Upper Extremity Injury Patterns in Side-Impact Crashes

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Abstract The objective of this study was to characterize upper extremity injuries in side-impact motor vehicle collisions from Crash Injury Research and Engineering Network data obtained between 1998 and 2012. Side-impact crashes were defined as a principal direction of force between 60° and 120°, or 240° and 300°. Injuries were stratified by type, anatomic location, and Abbreviated Injury Scale severity. Occupant variables (age, sex, height, weight, body mass index, Injury Severity Score, number of injuries, seat position) and crash variables (delta-V, maximum crush, injury source, vehicle type, object struck, near-side/far-side) were included in the analyses. Statistical analysis of the data included descriptive statistics and bivariate regression analyses. There were 917 injuries among 413 occupants included in the analyses. The most common injury type was soft tissue injury (72.3%). The majority of fractures were to the clavicle (41.5%). The door was the most common injury source for upper extremity injuries (33.7%). Side-impact collisions have greater proximal upper extremity injury incidence compared to frontal impact collisions. Due to the high number and severity of upper extremity injuries resulting from contact to the door, we recommend further study on door structure safety. Mitigating upper extremity injuries in collisions will potentially improve functional outcomes and reduce human and economic costs.

Keywords CIREN, Injury mechanism, Motor vehicle collision, Upper extremity injury, Vehicle safety.

I. INTRODUCTION

Side-impact motor vehicle collisions (MVC) represent a significant burden of mortality and morbidity among automotive crashes within the USA. In 2012, approximately 26% of all collision fatalities for passenger vehicles were from side-impact collisions [1]. While automotive restraint improvements in recent decades have increased survival in MVC, the number of upper extremity (UE) injuries has proportionally remained the same and the injury severity has actually increased [2-10]. One possible reason for this trend in UE injuries is the increased prevalence of airbags, which themselves may be associated with more severe UE injuries [11-12]. In one study, side airbags were associated with a significantly increased risk of moderate or severe UE injuries in side-impact crashes [11]. Another study of frontal MVC evaluated 25,464 National Automotive Sampling System (NASS) cases and reported that occupants exposed to an airbag deployment were significantly more likely to have a severe UE injury compared with those who were not exposed (p=0.01) [12]. There is a lower injury risk for both near-side and far-side occupants in side-impact MVC when they are belted, but belted far-side occupants benefit significantly more than belted near-side occupants [13-14]. Near-side occupants, even when restrained, are still at risk of serious injury due to vehicle crush and occupant compartment intrusion [15].

Upper extremity injuries in MVC are not commonly fatal, but may result in disability and other long-term effects on functional outcome. More severe (AIS2+) UE injuries, such as fractures, often require surgical treatment [11][16]. The injury pattern and severity is dependent on many factors, such as crash type (e.g. front, side, or rear), crash severity, occupant position, and restraint use [10-11][16-18]. Reducing the number and

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severity of UE injuries in MVC necessitates continued in-depth analysis of injury mechanisms in real world crashes. However, injury pattern characterization of the UE relating to injury source and other crash variables, especially in side-impact collisions, is limited. The vulnerability of the upper extremities during a side-impact collision is an important safety concern.

The National Highway Traffic Safety Administration's (NHTSA) Crash Injury Research and Engineering Network (CIREN) is a valuable tool in studying injury causation in real world crashes. CIREN is a multicenter research program comprised of engineers, clinicians, crash investigators, and government agencies, with a focus on studying occupant injuries associated with MVC. CIREN has created a database with detailed information about injuries sustained in MVC and their associated injury mechanisms. The objective of the current study was to use the CIREN database to examine the relationship between UE injury patterns in side-impact MVC with occupant and crash variables.

II. METHODS

All cases included in the CIREN database must meet inclusion criteria regarding injury and crash severity. Case occupants typically must have at least one AIS ≥ 3 injury or AIS 2 injuries in two separate AIS body regions and be in a vehicle that is not more that 6-8 years old from the crash date [19-20]. Detailed vehicle, crash, occupant, and injury data were extracted from the CIREN database on 23 August 2012 using the CIREN SQL interface and SQL developer (Oracle, Redwood Shores, CA). All cases selected had previously undergone a full case review with medical, engineering, and crash reconstruction specialists in order to determine injury causation. The years in this dataset ranged from 1998 to 2012. Inclusion criteria for this study were that the occupants must be at least 16 years old and seated in the first row (drivers and passengers) [16][21]. Only side-impact crashes with a known principal direction of force (PDOF) between 60° and 120° or 240° and 300° were included. Those with unknown belt status, change in velocity at the time of impact (ΔV), maximum crush (CMAX), or missing crash information were excluded, as were pregnant occupants.

Occupant variables included in the analysis were: age; sex; height; weight; body mass index (BMI); Injury Severity Score (ISS); number of injuries; and seat position (driver vs. passenger). Vehicle and crash variables included in the analysis were: delta-V (ΔV), a commonly used measure of crash severity that is determined using WinSmash software [22-23]; CMAX, maximum crush of the vehicle as measured by an on-scene crash investigator; vehicle type (automobile vs. truck/van/utility vehicle); object struck (fixed vs. vehicle); near-side vs. far-side; and injury source. Injuries were stratified by type, anatomic location and Abbreviated Injury Scale (AIS) severity [24-25]. Injury type was separated into four categories: fracture; joint soft tissue injury; joint dislocation; and soft tissue injury. Injury locations were categorized as: acromion/AC joint; clavicle; elbow; external/skin; forearm; glenohumeral joint; hand/wrist; humerus; muscle/tendon/ligament; scapula; sternoclavicular joint; and vessels. Descriptive statistics (count, percent, mean, standard deviation as appropriate) were used to examine occupant demographics as well as injury and crash characteristics. A generalized linear model was used to examine the association between sex and demographics of the study population (age, height, weight, BMI, ISS, number of injuries). In order to study the relationship between occupant variables and injury type and location, a linear mixed effects model was used, which accounted for multiple injuries of the same occupant. The association of natural-log ΔV and natural-log CMAX with injury type and location was also examined using a linear mixed effects model, accounting for multiple observations of the same occupant. Groups of injuries with sample sizes less than 10 were excluded from statistical tests. A Tukey-Kramer correction was applied for all statistical tests comparing injury locations. Significance level for all statistical tests was defined as $p < 0.05$ and all analyses were performed using SAS software version 9.4 (SAS Institute, Cary, NC, USA).

III. RESULTS

There were a total of 3,079 case occupants and 7,715 UE injuries within the CIREN database from 1998 to 2012. After applying our inclusion/exclusion criteria, there were 413 case occupants with 917 UE injuries. All subsequent analyses were derived from this subset.

Injury Patterns

The 917 UE injuries were stratified by type, location, and AIS severity (Table I). The most common type of injury was soft tissue injury (72.3%), followed by fractures (23.7%). Of the 217 fractures, the most common fracture location was the clavicle (90 fractures). The incidence of fractures decreased distally down the arm, with 70% of fractures proximal to and including the humerus and 30% distal to the humerus. Injury to the skin (external UE) was the most common injury location (71.6%). There were 48 AIS3 injuries, and of these injuries, the most common types were humerus (50%) and forearm (45.8%) fractures. Of the 183 AIS2 injuries, the majority were clavicle fractures (49.2%), followed by scapula (13.1%) and forearm (13.1%) fractures. The majority of UE injuries were AIS1 injuries, and 94.9% of these injuries were to the skin.

TABLE I
CIREN UE INJURIES STRATIFIED BY TYPE, LOCATION, AND AIS SEVERITY

	Total	**AIS Severity**		
		AIS1	**AIS2**	**AIS3**
Injury Type	*N*	*N (Row %)*	*N (Row %)*	*N (Row %)*
Fracture	217	3 (1.4%)	168 (77.4%)	46 (21.2%)
Joint Dislocation	14	4 (28.6%)	10 (71.4%)	0 (0.0%)
Joint Soft Tissue Injury	23	23 (100.0%)	0 (0.0%)	0 (0.0%)
Soft Tissue Injury	663	656 (98.9%)	5 (0.8%)	2 (0.3%)
Injury Location				
Acromion/AC Joint	11	2 (18.2%)	9 (81.8%)	0 (0.0%)
Clavicle	90	0 (0.0%)	90 (100.0%)	0 (0.0%)
Elbow	10	7 (70.0%)	3 (30.0%)	0 (0.0%)
Skin	657	651 (99.1%)	5 (0.8%)	1 (0.1%)
Forearm	46	0 (0.0%)	24 (52.2%)	22 (47.8%)
Glenohumeral Joint	13	10 (76.9%)	3 (23.1%)	0 (0.0%)
Hand/Wrist	23	10 (43.5%)	13 (56.5%)	0 (0.0%)
Humerus	35	0 (0.0%)	11 (31.4%)	24 (68.6%)
Muscle/Tendon/Ligament	5	5 (100.0%)	0 (0.0%)	0 (0.0%)
Scapula	24	0 (0.0%)	24 (100.0%)	0 (0.0%)
Sternoclavicular Joint	2	1 (50.0%)	1 (50.0%)	0 (0.0%)
Vessels	1	0 (0.0%)	0 (0.0%)	1 (100.0%)

Occupant Characteristics

There were 231 (55.9%) female and 182 (44.1%) male passengers. Males were associated with significantly higher mean height, weight, and BMI than females (Table II). There were no significant differences in the mean age, ISS, or number of UE injuries between males and females (Table II). The distribution of injury types and AIS severity of UE injuries were similar between males and females (Fig. 1). Drivers and front-row passengers accounted for 334 (80.9%) and 79 (19.1%) of the case occupants, respectively. The distribution of injury types and AIS severity of UE injuries were similar between drivers and passengers (Fig. 2). However, no passengers had joint dislocations, whereas there were 14 joint dislocations among drivers.

There were no significant differences in mean occupant age, height, or weight among injury types or locations. However, there were significant differences in mean occupant BMI among injury locations (p=0.01). Clavicle fractures were associated with a mean [95% CI] BMI of 24.8 [23.5, 26.0], which was significantly lower than the mean BMI associated with injuries to the skin (27.0 [26.5, 27.4], p=0.04) and injuries to the hand/wrist (29.3 [26.9, 31.9], p=0.04). Injuries to the hand/wrist were associated with the highest mean BMI of all injury locations. There were no significant differences in mean BMI among injury types.

TABLE II
DEMOGRAPHICS OF THE STUDY POPULATION

	Average ± Standard Deviation	Male (N=182)	Female (N=231)	p
Age (years)	45.0 ± 22.2	44.5 ± 23.2	45.4 ± 21.5	p = 0.7
Height (cm)	169.7 ± 10.2	177.7 ± 7.9	163.5 ± 7.2	p < 0.0001
Weight (kg)	77.0 ± 20.7	86.8 ± 19.6	69.3 ± 18.1	p < 0.0001
BMI	26.5 ± 6.0	27.4 ± 5.3	25.9 ± 6.3	p = 0.009
ISS	27.5 ± 16.7	28.6 ± 18.8	26.6 ± 14.9	p = 0.2
Number of UE injuries	2.2 ± 1.5	2.1 ± 1.4	2.3 ± 1.5	p = 0.3

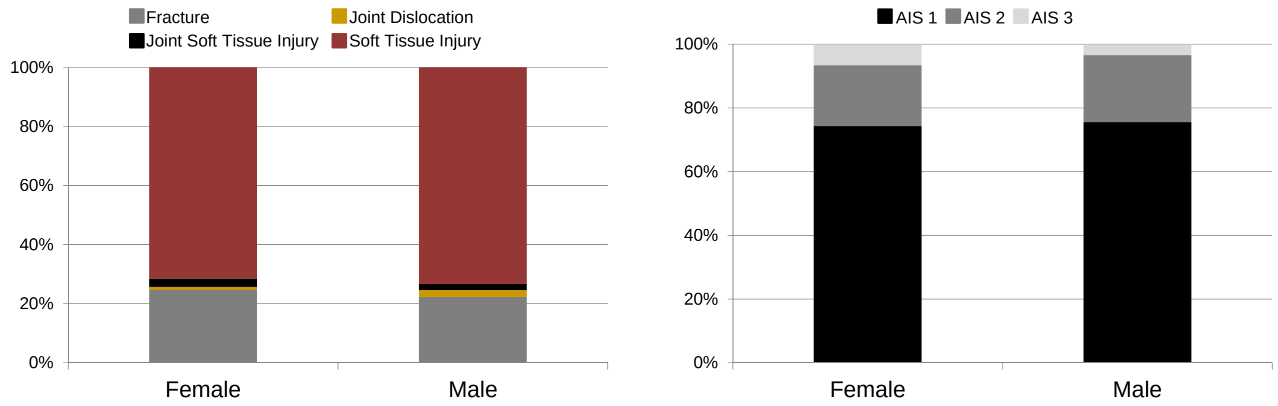

Fig. 1. Distribution of UE injury type (left) and AIS severity (right) for males and females.

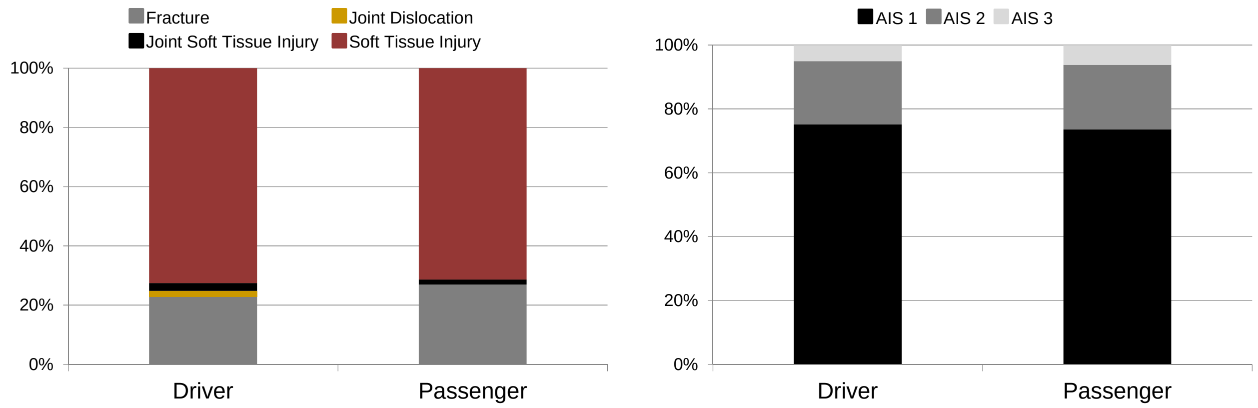

Fig. 2. Distribution of UE injury type (left) and AIS severity (right) for drivers and front-right passengers.

Crash Characteristics

The distributions of injury types, locations, and AIS severity were similar between automobiles vs. truck/van/utility vehicles, striking a vehicle vs. striking a fixed object, and near-side vs. far-side crashes (Table III). However, the percentage of injuries to proximal locations (i.e. clavicle and scapula) was greater in automobiles compared to trucks/vans/utility vehicles. Whereas the percentage of injuries to distal locations (i.e. hand/wrist and forearm) was greater in truck/van/utility vehicles compared to automobiles. Additionally, truck/van/utility occupants had a higher percentage of AIS3 injuries compared to car occupants. Near-side crashes had a higher percentage of fractures compared to far-side crashes. Further analysis of near-side and far-side crashes comparing drivers and passengers (near-side drivers vs. far-side drivers, and near-side passengers vs. far-side passengers) demonstrates differences in the distribution of injury locations and AIS severity. Only drivers sustained injuries to the acromion/AC joint, glenohumeral joint, muscle/tendon/ligament, sternoclavicular joint, and vessels, regardless of crash type. Near-side passengers sustained nine humerus fractures, but far-side passengers did not have any humerus fractures. Whereas drivers sustained a nearly equal number of humerus fractures in both near-side (14 fractures) and far-side (12 fractures) crashes. Additionally, only near-side passengers sustained AIS3 injuries, whereas both near-side (64.9%) and far-side (35.1%) drivers sustained AIS3 injuries.

TABLE III

DISTRIBUTION OF INJURY TYPES, LOCATIONS, AND AIS SEVERITY BY VEHICLE TYPE, OBJECT STRUCK, AND CRASH TYPE

	Vehicle Type		**Object Struck**		**Crash Type**	
	Automobiles	*Truck/van/utility*	*Fixed*	*Vehicle*	*Far-side*	*Near-side*
Injury Type	*N (Col %)*	*N (Col %)*	*N (Col %)*	*N (Col %)*	*N (Col %)*	*N (Col %)*
Fracture	169 (23.8%)	48 (23.3%)	50 (25.6%)	167 (23.1%)	51 (20.2%)	166 (25.0%)
Joint Dislocation	11 (1.6%)	3 (1.5%)	1 (0.5%)	13 (1.8%)	5 (2.0%)	9 (1.4%)
Joint Soft Tissue Injury	14 (2.0%)	9 (4.4%)	4 (2.1%)	19 (2.6%)	6 (2.4%)	17 (2.6%)
Soft Tissue Injury	517 (72.7%)	146 (70.9%)	140 (71.8%)	523 (72.4%)	191 (75.5%)	472 (71.1%)
Injury Location						
Acromion/AC Joint	5 (0.7%)	6 (2.9%)	2 (1.0%)	9 (1.3%)	5 (2.0%)	6 (0.9%)
Clavicle	79 (11.1%)	11 (5.3%)	22 (11.3%)	68 (9.4%)	18 (7.1%)	72 (10.8%)
Elbow	6 (0.8%)	4 (1.9%)	2 (1.0%)	8 (1.1%)	4 (1.6%)	6 (0.9%)
External	514 (72.3%)	143 (69.4%)	138 (70.8%)	519 (71.9%)	188 (74.3%)	469 (70.6%)
Forearm	28 (3.9%)	18 (8.7%)	13 (6.7%)	33 (4.6%)	9 (3.6%)	37 (5.6%)
Glenohumeral Joint	10 (1.4%)	3 (1.5%)	2 (1.0%)	11 (1.5%)	2 (0.8%)	11 (1.7%)
Hand/Wrist	15 (2.1%)	8 (3.9%)	1 (0.5%)	22 (3.1%)	7 (2.8%)	16 (2.4%)
Humerus	27 (3.8%)	8 (3.9%)	11 (5.6%)	24 (3.3%)	12 (4.7%)	23 (3.5%)
Muscle/Tendon/ Ligament	3 (0.4%)	2 (1.0%)	2 (1.0%)	3 (0.4%)	2 (0.8%)	3 (0.5%)
Scapula	22 (3.1%)	2 (1.0%)	2 (1.0%)	22 (3.1%)	4 (1.6%)	20 (3.0%)
Sternoclavicular Joint	2 (0.3%)	0 (0.0%)	0 (0.0%)	2 (0.3%)	1 (0.4%)	1 (0.2%)
Vessels	0 (0.0%)	1 (0.5%)	0 (0.0%)	1 (0.1%)	1 (0.4%)	0 (0.0%)
AIS Severity						
AIS1	535 (75.3%)	151 (73.3%)	143 (73.3%)	543 (75.2%)	195 (77.1%)	491 (74.0%)
AIS2	146 (20.5%)	37 (18.0%)	40 (20.5%)	143 (19.8%)	45 (17.8%)	138 (20.8%)
AIS3	30 (4.2%)	18 (8.7%)	12 (6.2%)	36 (5.0%)	13 (5.1%)	35 (5.3%)

The median (Quartile 1, Quartile 3) ΔV and CMAX for all UE injuries was 35 kph (26 kph, 44 kph) and 48 cm (36 cm, 61 cm), respectively. There were significant differences in geometric mean ΔV among injury types, p=0.03 (Table IV). Fractures were associated with a significantly higher mean ΔV than joint soft tissue injuries (p=0.04). Soft tissue injuries were associated with a significantly greater mean ΔV than joint dislocations (p=0.04) and joint soft tissue injuries (p=0.03). There were also significant differences in geometric mean ΔV among injury locations (p=0.03). Clavicle fractures were associated with the highest mean ΔV, which was significantly greater than the mean ΔV associated with the glenohumeral joint (p=0.03). There were significant differences in geometric mean CMAX among injury types (p=0.005). Fractures were associated with a significantly higher mean CMAX than joint dislocations (p=0.007) and joint soft tissue injuries (p=0.01). Soft tissue injuries were also associated with a significantly higher mean CMAX than joint dislocations (p=0.009) and joint soft tissue injuries (p=0.02). There were also significant differences in geometric mean CMAX among injury locations (p=0.001). Clavicle fractures and injuries to the skin were associated with a significantly greater mean CMAX than injuries to the glenohumeral joint (p=0.0009 and p=0.01, respectively).

TABLE IV
SUMMARY OF GEOMETRIC MEAN [95% CONFIDENCE INTERVAL], ΔV AND CMAX FOR EACH INJURY TYPE AND LOCATION. THE MUSCLE/TENDON/LIGAMENT, STERNOCLAVICULAR JOINT, AND VESSEL INJURY LOCATIONS ARE EXCLUDED FROM THESE ANALYSES BECAUSE N<10

	ΔV (kph)	**CMAX (cm)**
Injury Type		
Fracture	33.5 [31.7, 35.4]	47.1 [44.5, 49.9]
Joint Dislocation	26.8 [21.6, 33.3]	34.0 [27.1, 42.6]
Joint Soft Tissue Injury	27.9 [23.5, 33.0]	37.2 [31.2, 44.4]
Soft Tissue Injury	33.8 [32.7, 34.9]	46.3 [44.8, 47.8]
Injury Location		
Acromion/AC Joint	29.2 [22.9, 37.3]	41.1 [32.0, 52.9]
Clavicle	35.8 [32.9, 38.9]	52.1 [47.7, 56.9]
Elbow	35.1 [27.2, 45.3]	52.4 [40.2, 68.2]
External	34.0 [32.9, 35.1]	46.4 [44.9, 48.0]
Forearm	30.6 [27.2, 34.5]	41.5 [36.7, 46.9]
Glenohumeral Joint	23.9 [19.1, 29.8]	30.3 [24.0, 38.2]
Hand/Wrist	29.8 [25.2, 35.2]	40.7 [34.2, 48.5]
Humerus	32.3 [28.2, 37.0]	45.3 [39.3, 52.2]
Scapula	34.1 [28.9, 40.2]	44.9 [37.9, 53.3]

Injury Source

The possible injury sources included: air bag; seat belt; B-pillar; door; flying glass; instrument panel (IP)/knee bolster; seat; steering wheel/assembly; unknown; and other (Fig. 3). The majority of all UE injuries in side-impact crashes were due to contact with the door (33.7%). Injuries to the scapula were most commonly due to the B-pillar (50.0%). Of the UE injuries caused by the B-pillar, 61.2% (N=30) were AIS2+ injuries, which was the highest across all injury sources. Also, of all UE injuries caused by the door, seat, and steering wheel/assembly, there were relatively high percentages of AIS2+ injuries (33.0%, 35.0%, and 46.2%, respectively). Contact with flying glass resulted solely in AIS1 severity injuries (N=59). The distribution of injury source between near-side and far-side occupants differed considerably. Near-side occupants had 38.9% and 6.3% of their injuries result from contact to the door (N=258) and B-pillar (N=42), respectively. Far-side occupants had only 20.2% and 2.8% of their injuries result from contact to the door (N=51) and B-pillar (N=7), respectively. Additionally, only near-side passengers had UE injuries due to the B-pillar (N=11), while drivers who sustained injuries due to the B-pillar were in both near-side (N=31, 81.6%) and far-side (N=7, 18.4%) crashes. Although the majority of drivers who sustained UE injuries due to the steering wheel were in near-side crashes (N=20, 87.0%), some driver UE injuries due to the steering wheel occurred in far-side crashes (N=3, 13.0%). Drivers also sustained AIS2 and AIS3 severity injuries due to contact with the steering wheel in both near-side (AIS2: N=3 and AIS3: N=5) and far-side (AIS2: N=2 and AIS3: N=1) crashes. By comparison, only passengers in far-side crashes sustained injuries due to contact with the steering wheel (N=3), and they were only AIS1 (N=2) and AIS2 (N=1) severity. In addition, far-side drivers had four AIS3 severity injuries due to the driver-side airbag, whereas far-side passengers only had AIS1 injuries due to contact with an airbag (N=3).

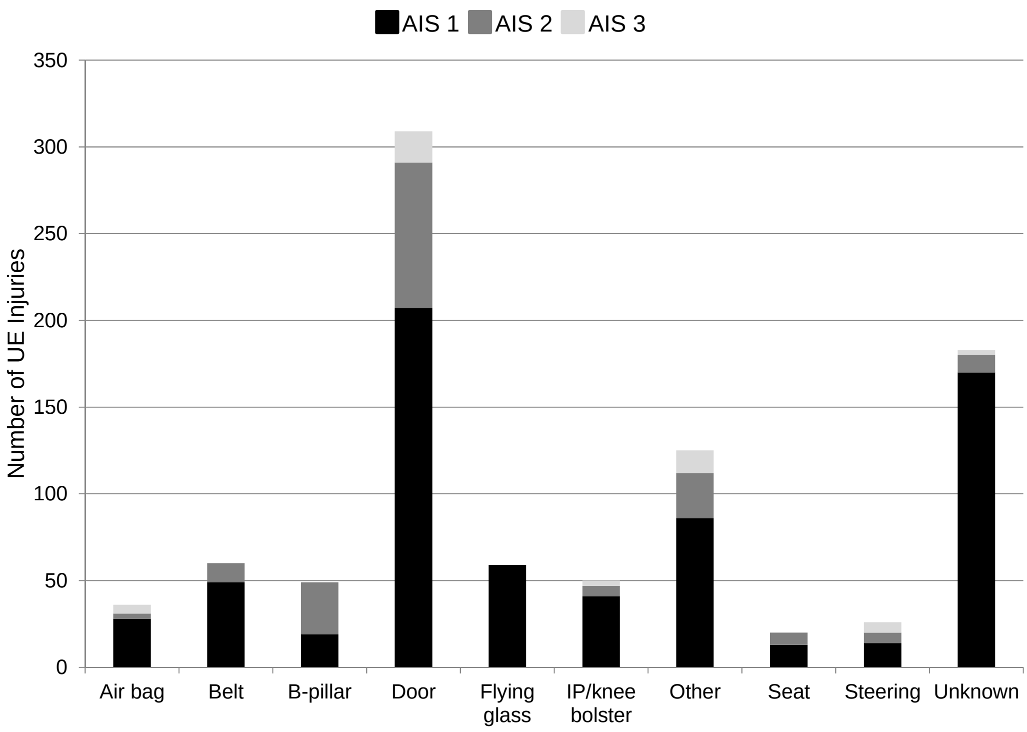

Fig. 3. The injury sources for all UE injuries, stratified by AIS severity.

IV. DISCUSSION

Improved vehicle safety design over the past few decades has reduced risk of fatality and serious injury in MVC [3][8]. However, UE injuries continue to be a consistent injury sustained in MVC and can result in disability and other long-term effects on functional outcome [10][16][18]. This study evaluated the distribution of UE injuries in side-impact collisions to provide insight into injury causation scenarios and recommendations for future study and improvements to vehicle design.

The study identified a subset of 413 CIREN occupants meeting the inclusion criteria described in Methods, above. The majority of all UE injuries from this subset were soft tissue injuries, followed by fractures. Of note, the incidence of fractures decreased distally down the arm, with the majority of fractures proximal to and including the humerus. The injury pattern in side-impact collisions contrasts with prior studies of UE injuries in other frontal impact collisions that have been associated with more distal injuries. A study evaluating crash and injury data from the Co-operative Crash Injury Study from 1983 to 1992 found that in frontal collisions the forearm accounted for the greatest incidence (46%) of AIS2+ UE injuries [26]. In the same study, they found that in side-impact collisions, injuries to the humerus or proximal accounted for the greatest proportion (65%) of AIS2+ UE injuries, which is a similar distribution to what was found in our study and suggests that UE injury patterns in side-impact collisions have remained relatively constant over the past few decades [26]. Additionally, another study evaluating UE fractures in restrained front-seat occupants found that fracture incidence of the hand (25%), wrist (25%), and forearm (23%) was greater than that of the elbow (9%), upper arm (10%) and shoulder (10%) in a large distribution of crash types [10]. In frontal collisions, the kinematics cause the occupant to move forwards relative to the vehicle, and prior studies have shown that forearm fractures are most commonly due to contact with the front vehicle interior and steering wheel [16][18]. Additionally, clavicle fractures are less likely in frontal MVC and are most commonly due to contact with the belt [18]. For side-impact collisions, the door was the most common injury source. The shoulder region has served as a target for occupant loading in side-impact MVC because of its relative structural strength and, given the positioning of occupants in the vehicle, the proximal UE is more likely to be contacted by the intruding door [27]. Specifically, the shoulder region may be more vulnerable to serious injury in side-impact collisions, as opposed to frontal collisions where the relative distance from the front of the vehicle combined with the protection of a frontal airbag may protect it more than the distal forearm [10].

In side-impact collisions, the B-pillar and door are typically crushed, causing intrusion into the near-side occupant compartment and in turn causing severe injury. The median CMAX of all cases was 48 cm, and there was only a single case with 0 cm of crush. There were significant associations between ΔV and injury type and location, as well as between CMAX and injury type and location. Clavicle fractures were associated with significantly higher mean ΔV and mean CMAX than injuries to the glenohumeral joint, potentially highlighting the severity of clavicle fractures. In contrast, joint dislocations were associated with significantly lower mean CMAX than fractures and soft tissue injuries, as well as significantly lower mean ΔV than soft tissue injuries, potentially highlighting increased susceptibility to these injuries in side-impact collisions. The door was the most common injury source of all UE injuries, but contact with the B-pillar resulted in the highest proportion of AIS2+ injuries. Fractures were most often due to contact with the door or B-pillar (when injury source was known), which may explain the higher percentage of fractures in near-side impacts compared to far-side impacts. Near-side occupants had nearly twice the relative percentage of injuries due to contact with the door and B-pillar compared to far-side occupants. Far-side passengers did not sustain humerus fractures, whereas far-side drivers did have humerus fractures. Also, drivers, both near-side and far-side, had AIS3 UE injuries, while only near-side passengers had AIS3 injuries. The higher severity injuries seen in drivers, regardless of crash type, compared to passengers are potentially due to the position of the driver's UEs relative to the steering wheel/assembly and associated airbags, which create more contact opportunities for the driver's UEs.

There are a few limitations to this study. The CIREN database is not a statistically random sample, there are various inclusion criterions regarding injury and crash severity that must be met and there are a limited number of CIREN centers across the United States, which limits the capacity to make inferences to nationwide trends and creates potential selection bias. CIREN inclusion criteria requires occupants to be severely injured, generally with injuries of at least AIS 3 severity, so the occupants enrolled in the CIREN study may not be representative of all occupants injured in MVC. However, CIREN provides detailed information about injury mechanisms and injury sources that is not found in larger, more population-based databases. Also, CIREN centers have uniform methods for enrollment, crash investigation, data collection, and biomechanical causation analysis. Another limitation is that the sample size within some injury groups is small, however groups with N<10 were excluded from statistical inferences. Injuries included in the analysis were coded using both the 1998 and 2005 versions of AIS and there are changes in severity for some injury codes from the 1998 to the 2005 version. However, the differences in severity between the two versions only affects 17 injuries (i.e. these injuries are considered AIS 2 severity in 2005 version, but AIS 3 severity in 1998 version). The severity of injuries was categorized as it was originally coded. Additionally, cases with missing data were excluded from the analysis. For instance, there are a number of cases with no ΔV calculated because the change in velocity could not be accurately determined. Excluding these cases may have biased the study results. Lastly, the majority of the injuries included in this analysis were AIS1 severity injuries, such as contusions and abrasions, which possibly overestimate the impact of side collisions on UE injuries that truly affect a particular patient.

V. CONCLUSIONS

This study characterized the distribution of UE injuries in side-impact collisions. We demonstrated that side-impact collisions increase proximal UE injury incidence compared to distal UE injuries, in contrast to frontal impact collisions. The most common fracture location was the clavicle. Our study demonstrated that the majority of injuries resulted from contact with the door, suggesting a need for further research on door structure safety and vehicle crashworthiness.

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