Investigation of Intraventricular Hemorrhage Volume in Motor Vehicle Crash Occupants

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Abstract

Motor vehicle crashes (MVCs) are a leading cause of traumatic intracranial injuries which often have devastating impacts on morbidity and mortality. Intraventricular hemorrhage (IVH) is one type of head injury that is identified on post-traumatic computed tomography (CT) scans. IVH is observed less frequently in patients with head trauma, however it is often associated with severe head trauma and negative prognostic outcomes and causation of traumatic IVH is not well-understood. The severities of injuries are often quantified by geometric and volumetric measurements. Studying the relationship between these measurements and MVC severity and occupant data may reveal important determinants of occupant head injury. The objective of this study was to quantify the volume of IVH of 30 occupants from the Crash Injury Research and Engineering Network (CIREN) database and evaluate how volumetric measurements of IVH relate to crash characteristics and occupant parameters. Significant relationships were observed between IVH volume, total head injury severity, occupant size (height, weight, and BMI), and ΔV/BES. Larger volumes of IVH were observed in occupants with SAH and/or DAI, both of which were found to be commonly associated injuries. The work presented in this study provides a brief case series demonstrating the associations between IVH volume, crash characteristics, and occupant parameters. This work may lead to improved methods to predict and prevent IVH and highlight the utility of combining clinical neuroimaging with occupant demographics and mechanical crash data for investigating mechanisms of TBI.

Keywords

Intraventricular hemorrhage, Motor vehicle crash, Computed tomography, Head injury

Introduction

Motor vehicle crashes are the leading cause of traumatic brain injury (TBI) related hospitalization and death [1]. Of the 1.7 million people who sustain a TBI per year, only 3% of these injuries result in death. Although the number of people who die from head trauma appears to be relatively small, the cognitive effects from TBI can cause devastating impacts on quality of life and those who sustain a TBI may result in premature mortality [2-4]. Intraventricular hemorrhage (IVH) is one type of head injury that is identified on post-traumatic computed tomography (CT) scans. It is thought to be the result of a shearing injury of the subependymal veins along the walls of the ventricles, extension of adjacent intraparenchymal hemorrhage, or intraventricular extension of SAH [5]. Patients with IVH often have visible radiologic signs of intraparenchymal injuries, as well as extra-axial masses [6]. Although IVH is less common, resulting in nearly 0.4 to 4% of patients with head trauma, it is often indicative of severe head trauma and is associated with negative prognostic outcomes [7-9]. There is currently a paucity of existing literature on the causation of traumatic IVH.

Clinical case reports of patients often rely on patient and/or observer information to determine the causation of the injury [10]. The Crash Injury Research and Engineering Network (CIREN) database contains detailed vehicle, crash, and medical data on injured MVC occupants [11] and has proven to be a valuable resource for documenting and understanding the mechanisms of injuries. It contains pre-crash information, along with data from detailed scene and vehicle investigation, as well as medical images, injury causation scenario (ICS), and patient outcome data. Patient injuries are coded using the Abbreviated Injury Scale (AIS) and International Classification of Diseases (ICD)-9 [12-14]. The CIREN database is unique in that it contains medical images documenting the intracranial injury, as well as vehicle evidence and full case review linking the mechanical insult to the injury. This has ultimately created a research paradigm in which researchers are able to relate information about the crash to the kinematics and loading of the occupant and resulting injury.

There are two AIS (version 2005) codes for IVH severity which are each classified by the presence and length of coma (AIS post dot code 2: not associated with coma > 6 hours and AIS post dot code 4: associated with coma > 6 hours) [13]. While coma may be indicative of IVH severity, the volume of hemorrhage has been previously shown to be the most significant prognostic sign of brain...
Intracranial injuries associated with MVCs often present as a mixture of intra-axial and extra-axial injuries. Intra-axial injuries, those occurring within the brain parenchyma, include diffuse axonal injury (DAI), cerebral contusion, and intraparenchymal hematoma (ICH). ICH, in particular, is defined as hemorrhage involving the ventricular system or subependymal region of the brain. However, ICH is a broad category that includes subdural hematoma (SDH) and epidural hematoma (EDH). SDH is a hematoma that accumulates in the subdural space, which is the potential space between the dura mater and the arachnoid membrane, while EDH is a hematoma that accumulates in the epidural space, which is the potential space between the dura mater and the periosteum of the skull. Both SDH and EDH are considered extra-axial injuries due to their location outside the brain parenchyma.

Scans were excluded if they compromised the visualization and/or volume calculation of the injury (i.e., motion artifact or poor scan resolution).

Detailed data regarding the occupant, injury, vehicle, and crash were also collected. These data included: age, gender, height, weight, seating position, and the involved physical component (IPC) in the vehicle attributed to the head injury. Vehicle data included: vehicle year, make, model, manual belt use, collision deformation classification (CDC) code, and maximum crush of the vehicle (Cmax). Crash type, change in velocity (ΔV), and barrier estimate speed (BES) were also collected for the highest severity impact. Rollover cases were excluded from the analysis due to complicated impact scenarios. Data were collected using the CIREN SQL interface and SQL developer (Oracle, Redwood Shores, CA). All cases selected underwent a full case review with medical, engineering, and crash reconstruction specialists to determine injury causation. Quality control checks have been undertaken, and the cases are designated as "complete" in the database.

**Segmentation**

Head CT scans were segmented using manual and semi-automated techniques within Mimics version 14 and version 16 (Materialise, Leuven, Belgium) (Figure 1). IVH was identified from descriptions within the radiology report and was individually segmented at the appropriate window level to identify the hemorrhage within the ventricular space. Injury segmentations were reviewed by three board-certified radiologists, two neuroradiology fellows, and one neuroradiology attending to ensure proper volume identification of the hemorrhage.

**Figure 1:** Image segmentation example. (A) Axial CT image of occupant with IVH; (B) Image segmentation of IVH shown in red.
hemorrhage (IPH). Extra-axial injuries, those occurring outside the brain parenchyma, include epidural hemorrhage (EDH), subdural hemorrhage (SDH) and subarachnoid hemorrhage (SAH). Although each is classified as intracranial hemorrhage, the head experiences a number of different forces during an MVC, and the mechanisms of injury resulting in these different patterns of hemorrhage vary. Twenty-eight (93%) of the occupants had other head injuries coded in addition to IVH, many of which were combinations of intraparenchymal and extra-axial injuries. SAH was identified in 56.7% (n = 17) of the occupants, DAI was identified in 33.3% (n = 10) of the occupants, and 23.3% (n = 7) had both SAH and DAI. Seven out of the 10 occupants with IVH and DAI were in frontal collisions. Of the occupants with SAH and IVH, there was a nearly even distribution between all crash types (Frontal, n = 6; Near-Side, n = 5; Far-Side, n = 4) and an even distribution was observed between crash types for those occupants with SDH and IVH (Frontal, n = 3; Near-Side, n = 3; Far-Side, n = 3). Skull fracture was identified in 23.3% (n = 7) of the occupants. The associated head injuries for each occupant are provided in figure 2. Cerebral edema, soft tissue contusions, and scalp abrasions and lacerations were commonly coded injuries for the occupants evaluated in this study; however these injuries are not represented in figure 2.

| Injury         | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
|----------------|---|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| IVH            | 15| 3 | 2 | 3 | 2 | 6 |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| SAH            |   | 2 | 2 | 2 | 2 | 4 | 6 | 3 | 2 | 2 | 1  | 1  | 1  | 2  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| DAI            |   |   | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| ICH            |   |   |   | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| SDH            |   |   |   |   | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| Skull Fx       |   |   |   |   |   | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| Brain Stem Inj |   |   |   |   |   |   | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |

Table 1: Summary of the crash, occupant, and injury data collected for the 30 IVH occupants. Data for age, ΔV/BES, and Cmax presented as mean (standard deviation). Data for IVH volume presented as median (95th percentile). B/NB = Belted/Non-Belted; IVH = Intraventricular hemorrhage.
Figure 3 shows the logarithmic transform of the measured IVH volume plotted by the associated head injury for each subject. As shown in figure 2, many subjects had intra-axial and/or extra-axial head injuries in addition to IVH. In figure 3, each occupant is represented by a single color circle. The volume of IVH for a single occupant with multiple head injuries is connected by a matching color line to demonstrate the measured IVH volume associated with the respective combination of head injuries. Occupants with SAH and DAI had higher volumes of IVH. A trending positive correlation was observed between IVH volume and total head injury severity (Figure 4).

Linear regression was performed to assess the relationship between occupant parameters, crash characteristics, and IVH volume. The p-values and r² values for correlations with occupant parameters are provided in table 2 and those with crash characteristics are provided in table 3. Linear regression plots with best fit lines of the significant relationships are provided in figure 5. IVH volume was found to be correlated primarily with occupant size (height, weight, and BMI). There was a significant relationship observed between delta-V and IVH volume for all crash types. The strongest correlation was observed between IVH volume and weight in frontal collisions, resulting in an r² value of 0.6096.

![Figure 4](image-url)

**Figure 4:** Regression plot of the log transformed IVH volume (mm³) and total head injury severity. The solid regression line is fit to all data within the plot (p = 0.1409, r² = 0.0785).

![Figure 5](image-url)

**Figure 5:** Regression plots for the significant relationships between the log transformed IVH volume (mm³) and occupant parameters (top) and crash characteristics (bottom).
that obesity may have a protective effect on the head [28,29]. Only five occupants in this study were obese (BMI ≥ 30), however the data presented in this study support that occupants with BMI ≥ 30 are at increased risk for increased head injury severity, specifically for IVH. This may be due to the increased loading to contact surfaces within the vehicle during the crash, however the relationship between body size and head acceleration is also not fully understood.

Crash severity metrics, such as ΔV and maximum crush, have been identified as reliable predictors of MVC occupant injury severity in individuals with head trauma [19,30-33] and without head trauma [16,34]. Many of the previous studies have investigated only injury incidence and mortality, with few exploring how specific crash characteristics affect MVC-associated head injury [27,30]. Analysis was performed to determine whether there was a significant correlation between IVH volume and crash characteristics for all crash types and by crash type. Delta-V was found to be significantly correlated with IVH volume, however maximum crush of the vehicle was not. The average ΔV for occupants in this study was 43 kph and the largest mean ΔV was observed in frontal collisions (52.0 kph). The average observed in this study is slightly higher than the average ΔV reported in occupants with SDH (41.3 kph) [19] and DAI (41.2 kph) [35]. A previous study from Yoganandan et al reported the average ΔV of MVC survivors with severe head trauma ranged from 32-35 kph and fatalities with severe head trauma ranged from 42-44 kph [30]. The range of ΔV for the cases evaluated in this study was 17-107 kph. The increased ΔV for those occupants evaluated in this study and significant positive correlation with IVH volume supports that IVH may be associated with higher severity crashes and that severity of this injury may increase with the severity of the crash.

Limitations

This retrospective observational study is subject to lack of control over study conditions and the bias that results. The labor-intensive process of image segmentation allows for inter-observer variability, which was minimized by using multiple independent observers and review of label maps by a board-certified neuroradiologist. Although there were a small number of subjects evaluated in this study, trends were observed which may encourage future evaluation of the contributing factors to head injury volume and severity. Lastly, there may be additional factors that contribute to the volume of the head injury and morbidity/mortality associated with the crash. Patients with underlying disease processes or trauma to multiple body regions may increase the risk of shock, injury severity, and death rate.

Conclusions

This study aimed to relate IVH volume to head injury severity, crash characteristics, and occupant parameters. Significant relationships were observed between IVH volume, total head injury severity, occupant size (height, weight, and BMI), and ΔV/BES. Most of the occupants evaluated in this study were found to have complex combinations of intraparenchymal and extra-axial injuries, with SAH and DAI being the most commonly associated injury. Additionally, subjects with these particular injuries had higher volumes of IVH. Further research into the presence of combined or complex injury presentations could provide a better understanding of injury patterns in MVCs, as well as injury mechanisms.

This type of work may lead to improved methods to predict and prevent specific serious injuries that may be life threatening or have an increased morbidity. Additionally, translational and rotational acceleration-based injury risks [36-38], safety rating systems based on these tools [39] and finite element-based injury metrics and criteria [22,25,40] can all be informed by this work. Consideration needs to be made for those cases with isolated injuries versus those sustaining multiple injuries [41]. Volumetric injury data with known exposure, such as that presented herein, will enable researchers to validate and improve engineers’ ability to predict and mitigate or prevent brain injury.

These data highlight the utility of combining clinical
neuroimaging with occupant demographics and mechanical crash data for investigating mechanisms of TBI. Such data may also be used in the future to design safer cars and to inform diagnosis and treatment algorithms for MVC-related head trauma. Although little information is provided upon arrival to the Emergency Department (ED), results from this and further studies may aid in the triaging of patients prior to arrival to the ED. Moreover, increased knowledge of crash and associated head injury severity may help guide emergent imaging and neurological decision making.

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