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EDITORIAL

Experimental models and investigations of blast-induced traumatic brain injury

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1 Overview

Given the contemporary concern surrounding blast injury and the breadth of work currently being conducted in this area of injury biomechanics, the primary objective of this thematic issue on blast-induced traumatic brain injury (bTBI) has been to provide a cross-sectional snapshot of the current status of research within the bTBI community. This journal issue is the second in a two-part thematic series on bTBI that brings together leading contributors from various sectors of this broad field of research.

The focus of the current issue is primarily experimental investigations into aspects of bTBI. The review process for this issue was particularly informative as it brought much of the existing controversy in the field to the forefront, particularly divergent and strongly held opinions regarding the design of experimental work. The review process was thorough, and a conscious effort was made to avoid any scientific bias from the editorial team. The most poignant point of contention surrounded the relative contribution of dynamic pressure in certain laboratory-simulated blast loading conditions. There is reason for concern that some laboratory methods do not reproduce the dynamic conditions relevant to an operational blast load and should not be seen as a direct analog to a blast event, despite being able to match the static pressure loading condition at a single specific location. Concerns over the relevance of the complete dynamic loading history on a test subject are well-founded and deserve careful attention in blast experiments. However, upon reviewing submissions for this issue, it appeared clear to the editorial team that work involving non-ideal blast conditions could still contribute significantly to the field, assuming that the limitations of the work are well-defined and that the effects of these conditions are well-characterized and understood. For example, the development of diagnostic tools, sensors, and surrogates can still be informed from shock experiments which may not present all the characteristics of an operational blast. In contrast, direct evaluation of injury thresholds most likely requires a faithful representation of all blast flow parameters.

Our views on proper experimental design and relevance of loading conditions are described in the editorial accompanying the first part of the thematic issue [1]. This earlier editorial also provided an overview of some of the intractable problems currently facing research in the bTBI field [1]. Through this overview, we sought to engage the shock physics community with the expectation that future research by this community will address these outstanding issues, particularly proper blast-loading experimental design considerations and the scaling of blast wave loading across different animal models.

2 bTBI thematic issue

The objective of the thematic issue at the outset of this endeavor was to bring together a broad range of researchers from every corner of the multi-disciplinary spectrum investigating this health issue. There are a number of outstanding issues from a shock wave physics perspective that require further engagement from the shock physics community to ensure the accuracy of experimental and numerical approaches taken in the literature. Better defining the nature of the exposure conditions, describing the interaction of

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a blast wave with the body, understanding internal wave mechanics, developing relevant scaling approaches, and refining methods to reproduce blast exposure in a laboratory environment are, among others, topics where input of the community is critically needed. We envisage this thematic issue as an important step in engaging the shock physics community. The intention of the thematic issue is to provide the reader with an overview of the current state of operational and occupational threats, numerical models, small-scale models, experimental head–brain surrogates, animal models, and medical perspectives on bTBI.

2.1 Editorial information on the thematic issue

Our call for papers received a total of 26 original research and review manuscripts that were considered for publication. As a result of this incredible response from the community, the thematic issue was divided into two parts focusing on different aspects of bTBI. The first part of this thematic series of issues (vol. 27, issue 6), which was published in November 2017, focused on characterizing occupational blast exposures as well as computational contributions to bTBI investigation. This current issue (vol. 28, issue 1), which is the second in the thematic series, focuses primarily on experimental models and investigations of bTBI.

Every article contained in the current issue was subjected to a rigorous peer-review process, as per the policies and procedures normally followed by the *Shock Waves* Journal. Each manuscript was reviewed by two or more independent referees, each of whom is an internationally recognized expert in the field. There were 26 submitted manuscripts, of which three were rejected, four were withdrawn by the authors after a "major revisions" decision, and 19 papers were finally accepted after, typically, two or three revisions. Thus, the effective rejection rate for the thematic issue is 27%. The present issue (vol. 28, issue 1), which is the second of the two journal issues on bTBI, contains nine accepted papers, which builds on the ten papers that were published in the previous issue of the journal (vol. 27, issue 6).

2.2 Content overview of part 2: experimental models and investigations of bTBI

Several contributions to this issue focus on simulators that are used in testing in vitro cell and tissue cultures, surrogates, and postmortem human subjects (PMHS). The experiments described in these articles use a variety of experimental techniques, including full-scale explosions and shock-tube-based techniques to approximate blast loads.

The first paper in the issue is a contribution from a private company with extensive experience in designing and testing explosive ordnance disposal suits. This article, written by Dionne et al. [2], presents a test methodology used to apply brain injury criteria to the development of engineering correlations that assist in the design of the personal protective equipment. The complexity of the headform used in blast testing was advanced significantly in the work of Ouellet and Philippens [3]. This paper provides a detailed description of a head surrogate developed through a series of live explosive blast tests and shock tube investigations, providing data over a wide array of loading scenarios. The focus of the analysis centers on the use of surface and intracranial pressure measurements to discuss the multi-modal response of the surrogate, which is linked to mechanisms of stress transmission in the head. Piehler et al. [4] describe a novel method of investigating small-scale explosive blast loading of cellular assays of NG108-15 neuronal/glia cells in a water-filled aquarium. The experiments were modeled using the CTH code to determine the pressure histories within the well-plate assembly containing the cells. The peak overpressures were correlated to measures of post-event cellular damage and cell viability.

In an evaluation of shock tube use for analyzing simulated blast loads, Alay et al. [5] conducted experiments to measure the dynamic loads generated on head surrogates at different locations under shock tube testing conditions. While peak pressures may be able to be matched in certain loading scenarios, the impulse and dynamic load to the surrogate are shown to be strongly dependent on the location of specimen placement within the shock tube. This study cautions against the use of shock tube end-jet configurations. Iwaskiw et al. [6] conducted a study on pressure wave loading of postmortem human surrogates, embedding radiopaque markers into the brain at specific locations to investigate brain displacements during loading. These experiments were conducted in a shock tube end-jet configuration with an incorporated high-speed X-ray capability. Sawyer et al. [7] describe several investigations involving different platforms (shock tube and underwater explosives testing) to probe the effects of blast loads on the response of rodent heads and brain cell aggregate cultures. Differences in the post-exposure levels of specific proteins are discussed for rodent heads that were restrained or left unrestrained. Changes in cellular function of rat brain cell aggregate cultures that were exposed to air and underwater blast loadings are investigated. The simulated blast loads were produced experimentally using a carefully designed shock tube with a diverging driver section and end wave eliminator section, which is described in the article. Ritzel et al. [8] describe an experimental investigation of the acceleration of spheres of different sizes and masses in a simulated blast wave loading event. This study used a square-profile shock tube with a divergent driver section to reproduce the conditions of a blast wave event. This work is focused on establishing appropriate scaling laws for blast injury models.

Thielen et al. [9] present a new approach to considering the effect of blast waves on biological systems, introducing

Caenorhabditis elegans (a roundworm) as a model organism for bTBI investigation. The organism was placed within wells and tested in an anthropomorphic head surrogate that was subjected to a pressure wave in a shock tube end-jet configuration. The results are used to link biological responses to the application of a short-duration complex pressure wave system.

In the final paper of the issue, Ganpule et al. [10] investigate the role of the bulk modulus on predictions of shear strain within the head for the purposes of bTBI modeling. The results are compared to non-injurious rotational accelerations of the head for validation.

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