Motor Vehicle Crash-Related Subdural Hematoma from Real-World Head Impact Data

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Abstract

Approximately 1,700,000 people sustain a traumatic brain injury (TBI) each year and motor vehicle crashes (MVCs) are a leading cause of hospitalization from TBI. Acute subdural hematoma (SDH) is a common intracranial injury that occurs in MVCs associated with high mortality and morbidity rates. In this study, SDH volume and midline shift have been analyzed in order to better understand occupant injury by correlating them to crash and occupant parameters. Fifty-seven head computed tomography (CT) scans were selected from the Crash Injury Research Engineering Network (CIREN) with Abbreviated Injury Scale (AIS) level 3+ SDH. Semi-automated methods were used to isolate the intracranial volume. SDH and additional occupant intracranial injuries were segmented across axial CT images, providing a total SDH injury volume. SDH volume was correlated to crash parameters and occupant characteristics. Results show a positive correlation between SDH volume and crash severity in near-side and frontal crashes. Additionally, the location of the resulting hemorrhage varied by crash type. Those with greater SDH volumes had significantly lower Glasgow Coma Scale (GCS) scores at the crash site in near-side crashes. Age and fracture type were found to be significant contributors to SDH volume. This study is a volumetric analysis of real world brain injuries and known MVC impacts. The results of this study demonstrate a relationship among SDH volume, crash mechanics, and occupant characteristics that provide a better understanding of the injury mechanisms of MVC-associated TBI.

Key words: adult brain injury; CIREN; head trauma; radiology; traumatic brain injury

Introduction

MOTOR VEHICLE CRASHES (MVCs) are the leading cause of traumatic brain injury (TBI) related hospitalization and death, with ~1,700,000 people sustaining a TBI each year in MVCs.¹ Many studies have been conducted to investigate the epidemiology of TBI using databases such as the Crash Injury Research and Engineering Network (CIREN) and the National Automotive Sampling System (NASS) database.^{2–6} The CIREN database contains detailed vehicle, crash, and medical data on injured MVC vehicle occupants.⁷ It contains pre-crash information, along with detailed scene and vehicle investigation, medical images, and injury causation scenario and patient outcome. Patient injuries are coded using the Abbreviated Injury Scale (AIS) and International Statistical Classification of Diseases and Related Health Problems, Ninth Revision (ICD-9). These studies have correlated demographics and crash characteristics including crash type and contact location. Brain injury severity is often identified

by the AIS code level based on volume, size, and midline shift. Few studies to date, however, have correlated the volume or location of injury to crash parameters or occupant characteristics that reveal important determinants of TBI.

One common manifestation of head trauma associated with MVC is intracranial hemorrhage. A National Automotive Sampling System (NASS)-Crashworthiness Data System (CDS) analysis of cases from 2000 to 2008 for AIS 3+ intracranial injuries⁸ showed subdural hematoma (SDH) to be the third most common traumatic hemorrhage after subarachnoid and intraventricular hemorrhages, with mechanisms previously described and a high mortality rate.^{9,10}

The severity of a SDH is quantified on brain imaging examination by volume or width, and is the most significant prognostic quality.^{11–14} Associated pathology of SDH includes cerebral edema, increased intracranial pressure (ICP), and midline shift.^{15–20} The lowest SDH AIS severity code is a 3, representing serious threat to life for a tiny SDH (<0.6cm thick). The greatest SDH AIS

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severity code is a 5, representing critical threat to life for a large or bilateral SDH (>1cm thick). Hematoma volumes with a width >5mm or that are associated with mass effect and midline shift may be evacuated to decrease ICP.^{17,21}

This study will correlate the volume of SDH to the total intracranial volume and relate it to crash and occupant parameters. The objective of this study is to quantify SDH volume with respect to object impacted to better predict occupant injury following an MVC. The information may inform clinical intervention for neurosurgeons evaluating a patient for whom crash characteristics are known. It is also useful for the engineering design of countermeasures to mitigate or prevent such injuries in the future.

Methods

Scan collection

Axial non-contrast head computed tomography (CT) data within the first 24 h post-crash and radiology reports were collected for 57 cases with CT data within the CIREN database demonstrating SDH (AIS 3+) based on 1998⁸ and 2005⁸ AIS coding (Fig. 1A). Soft tissue algorithm CT data were selected for this study to optimize visualization of intracranial blood products.²² Detailed data regarding the occupant, injury, vehicle, and crash were also collected. These data included: age, gender, height, weight, injury severity score (ISS), seating location, Glasgow Coma Scale (GCS) score post-crash, and the involved physical component (IPC) in the vehicle attributed to the SDH. In the CIREN database, IPCs are the objects thought to be contacted by the occupant considered to play a role in producing an injury. The IPCs are designated as “certain,” “probable,” and “possible” based on the confidence level of the reviewers and specific evidence-based coding guidelines from vehicle crash, occupant kinematics, and injury evidence. Vehicle data included: vehicle year, make, model, manual belt use, collision deformation classification (CDC) code, and airbag deployment for the associated occupant seating location. Crash type, delta-v, and barrier estimate speed (BES) were also collected for the highest severity impact. 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 cause. 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 (Materialise, Leuven, Belgium). Segmentations were conducted based on density thresholds of bone (skull) and soft tissue (intracranial and skin). Manual editing was applied to the skull mask below the foramen magnum (caudally towards the neck) to close off holes in the skull to separate skin and intracranial masks. The soft tissue mask was subtracted from the continuous bone mask to isolate the intracranial volume (Fig. 1B). All brain injuries were identified from descriptions within the radiology reports and verified by a board-certified neuroradiologist. The SDH and additional intracranial injuries were segmented using a semi-automated method to identify the hemorrhage as within extra-axial, intraparenchymal tissue, and cerebrospinal fluid (CSF) spaces (Fig. 1C). Because the focus was on the SDH volume, additional intracranial injuries were not isolated in this analysis, but were summed to create a total hemorrhage volume.

The volume of each hemorrhage was calculated from the size and number of voxels within the segmentation. Injury segmentations were reviewed by a board-certified neuroradiologist to ensure proper volume identification of the injury. The data were normalized by computing the percent injured intracranial volume. This

was calculated by dividing the total hemorrhage volume by the intracranial volume to generate the percent injured intracranial volume. Midline shift was measured using the standard clinical measurement.

The point of contact between the head and vehicle was identified by the presence of a superficial soft tissue/scalp contusion on the CT images and on the three-dimensional CT reconstructions of the skin. If swelling did not occur, the point of contact on the head was approximated by the IPC and the injury causation scenario. The point of contact was used to define coup or contrecoup intracranial injuries. Intracranial injuries were classified as “coup” if present on the same side of the cerebrum as the point of head contact. An intracranial injury was classified as “contrecoup” if present on the opposing side of the cerebrum from the point of head contact. Injuries isolated within or along the falx cerebri were classified as “falx” injuries.

Statistical analysis

Simple linear regression analyses were used to calculate regression coefficients, associated *p*-values, and prediction intervals with respect to the slope of the regression line between injury characteristics, as well as crash and occupant parameters. Dependent variables in this analysis include SDH volume, SDH volume as a percentage of intracranial volume, injured volume as a percentage of intracranial volume, midline shift, and ISS. Independent variables were maximum crush (C_{max}), delta-v/BES, occupant age, height, weight, and body mass index (BMI). BES was used only if delta-v was not available from the crash reconstruction. If delta-v or BES were not able to be calculated from WinSmash, they were not included in that particular analysis. Paired *t*-tests were used to assess the mean injured brain volume and the presence and type of skull fractures were significantly different. Statistical tests were grouped by crash type, occupant location, airbag deployment by location, and/or belted status. Because of the small sample size and the large number of crash and occupant variables, multivariate analyses were not conducted. The results presented from these analyses are all statistically significant or demonstrate mild significance.

Results

Of 89 occupants in the CIREN database with SDH, 57 had adequate soft tissue CT data collected within 24 h post-crash demonstrating the injury. The independent variables listed in the *Statistical analysis* section were collected for each occupant. A summary of the data is located in Table 1. The greatest delta-v/BES and maximum crush was observed for occupants in frontal crashes. The greatest percent SDH, SDH volume and midline shift was seen in the single occupant involved in a rollover crash. However, of the most frequent crash modes (frontal, near-side, and far-side), the greatest percent SDH and SDH volume was observed in far-side crashes, as seen in Table 1 and Figure 2. In Figure 2, the percent SDH is plotted versus the principal direction of force (PDOF). The PDOF is the angle between the vehicle's longitudinal axis and impulse vector resulting from the impact. Values in this plot have been symmetrically adjusted with respect to the occupant to represent the near-side or far-side value from the perspective of a United States driver. The majority of occupants in all crash modes were belted; however, a large number of occupants in frontal crashes were unbelted.

The occupants ranged in age from <1 year old to 86 years old. Thirty-two occupants were female and 25 were male. Of the 57 occupants, 5 died and 52 did not. Three out of the five fatalities were in frontal crashes. In addition to sustaining a SDH, a variety of additional intracranial injuries were present, including

FIG. 1. Image segmentation and three-dimensional reconstruction example. (A) Axial CT image of occupant with subdural hematoma (SDH). (B) Image segmentation of intracranial volume (IV). (C) Image segmentation of SDH. (D) Segmentation masks demonstrating volumes of interest (IV mask with SDH mask overlaid). (E) Three-dimensional reconstruction of injury within the intracranial volume.

subarachnoid hemorrhage (40%), unilateral intraparenchymal contusion (12%), intraventricular hemorrhage (12%), pneumocephalus (11%), multiple intraparenchymal contusions (7%), and epidural hematoma (5%). One occupant also sustained a diffuse axonal injury. The SDH was located unilaterally in 71% of occupants, bilaterally in 5.5% of occupants, and along the falx cerebri in 23.5% of occupants. In Figure 3 A and B, the location of the injury is identified by crash type and by passenger location. The occurrence of coup and contrecoup type injuries are discussed further in this article.

The majority of the results for the simple linear regression analysis of the 57 cases were not statistically significant because of the small sample size. However, a few key variables proved statistically significant. Statistically significant (p -value < 0.05) results and mildly significant (p -value < 0.1) results are reported in Table 2. Additionally, the prediction intervals (PI) are reported in Table 2. These results show increases in SDH volumes, with higher delta- v /BES in frontal and near-side crashes. In near-side crashes, there was a mildly significant positive correlation between ISS and

$C_{\max}$, as well as between ISS and delta- v /BES. Midline shift was significantly positively correlated with maximum crush in near-side crashes. Analysis of occupant position revealed a significantly positive correlation between delta- v /BES for drivers for all crash types and SDH volume. There was also a mildly significant positive correlation between delta- v /BES for drivers for all crash types and ISS. Of those occupants unbelted in frontal crashes, there was a mildly significant positive correlation observed between delta- v /BES and SDH volume, as well as between delta- v /BES and midline shift. No statistically significant correlation was observed for belted occupants. However, this may be because of the bias from recruiting 80% belted occupants in frontal collisions.

The resulting mean SDH volume in cases with airbag deployment was not compared using statistical tests because of the small sample sizes in each group; however, trends were observed with this data set (Fig. 4). Of the 57 occupants, 16 did not have airbag deployment from the available locations; none of the 8 occupants located in the back seat had airbag deployment. For drivers, the mean SDH volume was compared for the steering wheel airbag and

TABLE 1. SUMMARY OF THE CRASH, OCCUPANT, AND INJURY DATA COLLECTED FOR THE 57 SDH OCCUPANTS

	Frontal (n=22)	Near-side (n=21)	Far-side (n=12)	Rollover (n=1)	Rear (n=1)	Overall (n=57)
Age	43.15 (27.02)	35.01 (21.63)	37.42 (20.07)	37.2	41.3	39.20 (23.11)
Male/Female	7/15	9/12	3/9	1/0	0/1	25/32
Driver/FP/BP	15/2/4	16/2/3	10/1/0	0/1/0	1/0/0	42/6/7
$\Delta V/BES$ (kph)	47.47 (22.98)	32.73 (10.61)	45.73 (17.84)	NA	37	41.53 (18.95)
C_{max} (cm)	60.38 (31.76)	40.66 (12.74)	51.25 (29.31)	7	72	50.51 (27.39)
%SDH	0.511 (0.704)	0.644 (0.944)	0.808 (1.18)	0.917	0.450	0.516 (0.742)
SDH Volume (cc)	7.59 (10.52)	9.25 (9.93)	16.08 (27.57)	13.37	6.87	10.09 (15.47)
Midline Shift (mm)	1.27 (1.85)	1.80 (2.39)	2.66 (4.31)	6.33	2.16	1.728 (2.619)
Belted /Unbelted	13/9	19/2	10/2	1/0	1/0	45/12
SW airbag /ND	14/7	9/12	5/7	ND	ND	29/28
RSR airbag/ND	2/20	2/19	1/11	ND	ND	5/52
Fatality	3	1	1	NA	NA	5

Data presented as mean (standard deviation).

SDH, subdural hematoma; FP, front passenger; BP, back passenger; BES, barrier estimate speed; SW, steering wheel airbag; RSR, roof-side rail airbag; ND, not deployed/not available.

roof-side rail airbag in frontal and near-side crashes. The mean SDH volume was decreased with the deployment of the steering wheel airbag in frontal crashes. The greatest decrease in mean SDH volume (5.12 cc) was in near-side crashes when the roof-side rail airbag deployed. This finding agrees with previous studies showing reduced brain injury severity with side airbag deployment.^{23,24} All certain, probable, and possible IPCs were considered when computing IPC incidence. The most frequent contacts that resulted in SDH in frontal crashes were the A-pillar and steering wheel. In a near-side crash, the most common contact to result in SDH was the window frame, followed by the roof. In a far-side crash, the most

common contact was located on the opposite side of the vehicle. Contact with the door resulted in the highest number of SDHs in far-side crashes.

Age was of particular interest when analyzing the relationship among crash mechanics, occupant characteristics, and brain injury. For this analysis, two occupants, ages 16 and 29, were excluded for outlying SDH percentages of 4.4% and 3.35%, respectively. A mildly significant positive correlation was observed between SDH volume and age for near-side crashes as seen in Table 3. Twenty-nine

FIG. 2. Polar plot of % subdural hematoma (SDH) by principal direction of force (PDOF) with the radial measurement as the % SDH. The resulting near-side and far-side PDOF marker is relative to the seating location of the occupant within the vehicle and the location of the impact. (For example, a 60 degree PDOF for a right-sided occupant is a near-side crash. The point is symmetrically adjusted to the 300 degree PDOF on the plot to remain in the near-side category.)

FIG. 3. Distribution of location of injury by (A) crash type and (B) occupant location.

TABLE 2. STATISTICALLY SIGNIFICANT (*) AND MILDLY SIGNIFICANT RESULTS FOR THE SIMPLE LINEAR REGRESSION ANALYSIS OF THE CASES BY CRASH CHARACTERISTICS

Crash type	Occupant	Variable	By variable	r ²	p-value	PI (95%) [Lower, upper]
Frontal	All occupants	SDH volume (cc)	Delta-v/BES (kph)	0.2078	0.0659	[−0.016, 0.457]
	Unbelted occupants	SDH volume (cc)	Delta-v/BES	0.5505	0.0562	[−0.017, 0.918]
		Midline shift (mm)	Delta-v/BES	0.4882	0.0807	[−0.011, 0.140]
Near-side	All occupants	Midline shift (mm)	Maximum crush (cm)	0.2993	0.0190*	[0.019, 0.191]
		ISS	Delta-v/BES (kph)	0.2179	0.0510	[−0.001, 0.678]
			Maximum crush (cm)	0.4479	0.0060*	[0.212, 1.054]
All crash types	Drivers	SDH volume (cc)	Delta-v/BES (kph)	0.1210	0.0207*	[0.044, 0.344]
		ISS	Delta-v/BES (kph)	0.0758	0.0704	[−0.059, 0.595]

PI, prediction interval; SDH, subdural hematoma; BES, barrier estimate speed; ISS, injury severity scale.

of the 57 (51%) occupants had a midline shift. Of these, more than half (52%) sustained multiple intracranial injuries. For those drivers with midline shift, a mildly significant positive correlation was observed between midline shift and age in frontal crashes. The results of this analysis demonstrate a trend of increasing SDH volume with age. Four out of the five fatalities within this study had midline shift.

The mean percent SDH volume and mean percent injured intracranial volume was greatest for far-side crashes, followed by near-side and then frontal crashes. Additionally, the location of the SDH varied by crash type. SDH was most frequently observed along the falx cerebri (43%) in frontal crashes. A coup-type injury was also frequently observed in frontal crashes (38%). A contre-coup type injury was more common in the near and far-side crashes (37% and 50%, respectively). A very small number of occupants sustained SDH along the falx cerebri for near and far-side crash types (10% and 8%, respectively). Bilateral SDH was observed only in those occupants in near-side crashes (15%). The right and left mean SDH volumes were nearly double compared with SDH volumes along the falx. Volumes of SDH were also greater when located posteriorly. Bilateral SDH volumes were lower than those isolated along the right, left, or along the falx cerebri.

Cranial vault fractures, basilar fractures, and a combination of both were observed in 17 occupants. Those occupants who sustained a combination of vault and basilar fractures had significantly greater midline shift than those with no skull fracture ($p=0.0318$). Measurements of midline shift were greater for those occupants with multiple fractures than for those occupants with isolated

basilar or vault fractures, which demonstrated a mild statistical significance ($p=0.0995$ and $p=0.0669$, respectively). Two out of the five MVC fatalities sustained a vault fracture. Midline shift has shown to be indicative of increased intracranial pressure because of mass effect, and this study supports this clinical assessment, as SDH volume is significantly positively correlated with midline shift ($r^2=0.4386$, $p<0.0001$). As expected, there was a significantly negative correlation between lower GCS score at the crash site and greater percent SDH volume.¹¹ A similar significantly negative correlation was observed between lower GCS score measured in the controlled setting of the emergency department and greater percent SDH volume. There was a mildly significant negative correlation between lower GCS score at the crash site and greater magnitude of midline shift.

Discussion

This study correlates SDH volume with crash parameters and occupant characteristics. Frontal and far-side crashes had the highest and second highest crash severity, respectively, whereas the highest injury severity was seen in far-side crashes.

The greatest number of SDHs were seen in frontal and near-side crashes. These two crash types were associated with the greatest number of statistically significant correlations with crash parameters and occupant characteristics. Maximum crush and delta-v had the greatest correlation with injury severity, as defined by SDH volume, midline shift, and ISS. There were no statistically significant correlations between IPC and other variables, which may be because of the small sample size. These two parameters have been previously identified as reliable predictors of MVC occupant injury severity in individuals with head trauma^{5,25–27} and without head trauma.²⁸ Many of the previous studies have investigated only injury incidence and mortality, with only a few exploring how specific occupant parameters affect MVC-associated brain injury.⁴ The largest SDH volumes are seen in far-side crashes, but there are fewer correlations with crash parameters and occupant characteristics that are statistically significant, which may be related to the relatively small sample for this particular crash type. However, it is also possible that a greater sample size will be able to better predict the range of likely values, as well as anticipated clinically important correlations between dependent measures and crash variables. An increased sample size may also allow for increased statistical power for detecting statistically significant differences between dependent measures for this crash type. This possible sample size effect is supported by the observation that more statistically significant correlations with injury severity were seen for frontal and near-side crashes, which contained almost twice as many cases each as

FIG. 4. The resulting mean subdural hematoma (SDH) volume by crash type for airbag deployment. RSR, roof side rail airbag.

TABLE 3. STATISTICALLY SIGNIFICANT (*) AND MILDLY SIGNIFICANT RESULTS FOR THE SIMPLE LINEAR REGRESSION ANALYSIS OF THE CASES BY AGE AND GLASGOW COMA SCALE (GCS)

Crash type	Occupant	Variable	By variable	r ²	p-value	PI (95%) [Lower, upper]
Frontal	Drivers with mid shift	Midline shift (mm)	Age	0.6008	0.0702	[−0.006, 0.105]
Nearside	All occupants	SDH volume (cc)	Age	0.1830	0.0599	[−0.009, 0.399]
All crash types	All occupants	% SDH volume	GCS score at crash site	0.1287	0.0475*	[−0.100, 0.016]
			GCS score at the ED	0.1300	0.0138*	[−0.100, 0.016]
		Midline shift (mm)	GCS score at crash site	0.096	0.0899	[−0.337, 0.257]

PI, prediction interval; SDH, subdural hematoma; ED, Emergency Department.

far-side crashes. Despite this limitation, identifying far-side crashes as the type associated with the greatest volume of SDH both by total volume and by percent intracranial volume has important and clinically meaningful implications for developing better occupant restraint measures.

For each crash type, specific patterns in SDH location were observed. Volumes of SDH in various intracranial locations may reflect the anatomical variability of the subdural spaces. Greater SDH volumes were observed along the lateral convexities than in the falx cerebri. The location and volume of extra axial blood products also appeared to be affected by crash location, with greater SDH volume in far-side and near-side crashes than in frontal crashes, which had the greatest percentage of hemorrhage confined to the falx. This observation may have implications for the morbidity and mortality associated with SDH, as the lateral collections are more likely to exert a mass effect on the brain, increasing ICP, and leading to midline shift. The clinical importance of this association is supported by the observation that four out of five fatal crashes in this study experienced midline shift, the magnitude of which is known to be the most important parameter in predicting morbidity and mortality by CT imaging.^{29–30}

In this study, occupants with combined basilar and cranial vault fractures had statistically significantly greater midline shift than those who did not sustain a fracture. Although fractures were only observed in 17 of the occupants, these data support reported findings that skull fractures increase the risk of TBI.^{32–35} However, no studies have directly addressed the relationship between increased injury volume and fracture incidence.

Age is known to be an important factor in MVC-associated occupant mortality, with greater numbers of deaths in older occupants.^{6,36–38} In this study, age was found to be positively correlated with increased midline shift in frontal crashes, and increased SDH volume in near-side crashes, which may explain the reported higher mortality among older occupants. Future studies investigating the relationship between occupant age and incidence of fracture, as well as the effect of brain atrophy on increasing the volume of the subdural space for fluid collection, may be valuable considerations that further elucidate the link between increased age and MVC mortality. For the two fatalities who were <60 years of age, one case involved either partial occupant ejection from the vehicle or large intrusion into the vehicle resulting in brain injury. The other occupant developed serious complications related to the MVC injuries, including acute respiratory distress syndrome (ARDS), respiratory failure, and subsequent cardiovascular failure.

Limitations

This retrospective observational study is subject to all of the usual shortcomings of such a study including the lack of control

over study conditions and the bias that results. Thirty-two (36%) of 89 scans containing a SDH, were excluded because of low scan quality, CT after surgery, or incomplete imaging. This finding has been used to make recommendations to CIREN centers for future data collection. A labor-intensive process of semi-automated segmentation allows inter-observer variability, which was minimized by using two independent observers and review of label maps by a board-certified neuroradiologist.

The IPC involved predictor of injury pattern and severity. Several factors make such analysis of IPC in this study of TBI difficult, including small sample size (Table 3). Second, requiring ICS confidence to be “certain” or “probable” excluded several cases. Only broad categories of IPCs have been implicated in ICSs, which removes a certain degree of predictive value for these structure.³⁹

Finally, there may be additional factors that contribute to the volume of the SDH and morbidity/mortality associated with the crash. Patients with underlying disease processes or trauma to multiple body regions may have increased risk of shock, injury severity, and death.

Future work

Translational and rotational acceleration-based injury risks,^{40,41} safety rating systems based on these tools⁴² and finite element-based injury metrics and criteria^{43,44} can all be informed by this work. Consideration needs to be made for those cases with isolated injuries versus those sustaining multiple injuries, as well.³⁷ 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.

Conclusion

The greatest proportion of SDH occurred in frontal and side impacts with the greatest crash severity based on delta-v/BES and maximum crush in frontal crashes, and the largest SDH volumes in near- and far-side crashes. The variable most closely correlated with volume of hemorrhage and midline shift in frontal collisions was delta-v/BES. Midline shift was highly correlated with the maximum crush of the vehicle. In all crash modes combined, delta-v/BES was the variable best correlated with SDH volume. The most frequent contacts within the vehicle include the A-pillar and steering wheel in frontal collisions, the window frame in near-side collisions, and the opposing door in far-side collisions. Further investigation of the impact location and resulting injury location may be beneficial in validating parametric models for prediction of TBI, and understanding the biomechanics of extra-axial versus intraparenchymal injuries. These data highlight the utility of combining clinical neuroimaging with 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, results from this and further studies may aid in triaging of patients prior to arrival, and may offer insight into imaging and neurosurgical decisions with increased knowledge of crash severity and associated brain injury severity.

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