

# REPETITIVE BLAST EXPOSURE AND BRAIN INJURY

*Numerous research studies provide evidence that repetitive blast exposures harm the brain*

## I. INTRODUCTION

Trauma from blast exposure has become an increasing component of modern warfare. Blast injuries result from the sudden onset of shock waves generated by an explosion. This paper will first review scientific evidence that repetitive blast exposure harms the brain. It will underscore the vital need for blast pressure monitoring in military and tactical law enforcement personnel. Next, it will describe a recently available technology that enables this surveillance. Finally, it will emphasize the far-reaching benefits of blast pressure monitoring in protecting the health of military and tactical law enforcement personnel.

## II. EVIDENCE THAT REPETITIVE BLAST EXPOSURE HARMS THE BRAIN

The signature injury of modern warfare is **mild traumatic brain injury** (mTBI). Blast exposure is the leading cause of mTBI for US forces deployed to Afghanistan and Iraq in Operation Enduring Freedom (OEF), Operation Iraqi Freedom (OIF), and Operation New Dawn (OND).<sup>1</sup> The estimated prevalence of mTBI among returning service members is quite high, ranging from 15.2% to 22.8%.<sup>2-4</sup> Acute symptoms of mTBI include headaches, dizziness, fatigue, irritability, confusion, memory problems, and sleep disturbances. In some cases, blast exposure can harm the brain without producing any obvious acute symptoms. Blast-related symptoms can surface much later in such cases.<sup>5</sup>

Research provides evidence that *blast exposure damages the structure of the brain*. In one study, Yeoh and colleagues reported evidence that blast overpressure disrupts the highly protective blood-brain barrier in rats.<sup>6</sup> In a separate study, Meabon and colleagues found evidence that blast exposure in mice damages the blood-brain barrier and interferes with the brain's expression of a protein called tau.<sup>7</sup> Using a swine model of blast-induced TBI, Ahmed and colleagues found evidence that blast exposure damages brain cells, compromises the permeability of blood vessels, and causes brain inflammation.<sup>8</sup>

In a postmortem study of veterans exposed to blast and/or concussive injury, Goldstein and colleagues found evidence of a tau protein-linked degenerative brain disease known as chronic traumatic encephalopathy (CTE). Veterans' brain pathology was similar to that of athletes with a history of repetitive concussive injury.<sup>9</sup> In another postmortem study, Shively and colleagues compared the brains of blast-exposed military personnel with the brains of civilians who had no reported history of blast exposure (including cases with no TBI, cases with non-blast TBI, and cases with opioid abuse). In the brains of the blast-exposed military personnel, they found a unique pattern of damage called interface astroglial scarring. The investigators concluded that this pattern of damage may be specific to blast and explain the persistent neuropsychiatric symptoms of blast TBI.<sup>10</sup>

In a study of 134 veterans, Robinson and colleagues found that close-range blast exposure was associated with altered brain connectivity, even when the blast exposure did not result in concussion symptoms at the time.<sup>11</sup> In a study of 52 OEF/OIF veterans, Bazarian and colleagues found evidence that the severity of posttraumatic stress disorder (PTSD) is related to

the severity of combat stress and structural brain changes, but not to a clinical diagnosis of mTBI. They concluded that blast exposure may induce subclinical brain injury and contribute to the onset of PTSD in a combat environment.<sup>12</sup>

Furthermore, many studies have provided evidence that *the effects of blast exposure on the brain are cumulative and long-lasting*. In a study of 27,169 U.S. Army Special Operations Command (USASOC) personnel, Kontos and colleagues found that those with a history of blast-related mTBI were at greater risk of reporting PTSD symptoms than those with no mTBI history.<sup>13</sup> In a survey study, Carr and colleagues reported that repeated low-level occupational exposure to blast was associated with symptomatology similar to concussion. The number and severity of symptoms increased with history of blast exposure, and symptoms interfered with daily function.<sup>14</sup> In a longitudinal study, Mac Donald and colleagues found evidence that in patients with concussive blast TBI, *symptoms worsen, rather than resolve, over time*. From the 1-year to 5-year follow-up evaluations, 36 out of 50 patients with concussive blast TBI (72%) showed a decline in global outcome, compared with only 5 out of 44 combat-deployed control participants (11%). In addition, the group with concussive blast TBI showed a worsening of symptoms of PTSD and depression over this time.<sup>15</sup>

Meabon and colleagues found that in combat veterans with blast-related mTBI, the number of blast exposures correlated with symptoms of dizziness, loss of balance, and poor coordination. In addition, they found that an increase in the number of blast exposures was associated with lower glucose metabolism in the part of the brain known as the cerebellum.<sup>7</sup> In a study of 80 USASOC personnel, Kontos and colleagues reported evidence that a history of blast-related mTBI exacerbates the initial symptoms of a subsequent mTBI.<sup>16</sup> Trotter and colleagues, in a study of 249 veterans, found evidence that blast exposure accelerates the brain's aging process by reducing the integrity of the brain's white matter tissue (Figure 1).<sup>17</sup> In a study of 45 veterans, Taber and colleagues found evidence that primary blast exposure reduces the integrity of the brain's white matter tissue, *even in the absence of acute symptoms of TBI*.<sup>18</sup> In a recent article, Elder and colleagues reviewed substantial evidence that blast-related TBI is pathophysiologically distinct from non-blast TBI and that low-level blast has long-term effects on the brain.<sup>19</sup>

## III. THE CRITICAL NEED FOR BLAST PRESSURE MONITORING

Scientific studies have provided overwhelming evidence that blast exposure damages the brain, with long-lasting, adverse effects. However, our knowledge of the cumulative effects of blast exposure is severely limited by a lack of blast exposure monitoring. To estimate blast exposure, studies typically rely on self-report and semi-structured interviews of military personnel. **Without monitoring blast pressure in individuals and evaluating the relationship between blast pressure levels and acute/chronic injury, we will never fully understand the cumulative effects of blast exposure.** As noted by Belanger and colleagues, research with larger sample sizes is needed, as well as career-long objective monitoring.<sup>20</sup>

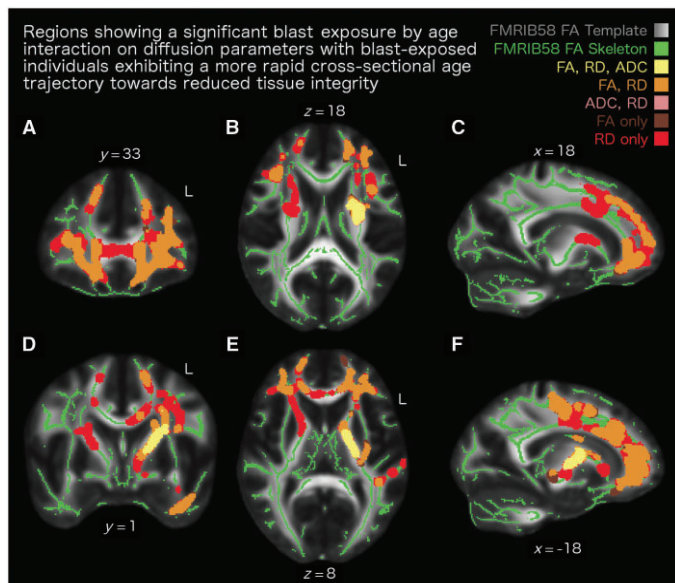


FIGURE 1. Regions of the human brain show a significant interaction between blast exposure and age on diffusion measures. Using a method called diffusion tensor imaging (DTI), researchers found that regions throughout the human brain's white matter tissue (presented in different views in A-F) showed a significant interaction between blast exposure and age on diffusion measures.<sup>17</sup> Fractional anisotropy (FA), radial diffusivity (RD), and the apparent diffusion coefficient (ADC) are measures of water diffusion in the brain that provide information about the integrity of the brain's white matter tissue. The data provide evidence that blast exposure accelerates the brain's aging process by reducing the integrity of the brain's white matter tissue. (The image in this figure, available at <https://academic.oup.com/brain/article/138/8/2278/330320/Military-blast-exposure-ageing-and-white-matter>, is the original image from Figure 2 of Reference 17. Reference 17 is distributed under the terms of the Creative Commons Attribution 4.0 International License at <http://creativecommons.org/licenses/by/4.0/>.)

Obtaining objective measurements of blast exposure is critical for developing effective prevention and treatment strategies.<sup>5</sup>

Following the introduction of film badges for personal radiation monitoring in the 1920s, it took approximately 40 years to understand how radiation exposure related to the development of cancers.<sup>21-23</sup> Measurement was the necessary first step in understanding the cumulative effects of radiation exposure. Likewise, measurement of blast overpressure is the crucial first step in understanding the cumulative effects of blast exposure.

With objective, accurate measurements of blast pressure exposure, we would be able to correlate blast pressure levels with levels of acute/chronic injury in individuals. The safety data from these studies would help us to identify blast pressure levels that put individuals at risk for brain injury and to tailor medical treatment to individual patients. Further, it would guide efforts to reduce blast pressure exposure and to determine how quickly to re-deploy individual service members.

#### IV. A PROVEN TECHNOLOGY FOR BLAST PRESSURE MONITORING

A recently available, proven technology exists to monitor individual dosing of blast exposure in training and operations. The Blast Gauge® System utilizes a breakthrough, wearable sensor technology to document and quantify individualized blast exposure. It is a lightweight, three-sensor set that is worn on the helmet, chest, and shoulder.<sup>24</sup> Data from combat training, obtained from the Blast Gauge System, show that military personnel experience high rates of repetitive overpressure exposures and support the need for cumulative overpressure monitoring.<sup>25-26</sup> Blast Gauge technology opens up a new approach to blast surveillance.

#### V. CONCLUSION AND CALL TO ACTION

Blast exposure is an occupational hazard that injures the brain. If we fail to take steps to reduce exposures, it represents a

significant liability for the VA System. Now that technology is available to measure individualized blast exposure, we need to use it to obtain critical data that will help us to develop effective prevention and treatment strategies. This will protect the long-term health of our warfighters and tactical law enforcement personnel.

#### VI. REFERENCES

- McKee AC, Robinson ME. Military-related traumatic brain injury and neurodegeneration. *Alzheimers Dement*. 2014;10(3):S242-S253.
- Hoge CW, McGurk D, Thomas JL, Cox AL, Engel CC, Castro CA. Mild traumatic brain injury in U.S. Soldiers returning from Iraq. *N Engl J Med*. 2008;358(5):453-463.
- Terrio H, Brenner LA, Ivins BJ, et al. Traumatic brain injury screening: Preliminary findings in a US Army Brigade Combat Team. *J Head Trauma Rehabil*. 2009;24(1):14-23.
- Polusny MA, Kehle SM, Nelson NW, Erbes CR, Arbisi PA, Thuras P. Longitudinal effects of mild traumatic brain injury and posttraumatic stress disorder comorbidity on postdeployment outcomes in National Guard soldiers deployed to Iraq. *Arch Gen Psychiatry*. 2011;68(1):79-89.
- Institute of Medicine. *Gulf War and Health, Volume 9: Long-Term Effects of Blast Exposures*. Washington, DC: National Academies Press; 2014.
- Yeoh S, Bell ED, Monson KL. Distribution of blood-brain barrier disruption in primary blast injury. *Ann Biomed Eng*. 2013;41(10):2206-2214.
- Meabon JS, Huber BR, Cross DJ, et al. Repetitive blast exposure in mice and combat veterans causes persistent cerebellar dysfunction. *Sci Transl Med*. 2016;8(321):321ra6.
- Ahmed F, Gyorgy A, Kamnaksh A, et al. Time-dependent changes of protein biomarker levels in the cerebrospinal fluid after blast traumatic brain injury. *Electrophoresis*. 2012;33(24):3705-3711.
- Goldstein LE, Fisher AM, Tagge CA, et al. Chronic traumatic encephalopathy in blast-exposed military veterans and a blast neurotrauma mouse model. *Sci Transl Med*. 2012;4(134):134ra60.
- Shively SB, Horkayne-Szakaly I, Jones RV, Kelly JP, Armstrong RC, Perl DP. Characterisation of interface astroglial scarring in the human brain after blast exposure: a post-mortem case series [published online June 9, 2016]. *Lancet Neurol*. doi:10.1016/S1474-4422(16)30057-6.
- Robinson ME, Lindemer ER, Fonda JR, Milberg WP, McGlinchey RE, Salat DH. Close-range blast exposure is associated with altered functional connectivity in Veterans independent of concussion symptoms at time of exposure. *Hum Brain Mapp*. 2015;36(3):911-922.
- Bazarian JJ, Donnelly K, Peterson DR, Warner GC, Zhu T, Zhong J. The relation between posttraumatic stress disorder and mild traumatic brain injury acquired during Operations Enduring Freedom and Iraqi Freedom. *J Head Trauma Rehabil*. 2013;28(1):1-12.
- Kontos AP, Kotwal RS, Elbin RJ, et al. Residual effects of combat-related mild traumatic brain injury. *J Neurotrauma*. 2013;30(8):680-686.
- Carr W, Polejaeva E, Grome A, et al. Relation of repeated low-level blast exposure with symptomology similar to concussion. *J Head Trauma Rehabil*. 2015;30(1):47-55.
- Mac Donald CL, Barber J, Jordan M, et al. Early clinical predictors of 5-year outcome after concussive blast traumatic brain injury. *JAMA Neurol*. 2017;74(7):821-829.
- Kontos AP, Elbin RJ, Kotwal RS, et al. The effects of combat-related mild traumatic brain injury (mTBI): Does blast mTBI history matter?. *J Trauma Acute Care Surg*. 2015;79(4):S146-S151.
- Trotter BB, Robinson ME, Milberg WP, McGlinchey RE, Salat DH. Military blast exposure, ageing and white matter integrity [published online June 1, 2015]. *Brain*. 2015. doi:10.1093/brain/aww139.
- Taber KH, Hurley RA, Haswell CC, et al. White matter compromise in veterans exposed to primary blast forces. *J Head Trauma Rehabil*. 2015 Jan-Feb;30(1):E15-E25.
- Elder GA, Stone JR, Ahlers ST. (2014). Effects of low-level blast exposure on the nervous system: is there really a controversy?. *Front Neurol*. 2014;5:269.
- Belanger HG, Bowling F, Yao EF. Low-Level Blast Exposure in Humans: A Systematic Review of Acute and Chronic Effects. *J Spec Oper Med*. 2020 Spring; 20(1) 87-93.
- Flakus FN. Detecting and measuring ionizing radiation - a short history. *IAEA Bulletin*. 1981;23(4):31-36.
- Inkret WC, Meinhold CB, Tashner JC. A brief history of radiation protection standards. *Los Alamos Sci*. 1995;23:116-123.
- Khare P, Nair P, Khare A, Singh V, Chatterjee R. The road to radiation protection: A rocky path. *J Clin Diagn Res*. 2014;8(12):ZE01-ZE04.
- BlackBox Biometrics, Inc. The Blast Gauge® System. <https://blastgauge.com>. Accessed July 13, 2017.
- Baillie JM, Ma AB, Gomez R, et al. Blast exposure from shoulder mounted rocket launchers. Poster presented at: The 2015 Military Health System Research Symposium; August 17-20, 2015; Ft. Lauderdale, FL.
- Da Silva UO, Lee G, Kamimori GH, Cho EG, Dark HE. Overpressure exposure to artillery and mortar crew members. Poster presented at: The 2015 Military Health System Research Symposium; August 17-20, 2015; Ft. Lauderdale, FL.

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