Does Blast Exposure to the Torso Cause a Blood Surge to the Brain?

Exposure to explosion-induced blast waves is suspected to cause traumatic brain injury (TBI). In order to prevent and develop effective personal protective equipment against this non-impact injury for our Warfighters, it is essential that we understand the underlying pathways by which such exposure can lead to blast-induced TBI. The proposed causes of this injury include a direct mechanism (i.e., the interaction of the blast wave with the head) and an indirect mechanism (i.e., the interaction of the blast wave with the body). A few studies reporting changes in brain tissues of animals exposed to a head-only blast support the direct-mechanism hypothesis. In contrast, despite years of research, the role of the indirect mechanism in causing blast-induced TBI remains inconclusive. To address this gap, Dr. Jaques Reifman, Director of the Biotechnology High Performance Computing Software Applications Institute (BHSAI) Data Sciences Division (DSD) here at TATRC, led an interdisciplinary study to investigate the potential effects of the indirect mechanism on the brain vessels and tissues.

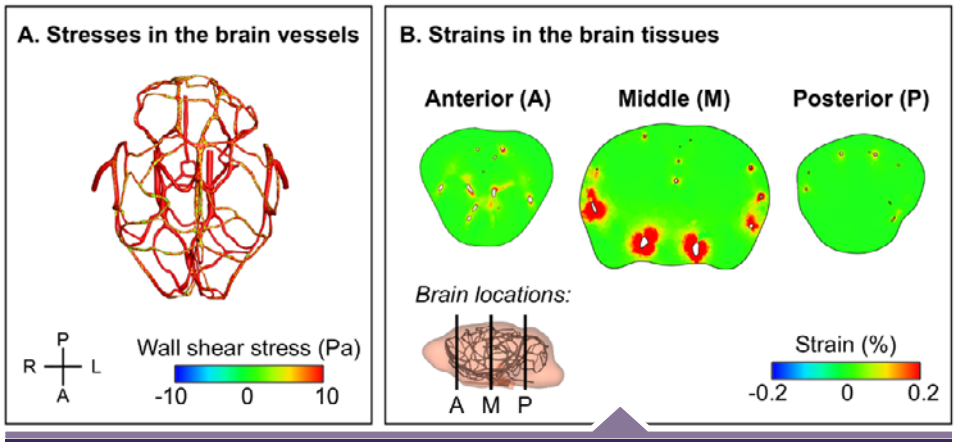

Figure 1. (A) Compared to a blast-free condition, the substantial increases in the peak shear stress in the cerebral vasculature of a rat caused by a torso-only exposure indicate that the indirect mechanism may cause vascular injury. (B) The predicted minimal increases in the peak strain in the brain tissues of a torso-only-exposed rat indicate that the indirect mechanism is very unlikely to cause strain-induced damage to the tissues.

The BHSAI DSD team, in collaboration with the New Jersey Institute of Technology (NJIT; Newark, NJ) and the University of Utah (UT; Salt Lake City, UT), conducted experiments and developed computational models to determine whether the indirect mechanism can damage the brain vasculature, the brain tissue, or both. To this end, using medical images acquired by the UT team and intravascular-pressure measurements from torso-only exposures (i.e., shock-tube experiments with blast exposures limited to the torso of a rat) conducted by the NJIT team, the BHSAI DSD team developed three-dimensional computational models of the neck and cerebral vasculature to characterize the pressure propagation through the blood vessels. Using these models, the team simulated the cerebral blood flow resulting from the torso-only exposure and predicted the amount of blood entering the brain and the resulting stresses in the brain vessels. In addition, the BHSAI DSD team developed a 3-D model of the rat brain to determine whether the torso-only exposure could induce significant strain in the brain tissues.

From the computer simulations, when compared to a blast-free condition, the BHSAI DSD team of researchers determined that a torso-only exposure increased the peak mass flow rate at the base of the brain by up to 255% and increased the wall shear stress throughout the entire cerebrovascular network by up to 290% (Figure 1A). In contrast, the simulations also showed that a torso-only exposure caused minimal strain increases (<1%) in the brain tissues (Figure 1B).

These results indicate that the indirect mechanism causes a sudden and abundant stream of blood to rapidly propagate from the torso through the neck to the cerebral vasculature. This blood surge, in turn, considerably increases the wall shear stresses in the brain vasculature, which may lead to vascular injury. However, because the predicted brain-tissue strains were much lower than the damage-causing levels identified in the literature, the results indicate that the indirect mechanism of blast exposure does not cause brain-tissue injury.

Dr. Reifman noted that "this very elegant interdisciplinary work allows us to ascertain with a high degree of confidence that, while a blast exposure to the human torso can potentially lead to brain-vessel pathologies, it is unlikely to directly damage brain tissues."

The full details of this study, which was supported by the DoD Defense Health Program, Joint Program Committee 5 managed by Military Operational Medicine Research Program at Ft. Detrick, Maryland, can be found in Rubio et al. Frontiers in Bioengineering and Biotechnology 8:573647, 2020.