

# Building and validating a model of human blast traumatic brain injury: a hybrid computational and experimental approach.

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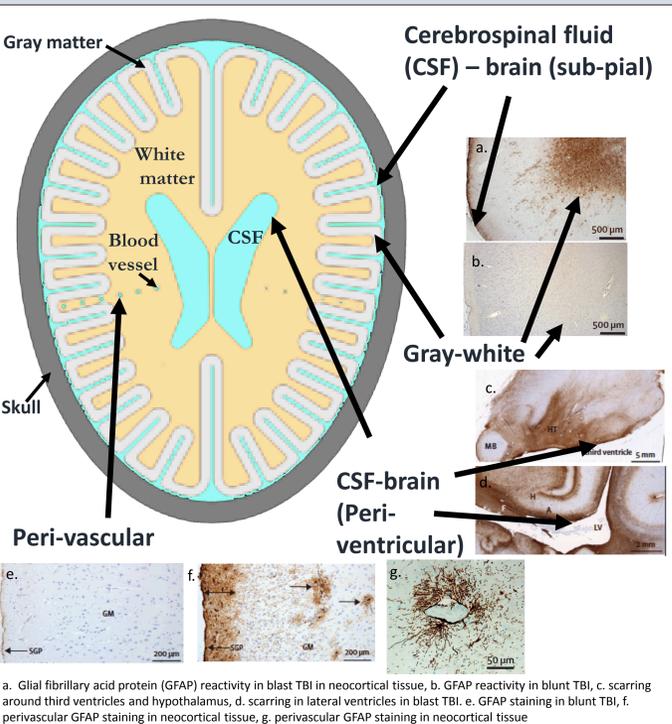
## Introduction

Nearly 150,000 of the returning soldiers from Iraq and Afghanistan have suffered blast-induced Traumatic Brain Injury (TBI), leaving the victims at risk for persistent neurologic/behavioral symptomatology, including headaches, sleep disorder, cognitive impairment and mood disturbance. Although defining what the injury of blast TBI is has been difficult and prone to confounders, looking to clinical data has helped differentiate this injury from other TBI. In theater experience from the physicians who treated blast victims identified some unique features of this injury; injury to the **blood vessels** at both large and small length scales manifesting with **brain swelling, subarachnoid hemorrhage or pseudoaneurysm and vasospasm**[1-4]. More recently, careful neuropathologic studies of victims of blast TBI demonstrated a unique pattern of astroglial scarring at multiple intracranial interfaces: **subpial, perivascular, periventricular, and gray-white junction**[5]. However, the mechanism(s) and threshold of these injuries have not been resolved mechanically, thus protective equipment cannot be optimized to reduce the injury. The goal of this work is build a model which reproduces the **human intracranial injury** after blast exposure in order to isolate the mechanism(s) of injury.

## Hypotheses

Observed patterns of blast traumatic brain injury can be explained by the focusing of blast stress waves that occur at the intracranial mechanical interfaces (CSF-brain, vessel-brain, gray-white, etc).

## Pathology of blast traumatic brain injury at mechanical interfaces [5]



## Mechanical Properties of Cranial Contents [6]

|              | Density     | Bulk Modulus | Shear Modulus  |
|--------------|-------------|--------------|--|
| Skull        | 1.21 (g/cc) | 4672 (MPa)   | 3270 MPa   |
| White Matter | 1.04        | 2371         | 41 kPa- $G_0$ , 7.8 kPa- $G_{inf}$ , $B = 40 s^{-1}$ |
| Gray Matter  | 1.04        | 2371         | 34 kPa- $G_0$ , 6.4 kPa- $G_{inf}$ , $B = 40 s^{-1}$ |
| CSF          | .9998       | 1960         |  |

## Computational Methods

### Material Models

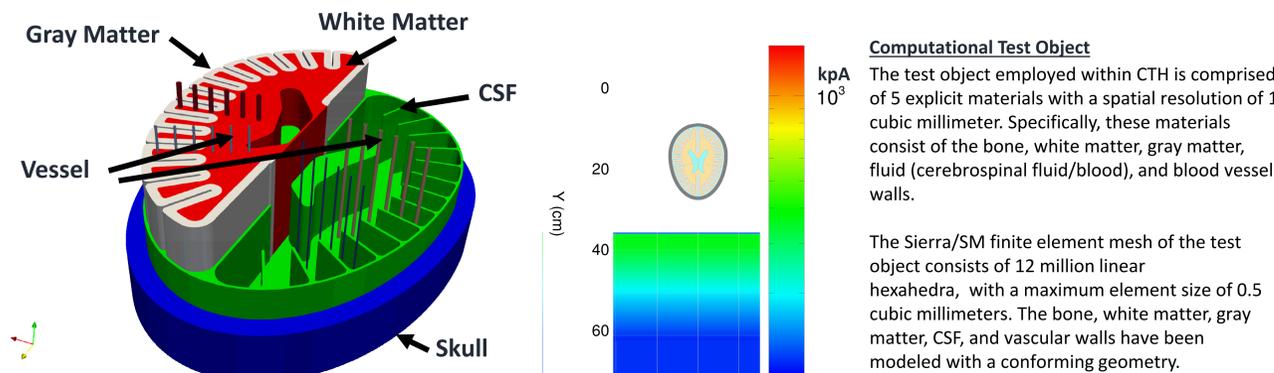
The material models utilized in CTH and Sierra are fit to material property data of human tissue published in the open literature for bone, white matter, gray matter, and cerebrospinal fluid. These material models have been previously employed and validated in modeling & simulation of blast and blunt impact of human models by Taylor et al. of Sandia National Laboratories [6-9].

### Computational integration - Eulerian (CTH)

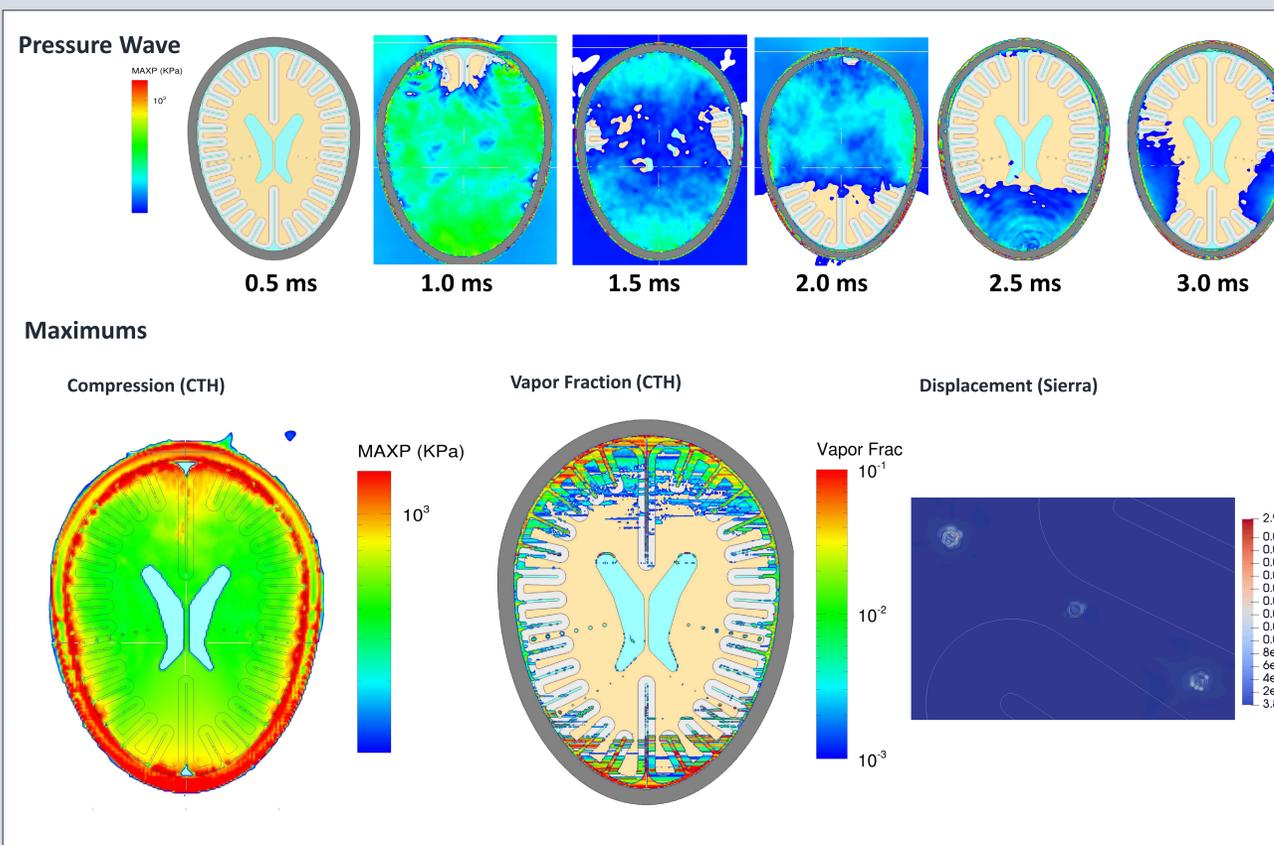
CTH is an Eulerian finite-volume computer simulation code that is capable of tracking 90+ materials simultaneously, simulating their interactions as they undergo blast loading. This code is a validated shock-physics simulation suite and has been used to study fluid-solid interactions that occur between blast waves and the test object model [10]. Blast wave was modeled as a slab of energized with overpressure of 260kPa.

### Computational integration - Immersed Lagrangian (Sierra)

Sierra mechanics is the finite element simulation suite developed by Sandia National labs to predict behavior of complex structures under extreme loading. Blast loading is accomplished by passing pressures from CTH to Sierra/SM, where they are used as a boundary condition for the finite element simulation. This one way coupling is sufficient for large over-pressure loadings. Future work will utilize a two-way coupling for lower amplitude blast studies.



## Computational Results



## Conclusions

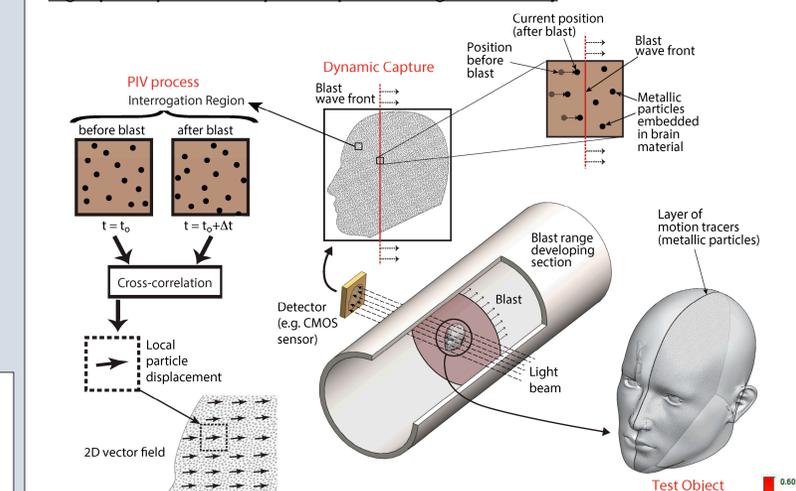
Computer simulations based upon material models matched to human tissue predict a predilection of cavitation and dilatational forces at the same interfaces found to have astroglial scarring in blast traumatic brain injury. Such findings require further experimental validation but may suggest cavitation and dilatation are mechanical forces important in causing brain tissue damage in blast traumatic brain injury.

## Experimental Validation

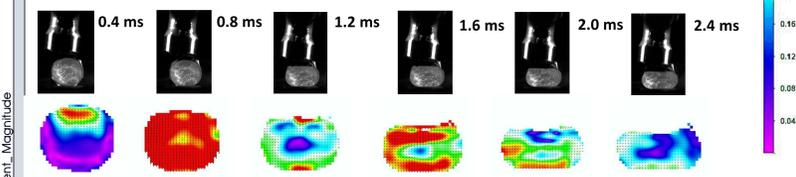
**Brain Simulant** - See poster [MHSRS-17-1710](#): Materials Characterization of Cranial Simulants for Blast Induced Traumatic Brain Injury

**Fabrication techniques** - See poster [MHSRS-17-1718](#): Additive Manufacturing of Cranial Simulants for Blast Induced Traumatic Brain Injury

### High speed optical techniques and particle image velocimetry



Dynamic measurement with ultra-high-speed imaging while the blast wave is crossing the test object (above). Cavities in the test object have dimensions similar to those in the brain (zoomed-in view, upper left corner). Metallic particles embedded in the test object will trace strain as the detonation wave propagates (zoomed-in view at the edge of the detonation wave, above -center). Particle Image Velocimetry (PIV) [11] will be used to generate 2D vector fields representing strain and strain-rate (schematic of PIV process on the right). Below is the material velocity vectors of ballistics gel undergoing blunt trauma (hammer). Far right is velocity magnitude of vectors in m/s.



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