Physical Mechanism of Brain Deformation under Operational Blast Exposure

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Non-Disclosure

MHSRS 2026
Military Health System Research Symposium

- **Enze Chen, Ph.D., has no conflicts to report.**
- **Disclaimer**: All analysis, findings, and conclusions were prepared independently by the author(s) and are not endorsed or verified by Iowa State University of Science and Technology, its College of Engineering, or the CARES Laboratory.

Acknowledgments

- **Dr. Christian Franck (PANTHER Director, University of Wisconsin-Madison)**
- Arvin Chen (University of Wisconsin-Madison)
- Cody Ottinger (University of Wisconsin-Madison)
- Dr. Sarah Bentil (Iowa State University)
- William Jackson (Iowa State University)
- Dr. Haneesh Kesari (Brown University)
- The PANTHER Team
- Aashutosh Kulakarni Prachet (Brown University)
- Dr. Rika Carlsen (Robert Morris University)
- Dr. Manik Bansal (Robert Morris University)
- Dr. Showren Datta (Robert Morris University)
- Dr. Aviad Hai (University of Wisconsin-Madison)
- Dr. Eric Johnsen (University of Michigan)
- Dr. Jing Zhang (University of Wisconsin-Madison)

Dr. Tim Bentley (ONR, Code 342)

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PANTHER Objectives

EXPOSURE

Blunt or inertial loading

Blast or repetitive blasts

Microwave/DE exposure

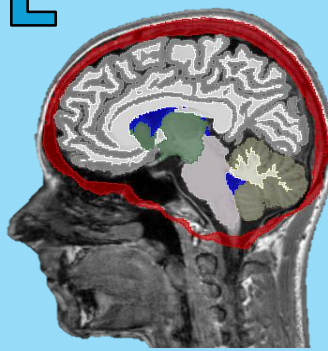
Unknown Source of AHI

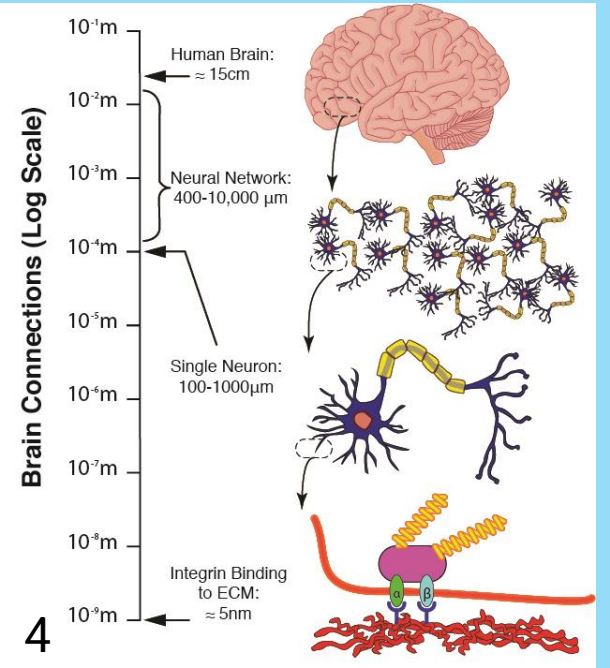
DEFINE BIO-PHYSICAL SAFETY LIMITS

What can the brain withstand?

When is safety limit exceeded?

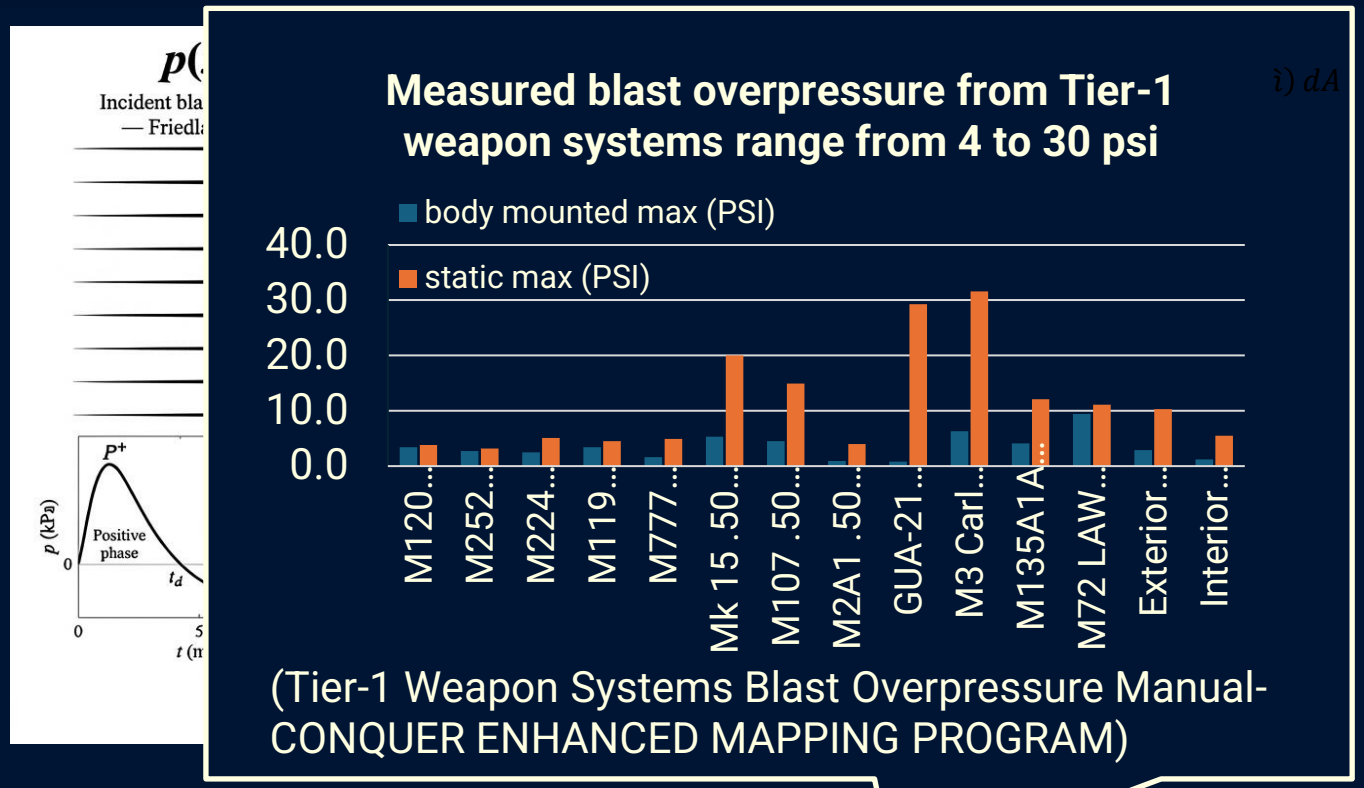
BRAIN CELLS DIE





For today's talk: Problem we want to solve…

Primary blast traumatic brain injury (bTBI)



(Tier-1 Weapon Systems Blast Overpressure Manual- CONQUER ENHANCED MAPPING PROGRAM)

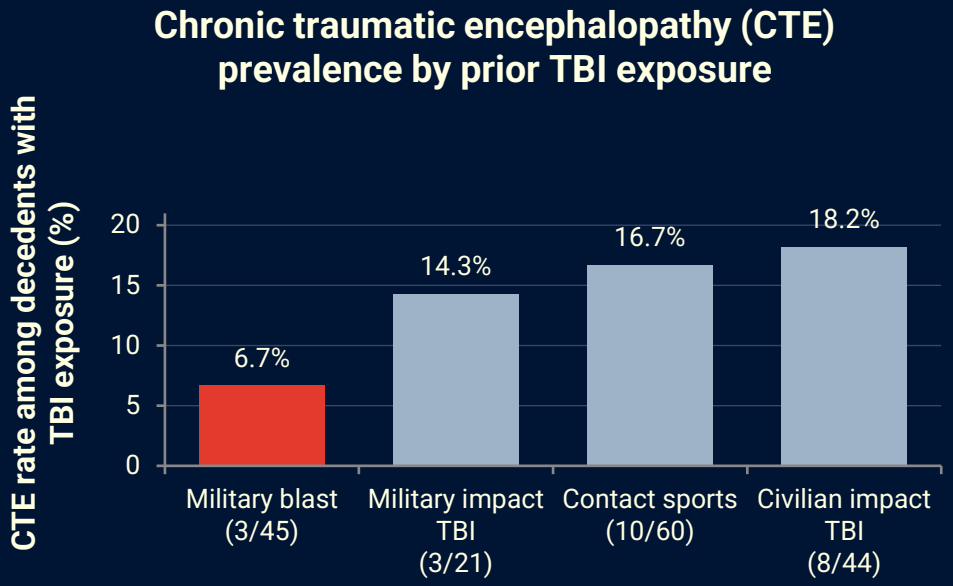
Question: What is the ***physica echanism*** of blast TBI?

Focus on BOPs of 4 – 30 psi (Tier 1 Weapons Range)

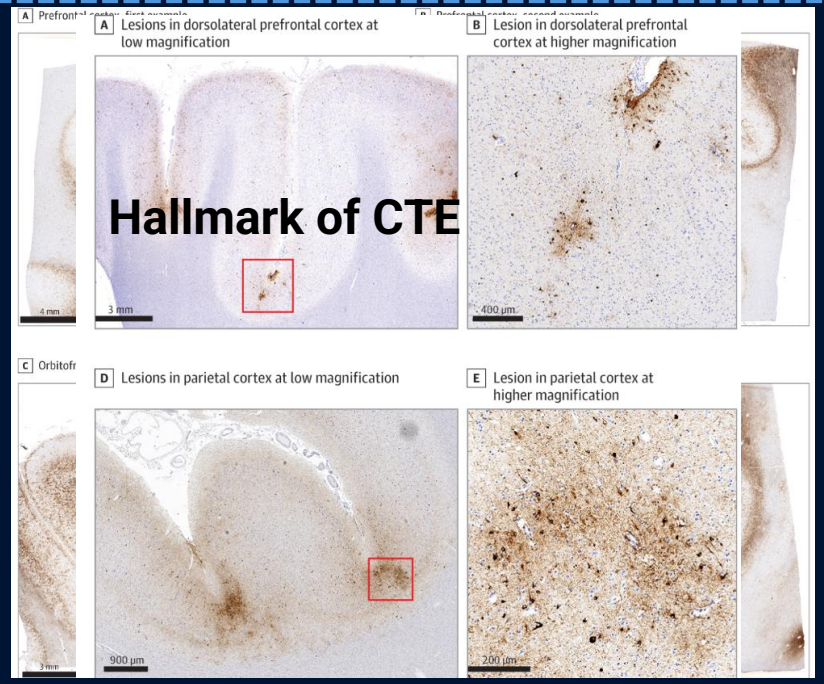
NY Times
https://www.nytimes.com/2023/12/21/us/army-blast-safety-brain-injuries.html

What do we know about bTBI?

- Blast-related traumatic brain injury (TBI) is a significant health burden for the US warfighter, often called the “signature injury” from the wars in Iraq and Afghanistan.
- The injury pathology is somewhat inconsistent with what we know from conventional TBIs



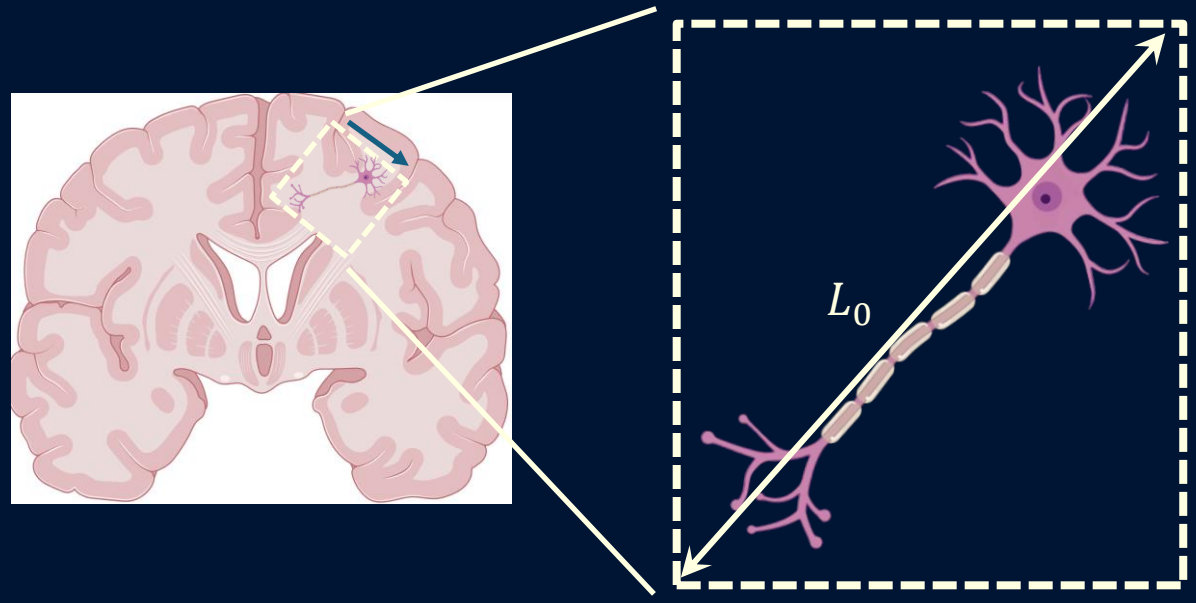
Much lower CTE rate from military blast vs impact TBI (n=225) [Premier et al., 2022.]



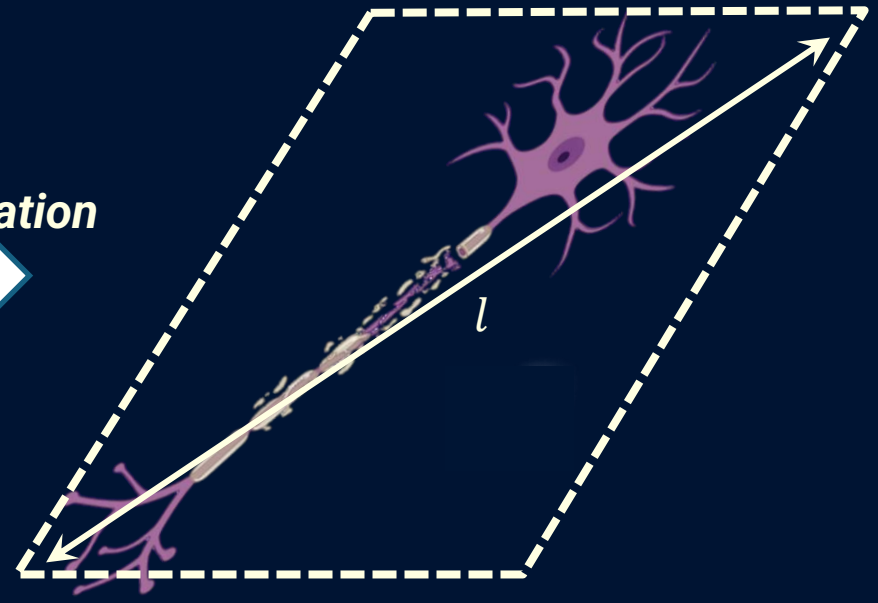
SWCC showing significant perivascular deposits of phosphorylated tau protein [Priemer et al., 2025]

***Question*: What underlying physics (mechanics) can explain both the shared similarities and differences in pathology? (Brain strain & strain rate)**

What do we know about bTBI?



Shear deformation



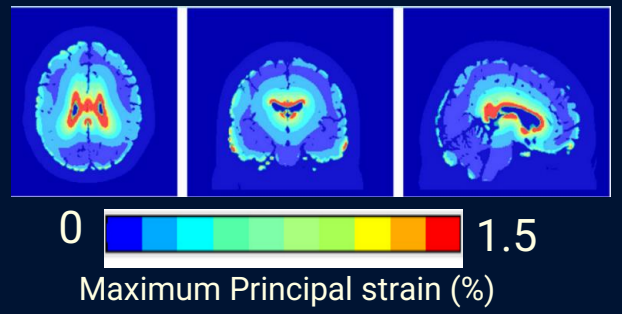
$$\text{Strain} \propto \frac{l - L_0}{L_0}$$

$$\text{Strain rate} \propto \frac{\text{strain}}{\Delta t}$$

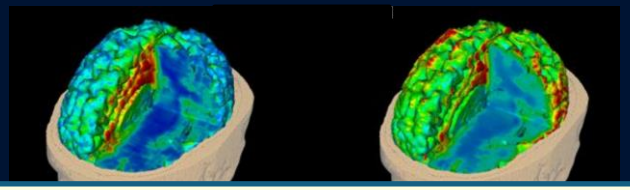
Can current hypotheses explain the pathology?

- Numerical Simulations have shown low tissue strains following blast exposure

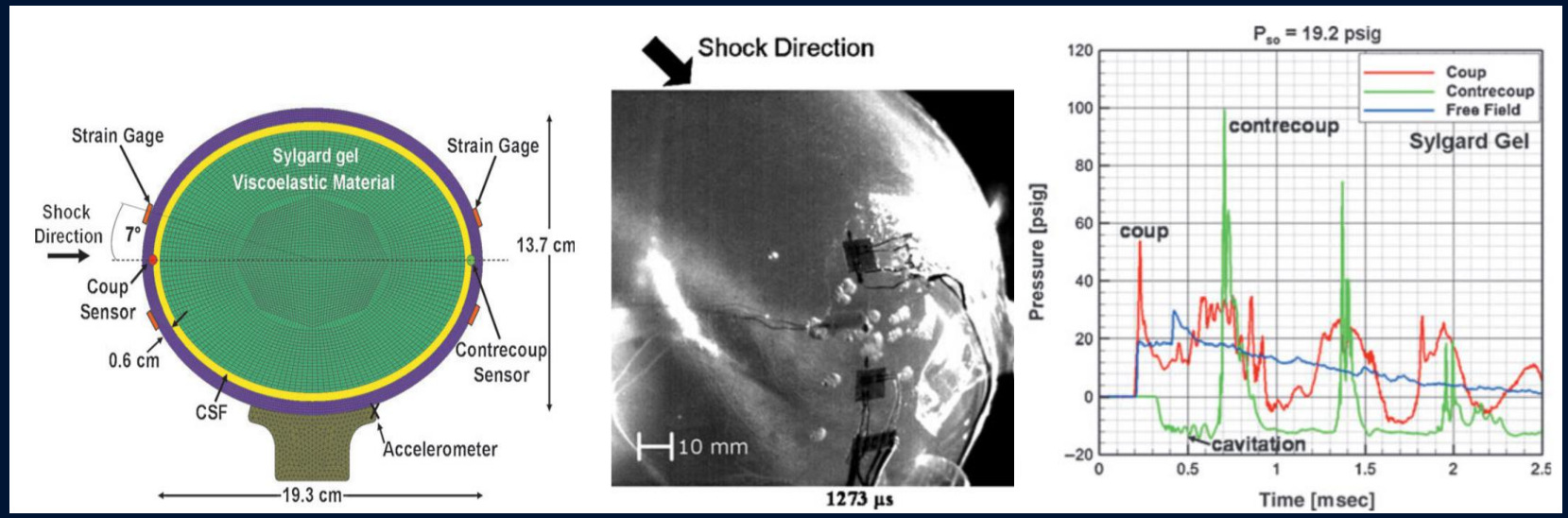
Frontal blast pressure of 73.5psi [1]



Frontal blast pressure of 44 psi [2]



- This motivated the hypothesis of *inertial cavitation* as an injury mechanism



Negative pressure from blast exposure [3]

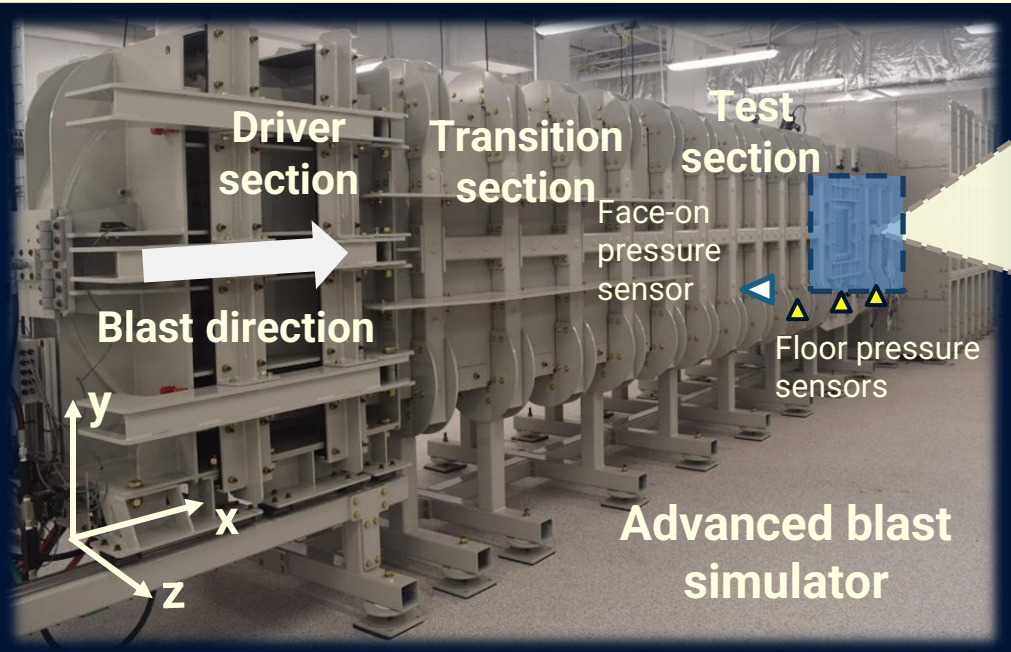
- Inertial cavitation is unlikely to account for **widespread injury** due to

without experimental validation.

Bottom Line: *Still lacking* a physical mechanism consistent with the observed post-mortem pathologies

[1] Krysl et al., 2012 [2] Yu and Mazdak, 2019 [3] Goeller et al., 2012

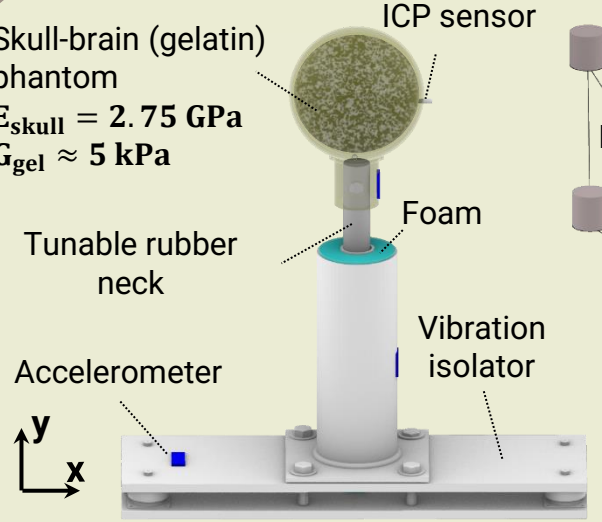
PANTHER Approach: Controlled blast exposure on transparent skull-brain phantom via the Advanced Blast Simulator (ABS)



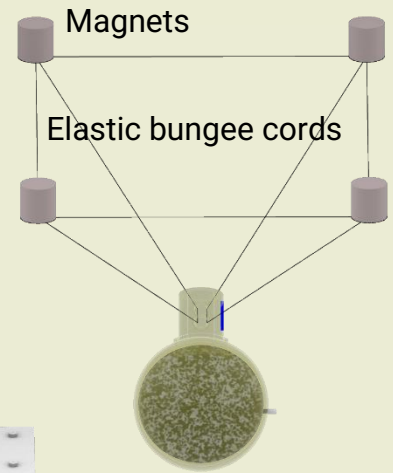
Skull-brain (gelatin) phantom

$E_{skull} = 2.75\ GPa$

$G_{gel} \approx 5\ kPa$

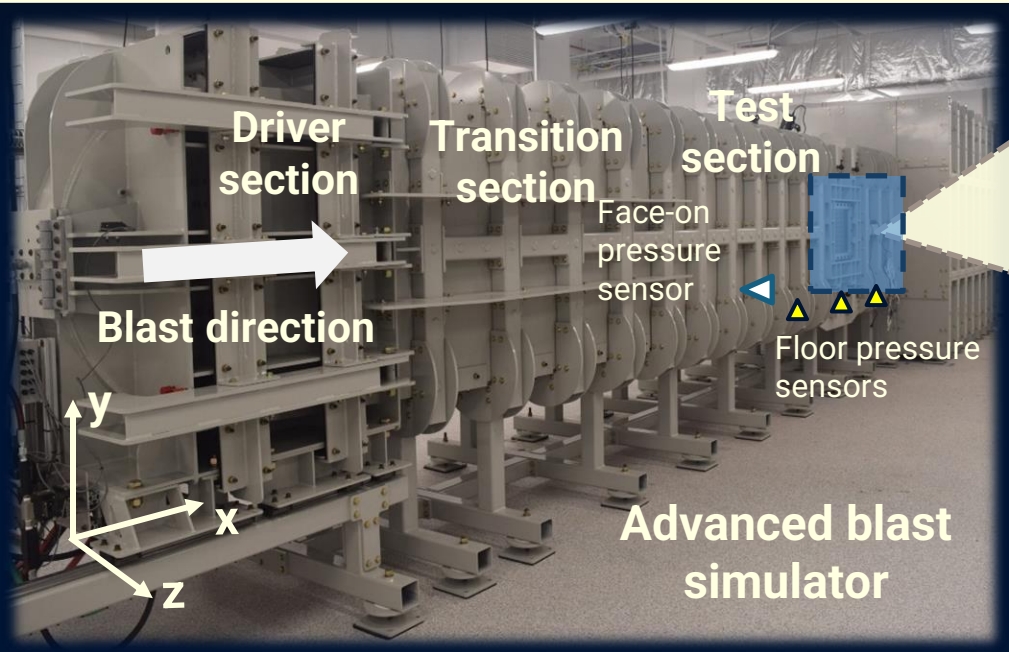


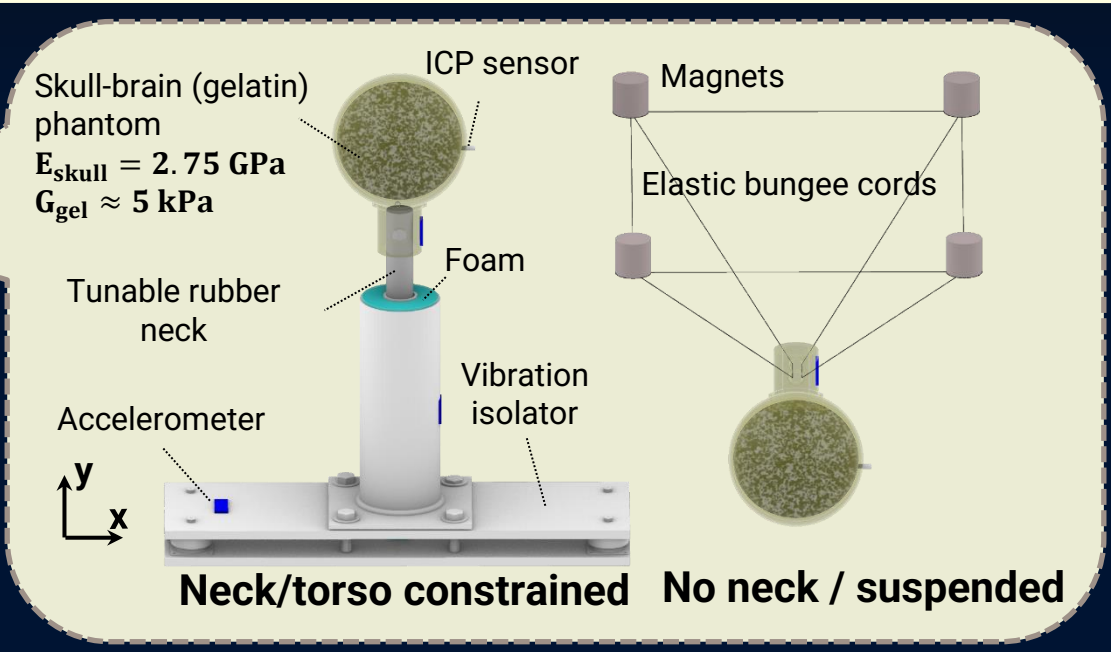
Neck/torso constrained

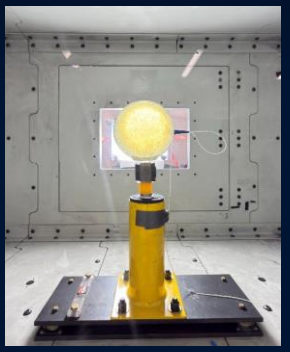


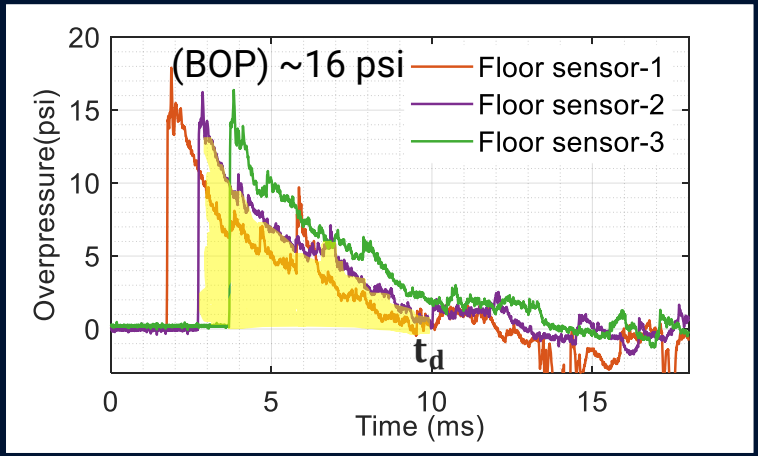
No neck / suspended

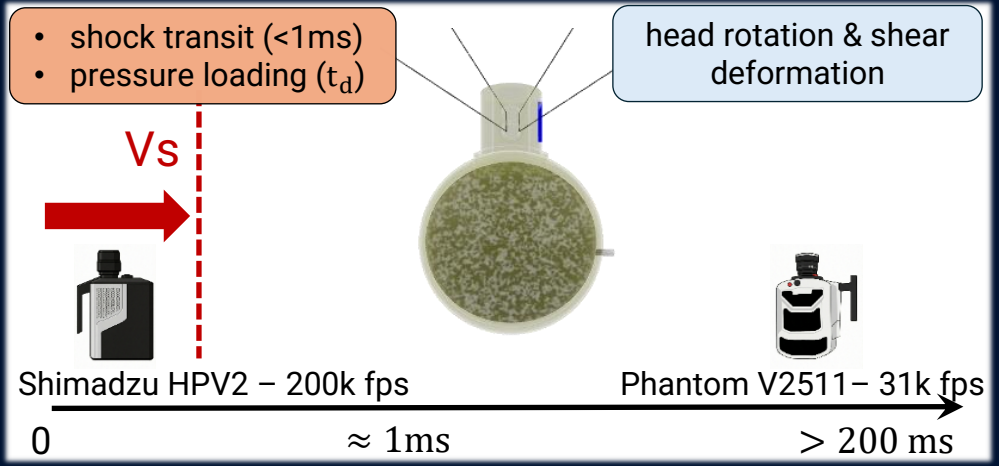
PANTHER Approach: Controlled blast exposure on transparent skull-brain phantom via the Advanced Blast Simulator (ABS)



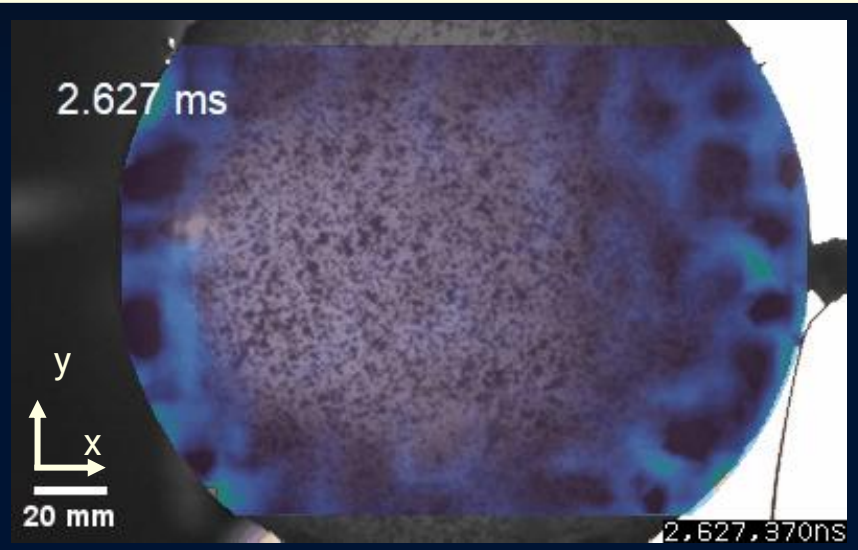




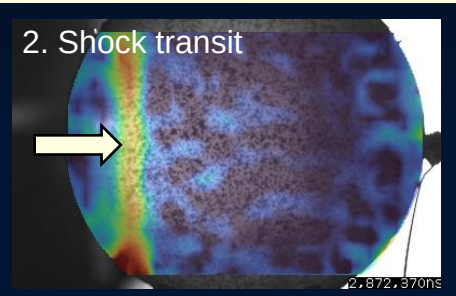


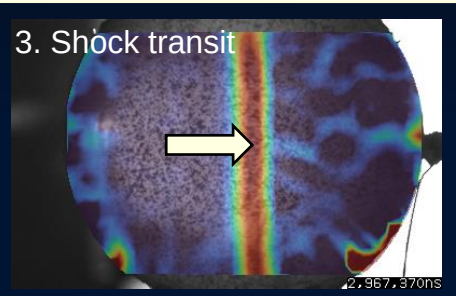


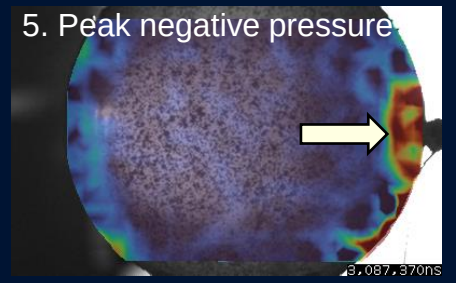
Shock transit dynamics – kinematics + pressure histories

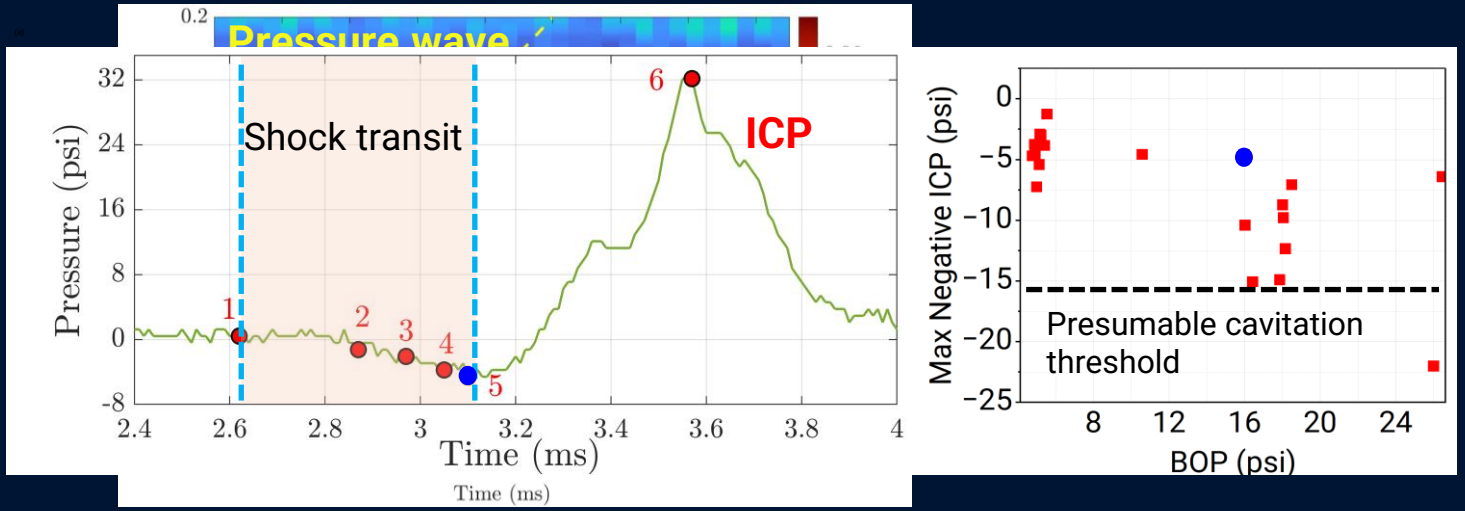


Shock front tracking via DIC (BOP: ~16 psi)





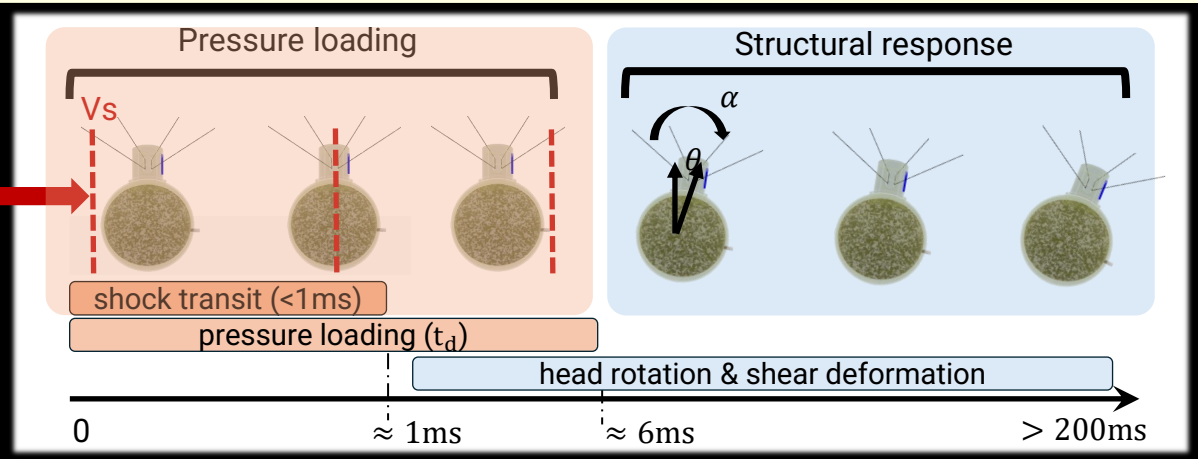


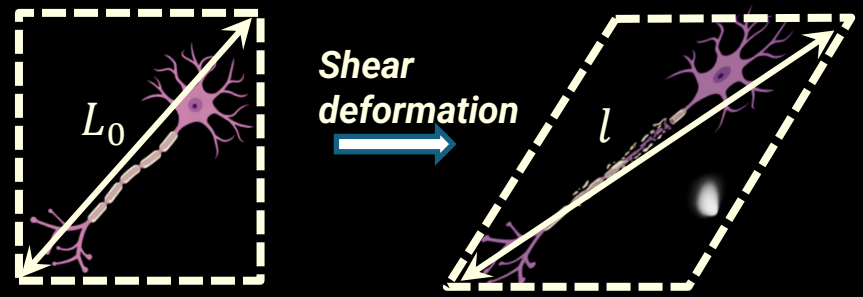


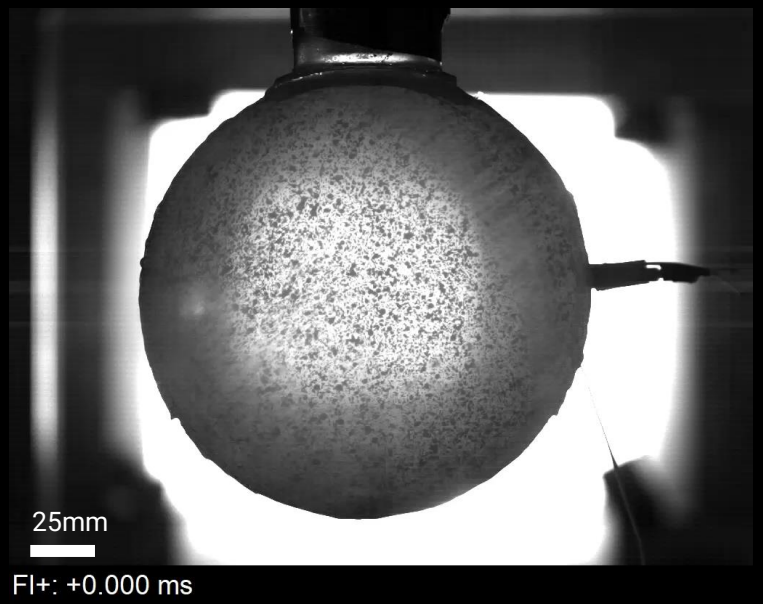
- **No observable deformation occurs within 1.2 ms of the shock–brain interaction!**
- **No cavitation is observed due to the small magnitude of the negative pressure.**

Shear wave regime – creation of internal deformations

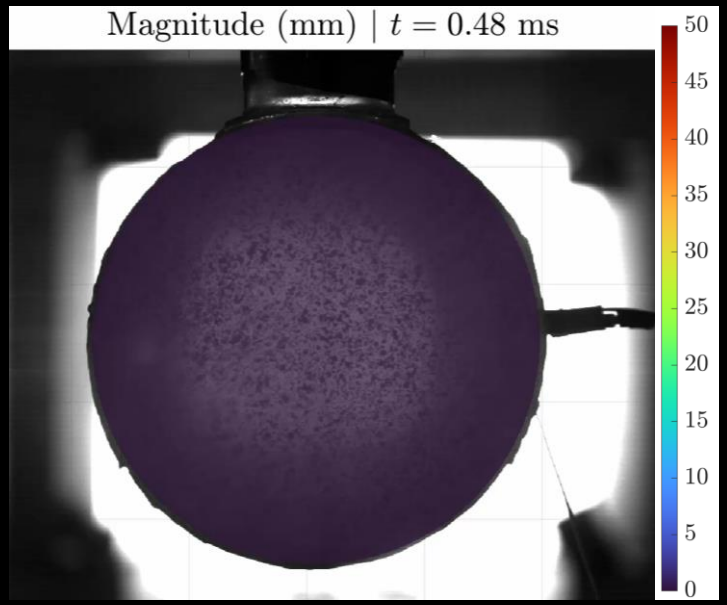
- No cavitation
- No deformation







Rigid body motion and gel deformation tracking via **RAFTcorr** deep learning image correlation [1]



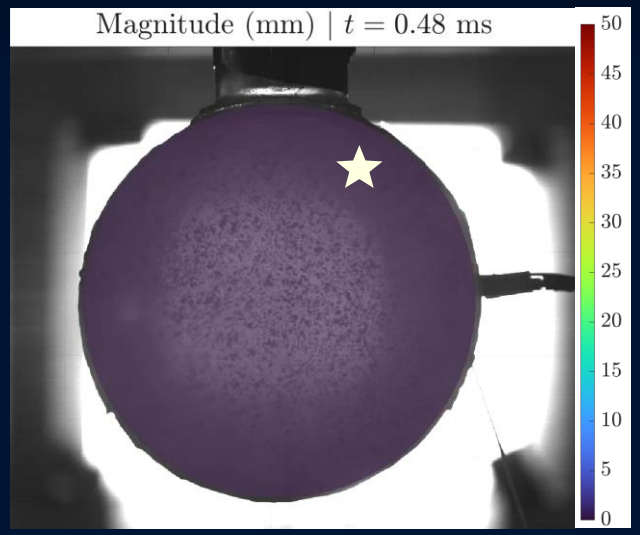
U_θ

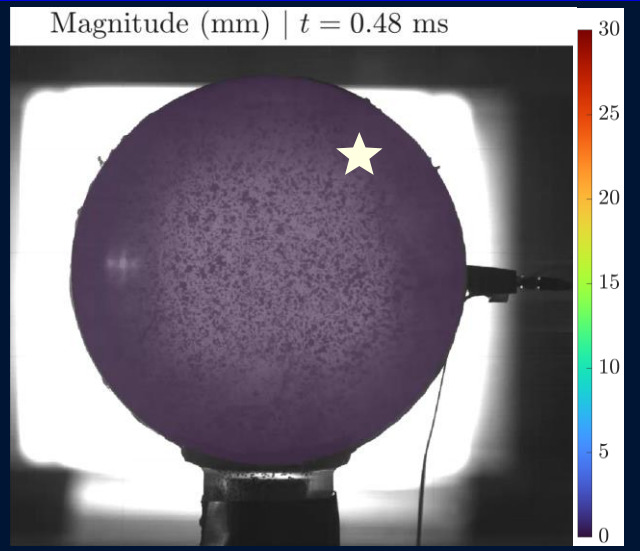
- Internal deformation is predominantly circumferential and is driven by skull rotation.

[1] Tong et al 2025

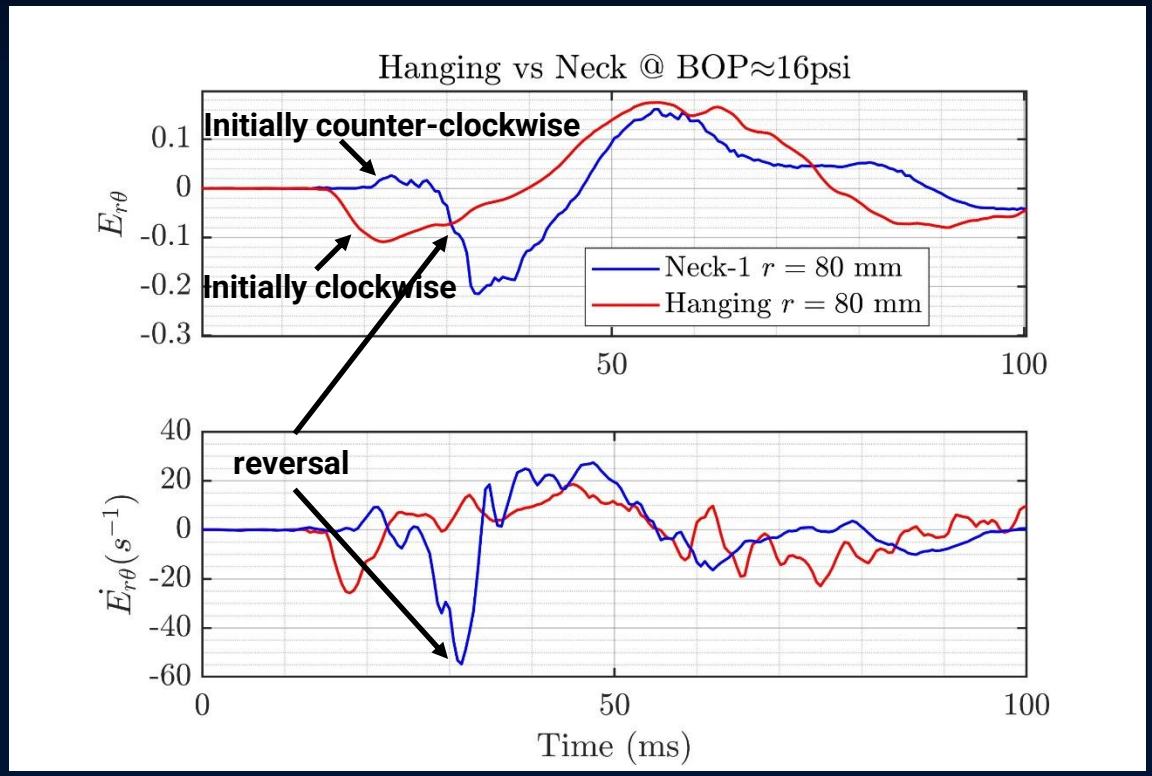
Spatiotemporal evolution of internal shear strains – the ”neck effect” (aka boundary condition effect)

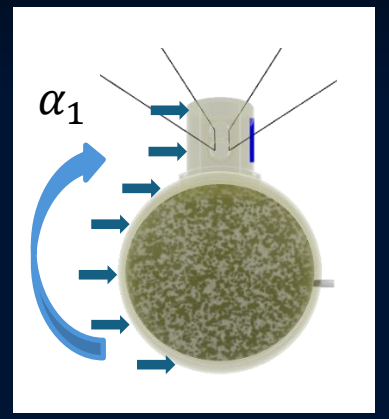
No neck

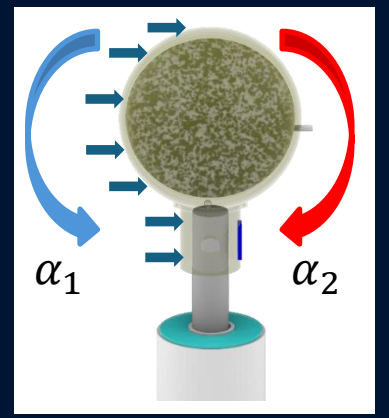




Neck/torso

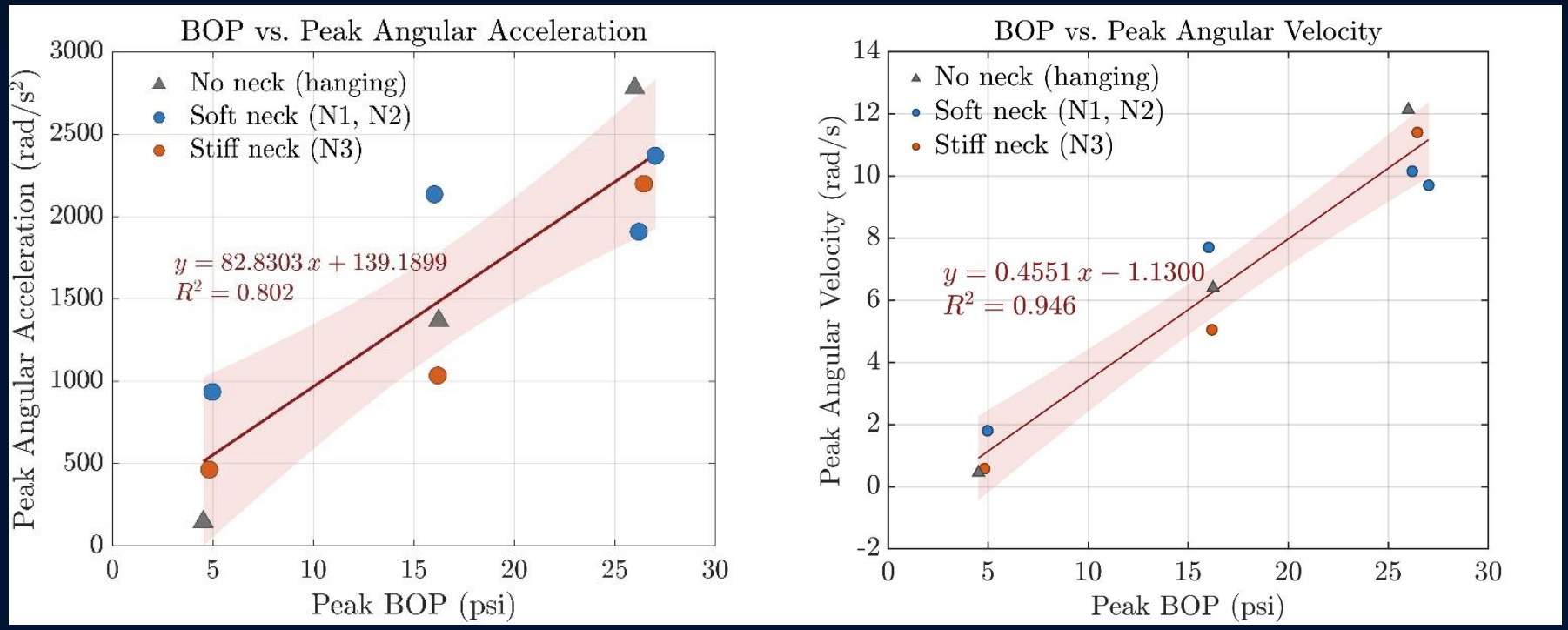






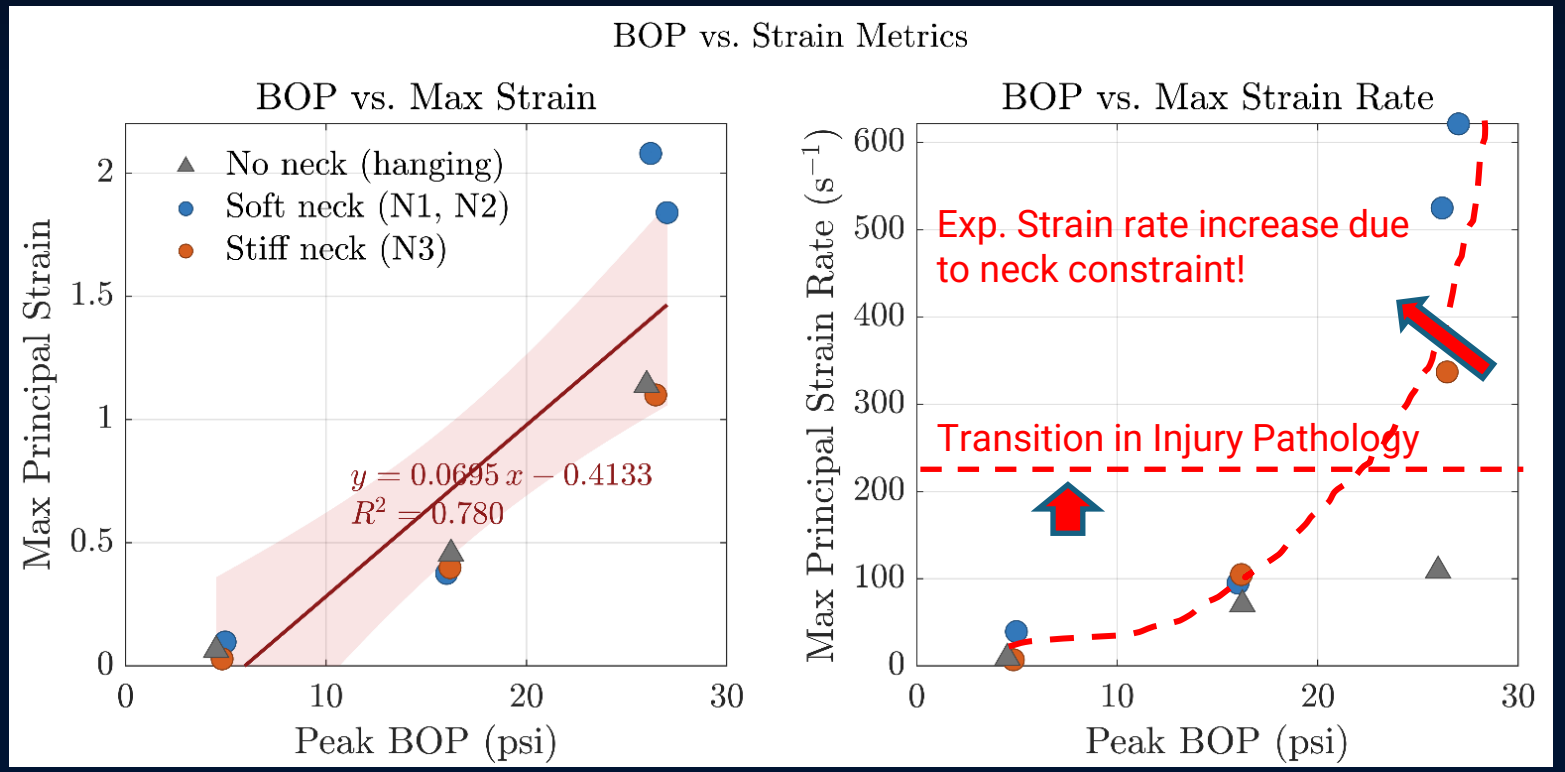
Neck/torso constraint rapidly reverse the skull motion that generates ***significant increase*** in shear strain rate!

Summary of Key Findings: Blast loading to skull kinematics



- Blast overpressure generates significant angular skull accelerations, albeit with small angular velocities.

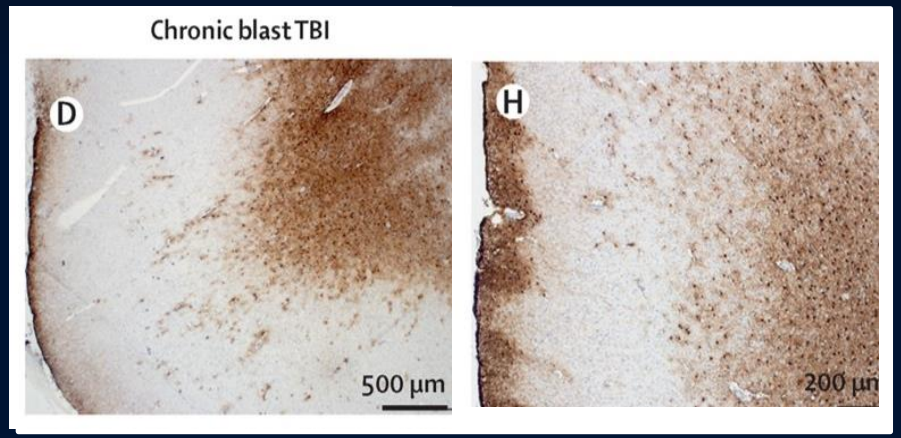
Summary of Key Findings: Blast loading to skull kinematics, to internal shear deformation



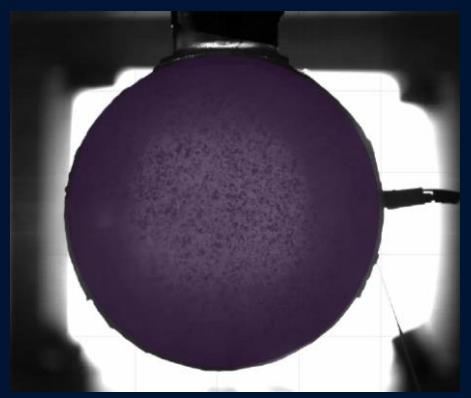
- Blast overpressure generates significant angular skull accelerations, albeit with small angular velocities.
- BOP correlates strongly with internal strain through peak angular acceleration— potential direct blast-to-injurious deformation link ($R^2 = 0.78$).
- Neck/torso constraint ***elevates*** strain rate, ***not*** peak strain.

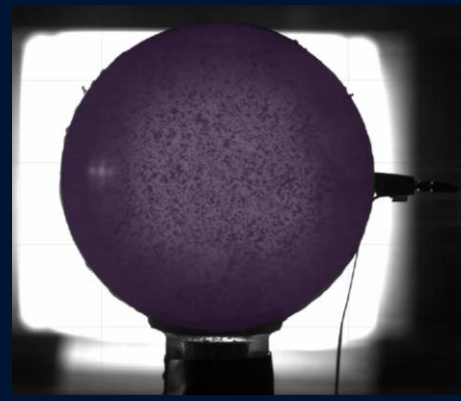
Conclusions

- **Key Findings**
  - Shock loading does not directly generate internal strain.
  - The ***dominant deformation mechanism*** comes from ***shear waves*** emanating from **rapid rotation of the head** (skull) due to a net moment from pressure loading.
  - Neck/torso constraint amplifies **strain rate** but not peak strain magnitude.
- **Significance & Broader Impact**
  - Results establish a direct, quantifiable blast-to-injury deformation pathway, ***providing a foundation for defining bio-physical safety limits for warfighters***



Widespread astrogliosis [Shively et al., 2016]





Questions?

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