Evaluation of external sources of bladder injury following motor vehicle collisions

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Abstract

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Introduction/Objective

Motor vehicle collisions (MVC) are the leading cause of bladder injury in the United States. The National Automotive Sampling System-Crashworthiness Data System (NASS-CDS), a national population based sample, was used to investigate sources of bladder injury following frontal impact and side impact MVC.

Methods

We queried the NASS-CDS database from 2000-2008. Possible predictors included primary direction of force, general area of damage, speed change at impact (delta v), seatbelt use, airbag deployment, sex, injury severity score, pelvic Abbreviated Injury Scale (AIS) and specific interior compartment sources. Backward stepwise logistic regression was utilized to assess important predictor variables as a cause of bladder injury following MVC. Final analyses accounted for sampling weights so that odd ratio estimates would be generalizable to the population. Age < 16, rollover MVCs, ejected passengers, and backseat occupants were excluded from analysis.

Results

After applying sampling weights, 39,721,871 occupants were available for analysis in NASS-CDS. Of these, 5,780 occupants had a bladder injury that allowed determination of frontal or side impact MVC. More injuries were due to front impact (3,155) than side impact (2,625). Following front impact MVC, pelvic AIS (OR 8.52, 95%CI 4.21,17.25) and the restraint system (OR 7.64, 95%CI 1.17,49.89) were significant predictor variables for bladder injury. Among left (driver) side MVCs, pelvic AIS (OR 5.40, 95%CI 3.84,7.59), ISS (1.06, 95%CI 1.04,1.08) and the restraint system (4.11, 95%CI 1.50,11.25) were the only variables that significantly predicted bladder injury. Among right side MVCs, the pelvic AIS (OR 8.72, 95%CI 5.98,12.70) was the only variable that statistically predicted a bladder injury.

Conclusion

Exploratory analysis reveals there to be significant differences in the internal design elements of automobiles that are associated with bladder injury after MVC. These sources of injury differ depending on front or side impact.

Introduction:

Motor vehicle collisions (MVC) are the leading cause of bladder injury in the United States. In 2009, approximately 5.5 million police-reported MVCs occurred resulting in 1.5 million injuries[1]. Additionally, World Health Organization data demonstrates that over 1.2 million people die annually worldwide, with an additional 20-50 million people suffering non-fatal injuries. Thus, by 2030, road traffic crashes will be the fifth leading cause of death with more than 2.4 million fatalities annually[2].

Preventing blunt traumatic injury due to MVCs and minimizing the morbidity of injuries when they occur requires coordinated efforts in diagnosis, injury management, and knowledge of collision kinematics. Prior studies have shown that primary direction of force (PDOF), change in velocity (delta v), and restraint use are important factors associated with both MVC morbidity and mortality[3,4], while side impact collisions are more lethal than frontal impact crashes[5-7]. Airbags are designed to protect the occupant from cranial, cervical, and thoracic injury. We have previously reported that airbags reduce the rate of renal injury during MVCs[8,9]. To our knowledge, sources of bladder injury following MVC have not been reported.

The National Automotive Sampling System-Crashworthiness Data System (NASS-CDS) was analyzed to identify vehicle kinematic collision patterns, personal injury demographics, and interior components that are associated with bladder injury following MVC. We hypothesized that specific interior compartment sources and a lower pelvic Abbreviated Injury Scale (AIS) would be protective against bladder injury following frontal and side impact MVCs.

Methods:

Data Source

The NASS-CDS is a nationwide crash data collection program sponsored by the United States Department of Transportation's National Highway Traffic Safety Administration (NHTSA). The data within NASS-CDS is a probability sample, ensuring that all injured persons have an equal opportunity of being included in the sample. A NASS-CDS crash must fulfill the following requirements: police report, a harmful event (property damage and/or personal injury) resulting from a crash, and at least one towed passenger car, light truck or van in transport on a traffic way. Currently, data are collected across the United States at 27 geographic sites called Primary Sampling Units. Approximately 5000 crashes are evaluated annually, with oversampling of crashes resulting in fatalities and serious injuries. These data can be weighted to represent all police-reported, tow-away crashes in the US. Injuries to all vehicle occupants are documented and scored using the AIS staging system[10].

Subjects and Method of Classification

Front seat driver and front seat occupants adjacent to the door panel that were > 16 years old and sustained bladder injury following front or side impact MVC in the NASS-CDS were analyzed. The following were excluded: age < 16, back seat occupants, front seat occupants that were not seated adjacent to the door panel, ejected front seat passengers (driver or occupant next to door panel), automobile rollovers, and rear impact MVCs.

The NASS-CDS database was queried from 2000-2008. Data were collected on all automobile drivers and front seat occupants who sustained a bladder injury. Bladder injuries were classified using AIS-90 definitions. Predictor variables for bladder injury following MVC were pre-defined and then modeled for significant variables via backward stepwise modeling. Pre-defined predictor variables included the following: primary direction of force (PDOF), general area of damage, speed change at impact (delta v), seatbelt use, airbag deployment (front and left side impact only), sex, pelvic AIS, injury severity score (ISS), and specific interior compartment sources. Interior compartment sources included the following: center console, door panel, armrest, steering wheel, instrument panel, b pillar, car door, and restraint system.

Crash severity was measured by the delta v sustained from the vehicle during the crash event. Delta v is calculated with a crash analysis program (Win SMASH, version 1.2.1, US Department of Transportation). Collisions with a PDOF between 2 and 4 o'clock (45-135°) or 8 and 10 o'clock (225-315°) were defined as right and left side impact collisions, respectively. Front impact collisions were defined as primary impact between 11 and 1 o'clock (315-360° or 0-45°). In order to more accurately assess front and side impact MVCs, NASS-CDS variables 'primary PDOF' and general area of damage (front, right, or left side) were combined as one variable.

Sources of possible bladder injury related to the vehicle's interior compartment source or occupant demographics were defined using dichotomous, ordinal, and continuous variables. Dichotomous variables related to the presence or absence of damage included: center console, door panel, armrest, steering wheel, instrument panel, and restraint system. Other dichotomous variables included: airbag deployment, seatbelt use, delta v (1-20, 21+), and occupant position (driver or front seat occupant). Ordinal variables included: degree of door panel intrusion (0-2.9, 3-7.9, 8-14.9, 15-29.9 30-45.9, 46-60.9, 61+ cm), ISS (0-75), and pelvic AIS score (1-5). Continuous variables included: age, height, and weight.

Statistical Analysis

Logistic regression was used to estimate odds ratios (OR) and 95% confidence intervals (CI) for the association between bladder injury following MVC and specific predictor variables. NASS-CDS is geographically divided into 12 strata and 27 probability sampling units that were utilized in all analyses. Backward stepwise multivariate analysis of pre-defined predictor variables was performed using Akaike Information Criterion. Important predictor variables were utilized in the final logistic regression model. The data in NASS is obtained from a probability sample of police-reported traffic crashes, thus national estimates can be derived. In order to provide estimates of national crash characteristics, sampling weights were computed. Final statistical analyses accounted for these sampling weights so that OR estimations would be more generalizable to the US population. Statistical analyses were performed using STATA® v11.2 (College Station, TX).

This study received a Certificate of Exemption from the University of Washington Human Subjects Institutional Review Board (UW HSD 00000241).

Results:

Based on the sampling weights, 39,721,871 persons were available for analysis in NASS-CDS (Table 1). Of the 5,780 persons who sustained a bladder injury following MVC: 3,155 were frontal impact, 1,640 were left side impact, and 985 were right side impact (Table 1, 2). Mean age of the cohort was 35.5, and the majority of injured persons were male (55.4%). Frontal impact (54.6%) MVCs were more common, while the left side was more commonly impacted than the right side (62.4% vs. 37.5%, respectively). In the setting of a bladder injury, a pelvic fracture occurred in 54.9% of injured front seat persons. Conversely, a bladder injury occurred in only 5.7% of all pelvic fractures.

Following backward stepwise logistic regression, important predictor variables specific for front, left side, and right side MVCs were determined (Table 3). Based upon these important predictor variables, the estimated OR and 95% CI of a bladder injury following front and side impact MVC was determined (Tables 3, 4). The variable *center console* perfectly predicted for bladder injury following front impact MVC. This is termed separation. As such, the variable was removed from backward stepwise calculations. When holding the other predictor variables fixed for front impact MVCs, pelvic AIS (OR 8.52, 95%CI 4.21,17.25) and restraint system (OR 7.64, 95%CI 11.7,49.89) were the only predictor variables that significantly predicted for a bladder injury. *Delta V* was removed from the left and right side logistic regression models due to separation during backward stepwise calculations. Among left (driver) side MVCs, pelvic AIS (OR 5.40, 95%CI 3.84,7.59), ISS (1.06, 95%CI 1.04,1.08), and the restraint system (4.11, 95%CI 1.50,11.25) were the only predictor variables that significantly predicted bladder injury. Among right side MVCs, the pelvic AIS (OR 8.72, 95%CI 5.98,12.70) was the only predictor variable that statistically predicted for a bladder injury.

Discussion:

To our knowledge, examination of sources of bladder injury following MVC has not been studied. The NASS-CDS data set was utilized to assess important variables that predicted for bladder injury following front and side impact MVCs. The data was weighted so that final OR estimates and 95% CI's would be generalizable to the US population. Among frontal impact MVC's, the pelvic AIS and automobile restraint system were significant predictors for a bladder injury. Following left (driver) side MVCs, the pelvic AIS, ISS and restraint system were significant predictor variables, while only the pelvic AIS was a significant predictor variable for bladder injury following right side MVCs.

Given the close association between pelvic fracture and bladder injury following blunt force trauma[11,12], the significant association between pelvic AIS and bladder injury following front, left, and right side MVC was not surprising. This is expected because major pelvic force is required to damage an organ protected by the bony pelvis. Following frontal MVC, bladder injury secondary to the restraint system is also plausible, as compression from the lap belt can provide external pressure on a full urinary bladder resulting in an intraperitoneal bladder injury. Unfortunately, bladder AIS scores do not distinguish between extra- and intraperitoneal bladder injuries, preventing stratification of bladder injury by type following frontal MVC. ISS as a predictor for bladder injury was only significant for left side MVC's; however, the association is strong considering that the odds of a bladder injury increases by 1.06 for each one-point increase in ISS (mean ISS of weighted sample = 1.44). Our hypothesis was that degree of door intrusion would predict for bladder injury following side impact MVC. While the degree of door intrusion was an important predictor in backward stepwise modeling for driver side MVC, the degree of door intrusion only showed a trend toward significance (OR 1.33, 95%CI 0.91,1.94).

Delta v is the change in automobile velocity associated with the primary direction of force of the crash event. It is an important predictor of serious injury following MVC[13]. Unfortunately, *delta v* could not be fit into the right or left impact logistic regression models due to statistical separation. While all other variables had missing data that was <15%, the percent missing variables for delta v was burdensome (47%). Increased data capture of delta v could aid in avoiding this statistical phenomenon. While imputation of delta v would help to account for the high number of missing variables, it would not be a definitive treatment to remedy statistical separation. Statistical separation was also noted for the predictor variable *center console* among front impact MVCs. The percent missing data for center console was much less than for delta v (< 10%); however, gathering more data could potentially resolve this issue.

Separation is associated with models for dichotomous or categorical data that utilize logistic regression. Both of the variables *delta v* and *center console* are categorical variables. To reduce statistical separation, the predictor variables can be removed from the model, more data can be gathered, or penalized likelihood logistic regression[14] can be utilized. Unfortunately, weighted samples and stepwise modeling cannot be applied to penalized likelihood logistic regression models. As such, the affected predictor variables were removed from the respective logistic regression models.

There are several limitations to this study that must be considered before drawing conclusions. First, this study is an exploratory analysis rather than a confirmatory analysis. Outcomes of this study should be used only to guide future research pertaining to bladder injury following MVC. Second, the data for bladder injury was limited; therefore, backward stepwise modeling for final OR estimates was performed in lieu of a split sampling approach (fitting a model to a 'training dataset and using the model to score a 'validation' dataset). Another potential limitation is while the delta v measurements are the industry standard, there are certain assumptions that may lead to an underestimation of delta v by the WinSMASH program[15].

There are also limitations related to the bladder injury itself. The inability to individually assign a particular bladder injury with a source from the respective automobile crash is an unfortunate limitation. Further, there are limitations in the ability to report the degree and type of bladder injury. For example, the bladder AIS does not allow separate identification of extra- and intraperitoneal bladder injury (i.e., AIS 540624.3 = extraperitoneal wall > 2 cm or intraperitoneal wall ≤ 2 cm). Additionally, the association between front/side impact MVC and severity of bladder injury was not assessed. We hypothesized that the majority of surgeons do not rigidly adhere to bladder staging systems, as knowledge of the length of bladder injury is required. Not all bladder injuries require surgical intervention that would allow accurate determination of the length of bladder defect. Further, radiographic diagnosis (in the absence of surgery) of centimeter length of bladder lacerations is also inaccurate.

Despite the limitations of our exploratory analysis, the NASS-CDS data suggests that the restraint system (front, left side), severity of injury (left side), and concomitant pelvic fracture (front, left side, right side) are associated with an increased risk of bladder injury. Further study is needed in the area of abdominal solid organ injury related to automobile crashes to solidify these relationships. Further investigation is warranted with regard to vehicle compartment and safety device design in hopes of minimizing the physical, emotional, and financial strains traumatic MVCs place on society.

Table 1. Demographics of injured occupants.[α]

	Non-weighted	Weighted
Number	94438	39721871
Occupant seat position		
Driver	65625	34776473
Passenger	17568	7923527
Female sex	41447	17700000
Age[γ]	36.19	35.45
Height (cm)[γ]	171.14	171.33
Weight (kg)[γ]	77.04	76.11
ISS[γ]	5.02	1.44
Seatbelt use	61086	28700000
Pelvic AIS		
0	91345	39505931
1	51	2610
2	1457	112100
3	1462	95817
4	96	4211
5	27	1204
Total bladder injuries[δ]	130	5780
Front impact	47	3155
Side impact	83	2625
Right side	26	1640
Left side	57	985
Total pelvic fractures	2813	198121
Bladder/pelvic injury	7.20%	5.70%

[α]Only driver and far side front seat occupant
[β]Based on non-weighted sample
[γ]Mean
[δ]Based upon combined 'pdof' and general area of damage variables

Table 2. Demographics of MVC and number of injuries attributed to specific interior compartment source.

	Non-weighted	Weighted
Total frontal impact MVC	39494	15893549
Total side impact MVC	12878	4661809
Right side	6155	2536427
Left side	6723	2125382
Delta V$^{\alpha}$	25.3	20.02
Airbag available	58967	24900000
Airbag deploy	29159	8956060
Door	6539	1420366
Door panel intrusion	13950	5079161
< 3 cm	80488	36585523
≥ 3 cm, <8 cm	6772	1890837
≥ 8 cm, < 15 cm	3973	758426
≥ 15 cm, <30 cm	2344	3444363
≥ 30 cm, < 46 cm	607	85029
≥ 46 cm, < 61 cm	143	47666
≥ 61 cm	111	9954
Center console	571	86936
Occupant seat position		
Driver	65625	34776473
Passenger	17568	7923527
Armrest	3039	597076
Steering wheel	9740	2278537
Instrument panel	12386	2692922
Restraint system	17539	4891354
B Pillar	2637	452250

$^{\alpha}$Mean

Table 3. Logistic regression of important predictor variables as a cause of bladder injury following front impact MVC.

Predictor Variable[α]	**OR (95%CI)**
Pelvic AIS	8.52 (4.21,17.25)
ISS	1.04 (0.99,1.08)
Weight	0.95 (0.87,1.04)
Restraint system	7.64 (1.17,49.89)
Seat position	0.11 (0.01,0.95)

[α]Important predictor variables following backward stepwise logistic regression. Center console was dropped from model due to statistical separation

Table 4. Logistic regression of important predictor variables as a cause of bladder injury following left and right side impact MVC.

LEFT SIDE	
Predictor Variable[α]	**OR (95%CI)**
Pelvic AIS	5.40 (3.84,7.59)
ISS	1.06 (1.04,1.08)
Age	0.98 (0.95,1.01)
Height	1.03 (0.95,1.12)
Door panel intrusion	1.33 (0.91,1.94)
Armrest	2.75 (0.95,7.93)
Restraint system	4.11 (1.50,11.25)
Airbag deployment	0.41 (0.15,1.11)
Center console	3.95 (0.77,20.35)
RIGHT SIDE	
Predictor Variable[α]	**OR (95%CI)**
Pelvic AIS	8.72 (5.98,12.70)

[α]Important predictor variables following backward stepwise logistic regression. Δv was dropped from left and right side due to statistical separation.

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