Motor Vehicle Mismatch-Related Spinal Injury

Jason D. Cobb, BS⁴; Paul A. MacLennan, PhD³; Gerald McGwin Jr., MS, PhD¹⁻³; Jesse S. Metzger, MPH^{2,3}; Loring W. Rue III, MD³

¹Department of Ophthalmology, School of Medicine, University of Alabama at Birmingham, Birmingham, Alabama; ²Department of Epidemiology and International Health, School of Public Health, University of Alabama at Birmingham, Birmingham, Alabama; ³Section of Trauma, Burns, and Surgical Critical Care, Division of General Surgery, Department of Surgery, University of Alabama at Birmingham, Birmingham, Alabama; ⁴University of Alabama School of Medicine, Birmingham, Alabama

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Abstract

Background/Objective: Motor vehicle collision (MVC)-related spinal cord injury (SCI) is the most prevalent etiology of SCI. Few studies have defined SCI risk factors. Vehicle mismatch occurs in 2-vehicle MVCs in which there are significant differences in vehicle weight, stiffness, and height. This study examined SCI risk and vehicle mismatch.

Methods: A matched case-control study using the 1995 to 2003 National Automotive Sampling System (NASS). Study subjects were identified from 2-vehicle MVCs. Cases were occupants who had suffered a cervical, thoracic, or lumbar SCI. Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated.

Results: There were 101,682 cases of SCI matched to 805,091 controls. Occupants of passenger vehicles involved in MVCs with a light truck or van (LTV) were at increased risk for SCI (OR = 1.87, 95% CI = 1.07–3.24) and this risk was greatest for thoracic SCI (OR = 5.09, 95% CI = 2.33–11.13). In addition, occupants of LTVs involved in MVCs with passenger vehicles were at significant increased risk for cervical (OR = 1.39) and lumbar (OR = 2.65) SCI; and occupants of LTVs involved in MVCs with other LTVs were at increased risk of any SCI (OR = 2.02, 95% CI = 1.52–2.69). For these subjects, significant increased risks were seen for all spine regions: cervical (OR = 1.41), thoracic (OR = 2.86), and lumbar (OR = 2.38).

Conclusions: The results of this study suggest that occupants of passenger vehicles are at increased SCI risk when involved in 2-vehicle MVCs with LTVs; and that occupants of LTVs are at increased SCI risk, regardless.

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Key Words: Risk factors; Spinal cord injuries; Motor vehicle crashes; Vehicle type; Epidemiology

INTRODUCTION

The incidence of spinal cord injury (SCI) in the United States (US) is estimated to be approximately 40 cases per million population, or approximately 11,000 new cases per year. The economic burden of SCI is large. Depending on case severity, first-year health and living expenses have been estimated to range from \$250,000 to \$683,000, and with increased survivability, average lifetime health costs easily approach or surpass \$1,000,000 (1). The largest proportion of SCI (38.5%) is related to motor vehicle collisions (MVC). Further, it has been suggested that with the increasing numbers on US highways of light

truck and vans (LTVs), defined as light trucks, vans, and sports utility vehicles (SUVs), 2-vehicle collisions where there is vehicle mismatch (also known as vehicle incompatibility) between the target vehicle and the crash-partner vehicle in weight, stiffness, and height result in increased mortality risk among passenger vehicles (2). In 1998, the market share of LTVs among all new cars was approximately 42% (3). Potentially, vehicle mismatch may be an important risk factor for MVC-related SCI.

To date, 3 studies have examined specific risk factors for MVC-related SCI (4–6). However, these studies were limited by small sample sizes and resulted in imprecise measures of association. A recent Australian study on SCI did not present specific collision characteristics (7). All of these studies failed to examine the independent effect of mismatch in 2-vehicle collisions, relating to both motor vehicle type and weight, on specific location of SCI. However, several studies have evaluated the independent

Please address correspondence to Paul MacLennan, PhD, Department of Surgery, School of Medicine, University of Alabama at Birmingham, 115 Kracke Building, 1922 7th Avenue South, Birmingham, AL 35294; phone: 205.934.2304 (e-mail: pmac@uab.edu).

effects of varying vehicle size and mass on MVC-related injury or fatality risks (2,8–10). A recent case series described injuries experienced by 41 occupants of passenger vehicles and LTVs involved in 2-vehicle frontal and side impact MVCs (11). For target passenger vehicle occupants ($N=35$) involved in side and frontal impact MVCs, 3 cases of vertebral fracture (1 with SCI), and 3 cases of subluxation (C1-C2 and 2 atlanto-occipital) were reported. For target LTV occupants ($N=6$) involved in frontal impact MVCs, there were 2 vertebral compression fractures reported for 2 occupants of the same vehicle (11). Thus, there is anecdotal evidence for a relationship between vehicle mismatch, but the relationship has not been quantified.

This study's objective is to examine the relationship between MVC-related SCI and vehicle mismatch.

MATERIALS AND METHODS

Data Source

The data used in this study were obtained from the National Automotive Sampling System (NASS) Crashworthiness Data System (CDS). The National Center for Statistics and Analysis, a component of the National Highway Traffic Safety Administration, operates the NASS-CDS. The CDS data files represent a sample of light passenger vehicles (passenger cars, light trucks, vans, and SUVs) involved in police-reported tow-away crashes (12). The CDS records focus on MVCs that resulted in death, injury, or major property damage and collects data on approximately 5,000 actual motor vehicle traffic crashes annually. The crashes selected in the CDS are a probability sample of all crashes occurring in the survey year, the data from these crashes are weighted to produce estimates of the injuries found in all collisions in the United States for a given year. The NASS assigns each crash a numeric sample weight based on the inverse probability of the crash being selected for the sample, which must be accounted for to derive national estimates. The CDS investigators rely on 3 sources of data for each MVC studied: official documents, physical evidence, and interviews with individuals associated with the traffic crashes. Cooperation with police agencies and hospitals provides copies or transcripts of official records. Tow yards, police impound yards, and crash-involved parties are contacted to obtain permission to inspect vehicles to determine vehicle damage and crash dynamics. Vehicle occupants and medical personnel are contacted to obtain information about occupant characteristics and crash circumstances. Trained professional crash research teams collect data by conducting crash investigations following established procedures and protocols.

Study Design and Subject Selection

A matched case-control study design was used to evaluate the association between the risk of SCI and selected occupant, vehicular, and collision characteristics. The study population was restricted to subjects who were occupants in vehicles that struck or were struck by

another vehicle. Cases were identified based on Abbreviated Injury Scale (AIS) information contained within NASS-CDS occupant injury records. Specifically, cases had to have had a cervical, thoracic, or lumbar spinal injury of AIS severity score of 2 (moderate) or greater. Introduced in 1971, the AIS is an anatomical scoring system used to classify injuries by severity using an ordinal scale from 1 (minor injury) through 6 (fatal injury). AIS values of 3, 4, and 5 correspond to injuries described as serious, severe, and critical, respectively (13). AIS values do not represent the combined effects of multiple injuries. Injury information is obtained from autopsy records with or without medical records; hospital discharge summaries; emergency room records; or private physician, walk-in, or emergency clinic records. Information is also obtained from lay coroner reports and interviews with emergency medical services personnel, police, or occupants. Injuries were classified according to the AIS, 1990 Revision (13). For the purpose of this study, the regions of injury examined were confined to cervical, thoracic, and lumbar spinal cord segments.

Ten controls were selected for each case among study population occupants who did not sustain a SCI and matched on sample weight ($\pm 20\%$) and Injury Severity Score (ISS; ± 5). The ISS, which has a range of values from 0 (no injury) to 75 (most severe), is calculated by squaring the highest AIS score from the 3 most severely affected body regions, and offers an overall score for patients with multiple injuries (14). Because NASS-CDS is a multistage probability sample whose estimates are used to generate national estimates, it was necessary to match on sampling weight for correct statistical analysis. For example, if a case subject's sample weight was equal to 100, a matched control would have to have a sample weight in the range of 80 to 120. In addition, ISS was matched to ensure that cases and controls had sustained injuries of similar severity. Thus, any observed associations would reflect risk factors for SCI and not risk factors for serious MVC-related injuries.

Variable Definition

Information on occupant (age, gender, restraint use, seating position, seat track position), vehicle (body type, model year, curb weight), and collision (collision type, rollover, maximum crush, change in velocity at the time of collision [ΔV], compartmental intrusion) characteristics was also obtained from the 1995 through 2003 NASS data sets. Target and crash-partner vehicle body types were classified into 2 categories: passenger and LTV. Passenger cars include automobiles and automobile derivatives (ie, passenger vehicles that have been modified to perform a cargo-related task); LTVs include compact and large utility vehicles, van-based light trucks, and light conventional and other light trucks. Target and crash-partner vehicles were also classified according to curb weight (ie, small, $< 2,500$ lb; mid-size, $2,500$ – $3,000$ lb; or large, $> 3,000$ lb). Subjects' MVCs were also grouped

according to weight differences between their vehicle (target vehicle) and the striking vehicle (crash partner). Compared with subjects' target vehicles, crash-partner vehicles were classified as having similar curb weight (± 250 lb), lighter curb weight (> -250 lb) or greater curb weight ($> +250$ lb). The type of collision was classified according to the primary area of vehicular damage (front, rear, and side); vehicular rollover was also examined. Compartmental intrusion was defined as frontal and lateral and further subdivided (< 15 cm and ≥ 15 cm). Mean ΔV (ie, vector velocity change during the collision phase of the crash) and maximum crush were also 2 independent variables examined.

Statistical Analysis

All analysis accounted for the probability sampling used by CDS. Differences between cases and controls with

respect to occupant, vehicle, and collision characteristics were assessed by t tests and χ^2 tests. Overall, and for each spinal region injury, conditional logistic regression was used to compute crude odds ratios (ORs) and their 95% confidence intervals (CIs) for the associations between vehicle mismatch (vehicle type and curb-weight differences) between subjects' vehicles and striking vehicles. SUDAAN 8.0.0 (Research Triangle Institute, Research Triangle Park, NC) was used for all statistical analyses to account for multistage sampling in the CDS.

RESULTS

A total of 101,682 (weighted) cases of SCI were identified and matched to 805,091 (weighted) non-SCI controls. The planned 1:10 ratio was not possible because of the difficulty matching on the weighting variable. Table 1

Table 1. Occupant, Vehicle, and Collision Characteristics Among Cases and Controls

Characteristics	Cases	Controls	P value
Subjects (N)			
Unweighted	1,027	9,496	...
Weighted	101,682	805,091	...
Age, mean (SE)	48.2 y (4.0)	38.8 y (0.6)	0.0349
Male	54.0%	49.7%	0.5122
Seatbelt use	51.7%	62.0%	0.1650
Airbag deployed	24.7%	21.9%	0.4118
Vehicle body type	...	...	0.5231
Passenger	71.6%	75.2%	...
SUV	15.4%	13.9%	...
Truck	13.0%	10.9%	...
Vehicle year, mean (SE)	1991 (0.8)	1990 (0.2)	0.9169
Vehicle curb weight	...	...	0.0977
Small ($< 2,500$ lb)	20.3%	26.5%	...
Mid-size (2,500–3,000 lb)	19.9%	32.8%	...
Large ($> 3,000$ lb)	59.7%	40.7%	...
Seating position	...	...	0.4667
Driver	72.1%	70.6%	...
Front seat passenger	18.4%	22.4%	...
Rear passenger (driver side)	2.5%	3.1%	...
Rear passenger (passenger side)	7.0%	3.9%	...
Seat track position	...	...	0.1511
Forward	16.4%	23.6%	...
Middle/back	83.6%	76.4%	...
Collision type	...	...	0.1260
Frontal	52.4%	55.7%	...
Lateral	38.3%	39.3%	...
Rear end	9.3%	5.0%	...
Rollover	10.6%	6.0%	0.2645
ΔV , mean (SE)	34.2 km/h (1.7)	33.4 km/h (0.7)	0.5853
Maximum crush, mean (SE)	48.4 cm (3.7)	48.2 cm (1.8)	0.9586
Frontal intrusion > 15 cm	11.6%	13.3%	0.4594
Lateral intrusion > 15 cm	16.9%	18.6%	0.7127

Table 2. Odds Ratios and 95% CIs for the Association Between Spinal Injury Risk and Differences in Crash-Partner and Target Vehicle Curb Weight

Injury Location	Crash-Partner Vehicle Compared With Target Vehicle Weight		
	Similar	Lighter	Heavier
Any spinal injury	1.00 (reference)	1.10 (0.73–1.66)	1.12 (0.54–2.32)
Cervical	1.00 (reference)	1.13 (0.79–1.61)	0.90 (0.55–1.48)
Thoracic	1.00 (reference)	1.11 (0.35–3.53)	2.47 (0.54–11.37)
Lumbar	1.00 (reference)	1.05 (0.57–1.92)	0.82 (0.48–1.40)

presents occupant, vehicle, and collision characteristics among cases and controls. Cases were significantly older than controls (48.2 years vs 38.8 years). Cases and controls did not differ significantly ($P < 0.05$) in any of the other characteristics considered, but there were some interesting differences (Table 1). There were more male cases (54.0%) than male controls (49.7%). Fewer cases than controls were restrained by seatbelt, but slightly more cases had an airbag deployed. Additionally, a greater proportion of control vehicles were small (26.5%) and mid-size curb weight (32.8%), but a greater proportion of case vehicles were large curb weight (59.7%). A greater number of cases were involved in rollovers (10.6%). Generally, measures of MVC severity (ΔV , maximum crush, and frontal intrusion) were similar.

Table 2 presents ORs for the association between SCI risk and differences in target and crash-partner vehicle weight. Overall, MVC occupants of target vehicles involved in 2-vehicle collisions with crash-partner vehicles that were lighter had no increased risk of any SCI (OR = 1.10, 95% CI = 0.73–1.66). In addition, no significant association was observed when the crash-partner vehicle was heavier (OR = 1.12, 95% CI = 0.54–2.32). However, associations of varying magnitude were found by region of SCI.

For cervical SCI, similar null associations were seen for occupants of target vehicles in MVCs with crash-partner vehicles of lighter and heavier weight (OR = 1.13, 95% CI = 0.79–1.61; OR = 0.90, 95% CI = 0.55–1.48, respectively). For thoracic SCI, MVCs with lighter crash-partner vehicles were near null (OR = 1.11, 95% CI = 0.35–3.53), but MVCs with heavier crash-partner vehicles had a large but nonsignificant increased risk (OR = 2.47, 95% CI = 0.54–11.37). For lumbar SCI, MVCs

with either lighter or heavier crash-partner vehicles had no increased risk (OR = 1.05, 95% CI = 0.57–1.92; OR = 0.82, 95% CI = 0.45–1.40, respectively).

Table 3 displays crude ORs for the association between regional spinal injury risk and combinations of target and crash-partner vehicle types. The referent was occupants of passenger vehicle involved in MVCs with other passenger vehicles. No significant association was observed for cervical SCI when target passenger vehicles were involved in MVCs with crash-partner LTVs (OR = 0.95, 95% CI = 0.78–1.16). However, for this same target–crash-partner combination, there were increased risks for thoracic (OR = 5.09, 95% CI = 2.33–11.13), lumbar (OR = 1.47, 95% CI = 0.96–2.24), and SCI overall (OR = 1.87, 95% CI = 1.07–3.24). Interestingly, LTV target vehicle occupants involved in MVCs with passenger vehicle crash partners were at slight increased risk of cervical SCI (OR = 1.39, 95% CI = 1.02–1.91) and for lumbar SCI (OR = 2.65, 95% CI = 1.02–6.89), but no significant increased risk for SCI injury overall.

Finally, LTV target vehicle occupants involved in MVCs with LTV crash partners were at significant increased risk for cervical injury (OR = 1.41, 95% CI = 1.09–1.82), thoracic injury (OR = 2.86, 95% CI = 1.11–7.37), lumbar injury (OR = 2.38, 95% CI = 1.47–3.87), and overall SCI (OR = 2.02, 95% CI = 1.52–2.69).

DISCUSSION

MVCs are the leading cause of SCI in the US, accounting for approximately 38.5% of all SCI cases (1). This study represents the only investigation of vehicular compatibility in 2-vehicle MVCs as a potential risk factor for SCI and by spinal region. With the growing numbers of SUVs and

Table 3. Crude ORs and 95% CIs for Target Vehicle Occupants for the Association Between Regional and Overall Spinal Injury Risk and Combinations of Target and Crash-Partner Vehicle Types

Target Vehicle	Crash-Partner Vehicle	Cervical	Thoracic	Lumbar	Spine
Passenger	Passenger	1.0 (reference)	1.0 (reference)	1.0 (reference)	1.0 (reference)
	LTV	0.95 (0.78–1.16)	5.09 (2.33–11.13)	1.47 (0.96–2.24)	1.87 (1.07–3.24)
LTV	Passenger	1.39 (1.02–1.91)	0.74 (0.12–4.42)	2.65 (1.02–6.89)	1.46 (0.74–2.90)
	LTV	1.41 (1.09–1.82)	2.86 (1.11–7.37)	2.38 (1.47–3.87)	2.02 (1.52–2.69)

light trucks relative to passenger vehicles on the US highways, vehicle incompatibility may be an important risk factor for SCI. Because no previous research has examined vehicle mismatch as a potential risk factor for MVC-related spinal injury, the results of this study are difficult to compare with the existing literature.

Past studies have been descriptive, reporting on frequencies of vehicle type by SCI, but limited to relatively few cases (4,5). For example, O'Connor reported on 57 SCI cases consisting of 75.4% car occupants, 1.8% truck occupants, and 19.3% motorcyclists. That study reported that 61% of MVC-related SCI were cervical cord lesions (5). A similar descriptive study (N = 265 cases) examined specific patterns of SCI and reported that 28% of SCI cases were motor vehicle occupants. These occupants were found to most commonly suffer an incomplete cord injury affecting the cervical region of the spine, with resultant tetraplegia in 63% of cases, followed by lumbar and thoracic regions (7). Finally, a recent case series from one of the Crash Injury Research and Engineering Network centers indicated a relatively high prevalence (> 10%) of SCI among occupants involved in mismatch MVCs (11).

Other studies have examined risk factors for MVC-related SCI. A 1995 study by Thurman et al reported on 110 MVC-related SCI cases. Of these, 59% were injuries of the cervical cord segments, resulting in tetraplegia. That study reported that vehicle rollover was a major contributor to SCI, and that approximately 25% of injuries were related to alcohol usage (4). An earlier study of 30 MVC-related SCI cases sought to identify various risk factors of collision type, driver impairment, restraint use, and road conditions, but reported only significant risks for unrestrained occupants (6).

Unlike previous research of MVC-related risk factors for SCI, the current study included a relatively large number of study subjects. The case-control study design enabled estimation of risk estimates. Although the planned 1:10 case to control matching ratio was not reached, the inclusion of the NASS-CDS weighting variable in the matching scheme insured a balanced design. However, no ORs for vehicle curb-weight mismatch reached statistical significance. Although the study was based on a large public-use data file, there were still relatively few numbers of cases, which could explain why some of the associations failed to reach statistical significance.

CONCLUSION

For our analysis of mismatch based on vehicle curb weight, the referent group was occupants involved in MVCs between vehicles of similar weight. Results from the current study suggest that risks for any SCI and SCI by region are not greatly influenced by differences in vehicle weight. However, an exception was seen for the non-significant, approximately 2.5-fold increased risk of thoracic SCI among occupants involved in MVCs with heavier vehicles. Because our analysis was based on differences in curb weight rather than simple comparison

of light vs heavy vehicles, for instance, the impact of the subjects' own vehicle weight was removed and only the differences considered. However, it is likely that curb-weight differences play a greater role in SCI risk in lighter vehicles than in medium-sized vehicles. Because we were interested in weight differences regardless of combinations of vehicle curb weight (eg, light vs medium weight was equivalent to medium vs heavy), overall vehicle curb-weight differences did not show significant differences.

The examination of mismatch by vehicle type appeared to have results that are more meaningful. For this analysis, the referent group was passenger vehicle occupants involved in 2-vehicle MVCs with other passenger vehicles. Relative to this group, there was a significant increased risk of thoracic, lumbar, and overall SCI for occupants of passenger vehicles involved in MVCs with LTVs. In addition, occupants of LTVs involved in MVCs with passenger vehicles were at increased risk for cervical and lumbar SCI. Finally, occupants of LTVs involved in MVCs with other LTVs were at significant increased SCI risk overall and by injury location.

Previously, Acierno et al reported increased head and upper thorax injuries for passenger vehicle occupants in side impact MVCs with LTVs (11). A potential mechanism for this increase was thought to be from the LTV bumper making contact above the passenger vehicle side-door reinforcement. For frontal collisions, LTV bumper override was thought to be responsible for intrusion that caused increased risk of upper extremity and head injuries among passenger vehicle occupants. The greater height of LTVs over passenger vehicles likely plays a role in the observed increased risk of thoracic SCI among passenger vehicle occupants (15).

We also reported results of an increased risk of SCI among LTV occupants. Other investigations have established that relative to passenger vehicles, LTVs offer less self-protection to vehicle occupants (2,15). For example, LTVs have a much greater risk of rollover, and because of their truck classification, they are not required to have the same safety features as passenger vehicles. It is likely that these 2 factors played an important role in the increased SCI risk reported.

The current study's results should be considered for future design of trucks and SUVs to reduce injuries caused by vehicle mismatch.

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