

Blast, impact simulations could lead to better understanding of injuries and body armor

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Sandia National Laboratories researchers Candice Cooper, left; Shivonne Haniff, center; and Paul Taylor are studying mechanisms behind traumatic brain injury to better understand how blasts on a battlefield can lead to such injuries and injuries to vital organs, such as the heart and lungs. The 351st Battlefield Airmen Training Squadron at Kirtland Air Force Base, through a connection with Nathan Davey of Sandia, provided the vest armor for the project. Credit: Randy Montoya

Sandia National Laboratories is developing specialized computer modeling and simulation methods to better understand how blasts on a battlefield could lead to traumatic brain injury and injuries to vital organs, like the heart and lungs.

Researchers at Sandia have studied the mechanisms behind [traumatic brain injury](#) for about a decade. Their traumatic injury modeling and simulation project began with a head-and-neck representation, and now they've created a high-fidelity, digital model of a man from the waist up to study the minute mechanisms behind trauma.

"We're also concerned about the possibility of injury to the life-support systems in the torso. Everything's interconnected," said Paul Taylor, who leads the project. "Clearly, we would love to have a representation of a full human but certainly capturing all the regions where life-critical organs are located is a very good start."

The information could help manufacturers develop better designs for helmets and [body armor](#).

"Protection of the soldier, sailor or marine is essential, and well aligned with our national security mission against challenging and new lethal threats," said program manager Doug Dederman. "It is a privilege for our integrated military systems staff to team with the Department of Defense and medical communities to improve both diagnostic capabilities and mitigation of risk with improved protective equipment."

Sandia's most recent work grew from a Laboratory Directed Research and Development-funded project that wrapped up in late 2016. Along the way, the team conducted both macroscale and microscale traumatic brain injury simulations, began working with doctors to correlate simulation predictions with clinical assessments of people with brain injury and increased the size of their team.

They theorize that a phenomenon called fluid [cavitation](#) can lead to traumatic brain injury. They've developed macroscale simulations to test the hypothesis and extended their work into microscale studies to examine whether blast and short-pulse blunt impact, such as a projectile hitting body armor, could lead to fluid cavitation, forming bubbles whose collapse could damage sensitive brain and lung tissue, Taylor said.

Cavitation is the formation of vapor cavities—bubbles—caused by rapid pressure changes in fluid, which can occur from blast exposure. Bubbles form and, because they're unstable, immediately collapse, generating a microjet or miniature localized shock wave. It's a physics phenomenon commonly seen at the leading edge of spinning ship propellers, eroding those propellers.

Studying the mechanisms behind damage to brain, organs

"We've been able to demonstrate, at least theoretically, that the individual experiences fluid cavitation in the brain. We've subjected our head-neck model to blasts from the front, from the side, from the rear, and what we see are what looks like peppered regions in the brain," localized regions experiencing cavitation, Taylor said, pointing to the occipital, temporal and brain stem areas on a slide from a simulation.

"Does cavitation occur, and if so, where might it be occurring?" said team member Candice Cooper, who developed the macroscale simulation. "Then we look at those areas on the microscale to see if cavitation is indeed occurring, how might it damage these tissues and lead to traumatic brain injury."

The smallest area in the macroscale simulation is 1 cubic millimeter, which isn't small enough to capture the physics of fluid cavitation very

well, Taylor said.

Enter Shivonne Haniff, who performs microscale modeling and simulation to complement Cooper's macroscale work, simulating the formation and collapse of cavitation bubbles in the brain in scales below 1 millimeter.

One of Haniff's models represents axonal fiber bundle tracks within the brain's white matter. Typically, white matter axons have myelin sheaths, a protective coating, similar to how insulation protects electric wiring. Myelin sheathing accelerates neurological pulses, allowing humans to process information very quickly. Diseases, such as multiple sclerosis, degrade myelin sheathing and drastically reduce pulse transmission.

The team hypothesizes that blast- and impact-induced cavitation and subsequent bubble collapse also could damage myelin sheathing.

Haniff's video of a microscale simulation of cavitation bubble collapse within the white matter axon fiber bundle introduces a pressure pulse from one side, causing asymmetric collapse of the bubbles, generating highly localized pressure pulses and microjetting that damages neighboring axons and their myelin sheathing.

The team studied how compressive wave amplitude and bubble size influenced microjetting strength.

"To assess damage potential from bubble collapse-induced microjetting, we looked at pressures and shear stresses downstream of the bubbles. The shear stresses in the myelin sheathing were considerably higher than the shear stresses in the axon core, indicating the myelin acts as a protective barrier," Haniff said. "However, damage to this [myelin sheathing](#) could impair the transmission of nerve signals, which can lead to neurological problems."

She's focusing now on modeling cavitation damage within the blood-brain barrier, a semi-permeable vascular system that allows passage of nutrients and gases needed by the [brain](#) but blocks harmful toxins. A video simulation shows [cavitation bubbles](#) suddenly collapsing under pressure, drastically increasing pressure and shear loading on surrounding tissue, which can damage it. Simulations look at the effects of different bubble diameters, bubble density and pressure wave amplitudes on the degree of damage.

Working out how to model damage mechanisms

Cooper also conducted modeling and simulations for a generic body armor configuration. The work was aimed at understanding the modeling problem rather than reaching conclusions applicable to specific armor. Her simulation studied pressures within the heart, lungs and other organs in different scenarios, such as a soldier standing about 10 feet from a roadside bomb blast.

"We looked at pressure as well as the shearing stress that can lead to tissue tearing, and found that in this notional case, having padding behind the armor actually increased peak pressures in life-critical organs, the heart and the liver, which could lead to damage," Cooper said. "It also led to an increase in shear stresses in all of the organs that we looked at.

"This is just an example of how we can use our modeling and [simulation](#) tools. If someone came to us with their armor design and said, 'Would you take a look at this,' we could vary the materials of the foam padding, the positioning of the foam padding, the size or geometry of the foam padding or of the armor plate itself," she said. "We could look at variations on their design and let them know this change makes it better, that change makes it worse."

Provided by Sandia National Laboratories

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