CrossMark
texas orthopaedic journal®

ORIGINAL RESEARCH

Upper Extremity Injuries in Airbag-Equipped Vehicles: Are Newer Vehicles Safer?

Eric Waetjen, MD[1]; Jeremy S. Somerson, MD[2]; Gregory V. Gomez, MD[1]; Mark Bagg, MD[1]

[1]*Department of Orthopaedic Surgery, University of Texas Health Science Center; San Antonio, TX, USA*
[2]*Department of Orthopaedic Surgery & Rehabilitation, University of Texas Medical Branch; Galveston, TX, USA*

ABSTRACT

Introduction: Upper extremity injuries (UEIs) in motor vehicle collisions (MVCs) have increased attributable to airbag deployments. Since 2017, United States passenger vehicles are required to have new generation airbags. This research compares the rate of upper extremity injuries in pre- and post-2007 vehicles and analyzes associations with the occupant and impact characteristics.
Methods: The Crash Injury Research Network (CIREN) database was queried for MVCs for which an airbag was available for the years 2008 to 2010. Information on crash, occupant, airbag deployment, seatbelt usage, vehicle year, and UEIs was collected. Univariate analysis was used to identify associations between crash and vehicle occupant characteristics and the types of UEIs sustained.
Results: Between 2008 and 2010, 211 MVCs took place with airbags available. Airbags were more likely to deploy in vehicles with model year 2007 or later (p=0.015). No significant differences were noted in the UEI rate in pre-2007 vehicles (36%) compared to vehicles 2007 or later (31%; p=0.501). No delineation was made between front or side airbag deployment. Airbag deployment was associated with a 12-fold increased rate of upper extremity open fracture and a 3-fold increase of forearm fracture, while scapula fracture was 3.5-fold more likely in cases without airbag deployment.
Discussion: UEIs remain commonplace in the context of MVCs. Clinicians should remain vigilant for UEIs in cases of airbag deployment despite the presence of advanced airbag systems in newer vehicles, as they are associated with an increased risk of upper extremity fracture.
Level of Evidence: IV; Case series.
Keywords: Upper extremity injury; Motor vehicle collision; Airbag safety; Airbag injury.

INTRODUCTION

Changes in vehicle safety systems have led to different patterns of injury in motor vehicle collisions (MVCs). Seat belts and airbags have led to a clear decrease in overall mortality rates [1]. However, upper extremity injury (UEI) has increased in frequency, which some authors attribute to airbag deployment in modern vehicles [2,3].

Roth and Meredith reported first an injury to the upper extremity from airbag inflation in 1993 with a patient who presented with phalangeal fractures, concluding

Corresponding Author:
Jeremy S. Somerson, MD
Orthopaedic Surgery & Rehabilitation
University of Texas Medical Branch
301 University Blvd
Galveston, TX 77555, USA
jesomers@utmb.edu

that "no security system is free from side effects" [4]. Early investigations using pre-1997 data revealed evidence of injuries from the force of the airbag deployment as well as secondary injury after the upper extremity was propelled into interior structures [5,6]. As a result, most vehicles manufactured after 1997 were designed with second-generation airbags with decreased power, which was accompanied by a decrease in UEIs [7]. However, concerns regarding airbag-related injuries remained as multiple authors demonstrated a high rate of UEIs using post-1997 data [2,3,8-12]. This led to calls for further vehicle safety improvements.

In the United States, vehicle manufacturers were required to equip all passenger vehicles with a new generation of airbag by model year 2007. These airbag systems included functionality to distinguish between adult and child vehicle occupants and adjust deployment to match the size of the occupant, seat belt status, occupant position and crash severity [13]. Although prior studies [1,2,7,8,11,12] have explored UEI in MVCs that occurred prior to 2007, published analyses of more recent data are lacking. In this research study, we analyzed data from MVCs that occurred from 2008 to 2010 to answer the following questions: (1) At what rate do occupants sustain upper extremity injuries from MVCs? (2) Is this rate different between pre-2007 and post-2007 model years? (3) What specific injury types were attributed to airbag deployment? (4) What impact and occupant characteristics correlated with upper extremity injury?

MATERIALS & METHODS

Data Registry

The National Highway Traffic Safety Administration (NHTSA) sponsors the Crash Injury Research and Engineering Network (CIREN) database of motor vehicle crashes with information regarding injuries sustained by the occupants. Multiple trauma centers share cases with the CIREN network to study crash data and injury patterns. After reviewing all medical chart data and performing interviews with patients, a multidisciplinary team works to assess which specific structures of the motor vehicle that caused each injury.

Data Extraction

The CIREN online public database was queried for motor vehicle collisions for which an airbag was available for the years 2008 to 2010. A range of data was collected, including crash year, gender, age, height and weight, deployment of airbags, seatbelt usage, vehicle year and presence of upper extremity injuries. UEIs were further classified into those directly caused by airbag deployment and those with unknown or other etiology. Further, upper extremity severity was stratified into mild injury (low-grade laceration, abrasion or contusion) versus moderate or severe injuries with Abbreviated Injury Score (AIS) ≥ 2. Collisions were considered frontal impact collisions if the primary vector of force was between 11 o'clock and 2 o'clock. Collisions with a change in velocity of ≥ 35 miles per hour were considered high-speed collisions.

Injury Types

Full text descriptions were used to classify injuries by severity and anatomic location. Fracture locations were classified to the scapula, clavicle, humerus, forearm or carpus/hand. More severe injuries were marked by the presence of a fracture or open fracture, while patients sustaining low-grade laceration, abrasion or contusion were considered to have sustained a minor injury.

Statistical Analysis

Univariate analysis was used to identify associations between crash and vehicle occupant characteristics and the types of injuries sustained. Chi-Square likelihood ratio was used for categorical data with $n \geq 5$ in all quadrants. Two-tail Fisher's exact tests were used for categorical data with $n<5$ in any quadrant. Odds ratios (ORs) and 95% confidence interval (95%CI) were reported. For specific injuries, logistic regression was used to identify correlation with continuous variables.

RESULTS

Cohort Data

For the defined crash years (2008 to 2010), 211 unique occupant cases were identified in which a collision took place and an airbag was available. There were 120 female occupants and 91 males. Median age was 47 years old (range 10 to 94). Median hospital stay was 6 days (range 0 to 81 days). Median injury severity score (ISS) was 10 (range 0 to 75) with 53 of 211 patients (25%) requiring an ICU admission. Median occupant height was 168 cm (range 129 to 193) and weight was 77 kg (range 29 to 154). Drivers comprised 172 of the occupants while front right passengers made up 39 of the total. Of these, 34% of drivers and 38% of front right passengers sustained moderate/severe upper extremity injuries (AIS ≥ 2).

Impact Characteristics

Mean change in velocity (ΔV) at impact was 41.4±21.1 km/h. Airbags deployed in 56 cases (73%) and rollover-type collisions were reported for 46 of the 211 cases (22%). Impact direction variables were available for 174 of the 211 cases. Among these, 110 of the 174 cases (63%) were reported as a frontal collision (primary direction of impact between 11 o'clock and 1 o'clock on a simple clock face direction scale). The majority of patients (172 of 211; 82%) used a safety belt. Among restrained patients, 61 had an upper extremity injury (35%) compared to 12 of 39 unrestrained patients (31%), with no significant difference between these groups (p=0.575).

Car Year and Upper Extremity Injury

Vehicle model years ranged from 1997 to 2010 with a median model year of 2005. Vehicles with model years 2007 or later in which advanced airbag systems were mandated accounted for 55 of 211 cases (26%); among these cases, 17 occupants sustained moderate/severe UEI (31%). Pre-2007 model year vehicles accounted for 156 cases with 56 associated moderate/severe UEIs (36%), with no significant differences noted between these groups (p=0.501). Women heavier than 65 kg (n=73) were more likely to have sustained an UEI in pre-2007 vehicles (23 of 52 cases, 44%) than in later model year vehicles (3 of 21 cases, 14%; p=0.011). No such differences were noted for males heavier than 65 kg (n=84; p=0.614).

Airbag-Induced Injuries

Twelve of 155 crashes in which an airbag deployed resulted in injury that was determined to be caused directly by the airbag. This included two open distal radius fractures, five contusions, three skin abrasions, a tendon laceration and a combined ulna and carpal bone fracture. Rollover collisions were less likely to have an airbag-induced UEI compared to non-rollover collisions (p=0.0135), although the overall rate of UEI was not significantly different (p=0.27) between collision types.

Airbags were more likely to deploy in vehicles with a model year of 2007 or later (p=0.015). Airbag deployment was also more likely among high velocity collisions (p=0.0023) and frontal impact collisions (p<0.0001). Gender (p=0.23), obesity (p=0.92), and seatbelt use (p=0.16) did not correlate with airbag deployment rate.

Upper Extremity Injuries

Seventy-three occupants sustained moderate/severe UEI with AIS ≥2 (35% of total). Compared to occupants without moderate/severe upper extremity injuries, these occupants did not have a higher rate of rollover type collision (p=0.71), high-speed impact (p=0.14), frontal impact (p=0.72), airbag deployment (p=0.84), or female gender (p=0.89).

Of these occupants, 67 sustained an upper extremity fracture; 29 of these were open. The most common site of upper extremity fracture was the forearm (33 cases; 16% of all occupants). This was followed by the wrist or hand (18 cases), clavicle (16 cases) and humerus (14 cases). Airbag deployment correlated with a higher risk of upper extremity open fracture (OR=12.13; 95%CI [1.61,91.37]) and forearm fracture (OR=2.99; 95%CI [1.00,8.94]) as well as a lower risk of scapula fracture (OR=0.28; 95%CI [0.08,0.95]; Table 1). These correlations were no longer present when adjusted to include only vehicles with model year ≥2007.

Obesity, Collision, and Injury Type

Overall, 57 occupants were considered obese (BMI≥30), 66 were overweight (BMI≥25), 75 were normal weight (BMI=25-29.9) and 11 were underweight (BMI<25). Obese occupants were more likely to be female (39 of 57 occupants, 68% female) compared to non-obese occupants (81 of 152 occupants, 53% female; p=0.046). Obese occupants were also less likely to wear a safety belt (41 of 57, 72% restrained) compared to non-obese occupants (129 of 152, 85% restrained; p=0.0381). Occupants who were obese did not differ from other occupants in terms of airbag deployment at time of injury (p=0.92), frontal impact collision type (p=0.89), rollover collision (p=0.52) or vehicle year ≥ 2006 (p=0.81).

Obese occupants were significantly less likely to sustain serious upper extremity injury (OR=0.41, 95%CI [0.20,0.84]; p=0.01) and upper extremity fracture (OR=0.48; 95%CI [0.24,0.99]; p=0.04). However, obese occupants had a higher rate of death from collision (OR=4.78; 95%CI [1.10,20.68]; p=0.03). Occupants who were obese did not differ from other occupants in terms of hospital stay length (p=0.66). Mean length of intensive care unit (ICU) stay was shorter among obese occupants (2.7 days) compared to all others (4.5 days), although this did not reach the defined level of statistical significance (p=0.058).

DISCUSSION

This project evaluated the most recent available CIREN motor vehicle collision injury database for crash years 2008 to 2010 with the objective of determining the incidence of upper extremity fractures, as well as characteristics and correlative factors associated with upper extremity injury. Vehicles with a model year prior to 2007, when advanced airbag systems were mandated in all vehicles, were compared to more recent vehicles in terms of upper extremity injury rate. Specific upper extremity injury types were categorized and factors relating to the occupant and impact were explored for correlation.

Early reports of airbags and associated upper extremity injury were limited to case reports and small series [4,14-16]. The first database analysis to explore UEI was published in 1995 using the University of Michigan Transportation Research Institute (UMTRI) database, in which 375 crashes with positive airbag deployment were analyzed in detail [5]. These authors reported upper extremity "minor injuries in 20-25% of the airbag cases", with few cases of fracture or more severe injury.

Table 1. MVC Upper Extremity Injuries with and without Airbag Deployment.

Injury Type	Injuries Total	Airbag Deployment Yes	No	P Value	Odds Ratio [CI]
All cases	211	155	56		
Vehicle Year ≥2007	55	47	8		
UE fracture (any)	67	50	17	p=0.793*	1.09 [0.56,2.12]
Vehicle Year ≥2007	15	12	3	p=0.669†	
UE fracture (open)	29	28	1	p=0.001†	12.13 [1.61,91.37]
Vehicle Year ≥2007	7	6	1	p=1.000†	
Scapula fracture	11	5	6	p=0.043*	0.28 [0.08,0.95]
Vehicle Year ≥2007	32	1		p=0.382†	
Clavicle fracture	16	10	6	p=0.318	0.57 [0.20,1.66]
Vehicle Year ≥2007	44	0		p=1.000†	
Humerus fracture	14	12	2	p=0.363†	2.27 [0.49,10.46]
Vehicle Year ≥2007	33	0		p=1.000†	
Forearm fracture	33	29	4	p=0.028†	2.99 [1.00,8.94]
Vehicle Year ≥2007	86	2		p=0.329†	
Carpus/Hand fracture	816	2		p=0.096†	3.11 [0.69,13.97]
Vehicle Year ≥2007	33	0		p=1.000†	

Case subsets for vehicle model years ≥2007 are shown below each injury type. CI, 95% confidence interval; *Chi-Square likelihood ratio; †2-tail Fisher's exact test.

A larger series of 21,875 MVC occupants enrolled in the Pennsylvania Trauma Outcome Survey was used to explore the correlation of airbag deployment with both upper and lower extremity injury for collision years 1990 to 1995 [6]. It was noted that the deployment of airbags resulted in an increased incidence of both upper and lower extremity injuries compared to seat belts alone or unrestrained drivers. Data from the 1995 through 2002 National Automotive Sampling System Crashworthiness Data System (NASS-CDS) confirmed that occupants with seatbelt-only restraints had a lower risk of UE injury than patients with combined seatbelt-airbag deployment [3]. The overall rate of UEI was reported as 2.7% of all occupants.

The CIREN database has reported much higher rates of UEI than this, likely due to the nature of its data sources at high-level trauma centers. CIREN data from 1997 to 2004 reported by Conroy et al demonstrated a 24.8% rate of UEI with AIS≥2 among 584 cases [2]. This is lower than the present study, in which 35% of occupants sustained UEI with AIS≥2. Markers of collision severity were not substantially different in the cases reported by Conroy et al (mean ΔV=45 km/h, airbag deployment rate= 85%) compared to the present study (mean ΔV=41 km/h, airbag deployment rate 73%).

Side airbags were introduced for further protection against head and thoracic injury [17]. However, due to the proximity of the shoulder and elbow, side airbag deployment may place occupants at higher risk for UE injury. In a study of 6 cadaver dummies, side airbag deployment resulted in upper extremity injury in all 6 cases, including humeral shaft fracture, intra-articular distal humerus fracture and distal radius fracture [18]. This was confirmed in a database study by McGwin et al, in which vehicles equipped with side airbags demonstrated a relative risk of 2.75 (range 1.10-6.83) for moderate/severe UEI [8]. As recent literature has shown limited thoracic protection from side airbag deployment [19], further investigation is needed to optimize the risk/benefit ratio of these devices.

This work had several limitations that merit discussion: (1) the CIREN database includes primarily data collected from high-level trauma centers and likely includes cases of greater severity than would be expected from a general population-level study; (2) the number of total cases in this review was smaller than prior database studies, which was necessary in order to include only recent 2008 to 2010 data; (3) the multicenter nature of the CIREN data collection process creates the possibility of differences in data recording and coding between centers. The primary strength of this work is the recent nature of the data collected; it represents, to the best of the authors' knowledge, the first report of post-2008 MVC data with regard to UEI.

In summary, analysis of 2008 to 2010 CIREN MVC data for airbag-equipped vehicles revealed a 35% rate of moderate/severe upper extremity injury. No difference in UEI rate was noted between pre-2007 vehicles and vehicles produced in 2007 or later, when a new generation of airbags became mandatory for all vehicles. However, subgroup analysis showed a higher rate of UEI for women heavier than 65 kg in pre-2007 vehicles. Airbag deployment was associated with a 12-fold increased rate of upper extremity open fracture and a 3-fold increased rate of forearm fracture, while scapula fracture was 3.5-fold more likely in cases without airbag deployment; these correlations were no longer present when limited to 2007 or later model year vehicles. Clinicians should continue to be vigilant for upper extremity fracture in cases of airbag deployment despite the presence of advanced airbag systems in newer vehicles.

REFERENCES

[1] Cummins JS, Koval KJ, Cantu RV, Spratt KF. Do seat belts and air bags reduce mortality and injury severity after car accidents? Am J Orthop (Belle Mead NJ). 2011;40(3):E26-9.

[2] Conroy C, Schwartz A, Hoyt DB, Brent Eastman A, Pacyna S, Holbrook TL, Vaughan T, Sise M, Kennedy F, Velky T, Erwin S. Upper extremity fracture patterns following motor vehicle crashes differ for drivers and passengers. Injury. 2007;38(3):350-7.

[3] Goldman MW, MacLennan PA, McGwin G, Lee DH, Sparks DR, Rue LW. The association between restraint system and upper extremity injury after motor vehicle collisions. J Orthop Trauma. 2005;19(8):529-34.

[4] Roth T, Meredith P. Hand injuries from inflation of an air bag security system. J Hand Surg Br. 1993;18(4):520-2.

[5] Huelke DF, Moore JL, Compton TW, Samuels J, Levine RS. Upper extremity injuries related to airbag deployments. J Trauma. 1995;38(4):482-8.

[6] McGovern MK, Murphy RX, Okunski WJ, Wasser TE. The influence of air bags and restraining devices on extremity injuries in motor vehicle collisions. Ann Plast Surg. 2000;44(5):481-5.

[7] MacLennan PA, Ashwander WS, Griffin R, McGwin Jr. G, Rue III LW. Injury risks between first- and second-generation airbags in frontal motor vehicle collisions. Accid Anal Prev. 2008;40(4):1371-4.

[8] McGwin GJM, Modjarrad K, Duma S, Rue LWI. Association Between Upper Extremity Injuries and Side Airbag Availability. J Trauma. 2008;64(5):1297-301.

[9] Serra C, Delattre O, Despeignes RL, Cousin A. Upper Limb Traumatic Lesions Related to Airbag Deployment: A Case Report and Review of Literature. J Trauma. 2008;65(3):704-7.

[10] Coimbra R, Conroy C, Tominaga GT, Bansal V, Schwartz A. Causes of scapula fractures differ from other shoulder injuries in occupants seriously injured during motor vehicle crashes. Injury. 2010;41(2):151-5.

[11] Marshall R, Hunting K, McKay MP. The Effect of Driver Age On The Incidence And Severity Of Upper Extremity Injuries Due To Second Generation Front Air Bag Deployment. Ann Adv Automot Med. 2010;54:215-2.

[12] Chong M, Broome G, Mahadeva D, Wang S. Upper extremity injuries in restrained front-seat occupants after motor vehicle crashes. J Trauma. 2011;70(4):838-44.

[13] US Department of Transportation. Code of Federal Regulations; Title 49 Transportation, Part 571 Federal Motor Vehicle Safety Standards, Standard No. 208 Occupant Crash Protection. Washington (DC): National Archives and Records Administration; 2008.

[14] Freedman EL, Safran MR, Meals RA. Automotive airbag-related upper extremity injuries: a report of three cases. J Trauma. 1995;38(4):577-81.

[15] Huebner CJ, Reed MP. Airbag-induced fracture in a patient with osteoporosis. J Trauma. 1998;45(2):416-8.

[16] Lundy DW, Lourie GM. Two open forearm fractures after airbag deployment during low speed accidents. Clin Orthop. 1998;(351):191-5.

[17] McGwin G, Metzger J, Rue LW. The influence of side airbags on the risk of head and thoracic injury after motor vehicle collisions. J Trauma. 2004;56(3):512-6.

[18] Duma SM, Boggess BM, Crandall JR, Hurwitz SR, Seki K, Aoki T. Upper extremity interaction with a deploying side airbag: a characterization of elbow joint loading. Accid Anal Prev. 2003;35(3):417-25.

[19] Griffin R, Huisingh C, McGwin G, Reiff D. Association between side-impact airbag deployment and risk of injury: A matched cohort study using the CIREN and the NASS-CDS. J Trauma Acute Care Surg. 2012;73(4):914-8.