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Occupant and Crash Characteristics in Thoracic and Lumbar Spine Injuries Resulting From Motor Vehicle Collisions

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Abstract

Background context—Motor vehicle collisions (MVC) are a leading cause of thoracic and lumbar (T and L) spine injuries. Mechanisms of injury in vehicular crashes that result in thoracic and lumbar fractures and the spectrum of injury in these occupants have not been extensively studied in the literature.

Purpose—The objective was to investigate the patterns of T and L spine injury following MVC; correlate these patterns with restraint use, crash characteristics and demographic variables; and study the associations of these injuries with general injury morbidity and fatality.

Study design/Setting—Retrospective study of a prospectively gathered database.

Patient sample—Six hundred and thirty-one occupants with T and L (T1-L5) spine injuries from 4572 occupants included in the Crash Injury Research and Engineering Network (CIREN) database between 1996 and 2011.

Outcome measures—No clinical outcome measures were evaluated in this study.

Methods—The CIREN database includes moderate to severely injured occupants from MVC involving vehicles manufactured recently. Demographic, injury and crash data from each patient was analyzed for correlations between pattern of T and L spine injury, associated extra-spinal injuries and overall injury severity score (ISS), type and use of seat belts, and other crash characteristics. T and L spine injury pattern was categorized using a modified Denis classification, to include extension injuries as a separate entity.

Results—T and L spine injuries were identified in 631 of 4572 vehicle occupants, of whom 299 sustained major injuries (including 21 extension injuries) and 332 sustained minor injuries. Flexion-distraction injuries were more prevalent in children and young adults, and extension injuries in older adults (mean age 65.7 years). Occupants with extension injuries had a mean BMI of 36.0 and a fatality rate of 23.8%, much higher than the fatality rate for the entire cohort (10.9%). The most frequent extra-spinal injuries (Abbreviated Injury Scale grade 2 or more)

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associated with T and L spine injuries involved the chest (seen in 65.6% of 631 occupants). In contrast to occupants with major T and L spine injuries, those with minor T and L spine injuries showed a strikingly greater association with pelvic and abdominal injuries. Occupants with minor T and L spine injuries had a higher mean ISS (27.1) than those with major T and L spine injuries (25.6). Among occupants wearing a three-point seat belt, 35.3% sustained T and L spine injuries, while only 11.6% of the unbelted occupants sustained T and L spine injuries. Three-point belted individuals were more likely to sustain burst fractures, while two-point belted occupants sustained flexion-distraction injuries most often, and unbelted occupants had a predilection for fracture-dislocations of the T and L spine. Three-point seat belts were protective against neurologic injury, higher ISS and fatality.

Conclusions—T and L spine fracture patterns are influenced by age of occupant and type and use of seat belts. Despite a reduction in overall injury severity and mortality, seat belt use is associated with an increased incidence of T and L spine fractures. Minor T and L spine fractures were associated with an increased likelihood of pelvic and abdominal injuries and higher ISS scores, demonstrating their importance in predicting overall injury severity. Extension injuries occurred in older, obese individuals, and were associated with a high fatality rate. Future advancements in automobile safety engineering should address the need to reduce T and L spine injuries in belted occupants.

INTRODUCTION

Motor vehicle collisions are a common cause of thoracic and lumbar (T and L) spine injuries, accounting for between 22.5 and 51% of all T and L spine injuries in different series [1–3]. T and L spine fractures generally do not directly result in mortality but can result in substantial morbidity, especially when associated with neurologic deficit and deformity. Engineering analyses of vehicle crash mechanisms have resulted in numerous vehicular safety improvements and a substantial reduction in the incidence of fatal and non-fatal occupant injuries from car crashes over the last two decades [4]. There has, however, been little effort in characterizing the mechanisms of injury in vehicular crashes that result in thoracic and lumbar fractures and the spectrum of injury in these occupants.

A single database that provides comprehensive data on the crash characteristics, occupant demographics and clinical details of the injuries sustained has not been previously studied in relation to T and L spine injuries. A study reported in 1989 on T and L injuries following motor vehicle crashes included older vehicles, and did not consider advances in safety technologies such as airbags [5]. Other studies on T and L spine injury from motor vehicle collisions have either been restricted in their scope by studying thoracolumbar junctional injuries alone [6], injuries from frontal impact collisions alone [7–9], or front seat occupants alone [8]. Limitations in other studies include single hospital reported data [6,7], absence of correlation with airbag deployment [6,8], small numbers [10], or the use of databases with insufficient data to provide accurate correlation of clinico-radiographic findings with crash characteristics [8,11].

In the present study, we reviewed a multicenter national database of motor vehicle accidents, providing comprehensive crash and occupant information in a large number of moderate to severely injured occupants presenting at Level 1 Trauma Centers. The objectives of this study were to determine the types of injuries sustained to the thoracic and lumbar spine in motor vehicle crash occupants and to study the associated morbidity incurred by occupants with these fractures of the spine. Clinical and imaging data were analyzed, and fracture patterns were correlated with demographic and crash data. As a result of these findings, modifications have been proposed to the three-column injury classification system to accommodate for patterns of spinal injury that do not fit well into the current classification systems.

MATERIALS AND METHODS

The Crash Injury Research and Engineering Network (CIREN) database is a prospectively gathered database of motor vehicle collisions maintained by the National Highway Traffic Safety Administration (NHTSA). The database contains information on the specifics of the vehicular crash and from the medical records of the occupants of the involved vehicles, gathered currently from six centers across the United States. Motorcycle, bicycle and pedestrian accidents are excluded. Currently, crashes involving vehicles manufactured more than five years prior to the year of accident are excluded. Only those occupants sustaining systemic injuries with an Abbreviated Injury Score three or more [12], irrespective of region of injury, or AIS score two in at least two different regions of the body are included in the database. The database maintains de-identified clinical information on injuries, obtained from hospital medical records. Impact and engineering data related to the vehicular crash is input by specially trained engineers following vehicle inspection, road and physical environs of the collision. Clinical information is entered by clinical coordinators at individual centers. Additional information can be found on the CIREN database (http://www.nhtsa.gov/CIREN). The database was specifically queried for injuries to the thoracic and lumbar spine, between 1996 and 2011. Occupants of all ages were included.

4,572 occupants in motor vehicle collisions were registered in the CIREN database between 1996 and November 2011. Of these, 631 occupants were identified with 2,626 thoracic and lumbar spine injuries. The CIREN files for all 631 individuals were reviewed for demographic, injury and crash data. Subject demographics recorded included age, sex, body weight, height and BMI. Specific information on the thoracic and lumbar injuries included the type and level of spinal column injury, and the type and level of neurologic injury. Information on the extra-spinal injuries included the AIS scores in each body region (head, face, neck, thorax, abdomen, spine, upper extremity and lower extremity) [12], and the Injury Severity Score (ISS) [13]. Only AIS scores of 2 or more (moderate to severe injuries) were considered while studying the associations of these systemic injuries, in an attempt to derive meaningful conclusions from this analysis. The ISS, MAIS (maximum AIS score) and the occurrence of fatality were recorded for each occupant.

Vehicular crash data included vehicle make, vehicle model and year of manufacture, seat type and orientation, seat belt type (three point or two point lap belt), usage and whether seat belt was used appropriately. Seat belt usage was determined using a number of methods, including witness marks on the belt webbing and the points of friction or stretch of the belt; clinical photographs showing belt-induced bruises or injury; and police reports corroborated by reports of the Emergency Medical Services (EMS) crew involved in extrication of the occupant. The deployment and location of airbags in the vehicle was recorded. The specific location of the case occupant was recorded in terms of whether the occupant was on the passenger or driver side and specific seat row. Characteristics of the collision recorded included direction of impact and the change in velocity at impact. The direction of impact or the principle direction of force (PDOF) was defined as the force resultant vector for a given impact which was calculated using the mass (weight), velocity (speed) and angles of vehicles at impact.

Radiographs, computerized tomography images with sagittal and coronal reconstructions, and magnetic resonance images (where available) on the thoracic and lumbar spine for each case occupant were reviewed independently by two spine surgeons. Each occupant's thoracic and lumbar fracture was classified according to a modification of the Denis classification [14](Table 1). Minor injuries included isolated, stable fractures of the transverse processes, articular processes, pars or spinous process of the vertebrae. Major injuries were categorized as compression fractures, burst fractures, flexion-distraction injuries and fracture-dislocations, as in the original Denis' classification [14]. A number of occupants in the motor vehicle collisions sustained injury patterns that could not be accurately categorized in any of the original subtypes of the Denis classification. These injuries were characterized by distractive failure of the anterior column through the disc, or vertebral body and disc, with or without additional distraction of the middle column or translation at the fracture site. These distractive extension injuries were added as a distinct "major injury" group (Table 1) and not included in the original Denis classification. The vertebral level of each occupant's injury was noted, and major injuries were categorized by level into three regions; thoracic (T1 to T10–11), thoracolumbar junction (T11 to L2), and lumbar (L2–3 to L5–S1).

RESULTS

DEMOGRAPHIC DATA

Of the 4572 case occupants reported in the CIREN database, 631 occupants (13.8%) sustained T and L spine injuries. Of these, 299 occupants sustained major injuries, while the remaining 332 had minor injuries to transverse processes, facets, pars and/or spinous processes. The mean age of all 631 occupants was 45.8 years at the time of injury (range 21 months to 96 years), while the mean age of occupants with major injuries was 48 years and mean age of occupants with minor injuries was 44 years. The incidence of T and L spine injuries among all occupants in the entire CIREN database was found to increase with age from 4.9% (18/367) in the 0–9 years age group to 11–12% in 10–39 years age group, and then to 15–21% in occupants 40 years and above (Children below 10 years and older occupants 60 years and above sustained major T and L spine injuries more often than minor T and L spine injuries. As opposed to this, teenagers, young adults and middle-aged adults (10–60 years age) were more likely to sustain minor T and L spine injuries than major T and L spine injuries (Fig 1).

4538 occupants had sex data available; of these 2203 were male (48.6%) and 2335 female (51.5%). The likelihood of sustaining injury to the T and L spine was similar in either sex –

(13.4% male; 294/2203 and 14.4% female; 337/2335), and the sex distribution within the ensemble was similar (46.6% male 294/631 and 53.4% female 337/631). Males demonstrated slightly higher percentage of major T and L spine injuries (51.4%; 151/294) than minor ones (48.6%; 143/294). In contrast, females sustained minor T and L spine injuries more commonly (56.1%–189/337) than major ones (43.9%–148/337). The mean BMI of all occupants with T and L spine injuries was 27.2. Occupants with BMI >30 (obese) sustained minor T and L spine injuries more frequently than major ones, while those with BMI <30 sustained major and minor T and L spine injuries with almost equal frequency.

AGE VERSUS PATTERNS AND LEVELS OF T AND L SPINE INJURY

In our cohort, injury to the thoracic and lumbar spine occurred most frequently in occupants in the 20–29 year age group (17.3%; 109/631). The frequency of lumbar injuries tended to decrease with increasing age, while that of thoracolumbar junction and thoracic region tended to increase with age (Fig 2). Compression fractures were almost equally prevalent in all age groups, while other higher energy injuries like burst fractures and fracture-dislocations were most prevalent in middle-aged adults (30 to 60 years) (Table 2). Flexion-distraction and extension injuries showed prominent age peculiarities, the former seen almost exclusively in children and young adults (less than 30 years), while the latter seen almost exclusively in the elderly (50 years and above) (Table 2). Thoracic and thoracolumbar junction injuries peaked in the 40–60 year age group, while lumbar injuries showed a bimodal distribution with peaks at 0–20 and 60–80 year age groups (Fig 2).

PATTERNS AND LEVELS OF MAJOR THORACIC AND LUMBAR SPINE INJURY

Of 299 occupants sustaining major T and L spine injuries, adequate data were available in 237 subjects to allow sub-classification of injury; 329 fractures could thus be classified. Of the 329 major T and L spine injuries, 57.5% (189/329) were compression fractures, 24.9% (82/329) were burst fractures, 8.8% (29/329) were flexion-distraction injuries, 2.4% (8/329) were fracture-dislocations, and 6.4% (21/329) were extension injuries (Table 3). This pattern of predominant compression fractures followed by burst fractures was consistent in all three regions, with the exception of the thoracic region, where extension injuries were more frequent than burst fractures (Table 3). Most injuries (41%; 135/329) occurred at the thoracolumbar junction (T11-L2), followed by the thoracic (T1–10) (33.7%; 111/329) and lumbar regions (L3–5) (25.2%; 83/329) (Table 3).

MULTI-LEVEL MAJOR THORACIC AND LUMBAR SPINE INJURIES

Major T and L spine injury at two or more levels within the thoracic and lumbar spines occurred in 21.4% (64/299) of occupants. Of these 64 occupants, 23 had injuries at non-contiguous levels, 34 had injuries at two contiguous levels and seven occupants had injuries at three or more contiguous levels. Six of these seven occupants with contiguous injuries at three or more levels had injuries involving the thoracic spine. Concomitant injuries to the cervical spine (AIS 2 or more) were found in 137 occupants (21.7%) out of the 631 occupants. Occupants with major T and L spine injuries had concomitant cervical spine injuries 23.8% (71/299) of the time, while those with minor injuries had concomitant cervical spine injuries 19.9% (66/332) of the time.

ASSOCIATED EXTRA-SPINAL INJURIES

The commonest extra-spinal injuries associated with T and L spine injuries were injuries to the thorax (65.6%; 414/631), followed by head (43.1%; 272/631), lower extremity (42.8%; 270/631), abdomen (42.2%; 266/631), and pelvis (38.8%; 245/631). As opposed to occupants with major T and L spine injuries, those with minor T and L spine injuries showed greater association with pelvic (58.1%; 193/332 versus 17.4%; 52/299; abdominal (51.8%; 172/332 versus 31.4%; 94/299) and head injuries (47.9%; 159/332 versus 37.8%; 113/299).

OVERALL INJURY SEVERITY AND FATALITY

The mean ISS of occupants who sustained injury to the T and L spine was higher than those in the entire CIREN database (26.4 vs. 20.7). Patients who sustained major T and L spine injuries had an ISS of 25.6 while those with minor T and L spine injuries had an ISS of 27.1. Sixty-nine of 631 occupants (10.9%) with T and L spine injury had a fatal outcome. The occurrence of fatality was remarkably similar to occupants in the CIREN database who did not sustain T and L spine injury (10.4%; 408/3928). The percentage of fatality among occupants with major T and L spine injuries (15.7%; 47/299) was greater than in those with minor T and L spine injuries (6.3%; 22/332). 63 of 69 fatalities among all occupants with T and L spine injuries had concomitant (AIS 2 or more) injury to the chest. Fifteen of 69 (21.7%) fatalities had an AIS grade 6, an indicator of maximum severity, of which fourteen were in the major T and L spine injuries subgroup and one in the minor T and L spine injuries subgroup. The body regions with such AIS 6 injuries were head (9 occupants), chest (8 occupants), and cervical spine (5 occupants).

SEAT BELT USAGE AND ASSOCIATED T AND L SPINE INJURY PATTERNS

Seat belt usage data was available for 2500 occupants in the CIREN database and for 544 of the 631 occupants with T and L spine injuries. 41.3% (1033/2500) of all occupants in the database used a three-point belt appropriately, 54.4% (1360/2500) were unbelted, and 4.3% (107/2500) wore a two-point belt or were inappropriately belted. Paradoxically, the appropriate use of three-point seatbelts did not appear to have a protective effect against T and L spine injury, with 35.3% (365/1033) of appropriately belted individuals in the CIREN database sustaining T and L spine injuries, while 11.6% (158/1360) of unbelted occupants sustained T and L spine injuries. Major T and L spine injuries occurred more frequently in belted occupants (18.4%; 190/1033) than unbelted occupants (5.6%; 76/1360) in the entire CIREN database. Minor T and L fractures also occurred more frequently in appropriately belted occupants in the CIREN database (16.9%; 175/1033) than in unbelted occupants (6%; 82/1360). The 365 three-point belted occupants in our cohort with T and L spine injuries showed a mean ISS of 25, and a fatality rate of 9% (33/365), while the 158 unbelted occupants showed a mean ISS of 29.7, and a fatality rate of 16.5% (26/158) (Table 4). 215 of 329 major T and L spine fractures were sustained by appropriately belted individuals. In these occupants, 60% (129/215) were compression fractures, 27.4% (59/215) were burst fractures, 5.1% (11/215) were flexion-distraction injuries, 1.4% (3/215) were fracture-dislocations, and 6.1% (13/215) were extension injuries. The distribution of major fracture types was generally similar with and without seatbelt use, but flexion distraction injury pattern was markedly higher in the group that wore a two-point seatbelt or seatbelt with inappropriate use of the shoulder belt (Table 5).

EFFECT OF AIRBAG DEPLOYMENT

Airbag deployment occurred in 1,523 occupants in the entire CIREN database, of whom 345 (22.7%) sustained T and L spine injuries. Absence of airbag deployment was noted in 1,101 occupants in the CIREN database, of whom 162 (14.7%) sustained T and L spine injuries. Major T and L spine injuries were more frequent in occupants without airbag deployment (81.0%, 17/21 major versus 19.0%, 4/21 minor) than when airbags deployed (63.0%, 153/243 major versus 37.0%, 90/243 minor). The mean ISS of occupants with T and L spine injuries in presence of airbag deployment was 24.2, while the mean ISS of those without airbag deployment was 22.2. The fatality rate was marginally higher for those T and L spine injured occupants without airbag deployment (14.3%, 3/21) than for those with airbag deployment (9.9%, 24/243). Airbag deployment in three point belted occupants appeared to have a protective effect with a lower mean ISS and fatality rate (Table 6).

EXTENSION INJURIES

Extension pattern injuries accounted for 6.4% (21/329) of the 329 major T and L spine injuries sustained by occupants in our cohort. Twenty of these injuries were observed in the thoracic spine, one at the thoracolumbar junction, and none in the lumbar spine. All extension injuries occurred in occupants greater than 47 years of age (mean age: 65.7 years; range: 47 years 9 months to 85 years 7 months). Fourteen occupants with extension injuries were males and seven females. The mean BMI of these 21 occupants was 36.0, much higher than the mean BMI of the entire cohort (27.2). Thirteen of these injuries were seen in three-point belted occupants, 7 in unbelted occupants, and one in a subject with unknown seat belt status. None of these injuries were observed in two-point lap belted occupants, or in those wearing the shoulder belt inappropriately. Airbag deployment was noted in 17 of these 21 accidents. The mean ISS of occupants who sustained extension pattern injuries was 21.9, lower than the mean ISS of all 631 occupants with T and L spine injuries (26.4). Five of the 21 occupants with extension T and L spine injuries in our cohort had a fatal outcome (23.8%), much higher than the fatality rate of all occupants with T and L spine injuries (10.9%). Associated chest injuries of AIS 2 or more were seen in 17 of the 21 occupants with extension T and L spine injuries (81%). This was substantially higher than the incidence of chest injury in occupants with major T and L spine injuries other than extension injuries (59.7%, 166/278).

DISCUSSION

The CIREN database provides detailed data on the demographics, injury and crash characteristics in motor vehicle accident occupants. The stringent inclusion criteria of the CIREN database allow identification of occupants involved in moderate to severe collisions. Despite the implementation of vehicle safety features and the mandatory requirement of seat belts, we found that 13.8% (631/4572) of the occupants of vehicles involved in motor vehicle collisions sustained T and L spine injury. The exclusion of occupants with minor overall injury from the database suggests that the true number of occupants with T and L spine injury from motor vehicle collisions may, in fact, be even higher. These findings are consistent with another recent study that reported a 16.4% (578/3524) incidence of T and L spine and 11.6% (407/3524) incidence of cervical spine injury from motor vehicle collisions [15]. A population-based study of hospitalized front row occupants of vehicular crashes in Wisconsin between 1994 and 2002 in fact showed that the incidence of spine injury from motor vehicle crashes was increasing in recent years [11]. While some of this increase may be attributed to improved diagnosis with increased use of CT and MRI in recent years, the present data raises questions on whether vehicular safety restraints may be predisposing to T and L spine injury while protecting occupants from visceral or head injury.

The use of seat belts has been reported to be protective against fatalities and severity of injury following motor vehicle collisions [16–20], and has been shown to help in reduction of health care costs associated with accident victims [18,19,21,22]. Prior investigations have shown that the combined use of airbags and seat belts can reduce the incidence of spine injuries [11,23], but the use of seat belts alone has either shown no difference in the incidence of spine injuries [24], or shown an increase in the incidence of spine injuries [11,15]. Smith et al reported a lower incidence of neurologic injury in belted frontal impact victims with spinal column injuries that resulted from MVC at lower delta-V [25]. The protective effect of the seat belt was, however, lost when the MVC occurred at a delta-V higher than the average delta-V in their cohort. Wang et al also could not find a definite protective effect of seat belts alone against spine injuries of higher severity (AIS 3 or more) [11]. In the present series from the CIREN database, 35.3% of the appropriately three point belted occupants sustained T and L spine injuries, while 11.6% of the unbelted occupants sustained T and L spine injuries. Both major and minor T and L spine injuries were more frequent in belted occupants as opposed to unbelted occupants in the entire CIREN database. Appropriate use of a three-point seat belt was, however, associated with a lower mean ISS, a lower fatality rate, and lower neurological injury (Table 4). Results from this carefully evaluated ensemble are in concordance with prior data showing that while seat belt usage does appear to confer some protective effect against fatality and severity of injury, this does not necessarily transfer to a protective effect against T and L spine injury.

A recent study reported that the use of seat belt alone reduced mortality risk by 51%, deployment of airbag in unbelted occupants reduced the risk by 32% and the combination of airbag and belt use decreased the risk by 67% [26]. A similar conclusion was advanced in an earlier study wherein Wang et al found a protective effect against spine fractures when seat belt use was combined with airbag deployment [11]. The authors reported that the use of seat belt without airbags increased the likelihood of sustaining a spine fracture in their study. Further, an increased likelihood of sustaining thoracic spine fractures of higher severity (AIS >3) was reported in airbag-only protected occupants. In the present study, airbag deployment was associated with a higher incidence of T and L spine injuries (22.7%) than without deployment (14.7%). Further, airbag deployment was more frequently associated with major (63%) than minor T and L spine injuries (37%). Airbag deployment in three-point belted occupants resulted in more major (65.1%) than minor T and L spine injuries (34.9%) (Table 6). Airbag deployment in unbelted occupants in the present study occurred in roughly the same number of occupants who sustained major (32/63) and minor (31/63) T and L spine injuries and had the same mean ISS, but a lower fatality rate (20.6% versus 33.3%) when compared to unbelted occupants without airbag deployment. These results do not agree with the previous literature regarding the injury mitigating effects in belted occupants and airbag deployments compared to unbelted occupants, possibly due to small sample size of these studies and the selection criteria used in extracting data from the CIREN database. The focus on just the thoracic and lumbar spine trauma may also be a factor. However, with continued enrolling patients from the various CIREN centers, it should be possible to better delineate the role of belts use and airbag status on dorsal spine injuries in the future.

The use of the older lap-belt only restraint has a well-known association with flexion distraction injuries or Chance fractures of the lumbar spine [27,28]. The present study showed a similar association, with twelve of eighteen occupants restrained with two-point seat belt or three-point belt with the shoulder belt inappropriately worn behind the back or underarm (effectively acting as a two-point belt), sustaining flexion-distraction injuries. The present data also showed a higher proportion of burst fractures among occupants who wore three-point seatbelts compared to unbelted occupants (27.4%; 59/215 versus 20.3%; 16/79), but a lower proportion of compression fractures in belted versus unbelted occupants (60%; 129/215 versus 63.3%; 50/79). Fracture-dislocations occurred more in unbelted occupants than those who wore three-point seat belts appropriately (6.3%; 5/79 versus 1.4%; 3/215, Table 5). Some authors [6–8] have reported that seat belts usage is protective against more severe injury patterns such as fracture dislocation or flexion distraction patterns of thoracic and lumbar fractures, but was associated with a higher incidence of burst and compression fractures. The present study, while generally agreeing with trend, does not clearly substantiate this finding. While airbags and the diagonal shoulder belt offer a degree of restraint to the torso to protect against fractures and dislocations, the implications of the three point seatbelt and its interactions with seat contour and design are less clear. Seat pan loading continues as the occupant translates forward during the MVC. The potential increased stiffness of the seat especially at its forward region, coupled with its upward contour induces additional dynamic compressive forces on the spine, possibly increasing the likelihood of compression or burst fractures in the restrained occupant.

Extension injuries of the T and L spine have rarely been reported in the literature [29–31]. In 1971, Burke reported on four occupants with radiographic evidence of a hyperextension mechanism to their injury, among 154 occupants with T and L spine injuries. The injury occurred in the thoracic spine in all four occupants, and all four occupants were paraplegic secondary to their injury [29]. In 2006, Matejka reported four hyperextension injuries among 965 occupants treated for T and L spine injuries [31]. All four occupants were obese, elderly individuals with an average age of 63.75 years and average BMI of 32.75. The present cohort showed 21 extension injuries (6.4% of 329, Table 3), a much higher proportion compared to the previous studies [32], with thirteen of these 21 occurring in occupants appropriately using three-point seatbelts. The current data agrees with the previous studies indicating the propensity of obese elderly individuals to sustain extension T and L spine injuries. Airbag deployment occurred with seventeen of these 21 occupants, providing another factor that may play a role in the causation of these injuries. Although a clear explanation does not exist for the infrequency of extension pattern thoracic and lumbar fractures in past reports, it is postulated that increased awareness, better resolution imaging, and reliance on early CT scans for thoracic injury detection might play a role in the increased detection or incidence. It is also possible that older drivers with increasing kyphosis and a more obese population might be contributory factors. Finally, airbag deployment directly onto a torso restrained by seatbelts may contribute to extension injury in the thoracic spinal column. Based on these, it is recommended to examine vehicle safety technologies to determine whether the altered chest compliance in the elderly and their increased kyphosis in the thoracic spine warrant varied seat design, airbag trigger or levels of pretensioning in seat belt specifications.

Concomitant injuries to other organ systems increase morbidity and mortality following a motor vehicle accident. In the current cohort of 631 occupants with T and L spine injuries chest injuries were most frequently associated extra-spinal injuries, followed by head, lower extremity, abdomen and pelvis injuries. Chest injuries were most commonly associated with major and minor T and L spine fractures. This close association of T and L spine injuries with chest injury has been reported. In a cohort of T and L spine fractures from all causes, Saboe et al in 1991 reported that chest injuries were the commonest extra-spinal injuries associated with T and L spine fractures (25.9%), followed by long bone fractures (23.7%), head injuries (22.1%), pelvic fractures (7.6%) and abdominal injuries (3.8%) [33]. The stability provided by the rib cage, sternum and chest wall to the thoracic spine and the partial protective coverage provided to the lumbar spine by the lower ribs may be responsible for the high incidence of association of chest injuries with T and L spine injuries. Presence of multiple rib fractures adds to the traumatic instability of a co-existent thoracic spine fracture and increases the morbidity [33]. All occupants with severe chest injuries should be especially evaluated to rule out thoracic and lumbar spine injury. A CT scan of the entire thoracic and lumbar spine is thus justified in all occupants presenting with moderate to severe chest injuries.

Minor T and L spine injuries, generally transverse process fractures, were associated more often with an ISS >24 (indicating systemic injury of high severity) than were major T and L spine injuries. In addition, pelvic fractures and abdominal soft tissue injury were more commonly associated with minor T and L spine fractures. This association of pelvic fractures and abdominal injuries with minor T and L spine fractures has been noted [34,35], but to our knowledge, our study is the first to clearly demonstrate this increased incidence of visceral injury in minor compared to major T and L injury. It appears that visceral injuries of higher severity are possible when the skeletal structures of the torso are left relatively uninvolved and do not absorb the energy of impact. It is clear that physicians must maintain a high index of suspicion for thoracic, pelvic and abdominal visceral injury when dealing with an occupant of a high-energy motor vehicle collision who has only minor fractures of the T and L spine, and we recommend that all these occupants undergo a careful evaluation for systemic injury with current imaging techniques.

Multilevel non-contiguous spine fractures indicate a higher severity of spine injury, possibly involving multiple mechanisms of injury as might be seen in unbelted occupants, rollover accidents and ejections from the vehicle. This study showed 7.7% incidence of non-contiguous major T and L spine fractures at two or more levels, and 23.8% incidence of associated cervical spine injuries (AIS > 2). Henderson et al studied 508 occupants with spine fractures, and found 77 occupants (15.2%) with multi-level non-contiguous spinal fractures [36]. They reported a higher incidence of multilevel non-contiguous injuries among unbelted victims of vehicular accidents, and a higher rate of ejections in these occupants. The present study reinforces the recommendation that the entire spine should be imaged in all occupants with any spine injury. Missed or delayed diagnosis of a concomitant non-contiguous spine injury can have devastating consequences.

The limitations of our study include the following. Because of the use of several variables to analyze injury characteristics and associations from the CIREN database, data were analyzed from a fundamental perspective, i.e., determining the percentage occurrence based on different parameters and not resorting to a multivariate analysis. These results further underscore the need to obtain similar information in other national databases and increase the sample size for more detailed statistical examinations.

Since the CIREN database is not population-based, the demographic data and findings cannot be extrapolated to low energy motor-vehicle accidents frequently seen in an ambulatory or non-Level 1 Trauma Center setting. This restriction of the ensemble provides homogeneity, but renders the data less than comprehensive when discussing injury classification, outcomes and related demographics. Military literature has shown an increase in thoracic and lumbar trauma from explosive devices, with mechanisms of injury that may not translate to motor vehicle collisions [39]. Additionally, falls from a height are a common etiology of T and L spine injuries, and in some series these have formed the largest group [40, 41]. Nevertheless, vehicular trauma is in most studies the commonest cause of T and L spine injuries and has shown increasing incidence over the last two decades despite the increase in use of seat belts, airbags and other safety mechanisms [11]. Unlike fall victims, vehicular trauma victims more often sustain multi-systemic trauma [42] and provide a better understanding of the associations of different systemic injuries with these fractures. Another limitation is that because of case selection criteria, the database does not contain information about all occupants involved in the crash. Present conclusions assessing the impact of crash or vehicle factors on thoracic and lumbar injuries should therefore be viewed as a first step. This limitation also underscores the need to gather such data by modifying current enrollment procedures for the CIREN database itself. It would be necessary to gather complete records from all occupants to more accurately assess impact of crash or vehicle factors on thoracic and lumbar injuries, and the present analysis has identified an important deficiency in data collection and analysis of T and L spine injuries for examining vehicle technologies. While the present study highlights the presence of extension injuries in the thoracic and lumbar spine, and a possible predilection for this pattern of injury in older adults, the lack of long term follow up makes it difficult to test the validity of the modified injury classification with regards to treatment. Notwithstanding these limitations, the large sample size, multicenter nature of the database, and availability of substantial occupant and crash data provides a valuable dataset to characterize injury patterns from high energy collisions, understand crash related causative factors, and understand the association with systemic injury that frequently determines overall morbidity and mortality from these injuries.

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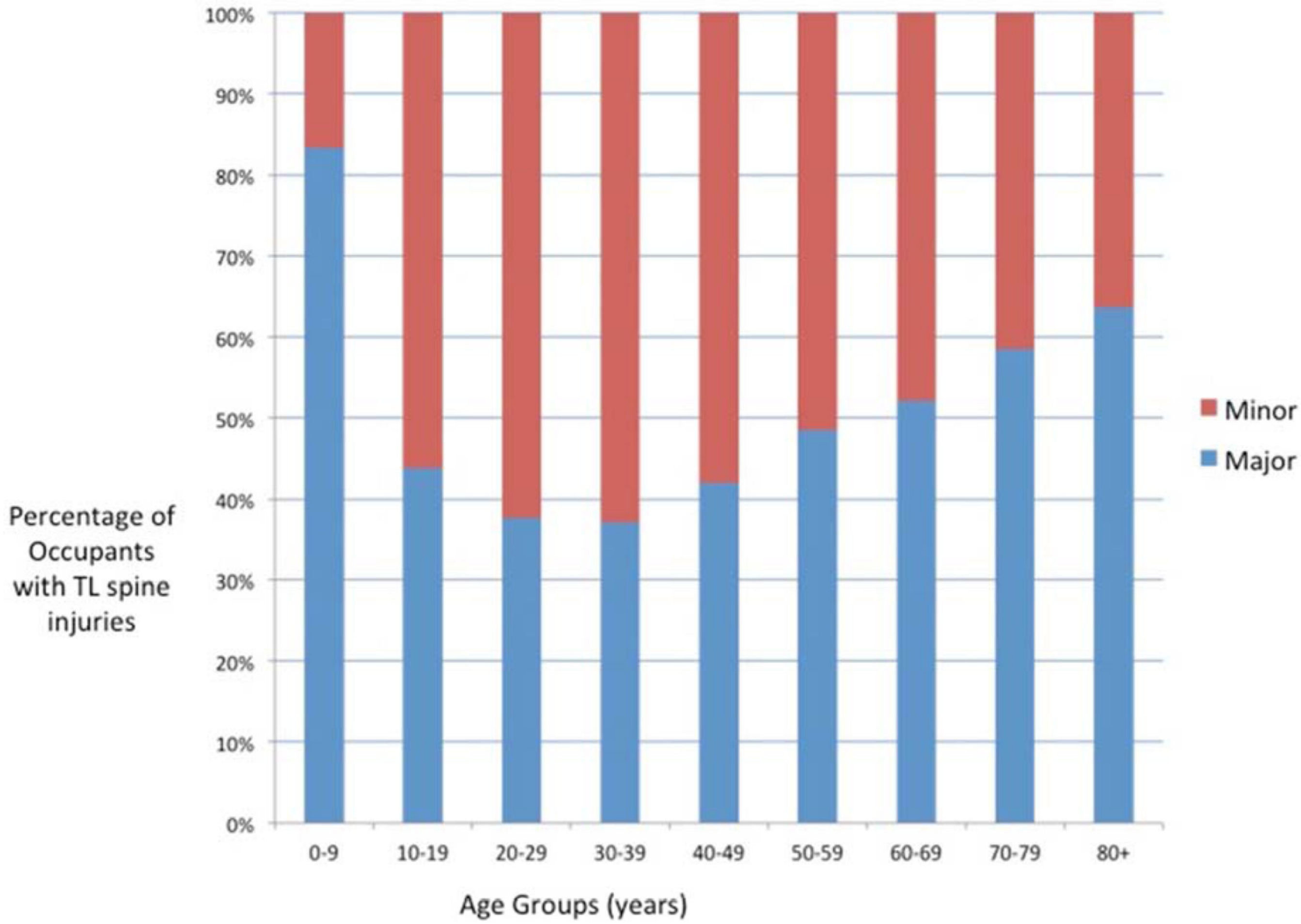

Fig 1.
0–9 and 60+ age groups show Major>Minor (Major above 50% line), while the rest show Major<Minor

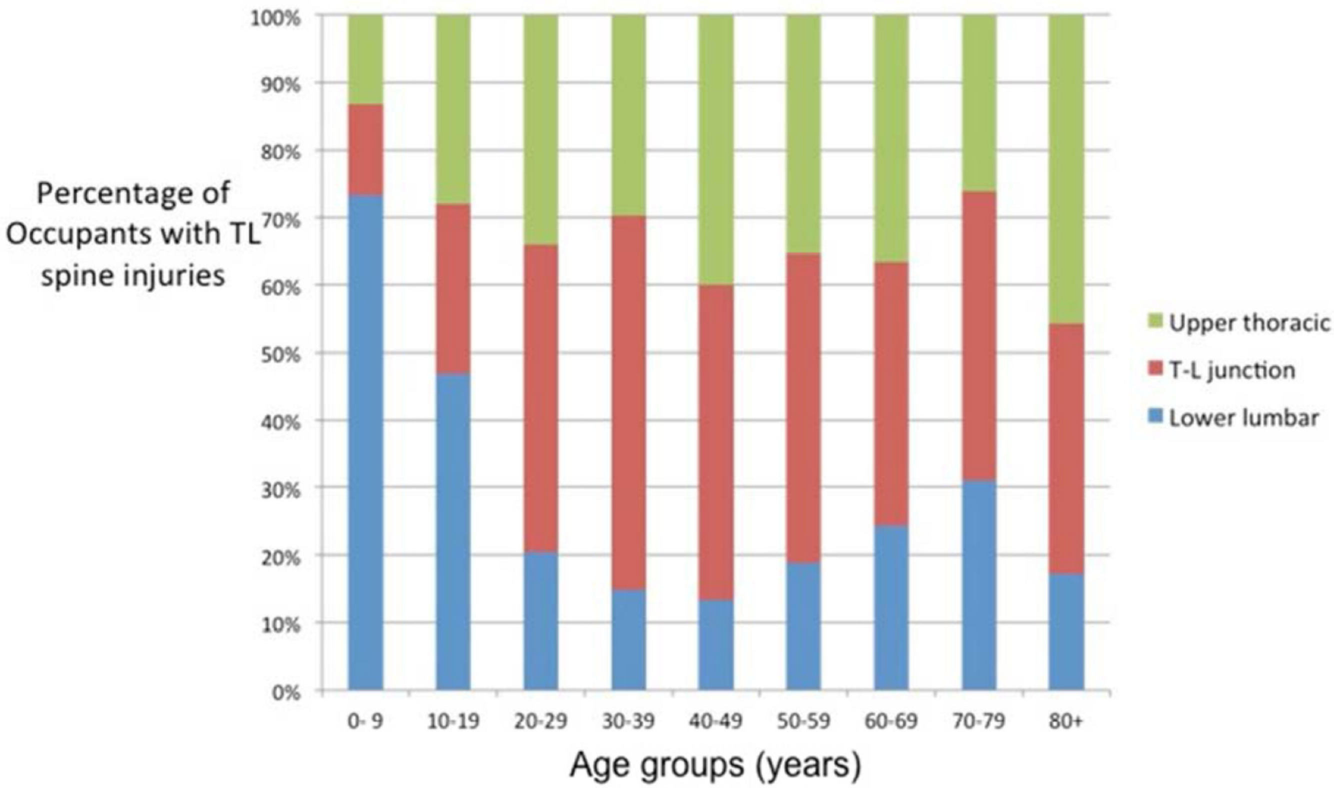

Fig 2.

The frequency of lumbar injuries tended to decrease with increasing age, while that of thoracic and lumbar junction and thoracic region tended to increase with age.

Table 1

Denis Classification (modified) used for categorization of thoracolumbar spine injury

Minor Injuries

Isolated fractures of transverse process/facet/pars/spinous process

Major Injuries

- Compression Fractures: Compression injury involving anterior column
- Burst Fractures: Compression injury involving anterior and middle columns
  - Stable burst fractures: Posterior ligamentous complex intact
  - Unstable burst fractures: Posterior ligamentous complex injured/disrupted
- Flexion-Distraction Injuries: Distraction injury of posterior and middle columns; Anterior column may fail in compression or distraction
  - Chance fracture (bony) or variant (ligamentous): Anterior column fails in distraction
  - Flexion-distraction with anterior column compression: Posterior and middle columns distract, while the anterior column fails in compression
- Fracture-Dislocations: All three columns injured
  - Flexion-rotation,
  - Shear, and
  - Flexion-Distraction mechanisms
- Extension injuries: Distraction injury of Anterior Column; Middle Column may or may not have distraction failure
  - Extension-distraction: Anterior column opening through disc, vertebral body, or combination thereof; Middle column intact (no posterior annular disruption, no retrolisthesis)
  - Extension injury with middle column injury
    - **i.** Middle column disrupted in extension with angulation alone
    - **ii.** Middle column disrupted in extension with angulation and / or translation

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Table 2

Age versus pattern of major TL spine injury

Age (years)	Compression fractures	Burst fractures	Flexion-Distraction injuries	Fracture-Dislocations	Extension injuries	Total injury levels
0–9	4	0	11	0	0	15
10–19	16	6	9	1	0	32
20–29	26	11	5	2	0	44
30–39	9	11	2	5	0	27
40–49	27	15	1	0	2	45
50–59	28	14	0	0	6	48
60–69	26	10	0	0	5	41
70–79	24	11	1	0	6	42
80+	29	4	0	0	2	35
Total	189	82	29	8	21	329

Table 3

Mechanisms and levels of major thoracolumbar spine injuries

Level	Compression	Burst	Flexion-Distraction	Fracture-Dislocation	Extension	Total
T1 to T10–11	70	13	4	4	20	111 (33.74%)
T11 to L2	76	43	13	2	1	135 (41.03%)
L2–3 to L5–S1	43	26	12	2	0	83 (25.23%)
Total	189 (57.45%)	82 (24.92%)	29 (8.81%)	8 (2.43%)	21 (6.38%)	329

Table 4

Seat belt usage patterns amongst subjects and in entire CIREN database

Description of belt use	Thoracolumbar injury data					Entire CIREN database
	Major	Minor	Total	Mean ISS	Fatality (major+minor)	
Appropriate 3-point use (belted)	190	175	365	24.97	20+13=33 (9.04%)	1033
2-point OR 3-point with improper shoulder belt use (equivalent to a 2 point)	19	2	21	28.9	3+0=3 (14.29%)	107
Belt absent OR not used (unbelted)	76	82	158	29.7	20+6=26 (16.46%)	1360
Unknown status of belt use OR different from above three OR Not coded	14	73	87			2072
Number of occupants with known seat belt status	285	259	544			2500
Total	299	332	631			4572

Table 5

Seat belt usage and major thoracolumbar spine injury patterns

Description of belt use	Compression	Burst	Flexion - distraction	Fracture - dislocation	Extension	Total
3 point-proper use	129 60%	59 27.44%	11 5.12%	3 1.4%	13 6.05%	215
2 point OR 3 point with improper shoulder belt use	4 22.2%	2 11.1%	12 66.67%	0	0	18
Belt absent OR not used	50 63.3%	16 20.25%	2 2.53%	5 6.33%	6 7.6%	79
Unknown status of belt use OR different from above 3	6	5	4	0	2	17
Total	189	82	29	8	21	329

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Table 6

Seat belt use pattern and airbag deployment

	Major injuries	Minor injuries	Total TL Injuries	Mean Injury Severity Score	Fatality
Belted + airbag deployed	110	59	169	22.9	9 (5.3%)
Belted + airbag did not deploy	10	4	14	22.8	1 (7.1%)
Unbelted + airbag deployed	32	31	63	28.0	13 (20.6%)
Unbelted + airbag did not deploy	3	0	3	28.0	1 (33.3%)