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TITLE: Sensors to Assess Pressure-Mediated Effects on Blast-Induced Traumatic Brain Injury

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14. ABSTRACT

This study was designed to investigate contributions of direct impact of blast on the skull in two different orientations; face-on and side-on orientation . To assess a loading force on a target with different impact area two piezoelectric (PCB) sensors were placed inside a shock tube in parallel and perpendicular orientation to blast wave. Results show that the face-on pressure is much higher than the static, side-on pressure. In addition, integral area under the pressure wave increases with the target size as a consequence of pressure wave reflection with increasing target. Rats were placed in a blast tube and exposed to 30-40 kPa blast overpressures in two different orientations: 1) with the head facing the blast wave; and 2) with one side of the body exposed to blast. Pressure wave inside the rat brain and lateral cerebral ventricle was measured simultaneously with Samba pressure microsensors and compared with the outside pressure waves. Pressure wave characteristics such as rise time, duration and amplitude were found to differ in respect to the orientation to blast.

15. SUBJECT TERMS
None provided..

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INTRODUCTION

The detonation of any powerful explosive generates a blast wave, a sudden and extreme differences in pressures that lead to significant neurological injury. About 1,800 US troops, according to the Department of Veterans Affairs, are now suffering from traumatic brain injuries (TBIs) caused by penetrating wounds. But neurologists worry that hundreds of thousand more – at least 30% of troops who have engaged in active combat for four months or longer in Iraq and Afghanistan, are at risk of potentially disabling, neurological disorders form the blast waves, all without sufferening a scratch. The standard care used for “closed-hear” injuries does not work with brains damaged by shock waves. Despite the usual interventions and treatments, the majority of blast-injury patients after exposure to blast do not fully recover. The precise mechanisms of brain injury after exposure to blast are not known. There is growing understanding within neurosurgeons that blast injuries are different from those caused by penetrating or skull-fracture trauma. Predominant types of brain injuries after exposure to blast are microscopical, sub-cellular diffuse axonal injuries. They result when shearing, stretching, and/or angular forces pull on axons and small vessels. It was suggested that the shock waves are transmitted to the brain via body fluids, blood and cerebrospinal fluid (CSF) after compression of thorax and abdomen resulting in intracerebral hemorrhages.

Direct recording of a pressure wave inside the brain during exposure to blast could be useful for discrimination between contributions of different mechanisms e.g. primary shock and pressure waves vs. secondary (systemic) factors to brain injury as result of exposure to blast. It would allow definition of threshold levels of blast pressure for brain damage. In addition, it could result in designing better protection by body armor against brain blast damage. This could be of a considerable progress in better protection of blast related casualties.

BODY

The blast wave from explosion interacts with a structure by coupling energy from the blast flow into the structure. This causes the structure to deform depending on the strength of the blast and the properties of the structure. The characteristics of an explosive blast wave that have the most influence on structural response are its peak pressure, impulse and overall shape. The strength, geometry and natural period of oscillation of the structure being loaded then determine the type of interaction and the response. While the blast wave is often characterized in terms of the blast overpressure (BOP), this metric usually refers to the static or side-on pressure. This pressure can be measured by a sensor aligned parallel to the direction of propagation of the blast flow. However, the static pressure is not the only component of blast interaction with structures. When a blast wave strikes a structure the pressure wave is reflected from the surface and can be significantly higher than the incident shock pressure.

At the first part of this study we measured some basic characteristics of the blast wave produced in an air compressed shock tube (Fig.1).

Fig. Air driven shock tube at the WRAIR/NMRC used for blast pressure wave generation.

We used two piezoelectric (PCB) sensors (PCB Piezotronics, NY) to measure side-on and face-on pressures after blast. One sensor for measurement of static face-on pressure was placed parallel to the direction of blast, while the second sensor was placed perpendicular to the blast flow. As expected, the reflected pressure was about 2 times higher than the static pressure (Fig.2). Next, we were interested if increasing target area around the sensor would influence pressure wave characteristic. For this purpose a solid disk with 1.5 inch diameter was placed around the sensor. This significantly changed the overpressure peak duration compared with the bare probe (Fig.2). This finding could have important implications for understanding blast injury in relation to object geometry and size relative to the explosion.

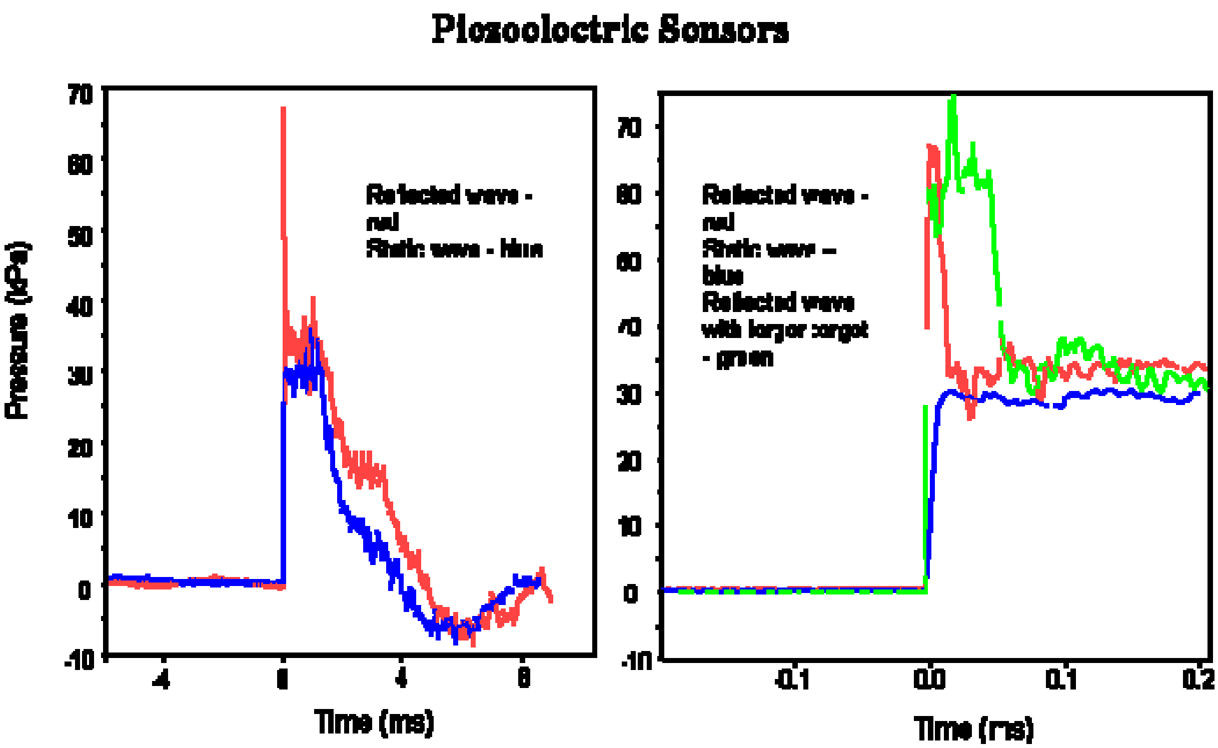

Fig.2. Blast wave detected by two PCB sensors aligned parallel (blue line) and perpendicular (red line) to the direction of the blast flow (left). Details of the blast wave front detected by parallel (blue) probe and by probes perpendicular to the blast flow. Significantly longer duration was observed with target enlarged by a disk around the probe (green line).

At the next part of the study we tested miniature fiber optic pressure sensors (Samba, Sweden) with O.D.0.46 mm (Fig.3) in the shock tube and compared pressure characteristics with PCB sensor response (Fig.4).

Fig.3. Microfiber optic pressure probe for blast pressure wave measurement.

Fiber Optic Sensors

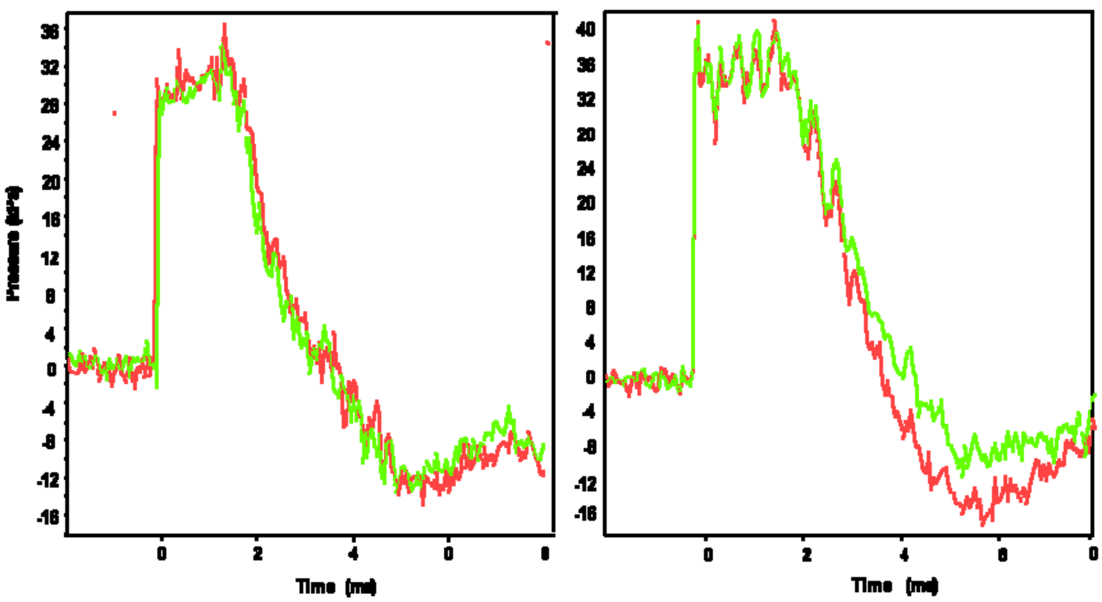

Fig.3. Microfiber pressure response to blast pressure in two different orientation; side exposed (left) and facing blast (right). Two sensors red and green lines) were tested simultaneously in each position.

The pressure duration and amplitude was comparable with PCB measurement. The only difference was lower initial peak response in face-on exposure, probably resulting from lower sampling rate 100 kHz compared with 200 kHz at PCB.

For intracerebral pressure measurement, male Sprague-Dawley rats were anesthetized and a plastic guide cannula (23-gauge) with a small pedestal was inserted through the hole 3.5 mm below the surface of the skull to reach the lateral cerebral ventricle. Another probe was inserted in frontal cortex 5 mm deep (1 mm anterior and 2.5 mm lateral to bregma). To protect the sensor element from direct mechanical influence by brain tissue, the optic fiber was inserted in a PTFE guide cannula (0.8 mm O.D.). Anesthetized animals were then placed into a pneumatic shock tube in two orientation; facing the blast wave or with one side exposed (Fig.3) with the mean peak overpressure of 30-40 kPa. After exposure, the animals were sacrificed and the position of the cannulas inside the brain was checked after injection of dye . Two PCB sensors were placed outside of the rat to measure external blast pressure intensity.

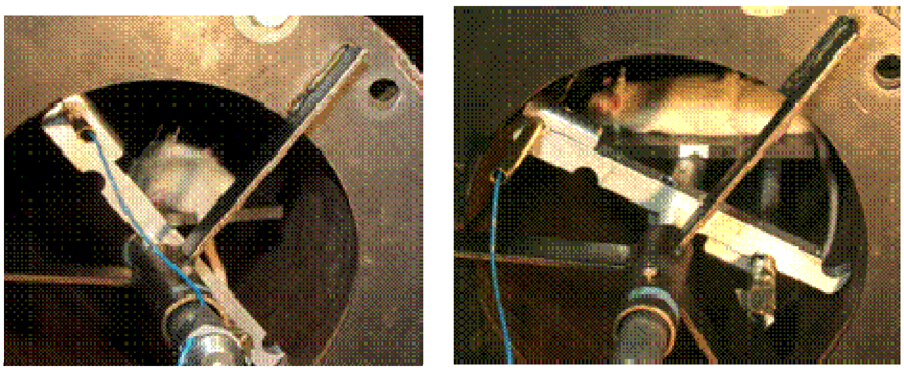

Fig.4. Front (left) and Side (right) orientation of rats placed inside the blast tube for intracerebral pressure recording.

In both position, frontal and side-on orientation pressure after blast was higher in lateral ventricle than in the frontal cortex (Fig.5). There were only small differences in the amplitude of the pressure wave at the front and side-on position. However, there was amarked differences in the duration of the shock wave between two orientation with the higher duration in front exposure.

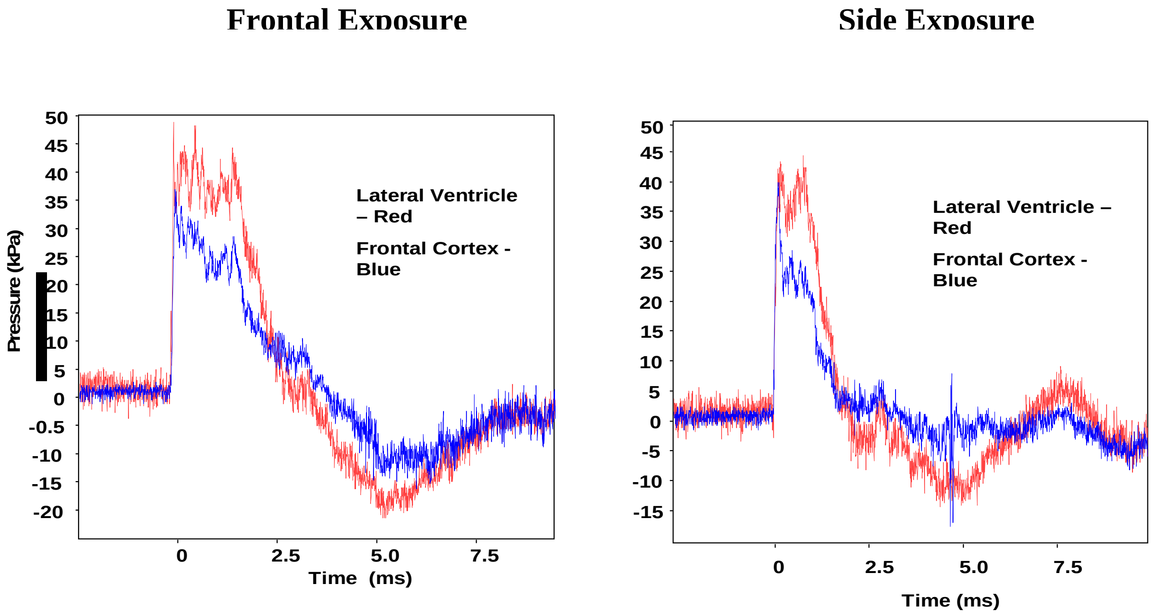

Fig.5.

Shock wave measured inside the brain in lateral ventricle and frontal cortex in two different orientation to blast.

KEY RESEARCH ACCOMPLISHMENT

- Animal protocol approved
- Installation and testing PCB sensors
- Characterization of the blast wave in a shock tube
- Installation and characterization microfiber SAMBA pressure sensors
- Measurement of the shock wave inside the rat brain in two orientation to blast

REPORTABLE OUTCOMES

None

CONCLUSION

Characterization of the shock wave after blast produced in a shock tube is one the basic assumption for blast related research. That was achieved by installation of two PCB sensors inside the shock tube. The basic characteristics of the blast wave measured by fiber optic pressure sensors is similar to the PCB sensors. This justifies the use of microfiber sensors for animal experiments. Shock wave after blast was detected simultaneously in two location of rat brain, and in two different orientation to blast wave.

Results show some differences that could be potentially of the great importance for understanding the mechanisms of pressure wave propagation and penetration into the brain and the mechanisms of brain blast injury.

REFERENCES

None

APPENDICES

None

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