Spinal Fracture-Dislocations and Spinal Cord Injuries in Motor Vehicle Crashes

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Purpose: This study estimated the annual count of spinal cord injuries (SCIs) in motor vehicles crashes by type and seat belt use using 18 years of NASS-CDS data. It determined the rate for SCI and fracture-dislocation of the spine.

Methods: 1994–2011 NASS-CDS was used to estimate the annual occurrence of spinal injuries in front seat occupants involved in motor vehicle crashes. Crashes were grouped by front, side, rear, and rollovers, and the effects of belt use were investigated. Light vehicles were included with model year 1994+. Spinal injuries were classified as minor (Abbreviated Injury Scale [AIS] 1), moderate (AIS 2), serious (AIS 3), fracture-dislocations, and SCI (AIS 4+). The annual count and rate for different types of spinal injury were estimated along with standard errors. The results were compared to estimates of head injuries. NASS-CDS electronic cases of SCIs in rear impacts were investigated.

Results: There were 5,592 ± 1,170 fracture-dislocations of the spine and 1,046 ± 193 AIS 4+ SCI per year in motor vehicle crashes. Most of the injuries occurred in rollovers and frontal crashes and the least occurred in rear impacts. The rate of SCI was 0.054 ± 0.010%. The highest rate was 0.220 ± 0.056% in rollover crashes and the lowest rate was 0.032 ± 0.009% in frontal crashes. The highest rate for spinal fracture-dislocation was 1.552 ± 0.455% in rollovers and the lowest was 0.065 ± 0.021% in rear impacts. The rate for SCI was 0.027 ± 0.005% in belted and 0.145 ± 0.028% in unbelted occupants giving 81% effectiveness of belt use in reducing SCI. The cervical spine was associated with 66.3 ± 11.3% of the AIS 4+ SCI with 30.5 ± 7.4% in the thoracic spine and 3.2 ± 1.3% in the lumbar spine. Severe head injuries occurred 13.3 times more often than SCIs.

Conclusions: Spinal cord injury occurred in one out of 1,860 front seat occupants in tow-away crashes. The rate was highest in rollover crashes and was reduced by seat belt use. Fracture-dislocation of the spine occurred about 5.3 times more often than SCIs and was also prevented by seat belt use.

Keywords: spinal cord injury, fracture, dislocations, seat belts, restraint effectiveness, motor vehicle crashes

Introduction

Injuries to the spinal cord can lead to paralysis and disability. They represent a major focus for traffic injury prevention. Cushman et al. (1991) analyzed field accidents and found that spinal cord injuries (SCIs) occurred most often in unrestrained drivers. Various factors affect the rate of spine injuries, including crash type (Bambach et al. 2013; Funk et al. 2012; Hu et al. 2007; Mandell et al. 2010), vehicle type (O’Connor 2002; O’Connor and Brown 2006), age (Bilston et al. 2011; Stein et al. 2011; Viano and Parenteau 2008b), gender (Harder et al. 1998; Kihlberg 1969; Parenteau et al. 2013; Viano 2003), and preexisting medical conditions (Santanello et al. 2001).

The long survival time and young age of many of those with SCIs in motor vehicle crashes add to the societal burden (DeVivo et al. 1990; Frankel et al. 1998). DeVivo (1997) determined the causes and costs of spinal cord injury in the United States. Burns et al. (2010) estimated the societal costs of rollover-related SCIs. Smith et al. (2005) studied motor vehicle injury of the spine and identified that 62% of SCI occurred to the cervical, 34% to the thoracic spine, and 4% to the lumbar spine. Though much is known about SCIs (Burney et al. 1993; Kraus et al. 1975; Viano 1992), a comprehensive study of SCIs in motor vehicle crashes is not available.

This study estimated the annual count of SCIs and fracture-dislocations of the spine in motor vehicle crashes by type, seat belt use, and severity (delta V) using 18 years of NASS-CDS data with a focus on seat belt effectiveness.

Methodology

NASS-CDS Data

NASS-CDS is a stratified sample of crashes that are prospectively selected for in-depth investigation. Most of the vehicles are towed from the scene because of damage. The data include information based on crash investigation teams, vehicle
registration, medical records, police report, and interviews. In this study, the data were extrapolated to national estimates using weighting factors provided by the NHTSA and standard errors (SE) were determined using the SAS procedure “SURVEYFREQ” accounting for PSU (psustrat) and weight factors (ratwgt).

NASS-CDS data for calendar years 1994–2011 were used to study spinal and head injuries in front seat occupants by crash type, belt use, and ejection. The study included all crashes and occupants aged 13–104 years old. Only light vehicles (passenger cars: body type: 1–9; SUVs: body type: 14–19; vans: body type: 20–29; and pickup trucks: body type: 30–33) with model year 1994+ were included. The data for calendar years 2009–2011 are representative of model year 2000+.

The annual count of AIS 3+, AIS 4+ spinal cord injury, and AIS 3 fracture-dislocation of the spine was determined. In addition, the distribution of spinal injuries to the cervical, thoracic, and lumbar spine was determined by crash type.

- **Crash types**: Crash types were defined as follows:
  - Front: Vehicles involved in frontal impacts where the greatest damage was to the front (GAD1 = F). Collisions in which a rollover occurred were excluded from the sample (Rollover ≤ 0).
  - Side: Vehicles involved in side impacts where the greatest damage was to the left or right side (GAD1 = L or R). Collisions in which a rollover occurred were excluded from the sample (Rollover ≤ 0).
  - Rear: Vehicles involved in rear impacts where the greatest damage was to the rear (GAD1 = B). Collisions in which a rollover occurred were excluded from the sample (Rollover ≤ 0).
  - Rollover: Vehicles involved in rollover were those with a rollover > 0.
  - Other: Vehicles involved in other impacts where the greatest damage was to the top or undercarriage (GAD1 = U or T). Collisions in which a rollover occurred were excluded from the sample (Rollover ≤ 0).
  - Unknown: Vehicles involved in impacts with unknown damage information.

- **Belt use**: Belt use was defined by the NASS-CDS investigator’s variables MANUSE and ABELTUSE. Unbelted was defined as MANUSE ≤ 1 and ABELTUSE < 1 or = 2. Belted was defined as MANUSE = 4.

- **Injury severity**: Injury severity of the occupant was assessed using the Maximum Abbreviated Injury Scale (MAIS) and the “TREATMNT” variable. MAIS represents the assessment of life-threatening injuries at the time of first medical evaluation and not long-term consequences. It ranges from MAIS 0 to 9, where MAIS 9 is an injury with unknown severity. MAIS 4–6 represents a severe to unsurvivable injury. Fatality was also used to determine whether the occupant died of injuries in the accident. To define a fatality (F), the following variables were used:
  - Treatment: TREATMNT = 1 because it means that the occupant was fatally injured and not transported to the hospital.
  - ISS 75: Injury Severity Score = 75 represents a fatality.
  - Police injury severity: INJSEV = 4 represents the fatality from police rating.

- Because fatalities can occur at any MAIS level, severely injured occupants were defined as those with MAIS 4–6 or fatality. The shorthand notation for this is MAIS 4+F.

- **Injuries were classified as**:
  - AIS 3+ spinal injuries were classified as serious (AIS 3–6) injuries to the spine (region90 = 6).
  - AIS 3 fracture-dislocations were classified as serious (AIS 3–6) injuries to the spine (region90 = 6 and struspec = 5). The AIS 3+ fracture-dislocations were all AIS 3.
  - AIS 4+ SCI was classified as severe (AIS 4–6) injuries to the spine (region90 = 6 and struspec = 6).
  - MAIS 4+ SCI represents the number of occupants with an AIS 4+ spinal cord injury.
  - AIS 3+ head injuries were classified as serious (AIS 3–6) injuries to the head (region90 = 1).
  - AIS 4+ head injuries were classified as severe (AIS 4–6) injuries to the head (region90 = 1).
  - MAIS 4+ head represents the number of occupants with an AIS 4+ head injury.

- **Spine injury location**: The location of spinal injury was identified as follows:
  - Cervical (region90 = 6 and struspec = 2)
  - Thoracic (region90 = 6 and struspec = 4)
  - Lumbar (region90 = 6 and struspec = 6)

- **Injury sources**: The contact sources of AIS 4+ spinal injuries were determined using the “injsou” variable. Because “injsou” coding may vary from year to year, the variations were taken into account for consistency of the injury source.

- **Weighted data**: National estimates for the number of occupants and injuries in each category were made using the ratio weight (ratwgt) variable in the NASS-CDS. All calculations were based on weighted values.

- **Rate analysis**: The rate of spinal injury was determined by dividing the number of injuries by the number of occupants with known injury status, MAIS 0–6 or F (MAIS 0+F). Occupants with unknown injury were removed from the exposure group used to determine rate. Because an occupant may experience more than one spinal injury of AIS 4+ severity, the rate for occupants with an AIS 4+ spine injury was also assessed.

- **Belt effectiveness**: Belt effectiveness was assessed by taking the difference of unbelted and belted injury rates and dividing by the unbelted injury rate.

- **NASS-CDS electronic cases**: All electronic cases of AIS 4+ SCI in rear impacts were downloaded from the NHTSA (http://www.nhtsa.dot.gov). The cases were analyzed for crash circumstances, occupant characteristics, and injury sources. Photographs of the vehicle and interior were reviewed. The tabulated data was grouped by belt use.

**Results**

Table 1 shows the annual count of motor vehicle injury by crash type based on 18 years of NASS-CDS data from 1994–2011 (Appendix 1 provides the unweighted counts; see online supplement). There were 2,043,753 front seat occupants exposed to tow-away crashes per year. There were 5,592 ± 1170 fracture-dislocations of the spine and 1,046 ± 193 SCIs...
The rate for an occupant to sustain a severe head injury (MAIS 4+ head) was 7.6 times higher than for an occupant to sustain a severe spinal cord injury (MAIS 4+ SCI). Severe head injuries occurred 13.2 times more often than SCIs. The rate for severe head injury (AIS 4+) was 0.712 ± 0.111%. The largest difference in relative rate was in side impacts, where severe head injuries occurred 21.7 times more often than SCIs. The relative rate was 9.1 for AIS 3+ head injuries compared to serious spinal injuries (AIS 3+) in side impacts. Overall, the relative rate was 4.5 for AIS 3+ head injury compared to AIS 3+ spinal injury.

Appendix 3 shows that the rate for SCI was 0.027 ± 0.005% in belted occupants and 0.145 ± 0.028% for unbelted occupants. Seat belts were 81% effective in preventing SCIs. They were 93% effective in preventing SCIs in side impacts and 89% effective in frontal crashes. Belts were least effective in preventing SCIs and fracture-dislocations in rear impacts at 76 and 31%, respectively.

Figure 1 compares the rate for SCIs and severe head injuries by lap–shoulder belt use and by crash type. For belted occupants, the relative rate of severe head injury compared to severe spine injury was 27.2 in side impact, 14.1 in frontal impact, 8.9 in rollover, and 3.7 in rear impact. For unbelted occupants, the relative rate was 18.5 in side impacts, 14.0 in rollovers, 12.9 in rear impacts, and 10.9 in frontal impacts.

Appendix 4 (see online supplement) summarizes the contact sources for AIS 4+ SCIs in belted and unbelted occupants by crash type. Overall, the leading source for injury in belted occupants was the roof, side rails, and header structures (21%). The source of injury varied by crash type, with the roof, side rails, and header structures contributing 56% of injury in rollovers and the seatbelt 54% of injury in rear impacts with belted occupants. For unbelted occupants, the ground was the leading injury source (25%) related to ejection and the roof, side rails, and header structures (18%) for the interior. The ground was the injury source for 31% of injuries in rear impacts. However, the result is based on one case with ejection. The case had the highest weighting factor, so the distribution of injury sources was skewed. In contrast,
the seatback was associated with 54% and the head restraints with 20% of SCIs in rear impacts with belt use. It was not clear whether the seatback was the front row or second-row seat. Individual cases with severe spinal injury in rear impacts were downloaded from the 1997–2011 electronic files at NHTSA to better understand the injury mechanism.

Figure 2 shows the proportion of spinal injuries by anatomical location in the spine and by the type of crash for SCIs. In rollovers, 69.5% of severe spinal injury was to the cervical spine. In rear impacts, there was an equal split between the cervical and thoracic spine.

Appendix 5 (see online supplement) provides the supporting data for Figure 2 and gives the annual distribution of injuries by location in the spine. Overall, 66.3 ± 11.0% of SCIs were in the cervical spine, with 30.5 ± 7.4% in the thoracic spine and only 3.2 ± 1.3% in the lumbar spine. In rear impacts, there were only 29 ± 17 SCIs in the cervical spine and 29 ± 12 in the thoracic spine annually.

Appendix 6 (see online supplement) summarizes the NASS-CDS electronic cases for belted and unbelted front occupants experiencing SCI in rear impacts. There were 11 belted occupants and 10 unbelted occupants with severe SCIs. One occupant (NASS-CDS 2010-11-240A) had two severe spine injuries, one in the thoracic spine and one in the cervical spine. One unbelted case was removed because it involved a driver who was parked on the side of the road and was in the cargo area when the vehicle was struck.

Appendix 6 also summarizes the key parameters in the cases, including injury source, intrusion, and the occurrence of severe head injury. Seatback was coded as the injury source for the SCI in 9 of the 21 cases reviewed. Out of the 21 cases, 13 cases had intrusion of the second-row seating area greater than 30 cm (12 in.) or coded as severe. Support of the seatback by intrusion was observed in 14 cases. Of the non-intrusion-related cases, two were low speed (<24 km/h or <15 mph). The cases involved drivers older than 70 years old.

For the belted occupants, the average age was 50 ± 20 years old. There were 7 thoracic and 5 cervical SCIs. One occupant had both a cervical and thoracic SCIs. The seatback was the source of injury and was either deformed forward or supported upright in many cases. For the 11 occupants, 6 also had AIS 4+ head injuries. There were 5 deaths. For the unbelted occupants, the average age was 42 ± 16 years old. There were 4 thoracic and 6 cervical SCIs. The seatback was often support by intrusion as the source of injury. There were 5 deaths.

Figure 3 shows the interior of 9 cases of SCI in belted occupants in rear impacts. The 3 cases at the top involved sufficient intrusion to support and deform the front seat forward. The 3 cases in the middle row involved sufficient intrusion to limit the amount of seatback rotation and the bottom 3 cases involved seatback rotation onto the cushion of the second row.

Figure 4 shows the interior of 6 of the cases of SCI in unbelted occupants. The top 3 photos involve intrusion or cab designs that supported the driver’s seatback, limiting rearward rotation in the crash. The two lower right cases involve seatback rotation. The bottom left case involved intrusion of the second row that supported the lower seatback. Severe head injuries were found in 11 of the 21 cases. This suggests an association between significant head loading and spinal injury in about half of the SCIs in rear impacts.

**Discussion**

This study found the rate for SCIs was 0.054 ± 0.010% in tow-away crashes. This means that one out of 1860 front seat occupants experienced SCIs in motor vehicle crashes. The count was 1046 ± 193 annually based on NASS-CDS data. In contrast, severe head injuries occurred 13.2 times more often. The rate for severe head injury (AIS 4+) was 0.712 ± 0.111%. Severely injured occupants were more likely to sustain more than one severe head injury than one SCI injury.
On average, an occupant with severe head injury sustained 1.83 AIS 4+ head injuries and occupants with severe injury sustained 1.05 AIS 4+ SCIs injuries. Because SCIs can involve severe head injury, the focus on prevention of head injuries is understandable. The NHTSA found that head impacts on the upper interior of vehicles were the leading cause of fatal head injury for nonejected occupants in all crashes (NHTSA 1992). They upgraded FMVSS 201 to include head impacts on the vehicle’s front, side, rear, and interior above the beltline. The testing uses an instrumented headform and limits the head injury criterion (HIC(d)) to 1000 for a 15 mph headform impact (NHTSA 1995). The revised FMVSS 201 had a 5-year phase-in from 1999 to 2003 model year (10% for MY 1999, 25% for MY 2000, 40% for MY 2001, 70% for MY 2002, 100% for MY 2003). The revision to FMVSS 201 caused upper-interior structures to be modified to lower impact forces and prevent head injuries. This has included energy-absorbing trim panels for the pillars, rails, and headers and the addition of inflatable curtains. Though these changes have reduced the rate of head injury in modern vehicles, the effect on spinal cord injury is unknown (McCarrt and Kyrchenko 2007).

A common cause for SCIs is flexion–compression of the neck due to head impact (Yoganandan et al. 1989). In rollovers, the continuing movement of the torso toward the head (torso augmentation) can lead to neck deformation and injury. Nightingale et al. (1996) conducted head–neck impacts and found that flexion–compression injuries occur early in head impacts with minimal head displacement. Traditionally, the mechanisms of injury to the cervical spine have been associated with flexion and extension motions of the head and neck. Eleven specimens were dropped in an inverted posture with the head and neck in an anatomically neutral position. The velocity of impact was 3.2 m/s (7.2 mph). Motion of the head did not correspond to the mechanism of the injury to the cervical spine.

Pintar et al. (1990) found that burst fractures occurred within 2.5 ms of head impact, whereas wedge fractures were progressive and took 4–5 ms. Pintar et al. (1995) tested 25 cadaver head–necks using a crown impact to the head at speeds of 2.5–8.0 m/s (5.6–17.9 mph). Mid-cervical column (C3–C5) vertebral body wedge, burst, and vertical fractures were produced in compression at mean failure loads of 3326 N (747 lb) and 18 mm (0.71 in.) deformation. They also found that posterior ligament tears in the lower column occurred under flexion and anterior longitudinal ligament tears and spinous process fractures occurred under extension. A review of the Pintar et al. (1995) tests found 6 cases of burst fracture with a mean load of 3060 ± 556 N (688 ± 125 lb). Injury occurred 2.2–18.8 ms after impact and before noticeable head motion. Buckling of the cervical spine, involving extension between the third and sixth cervical vertebrae and flexion between the seventh and eighth cervical vertebrae, was observed. Other, more complex, buckling deformations were also seen, suggesting that the deformations that occur during impact involve complex vertebral motion.

Myers and Nightingale (1999) summarized cervical and basilar skull injuries with impacts to the top of the head of 22 human cadaver heads. The tests showed the significance of head rebound, head and neck decoupling, and cervical spine buckling on the occurrence of cervical injuries. The data demonstrated that compliant pads increased the rate for spinal injury, even though the pads reduced peak head force and the HIC. Carter et al. (2002) conducted segmental cervical spine compression tests with flexion–compression, compression, and compression–extension. They found that the tolerance for compression was 3261 ± 707 N (733 ± 159 lb). Viano and Parenteau (2008) analyzed data on cadaver head impact tests involving spinal injury. There were 3 studies involving 33 inverted drop tests and 3 others involving 42 linear and pendulum impacts to the top of a cadaver’s head. Head velocity averaged 6.32 ± 1.29 m/s (n = 51) with serious injury and 3.75 ± 2.16 m/s (n = 24) without injury (P < .001). Impact force was 7382 ± 3632 N (1660 ± 816 lb) with injury and 3760 ± 3528 N (845 ± 793 lb) without (P < .001). Peak head velocity was determined for inverted drop and impact tests as a means of merging and analyzing cadaver data on serious injury for impacts to the top of the head. A 15% risk of serious injury is at 2.3 m/s (5.1 mph) head velocity and 50% risk at 4.2 m/s (9.4 mph).

The biomechanical data indicate that spinal fracture-dislocations and SCIs are related to relatively low-velocity head impacts. McElhaney et al. (1979) found that diving injuries of the neck involve head impact velocities of 3.6–5.0 m/s (8.0–11.1 mph) and recommended a tolerance of 3.1 m/s (7.0 mph). This is consistent with the other biomechanical studies on cervical injury. The goal for injury prevention is to reduce the speed of excursion in a crash. Seat belt use is effective in lowering the velocity of movement in a crash.

Seat belts are effective in reducing occupant excursion and injuries in motor vehicle crashes. Campbell and Kihlberg (1963) investigated belt effectiveness in preventing injury. Evans (1991) reported that the seat belt effectiveness in preventing fatal injury of the driver was 77 ± 6% in rollovers, 49 ± 14% in rear impacts, 43 ± 8% in frontal impacts, 39 ± 15% in far-side impacts, and 27 ± 17% in near-side impacts. Levine and Campbell (1971) found that seat belts reduced the risk of injury by 12% in rear impacts and serious injury by more than 57%.

Table 2 summarizes seat belt effectiveness found by the authors of this study. Seat belt use is effective for nonejected occupants, near- and far-side occupants, and front outboard occupants in different types of crashes where the rate for a severely injured occupants was determined by dividing the
number of severely injured occupants (MAIS 4+F) by the number of occupants with known injury status (MAIS 0+F). Lap and shoulder belts were most effective in rear impacts (90.3%), followed by front (88.3%), rollover (87.0%), and side (85.8%) impacts. In another study, Parenteau and Viano (2011) analyzed 15 years of accident data from the 1993–2008 NASS-CDS for front outboard seated occupants in 1994+ model year vehicles by the type of crash and seat belt use. The rate for head injury was determined by dividing the number of AIS 3+ head injuries by the number of occupants with known injury, MAIS 0–6 or F (MAIS 0+F). Seat belt use significantly reduced the rate for serious head injury. The effectiveness was greatest in rear impacts with a 95% reduction in head injury rate. The current study found seat belt effectiveness up to 94.3% in preventing serious head injury. The lowest effectiveness was 31.0% for spinal fracture-dislocations in rear impacts.

Many studies have reported significant belt effectiveness in preventing ejection and injury. Huelke and Gikas (1966) investigated fatal crashes and postulated that 80% of ejections could have been prevented with seat belt use. Hartemann et al. (1977) carried out a matched-pair analysis and estimated that seat belts could reduce crash fatalities by 23% solely by mitigating ejection. Esterlitz (1989) found high ejection risks for unbelted occupants. According to Evans (1991), the seat belt effectiveness in preventing ejection varied from 8 ± 1% in near-side impacts to 63 ± 1% in rollovers and 22 ± 1% in rear impacts. Table 2 shows that seat belt use is more than 99% effective in preventing ejection in all types of crashes (Viano and Parenteau 2010a).

There are a number of limitations to this type of field accident analysis. For example, the contact sources for SCIs were determined for belted and unbelted occupants by crash type. In rear impacts, the leading source was the seatback (54%), head restraint (20%), and other components (26%) for belted occupants. The other component was identified as noncontact and was based on one case (2002-8-13E). The case was reviewed and summarized in Appendix 6. It consisted of a low-speed (<24 km/h [<15 mph]) rear impact with a fatally injured 71-year-old driver. Viano and Parenteau (2008) studied serious injury in low-speed crashes and found that the elderly or individuals with preexisting medical conditions, such as spinal stenosis, could be seriously injured or killed in crashes that were not injurious to younger occupants. In this study, there were 12 SCI injuries in belted occupants (Appendix 6). Only one of the 12 injuries (8.3%) had the injury source coded as noncontact. When the data were weighted, the noncontact source accounted for 26% of the injury sources.

**Supplemental Material**

Supplemental data for this article can be accessed on the publisher’s website.

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