Modeling shear deformation in brain tissue during blast events

Aashutosh Kulakarni Prachet
Mechanics of Solids
Brown University

Non-Disclosure

Aashutosh Kulakarni Prachet, B.S., has no conflicts to report.

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The PANTHER team

Traumatic brain injury (TBI)

Traumatic brain injury is a degeneration in brain function due to an external force.

Blast injury

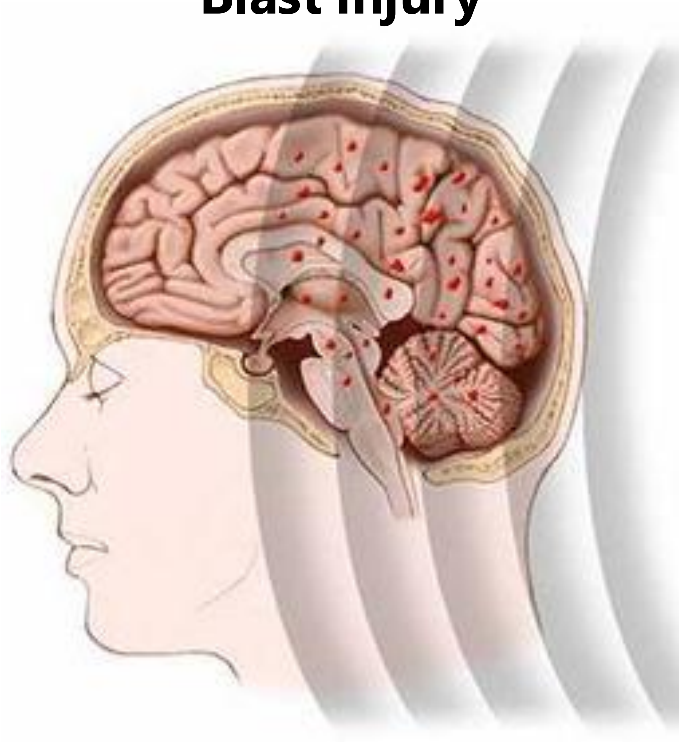


Image adopted from https://www.santephysique.com/blog/traumatic-brain-injury/

Blast related TBI (bTBI) in the military

"Since 2000, over 360,000 Service Members received a diagnosis of TBI and it is estimated that approximately half of these TBIs resulted from exposure to a blast."[1]

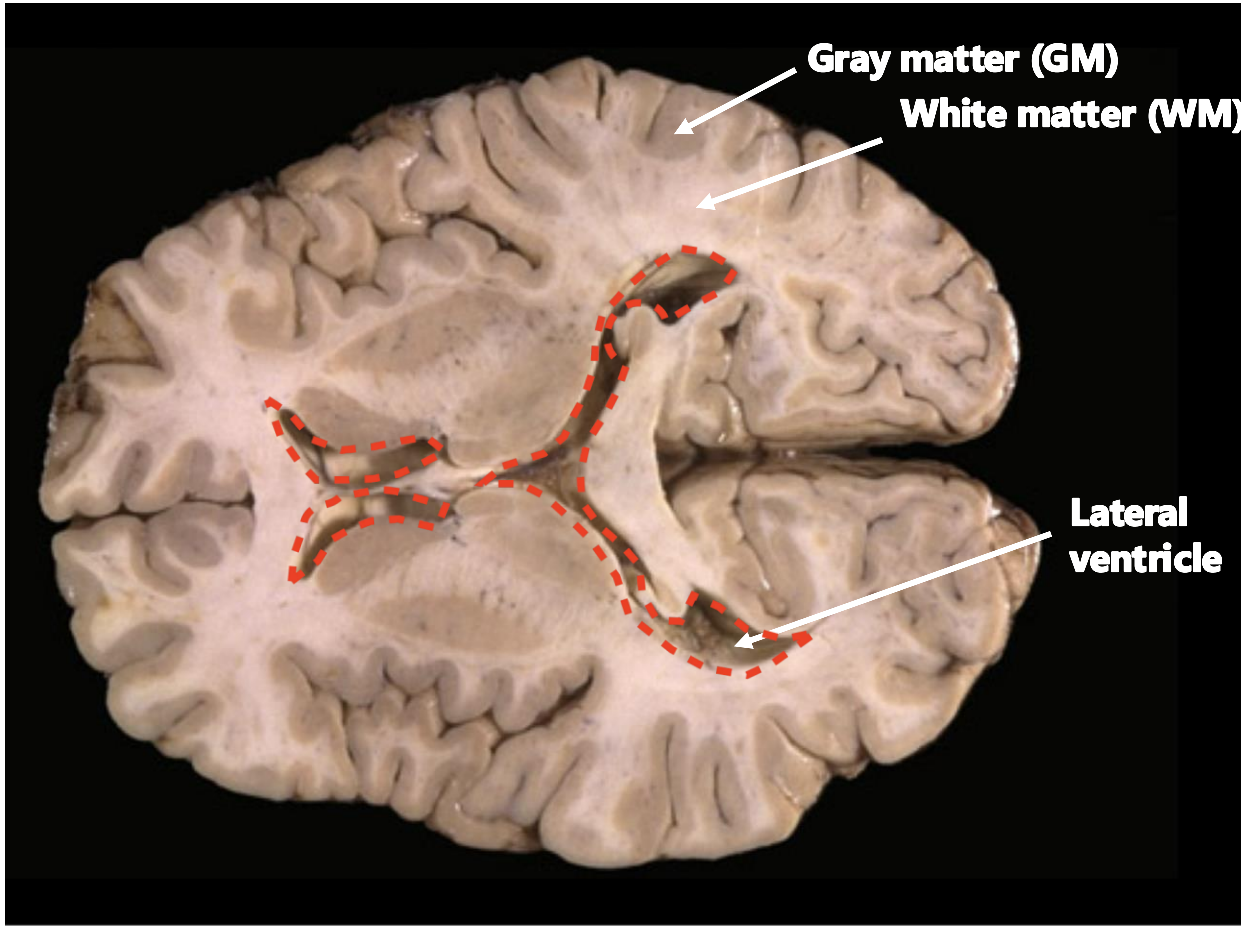
Left video credits: https://www.youtube.com/shorts/49YgZZeNJnA

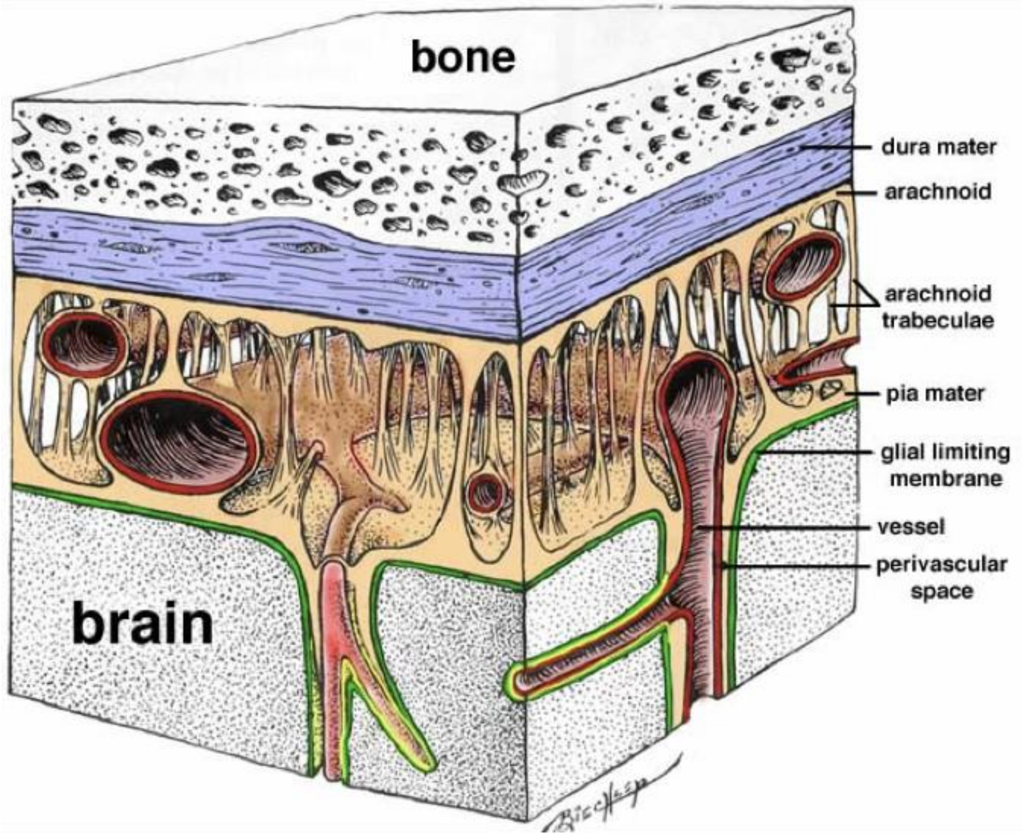
Right top image: https://www.safetyandhealthmagazine.com/25876-pentagon-takes-steps-to-protect-warfighters-from-blast-overpressure/

Right bottom image: RealClear Defense, September 7th, 2017, https://www.realcleardefense.com/2017/09/07/army039s_new_reusable_carl-gustaf_recoilless_84mm_rifles_296583.html

1. Source: A systematic review of traumatic brain injury outcomes, US Department of Defense. https://blastinjuryresearch.health.mil/index.cfm/news_and_highlights/research_highlights/FY17/systemic_review_of_TBI_outcomes?utm_source=chatgpt.com

Neuroanatomy



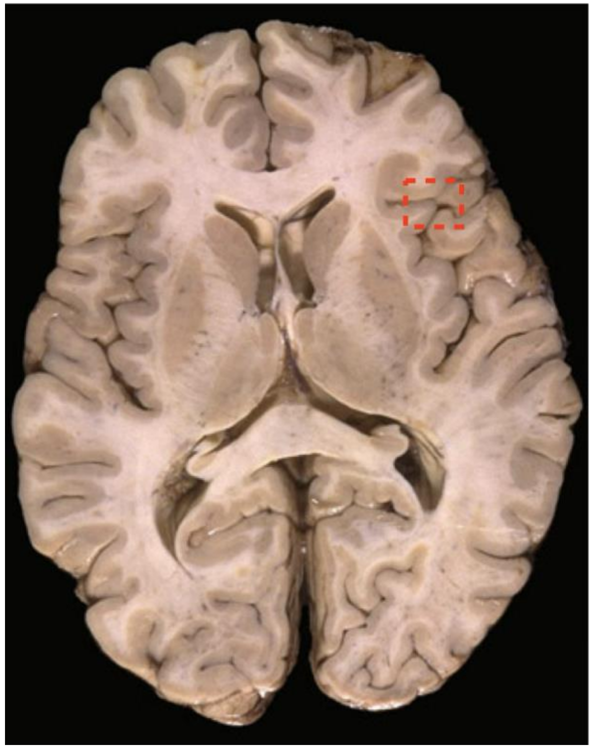


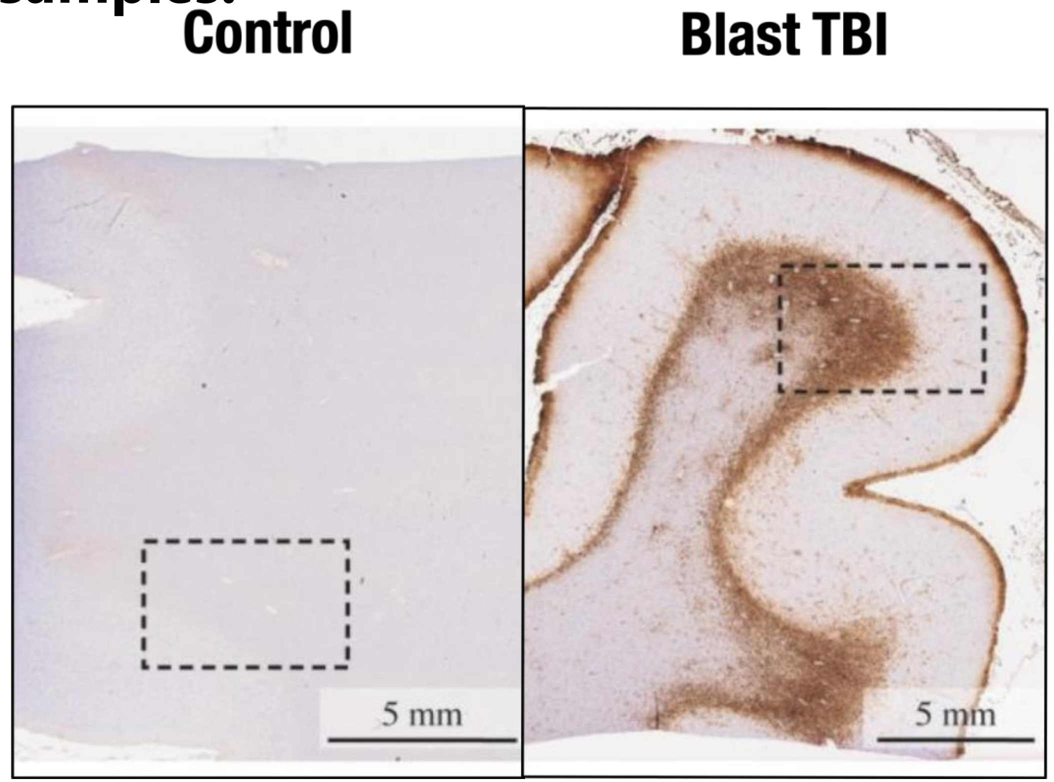
Left image adopted from https://webpath.med.utah.edu/HISTHTML/NEURANAT/CNS350A.html

Right image adopted from https://vanat.ahc.umn.edu/neurHistAtls/pages/men1.html

Benjamini et al. (Brain, 2022)

Postmortem brain tissues from 2 civilian subjects and 12 military subjects. Included control and bTBI samples.





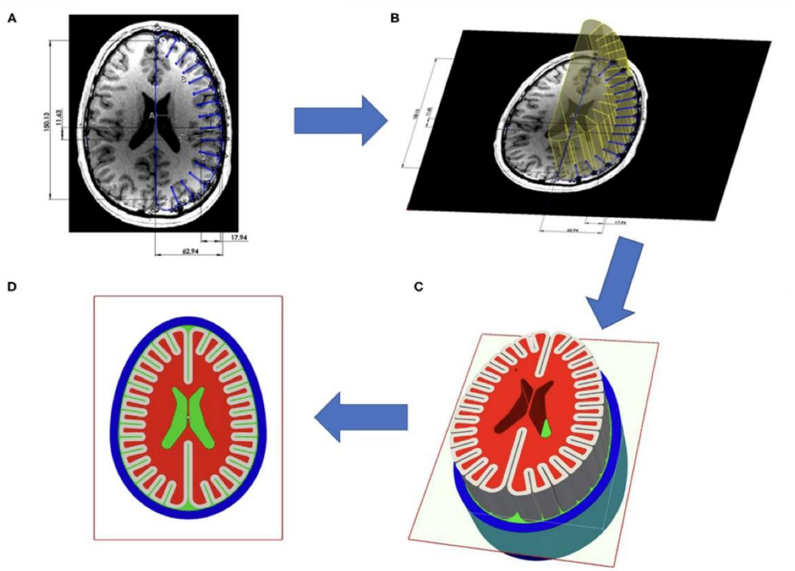
Glial fibrillar acidic protein (GFAP, scarring marker)

Astroglial scarring at subpial glial plate and GM-WM interface.

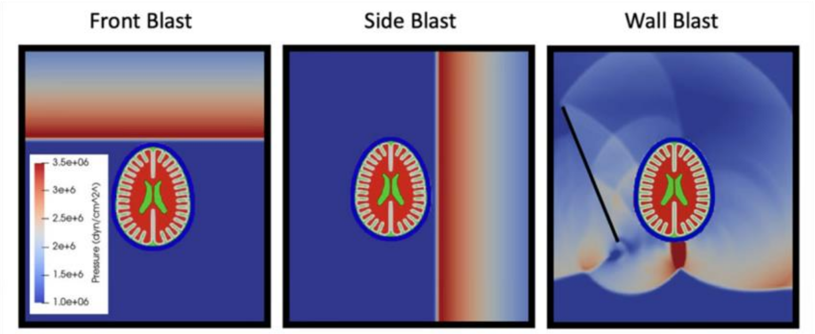
Current hypotheses of blast TBI

Finite element simulations to compute brain deformation for 6 ms after blast

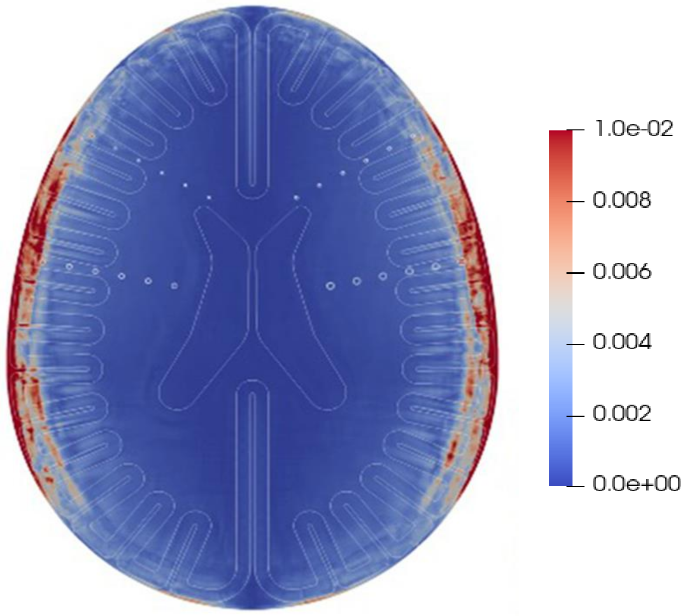
Gray/White Matter model with sulci & ventricles



Blast wave profiles



Max shear strain



Max shear strain is very low (< 1.0%) within 6 ms.

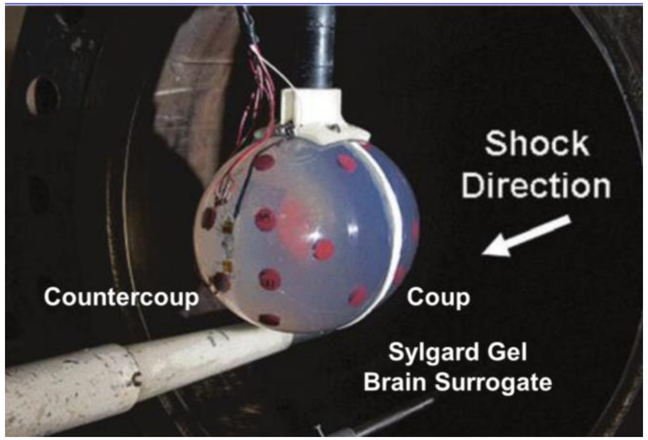
This motivated the hypothesis of cavitation.

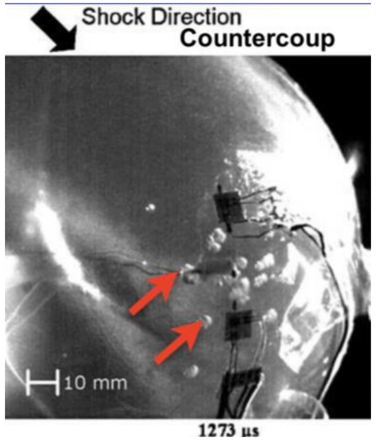
Miller ST, et al. Front Neurol. 2021 May 20; 12:547655

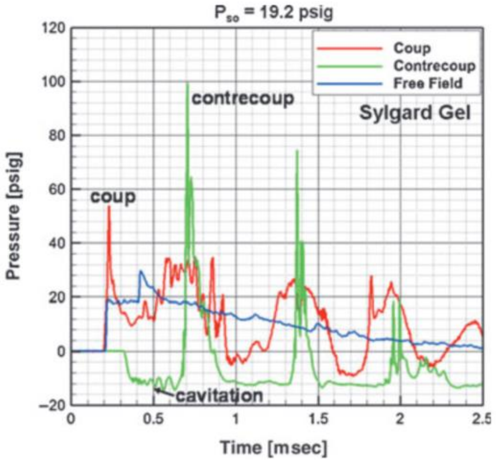
Current hypotheses of blast TBI

Cavitation is the formation of a vapor-filled cavity in a liquid due to a drop in the liquid's static pressure, and its subsequent collapse when subjected to higher pressures.

Blast experiments with a brain surrogate show countercoup bubbles.







Cavitation predicts focal injuries at regions of negative pressure. It is unlikely to account for the diffuse injury along the subpial glial plate, GM-WM interface.

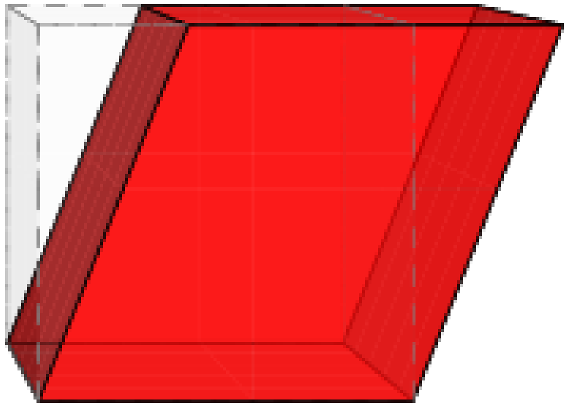
Most computational investigations are limited to 10 ms. However, there is not sufficient support that later time scales are unimportant.

We revisited the shear strain hypothesis and conducted simulations for long time scales.

Goeller J, et al. J Neurotrauma, 29:1970-81, 2012.

Shear deformation in the brain

Shear deformation

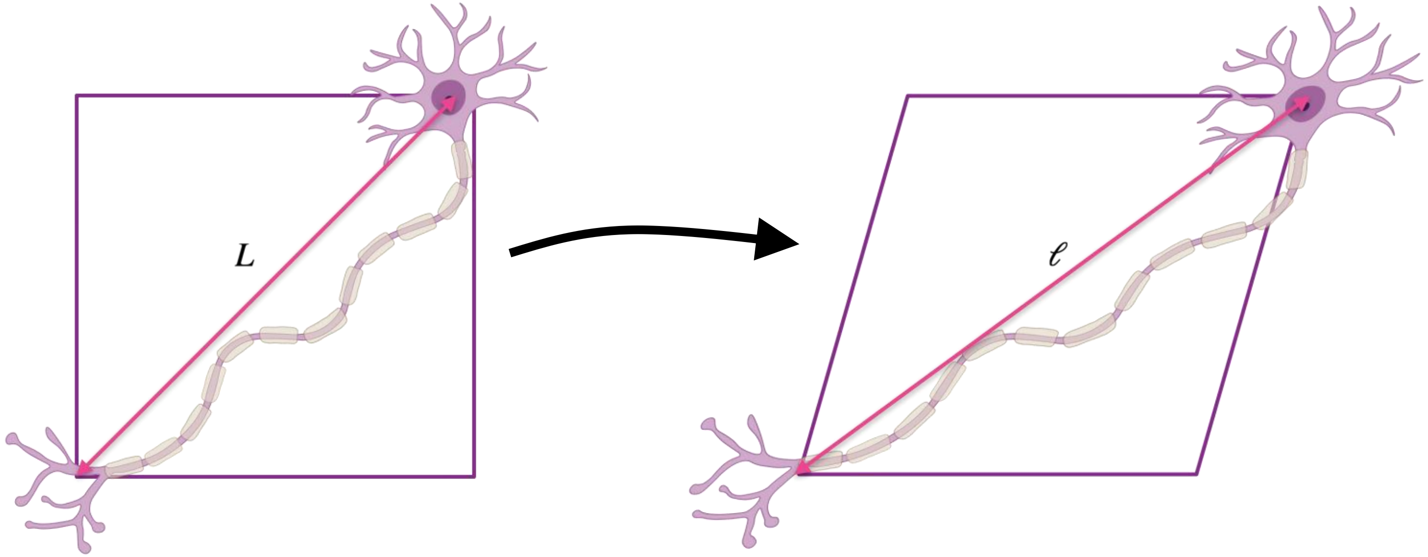


Shear modulus
$\mu \approx 1 \times 10^3$ Pa

The brain is not very resistant to shear.

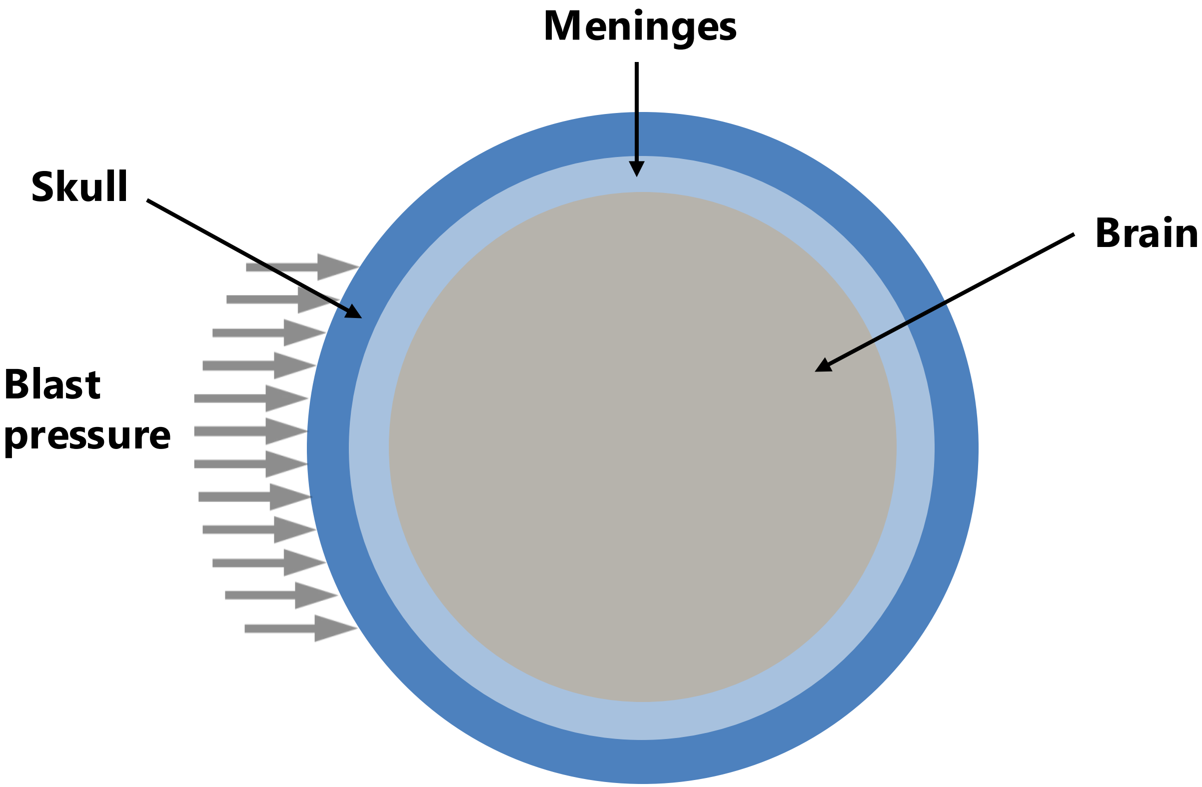
Shear deformations can take ~100 ms to propagate across the brain.

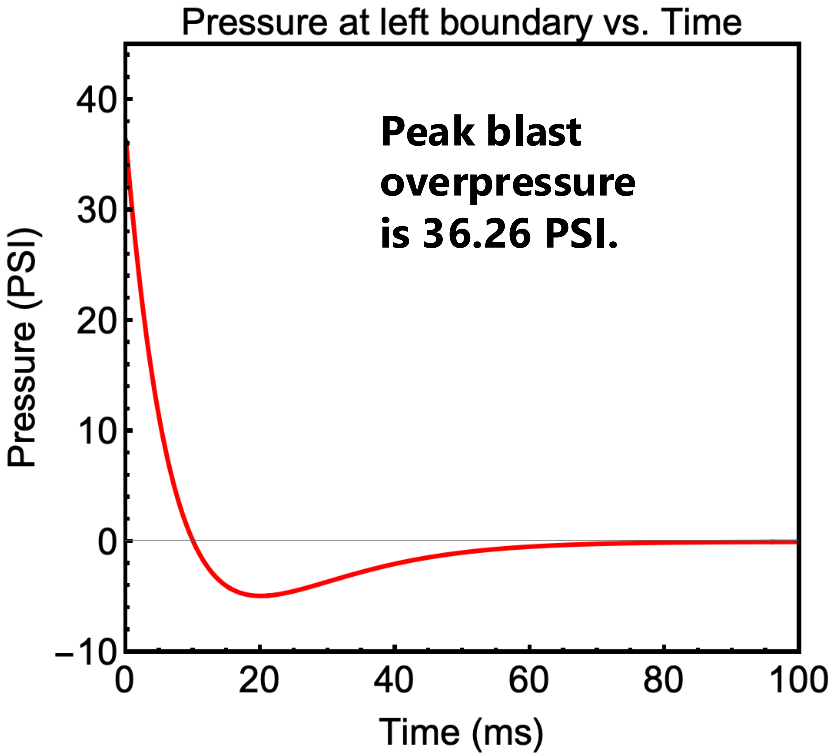
Shear deformation can correspond to stretching of cells



Shear strain $\propto \dfrac{(\ell - L)}{\ell}$

An idealized 2D head model



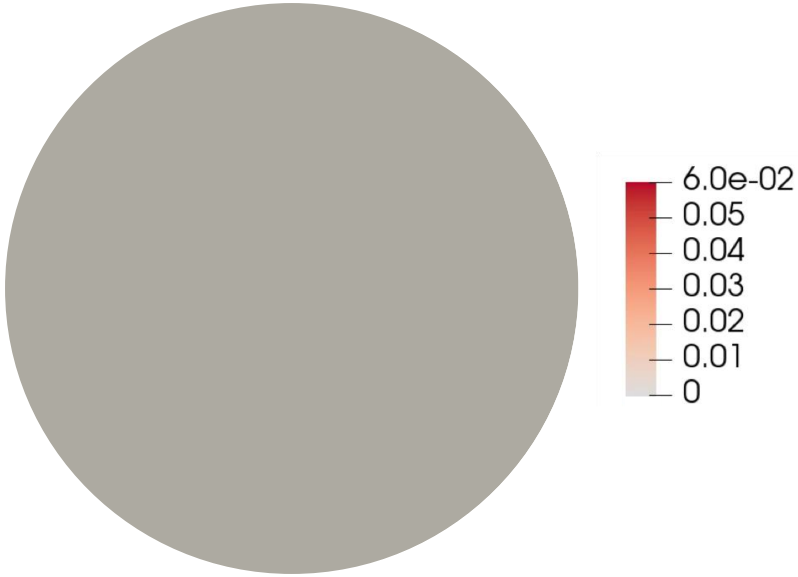


	μ [kPa]	κ [kPa]	ρ [kg/m^3]
Skull	10^6	5×10^6	2240
Meninges	0.3	5×10^6	1008
Brain Tissue	30	5×10^6	1081

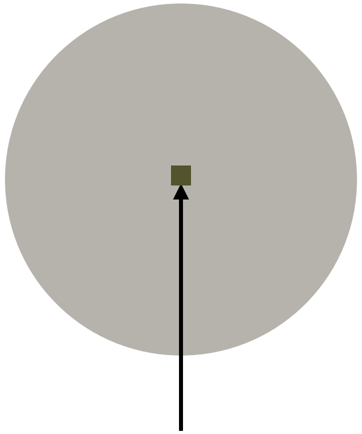
Shear strains in the simulation

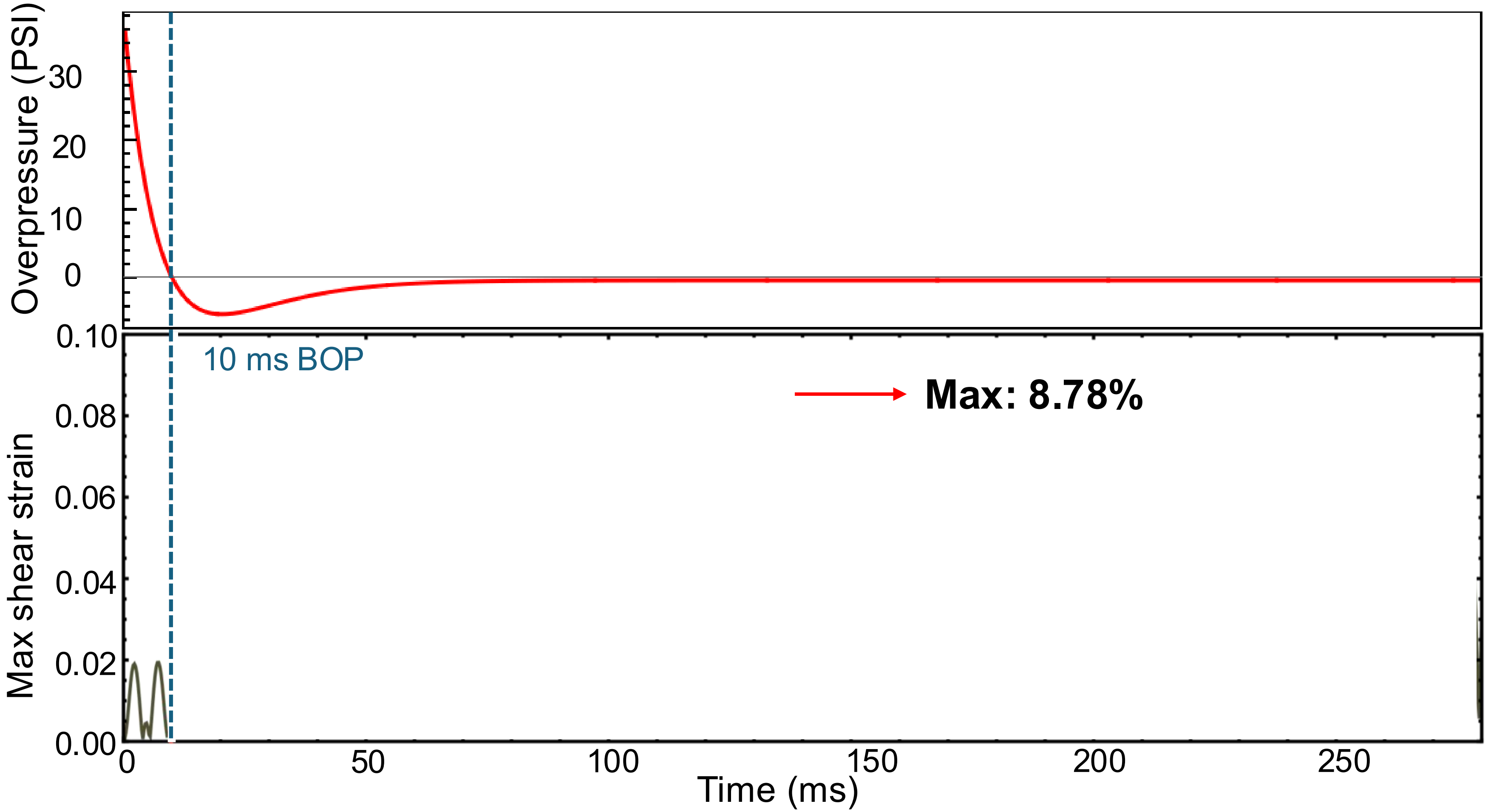
Red bands indicate regions where shear strain is significant.

Max shear strain



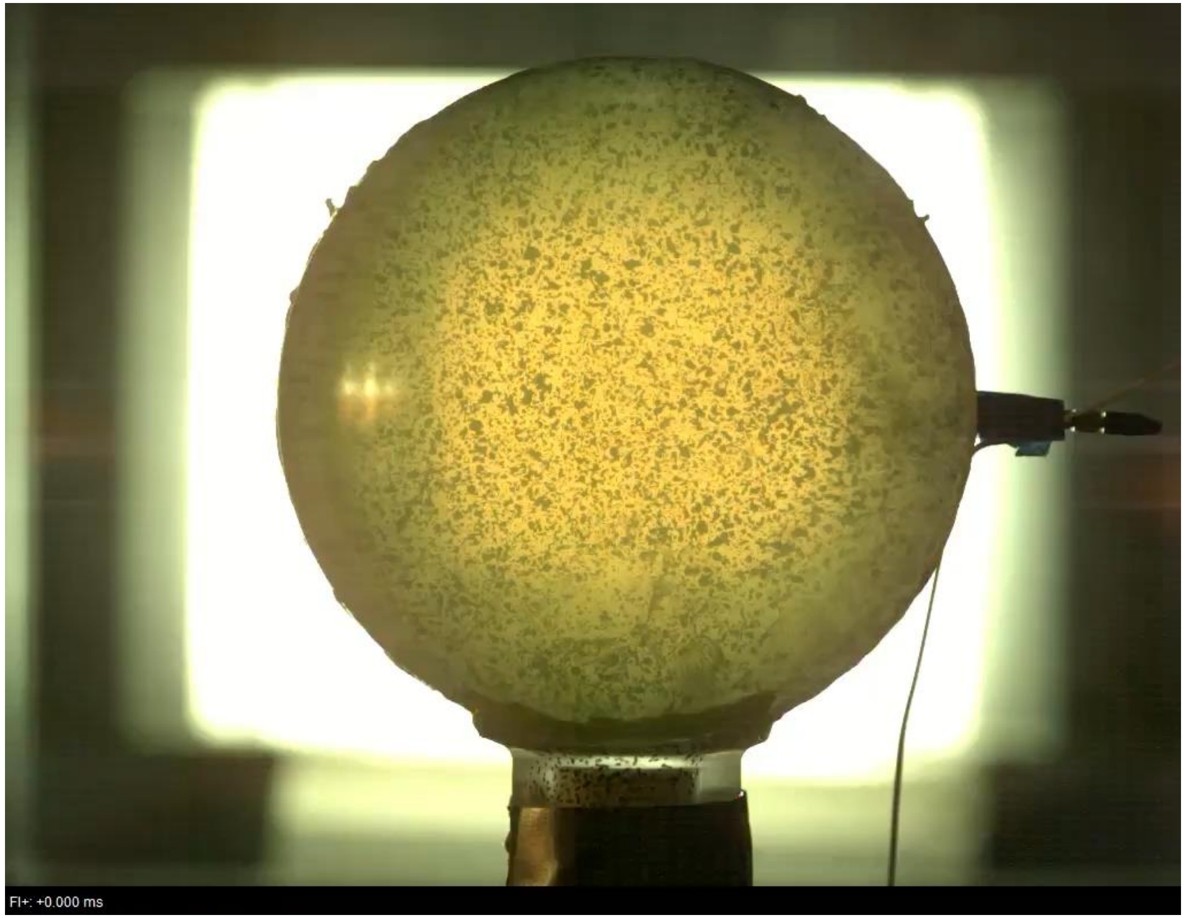
Shear strain at the center


Center of the brain region



Blast experiments conducted by Dr. Christian Franck's group

Blast experiments were conducted using a head surrogate in the Advanced Blast Simulator at Iowa State University.



A 3D printed resin shell filled with 6% homogenous gelatin was subjected to ~16 psi.

Significant skull rotations and shear strains in the brain matter were observed.

Dr. Enze Chen (MHSRS-26-4385) will present a more detailed experimental investigation on Wednesday at 1:15 PM, in Coastal B.

Summary

- **Shear deformations propagate at very slow speeds and can take hundreds of milliseconds to propagate.**
- **A 2D simulation revealed that significant shear strain in the brain may be observed at longer time scales (> 50 ms).**
- **Shear deformations propagate deep into the brain tissue.**
- **Experimental results show that skull rotations cause significant shear strains in the brain.**

Thank you.