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A FINITE ELEMENT STUDY OF BLAST OVERPRESSURE ON THE SKULL WITH AND WITHOUT HELMET

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INTRODUCTION

The use of advanced personal armor, especially the helmet, during combat has significantly reduced the incidence and severity of life threatening penetrating injuries from gunshot and blast shrapnel to the head and improved the overall survival rate of soldiers in combat [1]. On the other hand, the number of blast related injuries (68%) has increased to more than 4 times that of gunshot wounds (15%) and other injuries (17%), among which blast-induced traumatic brain injury (bTBI) has became the signature wound of the U.S. armed forces in Iraq and Afghanistan due to increased use of improvised explosive devices (IED) and rocket-propelled grenades (RPG) by the insurgents [2-4]. It is well known in detonation physics that the presence of a close proximity surface will increase the overpressure on the target due to blast wave reflection [5, 6]. The helmet, which has saved many lives from otherwise fatal penetration and blunt impact injuries, may unfortunately also serve as a reflecting surface and pose increased blast injury threat to the head. Consequently, the current study was designed to compare blast overpressures on the skull with and without helmet using a human head computational model.

MATERIALS AND METHODS

A Multi-Material-Arbitrary Lagrangian-Eulerian (MMALE) method was used to simulate the detonation of the explosive and the interaction of the blast wave with the head model and the helmet using a nonlinear finite element software package LS-DYNA (LSTC, CA). The head model and the helmet were simulated as Lagrangian parts. The three dimensional finite element head model consisted of scalp, three layered skull with cortical and trabecular bones, and facial bones. A half spherical shaped helmet with a rigid outer layer and soft inner layer padding were used to simulate a two layer military helmet. The explosive and the space enclosing the whole model were simulated using Eulerian parts. The spherical blast consisted of 250 gram of TNT. It was detonated at 0.5 meter ahead and 0.5 meter below the CG of the head model, simulating a blast from the ground. The detonation behavior of the explosive was described using the Jones-Wilkens-Lee-Baker equation of state. The space enclosing the head model and the blast were filled with hexahedral Euler elements. A non-reflection boundary condition was prescribed to the outer boundary of the Euler space to simulate an open field blast explosion. The interaction between the blast wave and the head model were simulated using the Euler/Lagrangian coupling method in the LS-DYNA package. An overview of the model is shown in Figure 1. Two scenarios, i.e., head model with and without helmet were simulated. Overpressure histories on the face, forehead, vertex, occipital and side for these two scenarios were exported and compared.

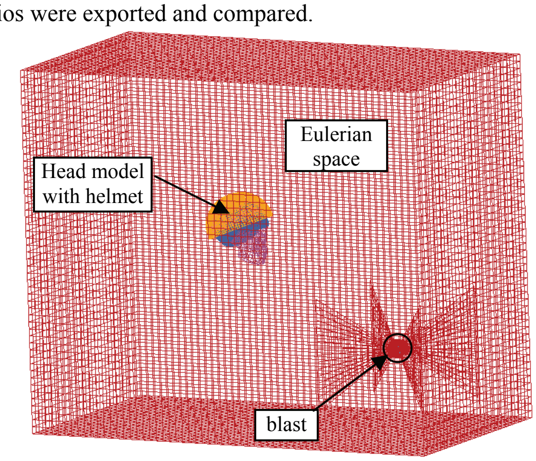

Figure 1. An overview of the head model with helmet and the blast enclosed in the Eulerian space

RESULTS

Peak overpressure on the face, forehead, vertex, occipital and side of the head with/without helmet were determined from the overpressure histories of representative elements at these anatomical regions (Figure 2). Overpressure impulses were computed by integrating the overpressure history over the pulse duration (Figure 3).

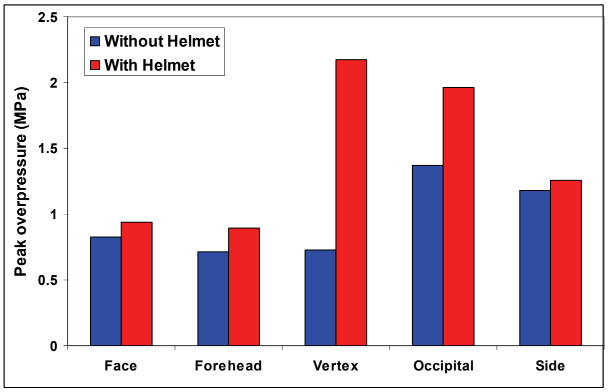

Figure 2. Comparison of peak overpressure on skull

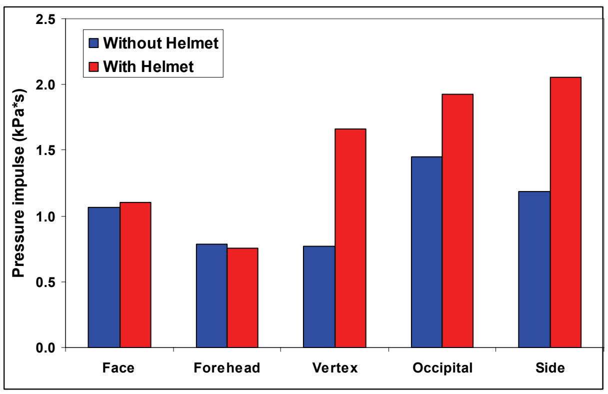

Figure 3. Comparison of overpressure impulse

DISCUSSION

The current study used the finite element method to compare overpressures on the skull with and without helmet. The MMALE method allowed the interaction and reflection of blast wave with the structures to be studied through Lagrangian/Euler coupling. Peak overpressure quantified the maximum overpressure experienced on the skull, whereas, pressure impulse quantified the accumulated effect of the overpressure on the skull. Results from the current study (Figure 2 and Figure 3) indicated that areas outside the helmet (face and forehead) were relatively unaffected by the helmet. However, considerable increases were found in both the peak overpressure and pressure impulses for areas inside the helmet (vertex, occipital, side). In particular, peak overpressure was 3x higher and pressure impulse was 2x higher at the vertex region when wearing a helmet. A comparison of the overpressure (Figure 4) on the vertex indicated that pressure histories were almost identical before 1 ms. Without helmet, the overpressure oscillated and subsided as time progressed. With the helmet on, due to the reflection and interaction of the blast wave with the 2 layer helmet, another higher peak (~3x) occurred at approximately 2 ms. Although the computation model has not been extensively validated due to the lack of experimental data from human subject experiments, the relatively higher overpressure and pressure impulse on the skull indicated a trend of increasing pressure effect on the skull due to the blast wave reflection effect from the helmet. The elevated overpressure and pressure impulse on the skull may induce increased skull deformations and pressure amplitudes transmitted into the brain that may lead to more severe brain injury [7].

It is no doubt that modern helmets have played an important role in protecting soldiers from fatal penetrating and blunt impact head/brain injuries in combat, and should continue to be worn during combat missions. The effect of blast wave reflection may be reduced by improving its blast protection using more efficient blast energy absorption padding materials or other modifications to prevent the blast wave reflecting between the helmet and head. For example, a face shield commonly used in humanitarian demining helmets may help to reduce peak overpressure on the skull [8].

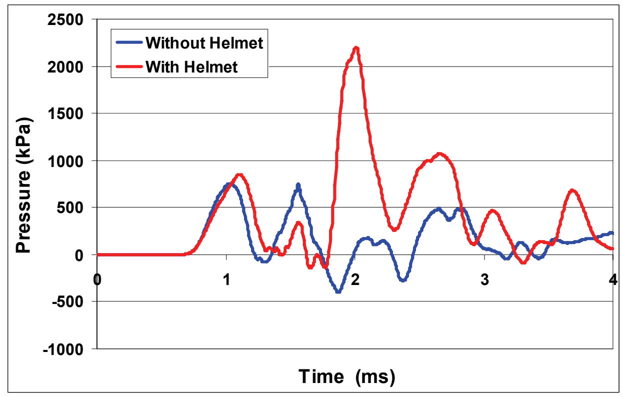

Figure 4. Comparison of overpressure at vertex

CONCLUSION

The military helmet is an essential personal protection gear that can defeat high-speed projectile and blast shrapnel etc. and save soldiers from life threatening penetrating head and brain injuries. However, under certain blast loading scenarios, such as ground blast, the helmet may act as a blast wave reflector that enhances overpressures on the skull, which may lead to elevated blast traumatic brain injury. Improvements are needed to reduce the blast reflection off the helmet to the human head.

ACKNOWLEDGEMENTS

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