Introduction: Blast-related Traumatic Brain Injury (bTBI) has become the signature injury of service members in United States (US) military conflicts. Finite Element Analysis (FEA) of the human head presents the most viable method to study bTBI and understand the physics of the deformation of human brain due to blast-induced shock waves. In this study, a human head Finite Element (FE) model was developed and simulated in ABAQUS/Explicit (Simulia Inc., 2009) under blast loading conditions. The FEA analysis gave new insights into the biomechanics of bTBI.

Methods: An image-based meshing software, ScanIP^{TM} (Simpleware Ltd., UK), was used to generate a three-dimensional mesh from the cryosection images of the human head. The generated human head mesh, which was used in FEA, consisted of scalp, skull, intracranial cavities and brain. For the brain parenchyma, an internal state variable (ISV) constitutive model (Bouvard et al. 2010) was calibrated to high strain rate experimental data for brain tissue (Prabhu et al., 2011). The human scalp, skull, and cerebrospinal fluid (CSF) were defined as elastic materials, and were obtained from published literature. Pressure-based blast boundary conditions, obtained from Mouritz's (2001) experiment, were applied to the human head mesh to model a blast event in Iraq as recorded in Warden et al. (2009) and which resulted in a female soldier sustaining bTBI.

Results and Discussion: The results from our FE simulations showed a highly non-uniform three dimensional stress state during the blast, with concentrated regions of peak negative (tensile) pressures and impulse (pressure history integrated over time) at the injury site (notably located *NOT* at the coup and countercoup sites; see Fig. 1). Furthermore, the FE simulations showed that bTBI is a tensile pressure dominated phenomenon, not dominated by the compressive pressure, maximum principal strain, nor the shear or deviatoric stress. We also show that the scalp, skull, and CSF played key roles in dampening the shock wave. Contrary to one dimensional argument about coup-countercoup injury sites, the shock wave propagation in the countercoup region originated from the wave propagating three dimensionally around the skull, as the wave from the coup site propagated through the cranium first, then reflected from the skull into the brain.

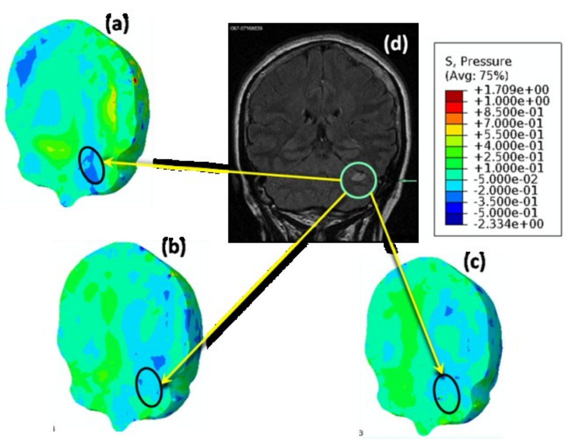

Fig. 1 Coronal view of the brain with the pressure contour snapshots at (a) 4.99×10-1, (b) 8.32×10-1, and (b) 11.14×10-1 ms that correlate well with (d) the hyperintensity region reported by Warden et al. (2009) for a war fighter who sustained bTBI. Negative pressures represent positive tensile stresses.

Conclusions: The current study is the first one of its kind to validate a real world Boundary Value Problem (BVP) regarding a warfighter's bTBI. Research on live humans for studying blast is inherently limited, because it necessarily lacks blast experiments, which are neither viable nor ethical. However, the paradigm described here of modeling the human head using FEA through a virtual human head is the most plausible way to study bTBI. The results from our FE simulations show that the popular belief that injury would occur either at the countercoup or coup sites has been shown here to be simply not true. Because the location of the brain injury in Warden et al. (2009) specified the location, we clearly show that the tensile pressure and associated impulse (pressure history integrated over time) is the key metric for bTBI.