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Associations between upper extremity injury patterns in side impact motor vehicle collisions with occupant and crash characteristics

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ABSTRACT

Introduction: Side impact motor vehicle collisions (MVC) represent a significant burden of mortality and morbidity caused by automotive injury within the United States. The objective of this study was to evaluate the relationship between upper extremity (UE) injury patterns and contact sources in side impact MVC with occupant and crash variables.

Methods: Crash Injury Research and Engineering Network data obtained from 1998 to 2012 were used to evaluate UE injuries in side impact crashes. First row drivers and passengers that were at least 16 years old with complete crash information were included. Side impact crashes were defined to have an area of deformation to the side of the vehicle and a principal direction of force between 60° and 120° or 240° and 300°. Injuries were stratified by type, anatomic location, and Abbreviated Injury Scale (AIS) severity. Occupant variables included age, sex, height, weight, body mass index, and Injury Severity Score. Vehicle and crash variables included in the analysis were change in vehicle velocity at the time of impact, maximum door intrusion, maximum B-pillar intrusion, seat track position, belt use, vehicle type, impact type, and injury source. Statistical analysis of the UE injury data included descriptive statistics, linear regression analyses with occupant variables, and logistic regression analyses with vehicle and crash variables.

Results: There were 903 UE injuries among 408 case occupants. The most common injury type was soft tissue injury (72.5%). The majority of fractures were proximal to and including the humerus (70.3%) with the clavicle being the most common fracture location (N = 89). AIS 2+ UE injuries were associated with a significantly higher mean occupant Injury Severity Score than AIS 1 UE injuries ($p = 0.01$). Contact with the door was the leading cause of UE injury (34.2%). The odds (OR [95% confidence interval], p-value) of an AIS 2+ UE injury due to contact with the B-pillar (5.3 [3.1, 9.1], < 0.0001), door (1.9 [1.3, 2.7], 0.0006), and steering wheel/assembly (2.7 [1.1, 6.3], 0.03) were significantly higher than all other injury sources combined. Scapula fractures were significantly associated with rearward seat track positions (1.46 [1.04, 2.05], 0.03).

Conclusions: This study provides insight into UE injury patterns in side impact MVC. The clavicle was the most common UE fracture location. Contact with the door resulted in the highest number of UE injuries and the B-pillar resulted in the most severe injuries. Additionally, exposure to greater B-pillar intrusion was associated with increased odds of scapula and clavicle fractures in side impacts.

1. Introduction

Side impact motor vehicle collisions (MVC) contribute to a substantial burden of automotive injury and fatality. Of all MVC fatalities for passenger vehicles in 2012 in the United States, approximately 26% resulted from side impact collisions (Insurance Institute for Highway Safety, 2016). The implementation of seat belts and air bags has reduced the risk of MVC-related death and severe injury in recent decades, but the improved safety from restraint devices does not protect all body regions in every crash type equally (Evans, 1987; Zador and

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Ciccone, 1993; Lund and Ferguson, 1995; Braver et al., 1997; Evans, 1999; Li et al., 2001; NHTSA, 2012; National Center for Statistics and Analysis, 2015). In recent decades the number of upper extremity (UE) injuries has proportionally remained the same and the injury severity has increased (Richter et al., 2000). A possible reason for this trend in UE injuries are airbags themselves. Despite the benefits, such as protection by side curtain airbags against the occurrence of severe UE injury due to partial ejection, they may increase the risk of some injuries (Jernigan and Duma, 2003; McGwin et al., 2008; Kaufman et al., 2017). One study evaluated the effect of side airbags (SAB) on the risk of UE injury and found that, even though SAB reduce the risk of head and thoracic injury, SAB increased the risk of moderate or severe Abbreviated Injury Scale (AIS) 2+ UE injury and the risk of dislocation (McGwin et al., 2008). Furthermore, an evaluation of 25,464 National Automotive Sampling System (NASS) frontal collision cases reported that occupants with an airbag deployment were statistically more likely to have a severe UE injury compared to occupants not exposed to airbag deployment ($p = 0.01$) (Jernigan and Duma, 2003). The upper extremities still remain vulnerable during MVC, even with modern safety devices.

UE injuries can be a significant cause of disability and negatively affect functional outcome and quality of life after a MVC (Chong et al., 2011; de Putter et al., 2014). The treatment of UE injuries can be costly and expensive; specifically, more severe (AIS 2+) UE injuries that involve fractures and often require surgical intervention (McGwin et al., 2008; Chong et al., 2011). For instance, a study of UE injuries in MVC reported that the average number of surgical procedures required to treat open fractures was 2.4 (Chong et al., 2011). UE injury patterns and severity in MVC vary depending on a number of factors including crash type (e.g. front, side, rear), crash severity, and restraint use (Richter et al., 2000; Goldman et al., 2005; Conroy et al., 2007; McGwin et al., 2008; Chong et al., 2011). Past studies evaluating UE injuries in MVC have made valuable contributions to our understanding of the effect of restraint use and overall characterization of UE injury patterns (Richter et al., 2000; Jernigan and Duma, 2003; Goldman et al., 2005; Conroy et al., 2007; McGwin et al., 2008; Yoganandan et al., 2014). Occupants with fractures are on average significantly lighter than those with soft tissue injuries, and clavicle fractures are 5 times more likely in occupants involved in side impacts compared to frontal impacts (Conroy et al., 2007). However, UE injury pattern characterization, especially relating to injury source, in side impact collisions is limited.

The National Highway Traffic Safety Administration's Crash Injury Research and Engineering Network (CIREN) provides important data concerning injury causation scenarios in real-world MVCs. The objective of this study was to use CIREN data to conduct detailed analyses to examine the relationship between UE injury patterns and contact sources in side impact MVC with occupant and crash variables.

2. Materials and methods

Detailed vehicle, crash, occupant, and injury data were extracted from the CIREN database on August 23, 2012 using the CIREN SQL interface and SQL developer (Oracle, Redwood Shores, CA). MVC crash years included in this dataset ranged from 1998 to 2012. The CIREN inclusion criteria generally require occupants to have sustained at least one injury with an AIS severity ≥ 3 or two injuries in separate body regions with an AIS severity ≥ 2 (Association for the Advancement of Automotive Medicine (AAAM, 1998, 2005). The model year of the case vehicle must also be within 6 or 8 years of the crash. All CIREN cases selected underwent a full case review with medical, engineering, and crash reconstruction specialists to determine a likely injury contact source validated with the mechanism of injury.

For this study, inclusion criteria were that occupants must be at least 16 years old and first row drivers and passengers only. Only side impact crashes with the area of deformation to the side plane of the vehicle and a known principal direction of force (PDOF) between 60° and 120° or 240° and 300° were included. Those with unknown belt status, change in vehicle velocity at the time of impact (ΔV), maximum crush, or missing crash information were excluded.

Occupant, vehicle, and crash variables were evaluated in this study. Occupant demographic variables included sex, age, height, weight, body mass index (BMI), and Injury Severity Score (ISS). Vehicle and crash variables included were ΔV (change in velocity is a commonly used measure of crash severity and was determined using WinSmash software (Hampton and Gabler, 2010; Johnson and Gabler, 2014)), maximum door intrusion, maximum B-pillar intrusion, seat track position (2: most-forward, 3: between most-forward and middle, 4: middle, 5: between middle and most-rearward, 6: most-rearward), belt use, vehicle type (automobile vs. truck/van/utility vehicle), impact type (near-side vs. far-side), and injury source (air bag, B-pillar, belt, door, flying glass, instrument panel (IP)/knee bolster, seat, steering wheel/assembly, other, unknown). The door contact was defined as any location on the interior surface and the associated hardware and armrest. UE injuries were stratified by type, anatomic location, and AIS severity (AIS 1 and AIS 2+). The four classifications for injury type were fracture, joint soft tissue injury, joint dislocation, and soft tissue injury. Injury locations were separated into twelve categories: acromion/acromioclavicular (AC) joint, clavicle, elbow, external/skin, forearm, glenohumeral joint, hand/wrist, humerus, muscle/tendon/ligament, scapula, sternoclavicular joint, and vessels.

UE injuries were examined descriptively (count, percent) by type, location, and AIS severity. Means and standard deviations were calculated for demographics of the study population overall and stratified by sex. The association between sex and each occupant demographic was evaluated using a generalized linear model. The relationships between occupant demographics and injury type, location, and AIS severity were evaluated using linear mixed effects models. This modeling takes into account the correlation within subjects and adjusts for multiple injuries observed within occupants. A Tukey-Kramer correction was applied for the statistical tests comparing occupant demographics and injury location. The association between injury characteristics (type, location, AIS severity) and crash variables (ΔV, maximum door intrusion, b-pillar intrusion, seat track position, belt use, vehicle type, impact type, and injury source) were examined using separate logistic regression models accounting for multiple injuries of the same occupant. For all logistic regression models, yes/no indicator variables were created for each injury type and location outcome. For the models evaluating injury source as the predictor, indicator variables were also created for each known injury source, where 1 = "injury was caused by that source" and 0 = "source was not the cause of injury". Injury sources that did not result in a specific UE injury type, location, or AIS severity were not modeled. Injury locations with sample sizes less than 10 were excluded from all statistical tests. 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).

3. Results

There were 3079 case occupants who sustained a total of 7715 UE injuries within the CIREN database from 1998 – 2012. After applying the inclusion/exclusion criteria, there were 408 case occupants with 903 UE injuries and all subsequent analyses were derived from this subset. To summarize the excluded case occupants, 2372 were not in side impact collisions, 62 case occupants were < 16 years old or not seated in the first row, 4 case occupants were pregnant, 212 cases had unknown or indeterminate crash information (e.g. ΔV could not be calculated), and 21 cases had a primary area of deformation that was not to the side of the vehicle.

3.1. Injury patterns

Of the 903 UE injuries, the most prevalent injury type was soft tissue

Table 1
CIREN upper extremity injuries stratified by type, location, and AIS severity.

	AIS 1		AIS 2+		Total (N = 903)	
	N	*(Row %)*	N	*(Row %)*	N	*(Column %)*
Injury Type						
Fracture	3	*(1.4%)*	209	*(98.6%)*	212	*(23.5%)*
Joint Dislocation	4	*(28.6%)*	10	*(71.4%)*	14	*(1.6%)*
Joint Soft Tissue Injury	22	*(100.0%)*	0	*(0.0%)*	22	*(2.4%)*
Soft Tissue Injury	648	*(98.9%)*	7	*(1.1%)*	655	*(72.5%)*
Injury Location						
Acromion/AC Joint	2	*(18.2%)*	9	*(81.8%)*	11	*(1.2%)*
Clavicle	0	*(0.0%)*	89	*(100.0%)*	89	*(9.9%)*
Elbow	7	*(70.0%)*	3	*(30.0%)*	10	*(1.1%)*
External	643	*(99.1%)*	6	*(0.9%)*	649	*(71.9%)*
Forearm	0	*(0.0%)*	44	*(100.0%)*	44	*(4.9%)*
Glenohumeral Joint	10	*(76.9%)*	3	*(23.1%)*	13	*(1.4%)*
Hand/Wrist	9	*(40.9%)*	13	*(59.1%)*	22	*(2.4%)*
Humerus	0	*(0.0%)*	33	*(100.0%)*	33	*(3.7%)*
Muscle/Tendon/ Ligament	5	*(100.0%)*	0	*(0.0%)*	5	*(0.6%)*
Scapula	0	*(0.0%)*	24	*(100.0%)*	24	*(2.7%)*
Sternoclavicular Joint	1	*(50.0%)*	1	*(50.0%)*	2	*(0.2%)*
Vessels	0	*(0.0%)*	1	*(100.0%)*	1	*(0.1%)*
Total	677	*(75.0%)*	226	*(25.0%)*		

injuries (72.5%), followed by fractures (23.5%) (Table 1). There were 212 fractures and the most common fracture location was to the clavicle (N = 89, 42.0%). Fracture incidence decreased distally down the arm with 70.3% of fractures proximal to and including the humerus and 29.7% distal to the humerus. The most common UE injury location was to the skin, i.e. external (71.9%). The majority of injuries were AIS severity 1 (75.0%).

3.2. Occupant characteristics

There were 227 (55.6%) female and 181 (44.4%) male occupants. The age distribution of occupants was 16–25 years: 29.4%, 26–35 years: 14.0%, 36–45 years: 11.0%, 46–55 years: 13.0%, 56–65 years: 10.8%, 66–75 years: 8.3%, > 75 years: 13.5%. A summary of the study population demographics is shown in Table 2. Males were associated with significantly higher mean height, weight, and BMI than females (all $p < 0.01$). There were no significant differences in the mean age or ISS between males and females.

There were no significant differences in mean occupant age, height, or weight among UE injury types, locations, or AIS severity (Table 2). However, there was a significant association between mean occupant BMI and UE injury location ($p = 0.03$). Clavicle fractures had the lowest mean [95% CI] BMI of 24.8 kg/m^2 [23.5, 26.0]. There were no significant differences in mean BMI among UE injury types or AIS severity. Mean occupant ISS varied significantly among UE injury types ($p = 0.04$), locations ($p = 0.001$), and AIS severity ($p = 0.01$). Fractures had a significantly higher mean ISS than soft tissue injuries ($p = 0.009$). Injuries to the elbow had a significantly lower mean ISS than fractures of the humerus ($p = 0.009$) and clavicle ($p = 0.02$). AIS 2+ UE injuries were associated with a significantly higher mean ISS than AIS 1 UE injuries ($p = 0.01$).

3.3. Crash characteristics

The results of the logistic regression models evaluating the associations of each UE injury type, location, and AIS severity with crash characteristics are shown in Table 3. Within injury type, the odds of sustaining a fracture, joint dislocation, or soft tissue injury did not significantly change with each unit increase in ΔV, but the odds of a joint soft tissue injury decreased significantly with each unit increase in ΔV ($p = 0.04$). Regarding the specific injury locations, the odds of a glenohumeral joint injury significantly decreased with each unit increase in ΔV ($p = 0.02$) and the odds of a clavicle fracture significantly increased with each unit increase in ΔV ($p = 0.03$), but no other injury locations had a significant association with ΔV. Furthermore, AIS severity was not significantly associated with ΔV. Door intrusion was not significantly associated with UE injury type, location, or AIS severity. However, the odds of a clavicle and scapula fracture significantly increased with each unit increase in B-pillar intrusion ($p = 0.009$ and $p = 0.02$, respectively).

The majority of occupants were drivers (80.6%) compared to right-front passengers (19.4%). Near-side and far-side crashes accounted for 302 (74.0%) and 106 (26.0%) of the occupants, respectively. Among the UE injuries in near-side impacts, 469 were to the out-board UE, 177 were to the in-board UE, and 15 were bilateral or to an unspecified

Table 2
Demographics of study population (Mean [95% Confidence Interval]) stratified by sex and UE injury type, location, and AIS severity.

	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)	ISS
Population					
Total (avg. ± std.)	45.1 ± 22.3	169.8 ± 10.3	76.9 ± 20.6	26.5 ± 5.9	27.7 ± 16.7
Female	45.5 [42.5, 48.4]	163.6 [162.6, 164.6]	69.3 [66.8, 71.8]	25.8 [25.0, 26.6]	26.8 [24.7, 29.0]
Male	44.6 [41.3, 47.8]	177.7 [176.6, 178.8]	86.7 [83.9, 89.5]	27.4 [26.5, 28.2]	28.8 [26.4, 31.2]
Injury Type					
Fracture	43.4 [40.3, 46.5]	169.2 [167.8, 170.6]	75.1 [72.3, 77.9]	26.1 [25.3, 26.9]	31.9 [29.5, 34.2]
Joint Dislocation	46.9 [34.8, 58.9]	171.7 [166.2, 177.2]	82.3 [71.4, 93.1]	27.8 [24.6, 30.9]	23.0 [13.8, 32.2]
Joint Soft Tissue	52.7 [43.1, 62.3]	170.0 [165.6, 174.3]	83.6 [74.8, 92.5]	28.6 [26.1, 31.2]	29.3 [22.0, 36.6]
Soft Tissue Injury	46.0 [44.2, 47.7]	169.6 [168.8, 170.4]	77.7 [76.1, 79.3]	26.8 [26.3, 27.3]	28.2 [26.9, 29.6]
Injury Location					
Acromion	44.7 [31.1, 58.3]	174.6 [168.4, 180.7]	81.0 [68.8, 93.2]	26.3 [22.8, 29.8]	23.0 [12.8, 33.2]
Clavicle	42.1 [37.4, 46.9]	169.5 [167.3, 171.7]	71.9 [67.6, 76.2]	24.8 [23.5, 26.0]	34.2 [30.6, 37.8]
Elbow	40.6 [26.3, 54.8]	167.7 [161.2, 174.2]	75.2 [62.4, 88.0]	26.4 [22.7, 30.1]	14.6 [3.9, 25.3]
External	46.1 [44.3, 47.8]	169.6 [168.8, 170.5]	77.8 [76.2, 79.4]	26.9 [26.4, 27.3]	28.3 [27.0, 29.6]
Forearm	45.6 [38.8, 52.4]	167.3 [164.2, 170.4]	75.3 [69.1, 81.4]	26.9 [25.1, 28.6]	28.2 [23.0, 33.3]
Glenohumeral Joint	53.3 [40.8, 65.7]	171.4 [165.7, 177.1]	85.5 [73.8, 97.2]	28.8 [25.4, 32.2]	30.2 [20.8, 39.6]
Hand/Wrist	48.8 [39.2, 58.4]	165.6 [161.2, 170.1]	79.0 [70.1, 87.9]	28.8 [26.3, 31.4]	24.7 [17.5, 31.9]
Humerus	43.3 [35.5, 51.2]	169.8 [166.2, 173.3]	82.0 [74.9, 89.1]	28.4 [26.3, 30.4]	37.5 [31.6, 43.4]
Scapula	44.1 [34.9, 53.3]	174.3 [170.2, 178.5]	77.3 [69.1, 85.6]	25.3 [22.9, 27.7]	31.8 [24.9, 38.8]
AIS Severity					
AIS 1	46.2 [44.5, 47.9]	169.6 [168.8, 170.4]	78.0 [76.4, 79.6]	26.9 [26.5, 27.4]	28.2 [26.8, 29.5]
AIS 2+	43.5 [40.5, 46.5]	169.4 [168.0, 170.8]	75.1 [72.4, 77.9]	26.1 [25.3, 26.9]	31.6 [29.3, 33.9]

Table 3
Summary of odds ratios and 95% confidence intervals, OR [95% CI], for each UE injury type, location, and AIS severity and crash characteristic, which are based on logistic regression models accounting for multiple injuries of the same occupant.

	ΔV (kph)	Max Door Intrusion (cm)†	Max B-pillar Intrusion (cm)†	Seat Track Position†	Belt Use = Y	Vehicle Type = Auto	Impact Type = Far Side
Injury Type							
Fracture	1.00 [0.99, 1.01]	1.00 [0.99, 1.02]	1.00 [0.99, 1.01]	0.95 [0.83, 1.08]	0.67 [0.45, 0.99]*	1.03 [0.63, 1.67]	0.70 [0.46, 1.06]
Joint Dislocation	0.97 [0.91, 1.03]	0.98 [0.94, 1.03]	1.00 [0.96, 1.03]	0.72 [0.43, 1.22]	1.81 [0.40, 8.20]	1.04 [0.22, 4.92]	1.53 [0.50, 4.71]
Joint Soft Tissue	0.96 [0.92, 0.99]*	0.98 [0.95, 1.03]	0.98 [0.95, 1.02]	1.01 [0.74, 1.38]	1.92 [0.40, 9.41]	0.48 [0.15, 1.54]	0.80 [0.17, 3.65]
Soft Tissue Injury	1.00 [0.99, 1.02]	1.00 [0.99, 1.01]	1.00 [0.99, 1.01]	1.08 [0.94, 1.24]	1.31 [0.89, 1.93]	1.08 [0.65, 1.80]	1.36 [0.90, 2.05]
Injury Location							
Acromion	0.97 [0.93, 1.01]	0.99 [0.95, 1.03]	0.99 [0.95, 1.03]	1.01 [0.61, 1.67]	0.80 [0.21, 2.98]	0.23 [0.07, 0.74]*	2.30 [0.71, 7.46]
Clavicle	1.01 [1.00, 1.03]*	1.01 [1.00, 1.02]	1.02 [1.00, 1.03]**	1.01 [0.85, 1.21]	0.66 [0.41, 1.05]	2.13 [1.13, 4.03]*	0.62 [0.35, 1.10]
Elbow	1.02 [0.97, 1.08]	1.02 [0.98, 1.06]	1.02 [0.98, 1.06]	0.79 [0.44, 1.40]		0.42 [0.11, 1.60]	1.83 [0.44, 7.71]
External	1.01 [0.99, 1.02]	1.00 [0.99, 1.01]	1.00 [0.99, 1.01]	1.08 [0.94, 1.23]	1.41 [0.97, 2.05]	1.13 [0.69, 1.87]	1.30 [0.86, 1.95]
Forearm	0.98 [0.95, 1.01]	1.00 [0.97, 1.02]	0.98 [0.95, 1.01]	0.76 [0.58, 0.98]*	0.79 [0.34, 1.82]	0.47 [0.21, 1.05]	0.50 [0.20, 1.28]
Glenohumeral Joint	0.93 [0.88, 0.99]*	0.97 [0.93, 1.01]	0.98 [0.94, 1.02]	0.89 [0.54, 1.47]	1.66 [0.36, 7.62]	0.94 [0.20, 4.49]	0.49 [0.11, 2.25]
Hand/Wrist	0.97 [0.94, 1.01]	1.00 [0.97, 1.03]	0.98 [0.96, 1.01]	0.89 [0.68, 1.16]	1.36 [0.37, 4.95]	0.60 [0.21, 1.71]	1.02 [0.36, 2.91]
Humerus	1.00 [0.97, 1.02]	0.99 [0.97, 1.01]	0.98 [0.96, 1.01]	0.91 [0.68, 1.22]	0.93 [0.42, 2.10]	0.88 [0.37, 2.07]	1.20 [0.55, 2.59]
Scapula	1.00 [0.97, 1.03]	1.01 [0.99, 1.04]	1.02 [1.00, 1.04]*	1.46 [1.04, 2.05]*	0.49 [0.21, 1.13]	3.18 [0.74, 13.67]	0.54 [0.19, 1.57]
AIS 2+	1.00 [0.98, 1.01]	1.00 [0.99, 1.01]	1.00 [0.99, 1.01]	0.94 [0.82, 1.08]	0.61 [0.41, 0.90]*	0.90 [0.54, 1.49]	0.79 [0.52, 1.21]

* $p < 0.05$.
** $p < 0.01$.
† 42, 25, and 33 injuries were excluded from the door intrusion, B-pillar intrusion and seat track position analyses, respectively, due to unknown/indeterminate measurements; Elbow and belt use was not modeled because only belted occupants had elbow injuries.

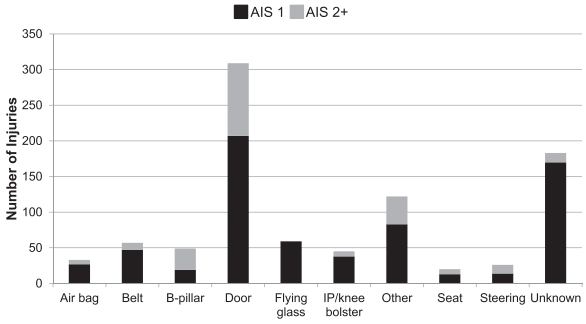

Fig. 1. Distribution of injury sources for all UE injuries stratified by AIS severity.

aspect. Among the UE injuries in far-side impacts, 93 were to the outboard UE, 139 were to the in-board UE, and 10 were bilateral or to an unspecified aspect. No significant associations existed within each injury type, location, or AIS severity and impact type (Table 3). Most occupants were in the most-rearward seat track position (N = 115), followed by middle (N = 95), middle to most-rearward (N = 87), most-forward to middle (N = 64), and most forward (N = 32). The odds of a forearm injury significantly decreased (p = 0.03) and the odds of a scapula fracture significantly increased (p = 0.03) with each rearward shift in seat track position. UE injury type and AIS severity were not significantly associated with changes in seat track position. Most occupants were belted (316 occupants, 77.5%), whereas only 92 (22.5%) occupants were unbelted. The odds of an UE fracture were significantly lower in belted occupants compared to unbelted occupants (p = 0.04). Additionally, the odds of an AIS 2+ UE injury were significantly lower in belted occupants compared to unbelted occupants (p = 0.01). There were no other significant differences in the odds of experiencing each injury type or location and the belt status of the occupant. The majority of occupants were in automobiles (N = 327, 80.2%) compared to those in truck/van/utility vehicles (N = 81, 19.8%). There were no significant associations among each injury type and vehicle type. However, the odds of an acromion/AC joint injury was significantly lower in automobile occupants compared to truck/van/utility vehicle occupants (p = 0.01). Conversely, the odds of a clavicle injury was over 110% higher in automobile occupants compared to truck/van/utility vehicle occupants (p = 0.02).

3.4. Injury source

The majority of UE injuries in side impact crashes were due to contact with the door (34.2%), as shown in Fig. 1. However, the B-pillar had the highest proportion (61.2%) of AIS 2+ UE injuries compared to all other injury sources. Near-side occupants had 39.0% (N = 258) and 6.4% (N = 42) of their UE injuries result from contact to the door and B-pillar, respectively. Whereas far-side occupants had only 21.0% (N = 51) and 2.9% (N = 7) of their UE injuries result from contact to the door and B-pillar, respectively. The greatest percentage of UE injuries in far-side occupants were due to an unknown source (N = 72, 29.8%).

The odds (OR [95% confidence interval], p-value) of an AIS 2+ UE injury due to contact with the B-pillar (5.3 [3.1, 9.1], < 0.0001), door (1.9 [1.3, 2.7], 0.0006), and steering wheel/assembly (2.7 [1.1, 6.3], 0.03) were each significantly higher than all other injury sources

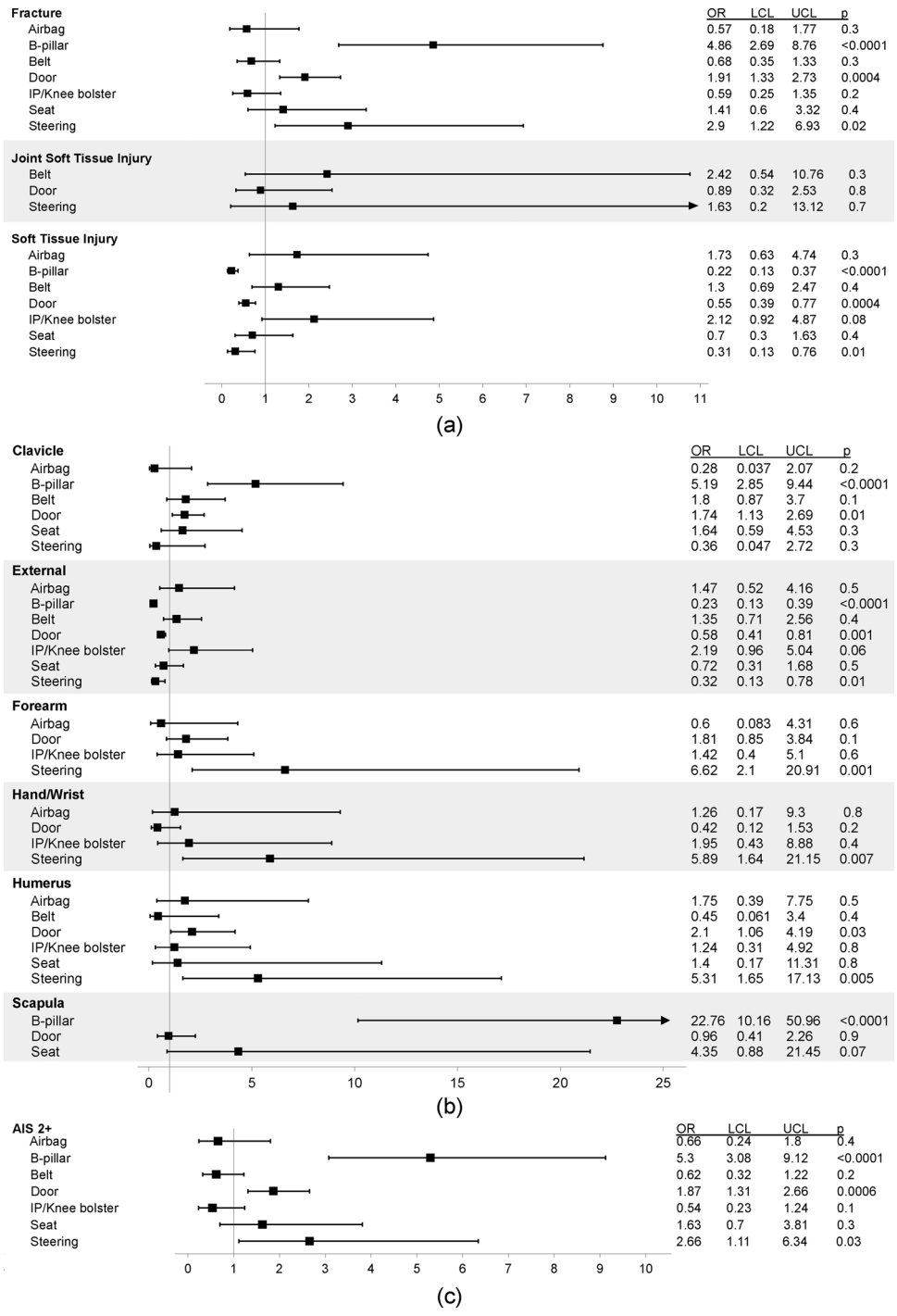

Fig. 2. Forest plots of the odds ratios and 95% confidence intervals of the association between each injury type (a), location (b), and AIS severity (c) and each known injury source. The OR and 95% CI are based on logistic regression models accounting for multiple injuries of the same occupant.

combined (Fig. 2). No other known injury sources had a significant association with AIS severity. Showing similar trends to AIS 2+ injuries, fractures had significant associations with occupant contact to the B-pillar (4.9 [2.7, 8.8], < 0.0001), door (1.9 [1.3, 2.7], 0.0004), and steering wheel/assembly (2.9 [1.2, 6.9], 0.02). In contrast, the odds of a soft tissue UE injury due to contact with the B-pillar (0.2 [0.1, 0.4], < 0.0001), door (0.6 [0.4, 0.8], 0.0004), and steering wheel/assembly (0.3 [0.1, 0.8], 0.01) were each significantly lower than all other injury sources combined.

Regarding specific injury locations, the odds of a clavicle (5.2 [2.9, 9.4], < 0.0001) or scapula (22.8 [10.2, 50.1], < 0.0001) fracture due to the B-pillar were each significantly higher than all other injury sources combined. The odds of a humerus fracture (2.1 [1.1, 4.2], 0.03) or a clavicle fracture (1.7 [1.1, 2.7], 0.01) due to contact with the door were each significantly higher than all other injury sources combined. Injury to the humerus (5.3 [1.7, 17.1], 0.005), hand/wrist (5.9 [1.6, 21.1], 0.007), and forearm (6.6 [2.1, 20.9], 0.001) were each significantly associated with the steering wheel/assembly. However, the majority of humerus (N = 17, 51.5%) and forearm (N = 21, 47.7%) fractures were due to contact with the door and the majority of hand/wrist injuries were due to an unknown source (N = 9, 40.9%).

4. Discussion

Improvements in motor vehicle restraint systems have reduced fatalities and severe head and chest injuries in MVC, but their effect in reducing the number and severity of UE injuries has been limited (Braver et al., 1997; Richter et al., 2000; Crandall et al., 2001; McGwin et al., 2004; Chong et al., 2011). This study aimed to characterize UE injury patterns in side impact collisions and, by isolating the analyses to side impact MVC, the confounding variable of crash-type (i.e. front, side, rear, etc.) has been removed. Results from this study demonstrate that a number of crash and occupant variables correlate with UE injury patterns. These results could inform clinicians on the likelihood of experiencing different types of UE injuries and their severity resulting from side impact MVC, which will help focus a secondary survey in these patients, especially for patients who cannot participate in an examination. In addition, these results provide insight to the contact sources associated with increased UE injury severity.

The most common UE injury type in this subset of side impact CIREN cases was soft tissue injury, with the majority being AIS 1 severity. Fractures accounted for the second greatest number of UE injuries, with the majority being AIS 2+ severity. The clavicle was the most common fracture location (N = 89, 42.0%), and more generally, the majority of fractures were proximal to and including the humerus. Interestingly, prior studies of UE injury patterns in frontal MVC have found that fracture incidence increases distally down the arm, the opposite of what we observed in side impact MVC (Frampton et al., 1997; Richter et al., 2000; Conroy et al., 2007; Chong et al., 2011). Crash and injury data from the Co-operative Crash Injury Study in the United Kingdom found that the forearm, wrist, and hand accounted for the largest proportion (72%) of AIS 2+ UE injuries in frontal MVC (Frampton et al., 1997). The kinematics in frontal collisions result in the occupants moving forward relative to the vehicle causing the distal UE to likely contact the front vehicle interior. Additionally, in frontal MVC the increased relative distance between the front vehicle interior and the proximal arm combined with the protection of a frontal airbag may better prevent proximal UE injury compared with more distal injuries. One study of UE injury sources in frontal collisions determined that forearm fractures were primarily due to contact with the front vehicle interior (31.2%) and the steering wheel (26.9%) (Conroy et al., 2007). However, in this study of side impact MVCs, the door was the most common injury source and was most often contacted by the occupant's shoulder region or upper arm. An occupant's UE is in close proximity to the door and B-pillar and there is little to protect the UE from contacting the (often intruding) side of the vehicle (Richter et al., 2000). The shoulder region has also functioned as a target for occupant loading in side impact MVC because of its relative structural strength, which puts the proximal UE at greater risk for injury (Forman et al., 2015).

There were correlations between occupant BMI and ISS with injury location as well as between occupant ISS with injury type and AIS severity. Clavicle fractures had the lowest mean occupant BMI among injury locations, however the effect of occupant BMI or weight on injury risk is not well understood and there are conflicting results from studies on whether increased BMI has a protective effect (Arbabi et al., 2003; Rupp et al., 2013; Yoganandan et al., 2014). AIS 2+ UE injuries were associated with a significantly higher mean ISS compared to AIS 1 severity injuries, which suggests that severe UE injuries may be a predictor of injuries in other body regions. One study evaluating humeral shaft fractures as predictors of intra-abdominal injury in MVC reported that occupants with humeral shaft fractures had a significantly greater number of liver injuries, forearm/hand fractures, tibial fractures, and femoral fractures compared to those without humeral shaft fractures (Adili et al., 2002). The significant correlation between ISS and injury type and location further supports that fractures to the humerus or clavicle, which were correlated with higher mean ISS compared to other injury locations, may be predictors of more severe injury in other body regions. However, further research is needed to better understand concomitant injuries in occupants with severe UE injury.

In this study, the odds of a clavicle or scapula fracture significantly increased with each unit increase in maximum B-pillar intrusion. The odds of a scapula fracture also significantly increased with a more rearward seat track position. Injury to the clavicle and scapula were also each significantly associated with contact to the B-pillar. Taken together, these results suggest that exposure to greater B-pillar intrusion is associated with increased odds of scapula and clavicle fractures in side impacts. However, more detailed analysis of the effect of intrusion and occupant position on injury patterns is warranted to better understand the confluence of these variables on UE injury risk. Unbelted occupants had significantly higher odds of an AIS 2 + UE injury compared to belted occupants. Additionally, the odds of a fracture were significantly reduced for belted occupants, suggesting seatbelts may contribute to reducing UE injury severity in side impact MVC. The odds of an acromion/AC joint injury were higher in truck/van/utility vehicles, whereas the odds of a clavicle fracture were higher in automobiles. The increased odds of a clavicle fracture occurring in automobiles compared to truck/van/utility vehicles may be due to differences in occupant compartment size and the decreased relative distance between the occupant and the side vehicle interior in automobiles. Specifically, occupants in passenger cars may sit lower in the vehicle relative to the window sill, compared to occupants in truck/van/utility vehicles, possibly creating greater exposure of the UE to contact with the door. The relative size of the striking and struck vehicle, body type, and occupant position may also affect injury patterns and should be considered in future studies. The comparatively small sample size of acromion/AC joint injuries also warrants further study relating injury patterns with vehicle types and occupant positioning.

The most common UE injury source in this study was the door, but the B-pillar had the highest proportion of AIS 2+ UE injuries. The odds of AIS 2+ UE injuries and fractures due to contact with the steering wheel/assembly, door, and B-pillar were each significantly greater than all other injury sources combined. In contrast, a study evaluating UE injuries in frontal MVC found that the majority of UE injuries were due to contact with the instrument panel or airbag, but the A- and B-pillars resulted in the fewest UE injuries (Chong et al., 2011). Restraint systems, airbags in particular, may contribute more frequently to the causation of UE injuries in frontal MVC compared to side impact MVC, where only 3.9% of UE injuries in this study were found to be due to contact with an airbag. However, this analysis did not control for the effect of side airbag deployment, which is something that should be investigated in future studies.

5. Limitations

A few limitations should be noted regarding this study. The CIREN database is not a random sample and is limited to MVC occurring near CIREN centers, which limits extrapolations to nationwide trends and creates potential selection bias. CIREN has inclusion criteria generally requiring that occupants have sustained injuries of at least AIS 3 severity, so the CIREN study was biased towards severely injured occupants and is not representative of all occupants injured in MVC. However, CIREN provides extensive data on MVC and detailed descriptions of the associated injury causation scenarios that are not found in larger, more population-based databases. This analysis did not account for multiple impacts, which may have affected the causation of some UE injuries, but the side impact was the primary and most severe event. It should be noted that, the majority of the injuries analyzed were AIS 1 injuries such as contusions and abrasions, which may overestimate the effect of UE injuries on patients and their outcome. While injury locations with N < 10 were excluded from statistical tests, the limited sample sizes for several other injury locations as well as within joint dislocation and joint soft tissue injury may impact the power to detect differences. Regarding the analysis of injury sources, the outcomes of joint dislocation, acromion/AC joint, elbow, and

glenohumeral joint injuries were also not examined due to small sample sizes and the lack of variability between these outcomes and various injury sources. Flying glass, other, and unknown injury sources were excluded from statistical tests as flying glass only resulted in AIS 1 soft tissue injuries and because we only evaluated known injury sources. Furthermore, additional injuries were excluded from the statistical analysis of B-pillar intrusion, door intrusion, and seat track position due to unknown or indeterminate measurements in those cases. Confounding variables were not evaluated in the statistical analyses due to the descriptive nature of this study, but will be part of future analyses that evaluate the confluence of multiple variables on UE injury risk. Lastly, the number of comparisons made here could result in apparent significance for some predictor/outcome pairs. Such occurrences are not considered highly important in this paper because of the descriptive focus.

6. Conclusions

This study evaluated UE injury patterns and contact sources in side impact MVC in terms of occupant and crash variables. The incidence of UE injury increases proximally in side impact MVC, in contrast to results from prior studies of UE injuries in frontal collisions. The clavicle was the most common UE fracture location and had increased odds of occurring in automobiles compared to truck/van/utility vehicles. Contact with the door resulted in the highest number of UE injuries. The B-pillar resulted in the highest proportion of AIS 2+ UE injuries and increasing B-pillar intrusion was significantly associated with increasing odds of clavicle and scapula fracture. Scapula fractures were significantly associated with rearward track positions that aligned the shoulder with the B pillar

Conflicts of interest

None.

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References

Adili, A., Bhandari, M., et al., 2002. Humeral shaft fractures as predictors of intra-abdominal injury in motor vehicle collision victims. Arch. Orthop. Trauma Surg. 122 (1), 5–9.
Arbabi, S., Wahl, W.L., et al., 2003. The cushion effect. J. Trauma 54 (6), 1090–1093.
Association for the Advancement of Automotive Medicine (AAAM), 1998. The Abbreviated Injury Scale. Des Plaines, Chicago, IL.
Association for the Advancement of Automotive Medicine (AAAM), 2005. The Abbreviated Injury Scale. Des Plaines, Chicago, IL. .
Braver, E.R., Ferguson, S.A., et al., 1997. Reductions in deaths in frontal crashes among right front passengers in vehicles equipped with passenger air bags. JAMA 278 (17), 1437–1439.
Chong, M., Broome, G., et al., 2011. Upper extremity injuries in restrained front-seat occupants after motor vehicle crashes. J. Trauma 70 (4), 838–844.
Conroy, C., Schwartz, A., et al., 2007. Upper extremity fracture patterns following motor vehicle crashes differ for drivers and passengers. Injury 38 (3), 350–357.
Crandall, C.S., Olson, L.M., et al., 2001. Mortality reduction with air bag and seat belt use in head-on passenger car collisions. Am. J. Epid. emiol. 153 (3), 219–224.
de Putter, C.E., Selles, R.W., et al., 2014. Health-related quality of life after upper extremity injuries and predictors for suboptimal outcome. Injury 45 (11), 1752–1758.
Evans, L., 1987. Fatality risk reduction from safety belt use. J. Trauma 27 (7), 746–749.
Evans, L., 1999. Traffic Safety. Kluwer Academic Publishers, Norwell, MA, pp. 63–108.
Forman, J.L., Lopez-Valdes, F.J., et al., 2015. The tolerance of the human body to automobile collision impact - a systematic review of injury biomechanics research, 1990-2009. Accid. Anal. Prev. 80, 7–17.
Frampton, R.J., Morris, A.P., et al., 1997. An overview of upper extremity injuries to car occupants in uk vehicle crashes. 1997 International IRCOBI Conference on the Biomechanics of Impact 37–51.
Goldman, M.W., MacLennan, P.A., et al., 2005. The association between restraint system and upper extremity injury after motor vehicle collisions. J. Orthop. Trauma 19 (8), 529–534.
Hampton, C.E., Gabler, H.C., 2010. Evaluation of the accuracy of nass/cds delta-v estimates from the enhanced winsmash algorithm. Ann. Adv. Automot. Med. 54, 241–252.
Insurance Institute for Highway Safety, 2016. Fatality Facts 2012, Passenger Vehicle Occupants. from. http://www.iihs.org/iihs/topics/t/general-statistics/fatalityfacts/passenger-vehicles/2012.
Jernigan, M.V., Duma, S.M., 2003. The effects of airbag deployment on severe upper extremity injuries in frontal automobile crashes. Am. J. Emerg. Med. 21 (2), 100–105.
Johnson, N.S., Gabler, H.C., 2014. Evaluation of nass-cds side crash delta-v estimates using event data recorders. Traffic Inj. Prev. 15 (8), 827–834.
Kaufman, R., Fraade-Blanar, L., et al., 2017. Severe soft tissue injuries of the upper extremity in motor vehicle crashes involving partial ejection: the protective role of side curtain airbags. Accid. Anal. Prev. 102, 144–152.
Li, G., Shahpar, C., et al., 2001. Secular trends of motor vehicle mortality in the united states, 1910–1994. Accid. Anal. Prev. 33 (3), 423–432.
Lund, A.K., Ferguson, S.A., 1995. Driver fatalities in 1985–1993 cars with airbags. J. Trauma 38 (4), 469–475.
McGwin Jr., G., Metzger, J., et al., 2004. The influence of side airbags on the risk of head and thoracic injury after motor vehicle collisions. J. Trauma 56 (3), 512–516 discussion 516–517.
McGwin Jr., G., Modjarrad, K., et al., 2008. Association between upper extremity injuries and side airbag availability. J. Trauma 64 (5), 1297–1301.
National Center for Statistics and Analysis, 2015. Occupant Protection: 2013 Data. U.S. Department of Transportation., Washington, DC.
NHTSA, 2012. Motor Vehicle Traffic Crash Fatality and Injury Estimates for 2012. Department of Transportation, Washington DC.
Richter, M., Otte, D., et al., 2000. Upper extremity fractures in restrained front-seat occupants. J. Trauma 48 (5), 907–912.
Rupp, J.D., Flannagan, C.A., et al., 2013. Effects of bmi on the risk and frequency of ais 3+ injuries in motor-vehicle crashes. Obesity (Silver Spring) 21 (1), E88–97.
Yoganandan, N., Arun, M.W., et al., 2014. Crash characteristics and injury patterns of restrained front seat occupants in far-side impacts. Traffic Inj. Prev. 15 (Suppl. 1), S27–34.
Zador, P.L., Ciccone, M.A., 1993. Automobile driver fatalities in frontal impacts: air bags compared with manual belts. Am. J. Public Health 83 (5), 661–666.