

**Unseen Wounds of War:
Blast-Induced Traumatic Brain Injuries**

When the IED exploded, Robert Anetz wasn't sure what hit him. The colossal force of the blast wave knocked him to the ground and his body went numb. He scrambled to check himself for wounds. What he found surprised him. There was no blood, no gaping wound. He seemed to be fine—safe and sound [1]. Seven months later, after returning from his deployment in Iraq, Robert suffered a seizure while driving his car. He suffered a second seizure six months later, a grand mal seizure, which is characterized by convulsions and loss of consciousness. Considering what happened to Robert in Iraq, it is likely that his seizures were connected with being hit by the blast wave. These blast waves are now known to cause traumatic brain injuries (TBIs), of which seizures are an associated symptom [1], [2].

The use of IEDs—improvised explosive devices—in modern warfare has created an increasingly dangerous environment for members of the United States military, and it is likely that the threat posed by these weapons will not subside [3]. In the past fifteen years, 325,000 soldiers returned home with a TBI [4] and an estimated 30% of those TBIs were caused by the blast wave of an IED [5]. A soldier's first defense against head trauma is the advanced combat helmet (ACH), the standard issue combat helmet for the U.S. military. However, the large number of blast-induced TBIs indicates that the ACH is not effective in guarding soldiers against these kinds of injuries.

When an IED detonates, it releases an immense amount of heat and energy. This results in a supersonic pressure wave known as a blast wave [6]. The heat produced by the explosion causes the surrounding air to expand, creating an overpressure, or a pressure that measures up to two times above atmospheric pressure [6], [7]. This pressure differential is thought to be the primary cause of blast-induced TBIs [7], [8], creating an increase in intracranial pressure and squeezing each part of the brain as the blast wave passes through the organ.

The typical TBI symptom seen in someone who has suffered a blast overpressure in the brain is a diffuse axonal injury [2], characterized by axonal shearing, wherein the axon of a neuron is damaged through a shear force. Axons, or nerve fibers, allow the brain to communicate via electrical signals and if these fibers become damaged, the result is often slowed information processing and diminished attentional capacity [9]. Over time, these injuries can continue to effect the brain and those who suffer a blast-induced TBI are at an increased risk for neurodegenerative diseases like late life dementia [9]. One way to prevent a blast-induced TBI from occurring is to provide better head protection that reduces the intracranial pressure resulting from blast overpressure.

The incidence of the two major types of war injury—ballistic and blast-induced—has changed with the development of new weapons and new methods for waging war. The incidence of blast-induced injuries in the U.S. military has increased since World War II, while the incidence of ballistic injuries has generally decreased and for the most recent conflicts has been at its lowest [10]. Although ballistic threats have decreased over time, the Department of Defense (DoD) still chiefly designs the ACH to protect against them [11]. While continuing to improve protection against ballistic threats is important, failing to adequately address the increasing threat from blast waves is an oversight. The current design standards set by the DoD specifically require that the ACH withstand impacts from a 9mm bullet and small pieces of shrapnel [12], with no mention of blast overpressure. These standards are what motivated engineers to construct the ACH from ballistic fabric (e.g., Kevlar), which has proven to be extremely effective in absorbing impact energy from solid projectiles. The ballistic fabric's immense tensile strength typically prevents projectiles from tearing through the helmet. Unfortunately, ballistic fabric is not effective in attenuating the overpressure produced by a blast wave [13].

While the ACH does not protect soldiers against blasts, another type of armor does. Bombproof suits are specifically developed to withstand blast waves [14], however, the technology in these suits does not necessarily translate into a better combat helmet. The suits are designed with a thick layer of foam to absorb blast wave energy [14], but using the same solution in a combat helmet would be problematic. Adding a thick layer of foam to the inside or outside of the helmet may greatly increase the helmet's dimensions, causing it to be clunky and uncomfortable for the user. A new technology is needed and researchers are working on at least two promising ways to improve the ability of the ACH to reduce overpressure: impregnating the ACH's Kevlar shell with a shear-thickening fluid and including a fluid liner inside the helmet.

Shear-thickening fluids have great potential in the field of body armor, and have already been used in conjunction with ballistic fabrics (e.g. Kevlar) to increase their stability and ballistic resistance [15]. A shear-thickening fluid exhibits a sharp increase in viscosity in response to an applied force. The fluid thickens in proportion to the applied force and resists deformation. In this case, the applied force would be the overpressure of a blast wave. The energy from the blast wave would be transferred into the fluid, which would stiffen upon impact and absorb more energy from the blast wave. Less energy would transfer through the helmet and to the brain. Preliminary studies show a potential to reduce overpressure by roughly 40% [15], a considerable improvement from the current performance of the combat helmet.

Another promising augmentation to the ACH involves the addition of a fluid liner between the helmet shell and its padding. The Naval Research Laboratory has tested a variety of fluids for this application [16], and glycerin, a dense, viscous fluid, with high energy absorption appears to be one of the more promising materials for this application. When inserted as a barrier between the blast wave and the head, overpressure can potentially be reduced by up to 60% [16]. The drawback

with this augmentation is that the fluid may add too much weight or bulk to the ACH. With proper research and development, this problem may be solved, producing an extremely promising technology for U.S. soldiers to utilize in combat.

While both augmentations promise to decrease overpressure, more research and development is needed to perfect them. There is not enough research on the injury mechanism of blast-induced TBIs to confidently say how much energy the ACH must absorb from a blast wave to stop a TBI from occurring. Blast sensors included in the ACH in 2011 [11] accurately measure the force exerted by the blast wave on a soldier's helmet, potentially aiding in diagnostics. While it is important to stress that the sensor does not *actively* defend soldiers against overpressure, correlating the data from these blast sensors to long-term TBI outcomes for soldiers could provide insight into the blast TBI injury mechanism.

These helmet augmentations cannot yet be implemented, but their development could be accelerated given more resources and funding from the DoD. Although it is not as “exciting” as a new weapons system, one of the DoD's chief responsibilities is to protect soldiers. Rather than focusing on offensive efforts, perhaps it is time for a paradigm shift that puts more focus on defensive efforts. This does not lack support from researchers and medical professionals [2], [9], [16]; however, the DoD has failed to implement an effective blast wave protection system within the ACH [11]. With such a system in place, injuries like Robert Anetz's could be a rare occurrence rather than a disturbing norm.

References

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