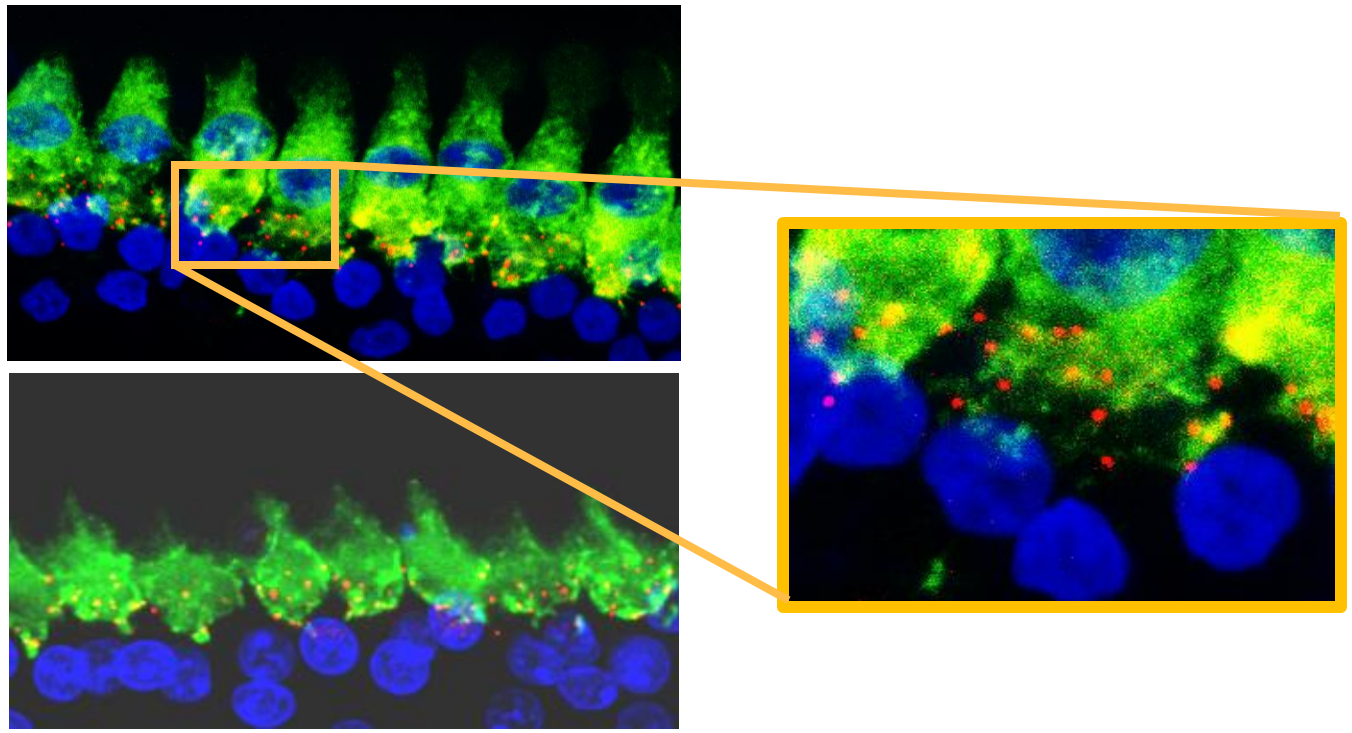
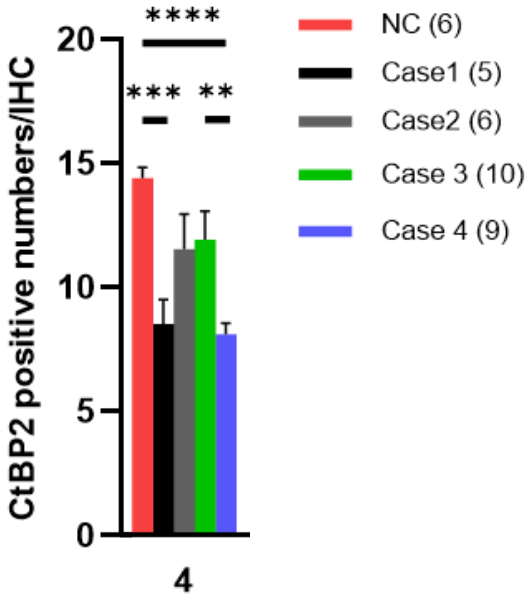
Ribbon synapses

NC

Post-Blast





- Confocal imaging shows the IHC ribbon synapses (CtBP2 immunolabeled)
- Blast exposure reduced the cochlear ribbon synapse counts in IHCs
- Dual-protection case generally preserved more ribbon synapses

Ribbon synapses

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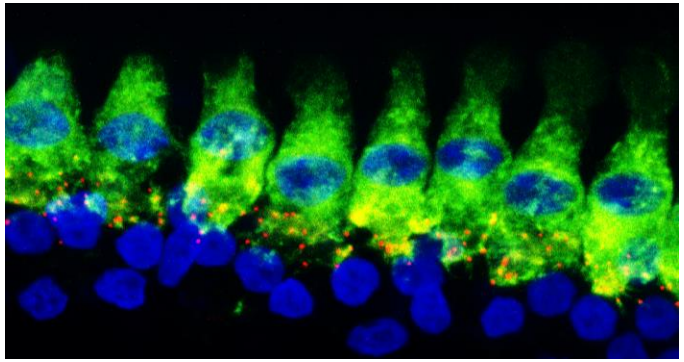
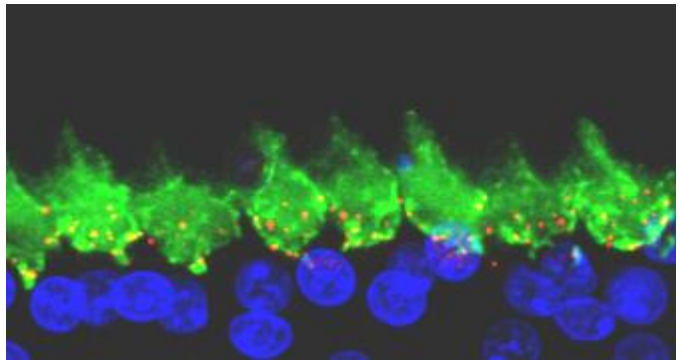
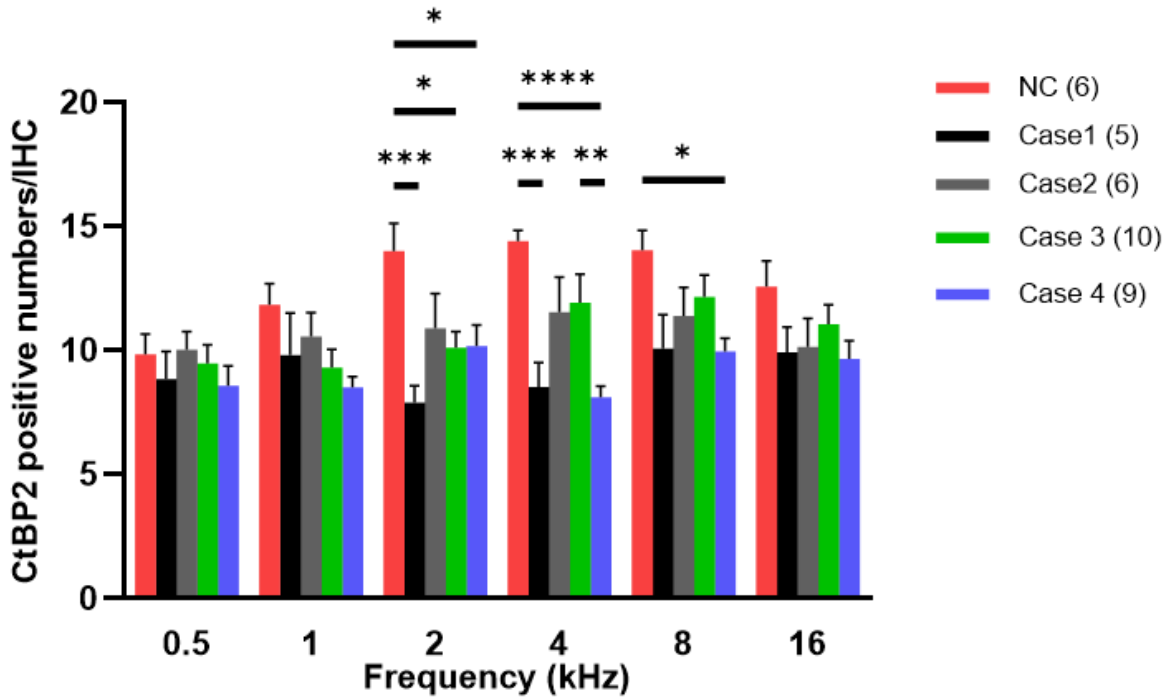


Post-Blast





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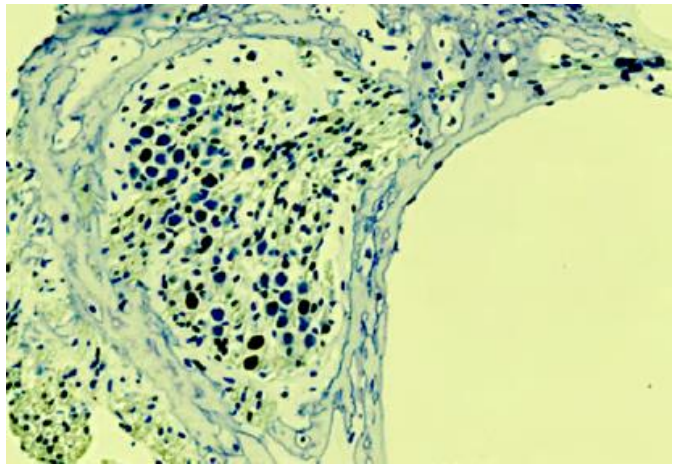
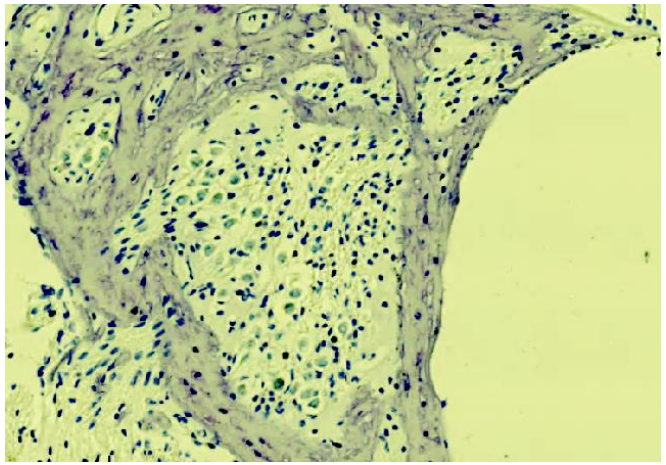
SGNs density

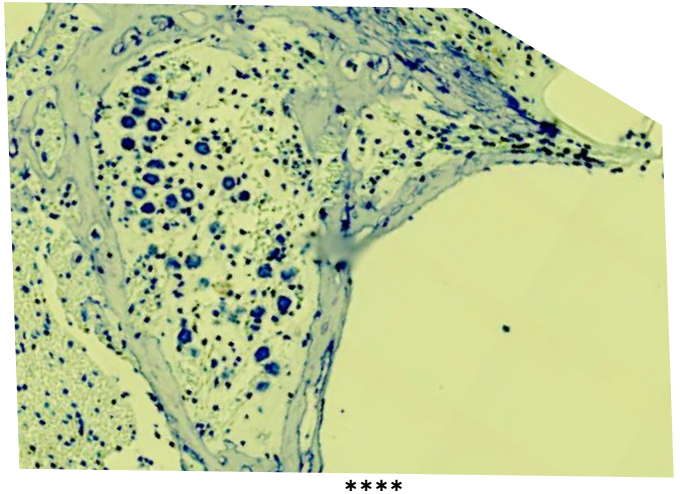
NC



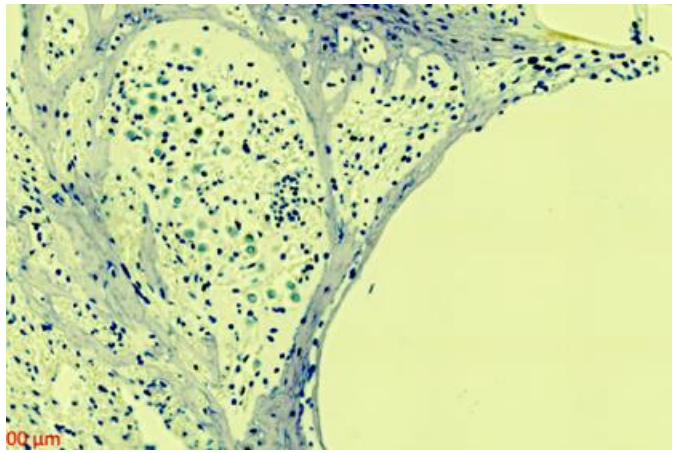
Case 1



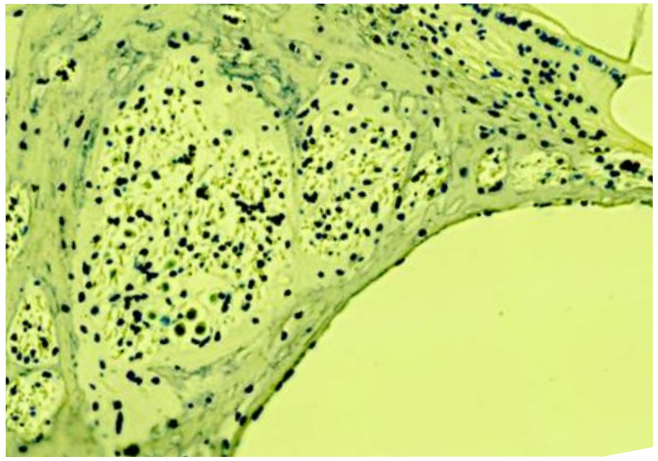
Case 2

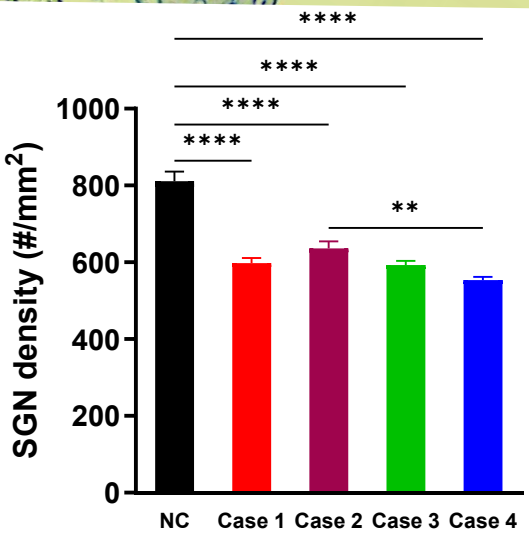


Case 3



Case 4





Conclusions

- BOPs caused significant auditory dysfunction and cochlear pathology, including HC loss, ribbon synapse injury, and SGNs degeneration.
- Dual-protection (combined earplug and helmet protection) provided a significant reduction in ABR threshold shifts and cochlear damage compared with single protection and no protection cases.
- These findings highlight the value of integrated protection strategies to mitigate blast-induced auditory injury

- Acknowledgement

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The views, opinions, and/or findings are those of the author(s) and should not be construed as an official Department of War, Defense Health Program position, policy, or decision unless so designated by other documentation.