Fabrication of a 3D Printed Transparent Skull for Traumatic Brain Injuries

Hiren Rana, Kyrollos Saad, Murad Elias, Saad Ali, Abdus Ali, Bryan J. Pfister

Biomedical Engineering Department
New Jersey Institute of Technology
Newark, New Jersey

Abstract— Spatial and temporal deformation in the brain is likely a cause of traumatic brain injury. Under extreme loading conditions, the brain will deform causing both stress and strain on the tissue resulting in injury. In an effort to study the effects of these mechanical inputs, the brain must be studied under various conditions. Many models lack a physiological system that is accurate in capturing what truly happens during a traumatic brain injury. To accurately understand how the brain deforms, blunt trauma is simulated using a system consisting of a physiologically accurate brain and transparent skull model. A 3D printed transparent skull was made out of Veroclear-RGD810, visual markers embedded on a brain mold can be tracked via high speed cameras when the skull is subjected to blunt trauma. Using these trackers, mechanical parameters such as principal tension, principal compression, and max shear can be measured.

I. INTRODUCTION

In the United States, there are a large number of people who sustain traumatic brain injuries (TBI) on a yearly basis. There are an estimated 1.7 million people who sustain TBI's annually [1]. A large demographic which may benefit from this project are athletes who are at high risk for brain injuries as well as members of the armed forces. As of 2011, TBIs for soldiers who were deployed in Iraq and Afghanistan totaled almost 320,000 [2]. The predominant causes of TBI are falls, motor vehicle collisions, and sports [1]. According to the World Health Organization, TBIs will become the major cause of death and disability by the year 2020 [3]. Clearly, there is a significant amount of people being affected and the trend will continue to increase. Therefore, there is a need to critically study the effects of TBIs so that solutions and treatments can then be implemented. The only way to truly overcome such an injury is to attempt to learn as much as possible about it through testing. It is not known how various impact conditions lead to a combined linear and rotational motion and the resulting deformation patterns on the brain & skull.

Some of the issues encountered when replicating concussion injuries and TBIs is the lack of proper engineering to replicate the event that caused injury, measure the loading at the brain tissue level and determine how the unique loading parameters affects brain function. One solution to this that allows the proper study of TBIs is the use of the Cadex Uniaxial Monorail Machine 1000_00_MIMA (Drop Tower) in conjunction with a 3D printed transparent skull model. Use of the drop tower, which allows for varying impact loads and heights, along with the transparent skull will give greater insight into the mechanics of TBIs and the underlying repercussions on the brain.

For this type of testing, a transparent skull is imperative in order for cameras to visualize the effects of a TBI on the brain. Other tests of this nature that used PVC-based skull models would not allow for the passage of light and, as a result, visualization with the cameras became difficult. Therefore, printing a transparent skull model, made from VeroClear RGD810, is the chosen method to properly study the effects of TBI on the brain and skull.

II. MATERIALS & METHODS

VeroClear RGD810 is a rigid, nearly transparent resin designed to be 3D printable. The skull shall be 3D printed in VeroClear using the Stratasys Objet30 Prime printer so that brain deformation can be measured via high speed tracking cameras. The CAD model used for the print, shown in Figure 1, is courtesy of U.S. Army Research Laboratory (ARL). This CAD model is an aggregate of hundreds of MRI scans from soldiers that was then converted to a CAD file for printing.

Figure 1: CAD model of skull courtesy of ARL. This model was originally an aggregate of hundreds of MRI scans from soldiers, later converted to a CAD file for printing.

The drop tower will be used for performance testing of the entire skull-brain system. By using an impactor at varying impact speeds and a skull-brain-neck surrogate made of the VeroClear RGD810, brain deformation can be measured. The brain model is fitted with non-electrical nylon markers that can be detected by a high speed camera that will allow for visualization of deformation on the brain and skull. The experimental setup is shown in Figure 2 where the impactor hits the skull model at varying speeds. The impact orientation can be adjustable at the crown and the front.
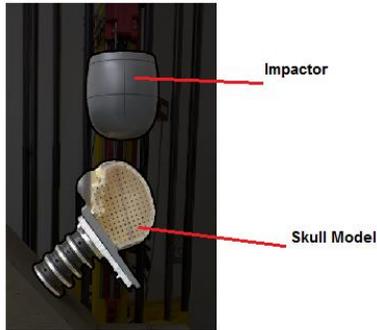
Figure 2: Impact Testing of the skull model using impactor. Impactor can be adjusted at various speeds while the skull orientation can be adjusted as well to give a wide range of testing conditions and potential deformation on both the brain and skull.

III. EXPECTED RESULTS

Previous tests of this nature used PVC-based skull models housing the brain for impact testing. Although a PVC skull may more accurately resemble mechanical properties of the human skull, in order to visualize the events occurring on the brain during a TBI, it is more appropriate to use a transparent skull model. This model, made from VeroClear RGD810, provides a balance of comparable mechanical properties to human skull, as well as a transparent surface for visualization. In high speed photography, it is important to allow as much light as possible to pass through the target in order for detailed and accurate images to be captured. For this reason, it is expected that much can be learned from testing using the transparent model versus an opaque one. Specifically, instead of only being able to see and compare the brain before and after a traumatic event, gradual deformation and events during impact on the brain can be seen.

In order to get an accurate representation of the average human skull, ARL took MRI scans of hundreds of soldiers and made a CAD file as an aggregate of all of the scans. In theory, this would result in a skull with average geometry representative of the population. However, because no skull is the same, there are variations in geometry, thickness, and cuts in shape that could potentially skew results. With that being said, use of this CAD model is still appropriate as it is taken from multiple people in order to mitigate the chance of circumstantial results.

IV. DISCUSSION

The goal of this system is to replicate the injury event: direction, speed, and momentum in traumatic brain injuries. As a result, the mechanical forces, accelerations can be measured and then translated to brain deformation. By tracking the movements of the markers on the brain mode, a strain field can be mapped based on the relative motion. This tracking is made possible by the 3D printed transparent skull model. This allows the deformation of the brain during the injury event to be seen, versus only seeing the before and after of the injury. Through this mechanical testing, a deeper understanding of the events that occur on the brain and skull during a TBI can be gained. This understanding will lead to potential solutions to TBIs in the form of treatment and prevention.

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