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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