http://news.nationalgeographic.com/2016/06/blast-shock-tbi-ptsd-ied-shell-shock-world-war-one/

Mystery of How Battlefield Blasts Injure the Brain May Be Solved

A landmark study sheds new light on the damage caused by “blast shock”—the signature injury of wars for more than a century.

Brain trauma from blast force is the signature injury of the Iraq and Afghanistan campaigns, afflicting hundreds of thousands of U.S. combat personnel. Although unseen, the damage strikes deeply into a soldier’s mind and psyche.

Blast Shock Revealed: These two postage-stamp-size sections of the cerebral cortex were stained to highlight the protein marker of brain damage. The brain tissue at left (gray coloring) is normal. But the section at right (red coloring), from a service member exposed to multiple high-explosive detonations, shows the distinctive and previously undescribed pattern of scarring. (Brain scans courtesy Daniel Perl)

By **Caroline Alexander**

PUBLISHED JUNE 9, 2016

A research team in the United States may have solved a mystery that has haunted soldiers and veterans for more than a century: how blast force from battlefield explosions injures the human brain.

The findings, published Thursday in the medical journal the *Lancet Neurology*, reveal a unique and consistent pattern of damage in the autopsied brains of eight military service members who had served in Iraq, Afghanistan, and elsewhere in the Middle East.

All had suffered trauma after exposure to blast force on the battlefield, mostly from improvised explosive devices (IEDs)—the signature injury of recent campaigns, just as shell shock from exploding artillery shells had been the signature injury of World War I, a hundred years before.

In medical terminology, traumatic brain injury, or TBI, covers conditions that range from penetrating head wounds to blunt-force trauma typical of concussions.

But as the new study claims to demonstrate, the pattern of damage caused by exposure to blast force observed in the eight military personnel is distinct from that commonly observed in the brains of football players or boxers who have suffered blunt-force TBI.

Outside medical opinion has yet to weigh in on the findings. But Daniel Perl—a neuropathologist at the Uniformed Services University of the Health Sciences, in Bethesda, Maryland, who led the team behind the groundbreaking paper—said that when he realized that the lesion representing blast damage was distinctive, he knew it was the kind of once-in-a-lifetime breakthrough scientists dream of.

“What we found was a pattern of scarring that in 40 years of examining thousands of brains at autopsy I’ve never seen before and as far as I know is not described in any of the medical literature,” Perl said.

Neuropathologists Daniel Perl, right, and Sharon Shively, a co-author of the study on brain scarring, photograph brain sections from the eight service members.
PHOTOGRAPH BY KURT MUTCHLER, NATIONAL GEOGRAPHIC

The implications of this finding are profound, pointing to the possibility that symptoms long thought to be psychological—ascribed to post-traumatic

stress disorder (PTSD)—may instead be direct results of physical damage to the brain.

“It will mean reevaluating people we’ve labeled as having PTSD,” Perl said. “There’s nothing obvious in terms of treatment, but at least it suggests that one should not think about approaching the problem as a purely mental health problem.” It would mean reexamining such treatments as talk therapy and psychological medications.

The blast shock finding also opens up potentially fertile new ground for research: Can the injury be healed or even mitigated? What equipment can be designed to protect service members against blast damage to their brains? Can tests be devised to identify damage in combatants on the battlefield in real time?

And it raises a philosophical question for young men and women drawn to military service: If you know that exposure to a blast event—the signature mechanism of injury in modern warfare–may well irreparably damage your brain, will you still join up?

Bewildering Symptoms

Left: This wounded German soldier, canteen in hand, rests on the battlefield, May 18, 1915. **Right:** Medics treat Specialist José Callazo after his mine-detecting vehicle detonated an IED in Iraq on August 4, 2007. Now, for the first time, it seems that the mystery of how battlefield explosions injure the brain may be solved.
PHOTOGRAPHS BY HULTON ARCHIVE/GETTY IMAGES (LEFT) AND BENJAMIN LOWY/GETTY IMAGES (RIGHT)

From the earliest years of the Iraq campaign, military personnel exposed to blast reported symptoms that included headache, sleeplessness, problems

with memory and concentration, mood disorders such as anger and depression, and impulsiveness. Many of these symptoms are also characteristic of PTSD, which afflicts an estimated 11 to 20 percent of all veterans of the wars in Iraq and Afghanistan in any given year.

Medical practitioners therefore initially assumed the symptoms to be psychological. Furthermore, no routine imaging technology had succeeded in identifying any evidence of physical injury to the brain. But by the end of the first decade of this century, researchers had begun to recognize that while blast damage could not be seen, it was nonetheless real.

The U.S. Department of Defense estimates that some tens of thousands of U.S. veterans and military service members deployed in Iraq and Afghanistan have sustained traumatic brain injury as a result of exposure to a blast event. But given that exposures to blast events were not even logged in the early years of the campaigns, the figure may be much higher.

ENLARGE

A shell bursts in 1916 behind a defensive wire entanglement in the village of Beaumont-Hamel, near the front line in the Battle of the Somme. The year before, the first medical case study of "shell shock"—the signature injury of World War I—was published in the*Lancet*.

PHOTOGRAPH VIA THE NATIONAL WORLD WAR I MUSEUM AND MEMORIAL

British soldiers surround a sea of artillery shells in 1917.

PHOTOGRAPH VIA IMPERIAL WAR MUSEUMS

A British airman leans out of his plane to drop a bomb during World War I.

PHOTOGRAPH VIA IMPERIAL WAR MUSEUMS

Trenches—with soldiers in them—slice across ground pocked with shell craters in the Champagne region of France.

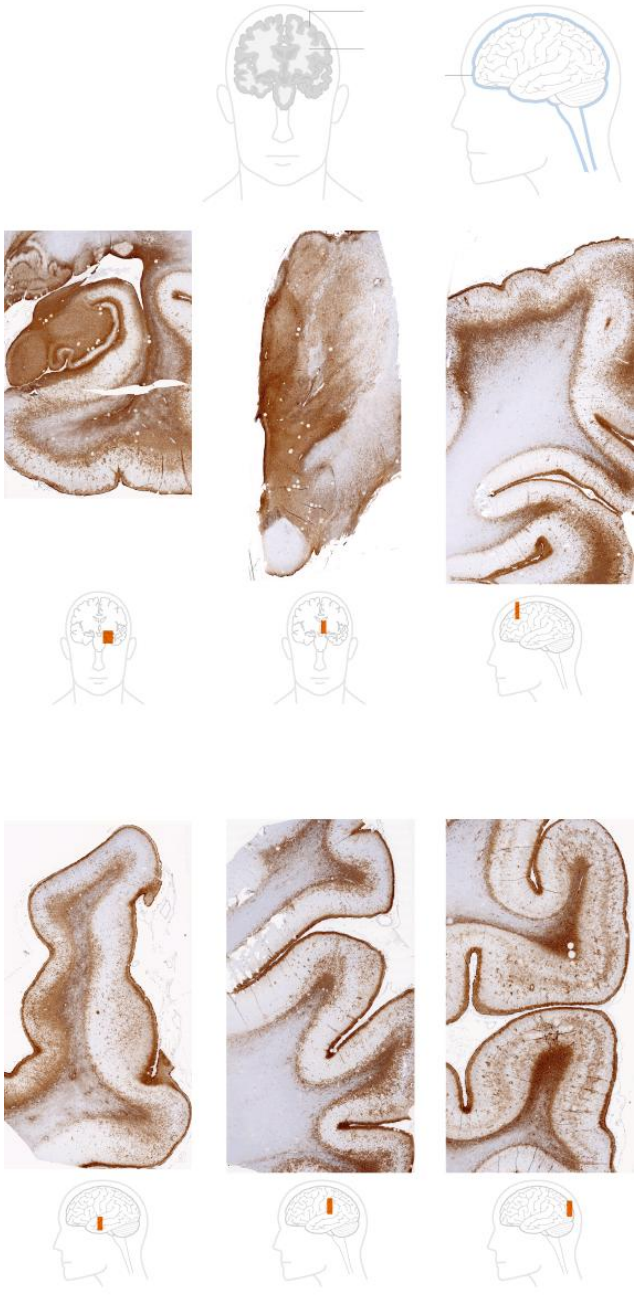
PHOTOGRAPH VIA THE NATIONAL WORLD WAR I MUSEUM AND MEMORIAL

Soldiers remove corpses from a trench in the Argonne region.
PHOTOGRAPH BY HULTON ARCHIVE/GETTY IMAGES
In this stereo card image from November 1917 German prisoners of war carry Allied wounded in northern France.
PHOTOGRAPH BY HULTON ARCHIVE/GETTY IMAGES
This World War I postcard came with a shell shock joke—not funny today in light of new understanding about how battlefield blast force affects the brain.
PHOTOGRAPH VIA THE NATIONAL WORLD WAR I MUSEUM AND MEMORIAL
Described as shell shock in 1918, the damage suffered by this British soldier, who had been captured by the Germans, was likely a unique pattern of scarring in his brain.
PHOTOGRAPH VIA IMPERIAL WAR MUSEUMS

One of the brains that the team studied also showed signs of chronic traumatic encephalopathy (CTE), a neurodegenerative disease caused by the repetitive blunt-force trauma typical of concussions sustained in contact sports. Another showed features suggestive of an extremely early stage of the disease.

“CTE is not what these service members are suffering when they come home,” Perl said. “But this study suggests there are further concerns. They come home with the symptoms caused by the immediate damage—the blast injury—but down the line, in decades, many of these guys will also be hit with CTE.”

The Puzzle of Blast

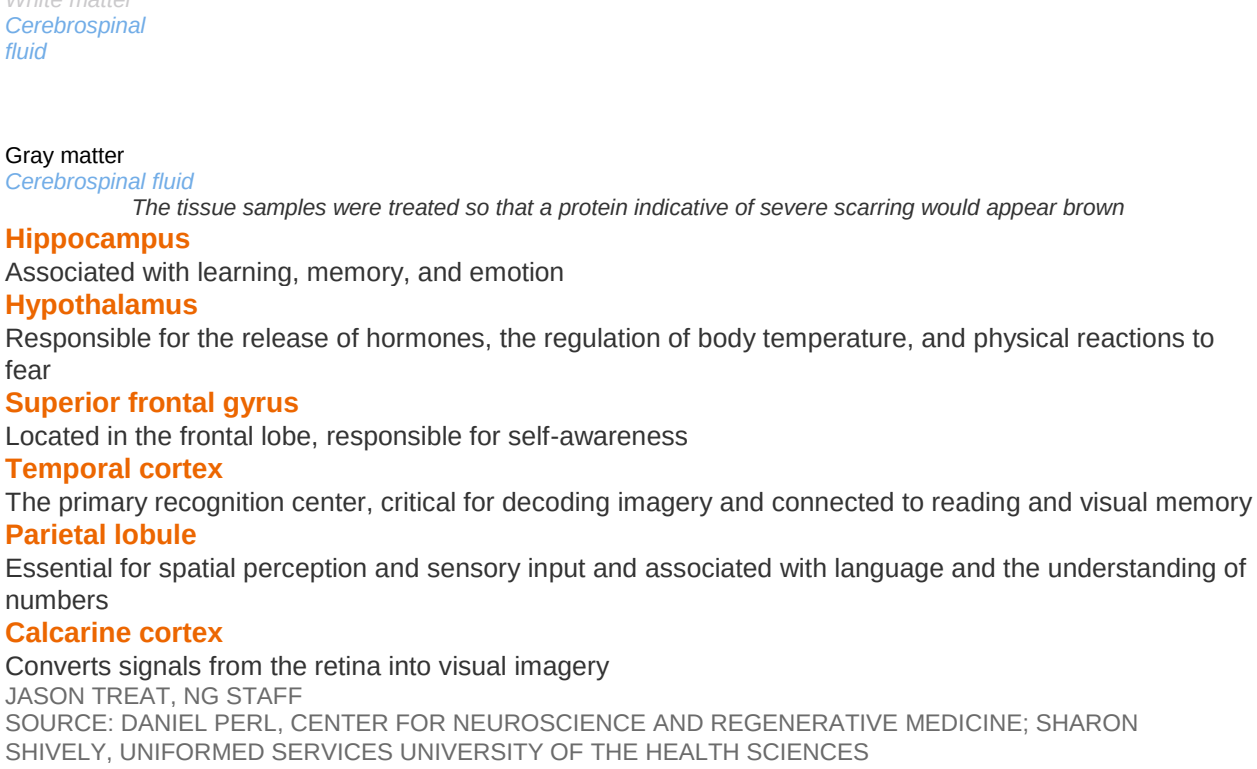


How Blast Shock Affects the Brain

Researchers examined tissue from the brains of eight military blast victims who had died. The images below reveal intense scarring in different regions of the brain.

Gray matter

Each case showed similar scarring patterns at the boundaries between tissues of different densities, such as gray matter and white matter, and between tissue and the cerebrospinal fluid that surrounds the brain.



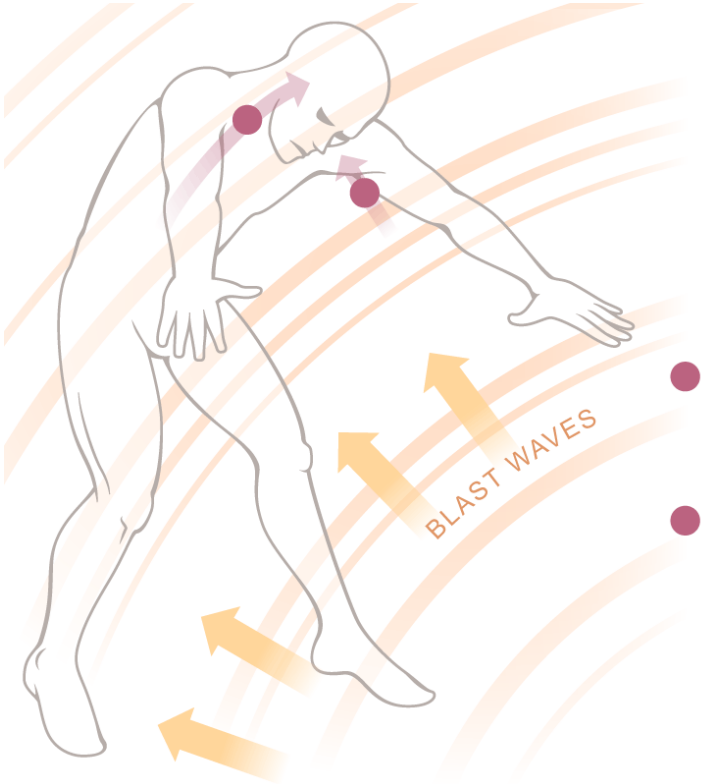
A wide array of research has attempted to discover the nature of blast injury. (See "The Invisible War on the Brain," *National Geographic,* February 2015.) Efforts have included sophisticated studies of the physics of blast itself, as well as lab experiments conducted on animals, computer modeling of blast effects, and searches for biomarkers of blast exposure.

An explosion is a complex event that unleashes multiple mechanisms of injury. The primary blast effect is the shock wave, a balloon of rapidly expanding gases that compresses surrounding air and advances outward from the detonation faster than the speed of sound. This shock wave is what enters the brain, passing so rapidly that it has come and gone before the people hit have even had time to move their heads.

Just how a shock wave enters the brain is still not understood. Some believe entry is through the natural openings in the skull: the eye sockets, ears,

nostrils, and mouth. Another theory is that since shock wave pressure hits the entire body, not just the head, it's transmitted into the chest or abdominal cavities and surges to the brain by way of the body's vasculature.

Once inside the skull, the wave advances through the brain at the speed of sound, passing through both fluids and matter, which respond differently to the wave's properties. As the new paper reports, the distinctive pattern of scarring occurs precisely in those places where different compositions of brain tissue intersect.



Lethal Shock

Blast waves expose the body to huge amounts of kinetic energy, which can damage areas in the brain where tissues of different densities interact. How blast waves enter the body is not fully understood, but two theories are foremost.

Kinetic energy hits the entire body and propagates as a shock wave traveling through blood vessels and tissues.

Shock waves pass through the skull, bruising the brain.

JASON TREAT, NG STAFF
SOURCE: IBOLJA CERNAK, UNIVERSITY OF ALBERTA

In 2013 the Department of Defense established the Center for Neuroscience and Regenerative Medicine Brain Tissue Repository, under the direction of Perl, to pursue postmortem study of brains at the tissue level.

“Our microscopes have resolutions a thousand times greater than any imaging technology,” Perl said. “Autopsy is the gold standard for this kind of investigation.”

The "Aha!" Moment On Shell Shock's Physical Injuries
Neuropathologist Dr. Daniel Perl talks with Nat Geo's Kurt Mutchler about the breakthrough on military brain injuries

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The eight brain specimens his team studied represented chronic cases, in which the person had lived at least six months after the blast event, as well as acute cases, in which death had followed within 60 days. “The acute cases are revealing,” Perl said. “The injury is only four days old, and yet we see the very beginning of the foundation of scars. And these early signs—these early scars—are in the right places, form the right pattern.”

Blast waves seem to cause damage at the boundaries of different structures, such as between brain matter and cerebrospinal fluids and between gray and white brain matter. That damage, Perl said, “is consistent with experiments that have modeled blast waves’ effects on the different substances forming the brain.”

More starkly revealing than any words are the brain images that illustrate what Perl describes. Panels show brain tissue, as delicate as butterfly wings, spatter-marked as if with buckshot, bearing outright tears surrounded by

broken tendrils of scarring or dark clouds of damage looming from the folds and furrows.

This blast damage reaches its spider legs into different regions of the brain: the frontal lobe, which controls attention span and emotional control; the hypothalamus, which regulates sleep; the hippocampus, responsible for the formation of memories. The symptoms resulting from damage to these areas are exactly the kinds of symptoms often attributed to PTSD.

The brown areas in this section of brain from a deceased service member with blast shock mark a particular protein that signifies something sinister: chronic traumatic encephalopathy, or CTE. Perl believes that blast shock may increase the chances that service members will develop CTE—a neurodegenerative disease typically associated with multiple concussions from contact sports—as they age.
PHOTOGRAPH COURTESY DANIEL PERL

What the Eight Men Endured

Emerging from the welter of medical data are details about the lives of the men who make up the research study. They had all been exposed to bombs, IEDs, and high explosives, and they had lived from as long as nine years after blast exposure to as little as four days. They ranged in age from 26 to 45 at the time of death. They had endured headaches, anxiety, depression, insomnia, memory and concentration problems, seizures, and chronic pain.

One was a Navy SEAL who conducted explosives training exercises and lost his coherence of thought; he began to jumble his speech and became overwhelmed by such routine tasks as driving or even packing a car.

Three of the men had acute brain injury and died shortly after exposure to the explosion, suffering burns, fractures, and hemorrhage. Four of the remaining five men who had chronic blast-induced brain injury died by

suicide or from drug overdoses. The cause of death of the eighth service member was not determined.

In December 2015, Congress passed a bill mandating the Department of Defense and the Department of Veterans Affairs to examine the effects of combat service "on suicides and other mental health issues among veterans."

The new paper may add to mounting evidence that destructive behaviors, including suicide, are outcomes directed by damaged regions of the brain—as symptomatic of blast damage as such common conditions as sleeplessness and ringing in the ears.

Déjà Vu

A century ago, in February 1915, the *Lancet,* the parent journal of the*Lancet Neurology,* published the first medical case study of shell shock in World War I. In the war's aftermath, medical judgment held that thousands upon thousands of shell-shocked men were "neurasthenic" or subject to "neuroses."

These mostly young veterans suffered through their lives in the belief that they had lost their nerve on the field of battle—in short, that they had failed. From the British government Ministry of Pensions files we can catch occasional glimpses of their postwar fates.

The Origins of "Shell Shock"

One case: a shell-shocked soldier who'd spent 118 days in the hospital being treated for loss of speech, inability to sleep, and loss of memory and concentration—and had been returned to active duty. Case notes made after the war remark on his complaints about "general weakness" and tremors in his hands. It is noted that his mental development is poor, and his answers to questions are "vague and contradictory." Then, like so many others, he slips from history's sight.

"We can't let this happen again," Daniel Perl said. "This study will certainly stimulate important further research and, we predict, will dramatically change how we think about these problems."

Beyond the specifically medical questions, the finding raises a number of issues, such as care costs many years into the future and whether those diagnosed with TBI should be awarded the Purple Heart.

“People that have seen the paper are very excited about it. Blast people working on military TBI are very excited,” Perl said. “Then they start asking questions: How large a dose of blast is damaging? Are multiple small exposures doing this? How common is this?—I have a feeling this is pretty common. Can you see it by imaging? And so far the answer to all of these is, we don’t know.”

Caroline Alexander *is the author of “The Invisible War on the Brain,”* National Geographic, *February 2015, which examined the mystery of blast force on the brain. She has written often about the toll of war, including a new translation of Homer’s* Iliad, *published in 2015.*

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The Lancet, Neurology

Characterisation of interface astroglial scarring in the human brain after blast exposure: a post-mortem case series

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DOI: http://dx.doi.org/10.1016/S1474-4422(16)30057-6

Summary

Background

No evidence-based guidelines are available for the definitive diagnosis or directed treatment of most blast-associated traumatic brain injuries, partly because the underlying pathology is unknown. Moreover, few neuropathological studies have addressed whether blast exposure produces unique lesions in the human brain, and if those lesions are comparable with impact-induced traumatic brain injury. We aimed to test the hypothesis that blast exposure

produces unique patterns of damage, differing from that associated with impact-induced, non-blast traumatic brain injuries.

Methods

In this post-mortem case series, we investigated several features of traumatic brain injuries, using clinical histopathology techniques and markers, in brain specimens from male military service members with chronic blast exposures and from those who had died shortly after severe blast exposures. We then compared these results with those from brain specimens from male civilian (ie, non-military) cases with no history of blast exposure, including cases with and without chronic impact traumatic brain injuries and cases with chronic exposure to opiates, and analysed the limited associated clinical histories of all cases. Brain specimens had been archived in tissue banks in the USA.

Findings

We analysed brain specimens from five cases with chronic blast exposure, three cases with acute blast exposure, five cases with chronic impact traumatic brain injury, five cases with exposure to opiates, and three control cases with no known neurological disorders. All five cases with chronic blast exposure showed prominent astroglial scarring that involved the subpial glial plate, penetrating cortical blood vessels, grey–white matter junctions, and structures lining the ventricles; all cases of acute blast exposure showed early astroglial scarring in the same brain regions. All cases of chronic blast exposure had an antemortem diagnosis of post traumatic stress disorder. The civilian cases, with or without history of impact traumatic brain injury or a history of opiate use, did not have any astroglial scarring in the brain regions analysed.

Interpretation

The blast exposure cases showed a distinct and previously undescribed pattern of interface astroglial scarring at boundaries between brain parenchyma and fluids, and at junctions between grey and white matter. This distinctive pattern of scarring may indicate specific areas of damage from blast exposure consistent with the general principles of blast biophysics, and further, could account for aspects of the neuropsychiatric clinical sequelae reported. The generalisability of these findings needs to be explored in future studies, as the number of cases, clinical data, and tissue availability were limited.

Funding

Defense Health Program of the United States Department of Defense.