Serious Spine Injuries Using 2017-2021 CISS and CIREN Data: Effect of Spinal Degeneration Comorbidities

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Abstract

This study seeks to elucidate the influence of spinal conditions in the causation of serious spinal injuries in motor vehicle crashes. Data from 2017-2021 Crash Investigation Sampling System (CISS) and 2017-2022 Crash Injury Research and Engineering Network (CIREN) databases were analysed to identify cases with serious spine injury with and without spine degeneration documented as comorbidities.

There were 12,416,823 occupants, estimated from weighted data, with known injury outcome in the five years of CISS data; about 1.6% were seriously injured, and 0.40% had at least one serious spine injury. Of the exposed occupants, 9.6% had documented spinal degeneration. The relative risk of serious injury was 7.0 with spinal degeneration compared to without (p<0.0001). It was 16.2-times higher for serious spine injury. Of the available CIREN cases, 82 individual case subjects sustained at least one serious spinal injury and 18 of those had a documented pre-existing spinal condition.

Individual serious spine injury cases were examined to explore the unique factors of each spinal injury. Spinal degeneration was common in cases with serious spinal injury. The mechanical behaviour of the spine can vary when the tissue properties are altered due to degeneration and/or prior fusion, and its potential influence was documented in spinal injury causation scenarios.

Keywords Spine degeneration, occupants, spine injury, injury databases, biomechanics / injury prevention for the elderly population.

I. INTRODUCTION

The spine is a complex structure that supports the body and encases the spinal cord. Its flexibility arises from its numerous interconnected motion segments. The spinal column is made of vertebral bodies with multiple articulations, cartilage, discs, and spinal ligaments, linking adjacent vertebrae and protecting the spinal cord. These components work together to manage loads across the joints while ensuring stability and mobility.

Spine degeneration can, however, affect the spine's flexibility, mobility, and stability since it involves the gradual loss of normal structure and functions; the mechanical properties and anatomic morphology of the vertebrae, discs, and surrounding soft tissues can vary, affecting not only flexibility but the loading patterns, and tolerance to traumatic events. Various factors can contribute to spine degeneration such as aging, diseases, infections, and/or arthritis.

Degenerative spinal changes can be found in the cartilage, discs, and ligaments. For example, bone spurs (extra bone) may limit the joints' range of motion or compress the nerve roots and spinal cord. Ligaments may also thicken, affecting stiffness and compression. Some common types of spine degeneration include stenosis, spine curvatures (kyphosis, lordosis, and scoliosis), diffuse idiopathic skeletal hyperostosis (DISH), spondylosis, ankylosing spondylitis (AS), osteoporosis, and disc degeneration.

Stenosis refers to narrowing of the spinal canal or neural foramina. Stenosis can be congenital but is commonly degenerative in origin. Kyphosis, lordosis, and scoliosis are types of spine curvature. Kyphosis refers to a convex curvature of the spine in the sagittal plane. Scoliosis is curvature of the thoracic or lumbar spine in the coronal plane. A diagnosis of lordosis typically refers to excessive concave curvature of the lumbar spine in the sagittal plane. DISH is a disorder characterized by excess bone formation and continuous ossification of soft tissue structures along the anterior and lateral aspects of the spine, with preservation of intervertebral disc height and apophyseal joints. Other terms used to identify DISH include ankylosing hyperostosis, Forestier disease, and Forestier-Rotes-Querol disease. DISH occurs most commonly in the thoracolumbar spine. Ossification of the posterior longitudinal ligament (OPLL) is often linked to DISH.

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Spine degeneration has been observed to influence injury outcomes in rear vehicle crashes [1-3]. The objective of this study was to expand prior studies using a larger sample and include other crash types. Field crashes involving serious spinal injury were identified and downloaded from the Crash Injury Research and Engineering Network (CIREN) and Crash Investigation Sampling System (CISS) databases and analysed by crash type. The prevalence of spine degeneration was determined. Some cases included radiology images and reports, which were reviewed to gain a better understanding of injury causation and the influence of spinal condition.

II. METHODS

Databases

Crash Investigation Sampling System (CISS): CISS data from 2017 to 2021 were analysed [4]. CISS collects data on a representative sample of minor, serious, and fatal crashes involving at least one passenger vehicle – cars, light trucks, sport utility vehicles (SUVs), and vans – towed from the scene. The data presented in this study was weighted using inflation factors (CASEWGT) to allow for estimation of population totals.

Crash Injury Research and Engineering Network (CIREN): 2017-2022 CIREN data was queried for relevant cases [5]. The CIREN process combines prospective data collection with professional multidisciplinary analysis of medical and engineering evidence to determine injury causation in every crash investigation conducted. CIREN collects approximately 180 cases per year in a purposive sample with 720 total cases available from the period considered in this study.

Both CISS and CIREN cases include vehicle and scene information collected using standard National Highway Traffic Safety Administration (NHTSA) field crash investigation protocols. The injury information for CISS cases is based on medical records and interviews. Because CIREN cases are initiated from an injured case subject at the treating trauma centre, more comprehensive medical information, including medical imaging, is available for coding injuries and assigning causation. Both data systems document injury causation using the BioTab methodology [4]. CIREN cases undergo a multi-disciplinary deliberative review process to assign injury causation scenarios.

Definitions

Crash types were defined using damage plane (CDCPLANE) for the vehicle's most significant event (DVRANK=1), or rollover if (ROLLTURN > 0). Passenger cars, SUVs, minivans, and pickup trucks were included in the analysis (BODYTYPE values 1-8, 14-17, 20, and 30-39). Only towed vehicles (TOWED = 2 or 7/ TOWSTAT = 1) were included. There were no adjustments for missing data.

Front-outboard occupants 15 years and older (15-104 yo) were included. The analysis only comprised of three-point lap and shoulder belted (BELTUSE=4) and non-ejected (EJECTTYPE=0) occupants. Injury severity of the occupant was assessed using the Maximum Abbreviated Injury Scale (MAIS) and fatality (F) data (MORTALITY= 1 or PARINJSEV = 4). Crash exposed occupants with known injury were defined as those with MAIS 0–6 or with fatality (F) with a shorthand notation of MAIS 0+F. Serious-to-fatally injured occupants: Because fatalities can occur at any MAIS level, serious-to-fatally injured occupants were defined as those with MAIS 3–6 or fatality. The shorthand notation for this is MAIS 3+F. Serious (Abbreviated Injury Scale, AIS 3-6) spine injuries were defined using the body region (REGION = 6) variable. Spine region (cervical, thoracic, or lumbar) was identified using the STRUSPEC variable (fourth position of AIS code).

The rate of serious injury was calculated by dividing the number of occupants with serious injury or greater (MAIS 3+F) or occupants with serious spine injuries by the number of exposed occupants with known injury status (MAIS 0+F).

Comorbidity variables for injured occupants in CISS include (if available in medical records): 1. Degenerative spinal condition (SPINEDEGEN =1), defined as *pre-existing degenerative spinal condition, and it had the potential to affect the injury severity*; 2. Osteoporosis/osteopenia (OSTEOCOND = 1), defined as *pre-existing history of osteoporosis or osteopenia, and it had the potential to affect the injury severity*; prior surgery (IMPLANTFUS = 1), defined as *history of musculoskeletal implant, surgery, or fusion and it had the potential to affect the injury severity*. Note that this variable is not specific to spinal implants or fusions, and 3. Obesity (OBESITY = 1), defined as *pre-existing history of obesity, and it had the potential to affect the injury severity*. Only degenerative spinal condition was analysed in this study. The other conditions are only discussed in the case review if present.

Analysis of CISS data: The SURVEYFREQ procedure from SAS (Release 9.4) is designed specifically for the analysis of complex survey data. The statistical significance of the rate difference and relative risk of serious injury was determined by the SURVEYFREQ procedure using the Rao-Scott chi-square test of association for contingency tables. All data and calculations presented in this study used weighted data. Unweighted data was provided in the appendix. Procedure SURVEYLOGISTIC was used to control for age and sex.

Case review: CISS and CIREN case data are available for public use via an internet-based case viewer. All CISS and CIREN cases involving a seriously injured occupant with serious spine injury and with a history of degenerative spinal condition were reviewed for additional information. Radiology records and BioTab information were analysed from the CIREN cases to explore the role of the spinal conditions in injury causation.

III. RESULTS

Occupants

CISS data: Table I shows the total number of exposed (MAIS 0+F) and seriously injured (MAIS 3+F) lap-shoulder belted occupants. It also shows the corresponding number of seriously injured with serious (AIS 3-6) spine injuries. The analysis was based on weighted data. Appendix A provides additional information including unweighted data. There were 12,416,823 estimated front-seat occupants, 15 years and older, with known injury outcome in the five years of CISS data; about 1.6% were seriously injured, and 0.40% had at least one serious spine injury. Of the exposed occupants, 9.6% had a documented history of spinal degeneration. Since comorbidity information is only coded for injured occupants when documented in the available medical records, this prevalence may be an underestimate of presence in the exposed population. The frequency increased to 42.6 % for seriously injured, and 63.2% for occupants with serious spine injury. The relative risk of serious injury was 7.0-times higher for occupants with spinal degeneration than without. It was 16.2-times higher for serious spine injuries.

TABLE I
SUMMARY OF EXPOSED (MAIS 0+F) AND SERIOUSLY INJURED (MAIS 3+F) LAP-SHOULDER BELTED AND NON-EJECTED FRONT-SEAT OCCUPANTS, AND WITH SERIOUS (AIS 3-6) SPINAL INJURY
(CISS 2017-2021 WEIGHTED DATA)

	Spinal Degeneration			
Occupants	No	Yes	Unknown	Total
MAIS 0+F	4,936,098	524,722	6,956,003	12,416,823
MAIS 3+F	112,190	83,365	3,568	199,123
w/ AIS 3+ spine	18,295	31,431	0	49,726
	Proportion			
MAIS 0+F	90.4%	9.6%	-	-
MAIS 3+F	57.4%	42.6%	-	-
w/ AIS 3+ spine	36.8%	63.2%	-	-
	Rate per MAIS 0+F			
MAIS 3+F	2.27%	15.9%	-	1.60%
SE	0.20%	3.02%	-	0.18%
95th percentile CL	1.85-2.70%	9.6-22.2%	-	1.22-1.99%
w/ AIS 3+ spine	0.37%	6.0%	-	0.40%
SE	0.08%	2.0%	-	0.10%
95th percentile CL	0.21-0.54%	1.9-10.1%	-	0.19-0.62%

Figure 1 shows rate of seriously injured (MAIS 3+F) occupants per 100 exposed occupants by crash type and presence of spinal degeneration. The rate was highest in rollover crashes. Relative risk was assessed as the rate ratio with and without spinal degeneration. The results indicate that the relative risk was 8.4 in frontal and in side impacts ($p<0.0001$) and 6.4 in rollover crashes ($p=0.0001$). The rate was 3.9-times higher in rear crashes, but the results were not statistically significant (NS).

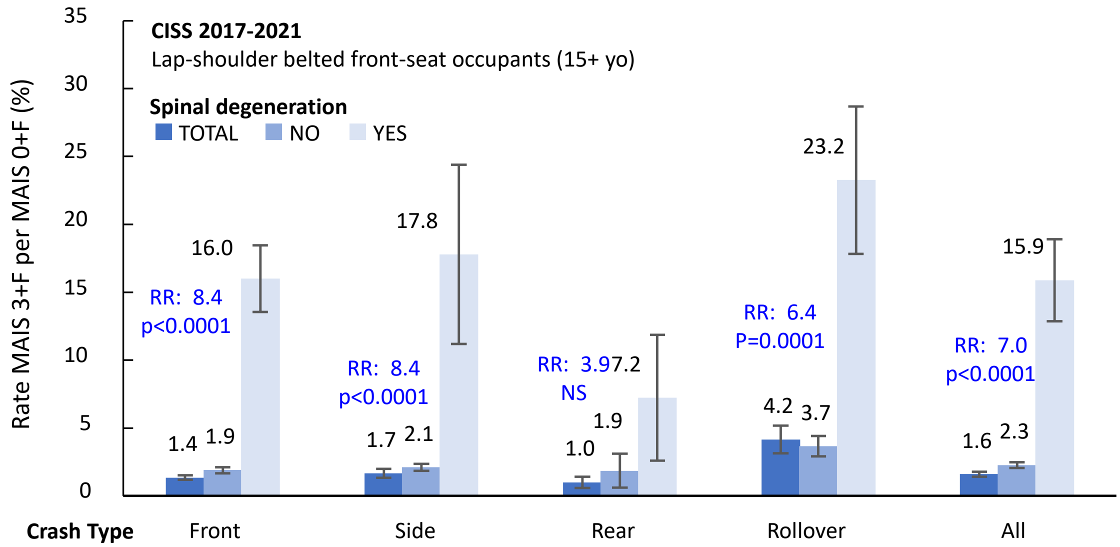

Fig. 1. Rate of serious injury in non-ejected and belted front-seat occupants by crash type and presence of spinal degeneration. (CISS 2017-2021 weighted data).

CIREN data: Table II provides a summary of the CIREN case occupants by crash type. There were 82 lap-shoulder belted and non-ejected front-seat occupants with serious spine injuries among the cases from 2017-2022; most were involved in frontal crashes. Of the 82 occupants, 22% had a pre-existing spinal condition documented in their medical record. The frequency of spine degeneration was higher among the occupants in rear crashes than other crash types. The sample size was however small.

TABLE II
SUMMARY OF LAP-SHOULDER BELTED AND NON-EJECTED FRONT-SEAT OCCUPANTS WITH SERIOUS (AIS 3-6) SPINAL INJURY

	Occupants with AIS 3+ spine injuries		
Crash Type	All	With spine degeneration	Frequency
All	82	18	22.0%
Frontal	61	12	19.7%
Side	16	4	25.0%
Rear	5	2	40.0%

Injuries

CISS Data: Table III shows the total number of serious (AIS 3-6) spine injuries by spine degeneration and spine location. There were 57,347 estimated serious spine injuries. Table A3 provides additional information including unweighted data. More than 50% of spinal injuries were in the lumbar, 31% in the thoracic, and 18% in the cervical area. Overall, more than 60% of serious spinal injuries occurred among occupants with spinal degeneration documented as a comorbidity. Spine degeneration was most frequent among occupants with serious injuries in the lumbar spine, followed by thoracic spine.

TABLE III
SUMMARY OF SERIOUS (AIS 3-6) SPINAL INJURY IN NON-EJECTED AND BELTED FRONT-SEAT OCCUPANTS BY SPINE REGION AND DEGENERATION. (CISS 2017-2021 WEIGHTED DATA)

	Spinal degeneration				
Spine region	No	Yes	Total	% yes	*Region distribution*
All	21,511	35,835	57,347	62.5%	100%
% female	42%	78%	65%	-	-
Mean age	45	69	60	-	-
Cervical	7,325	3,222	10,546	30.5%	18.4%
% female	40%	64%	47%	-	-
Mean age	44	73	53	-	-
Thoracic	7,138	10,798	17,936	60.2%	31.3%
% female	53%	73%	65%	-	-
Mean age	44	61	54	-	-
Lumbar	7,048	21,816	28,864	75.6%	50.3%
% female	35%	83%	71%	-	-
Mean age	46	72	66	-	-

Figure 2 shows the distribution of serious (AIS 3-6) spine injuries by crash type. Frontal impacts accounted for more than 40% of spinal injuries, irrespective of spine degeneration presence. Table A3 in Appendix A provides additional information including unweighted and weighted data including spine location.

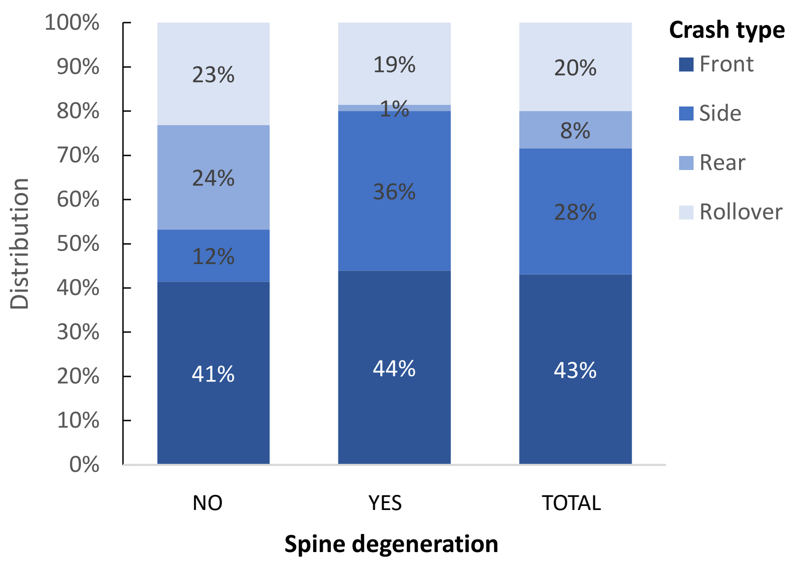

Fig. 2. Distribution of serious (AIS 3-6) spinal injury in non-ejected and belted front-seat occupants by crash type, and degeneration (CISS 2017-2021 weighted data).

CIREN data: Table IV summarizes the spinal injury CIREN data. There were 82 occupants with 103 serious spine injuries. About half (51.5%) of the injuries were in the lumbar area. Spine degeneration was most common in the thoracic area.

TABLE IV
SERIOUS (AIS 3-6) SPINAL INJURY IN NON-EJECTED AND BELTED FRONT-SEAT OCCUPANTS BY SPINE LOCATION AND DEGENERATION

		AIS 3-6 spinal injuries			
	Occupants with spine injury	Total	Cervical	Thoracic	Lumbar
Total	82	103	25	25	53
Proportion	-	-	24.3%	24.3%	51.5%
With spine deg.	18	19	3	9	7
Frequency	22.0%	18.4%	12.0%	36.0%	13.2%

Case review

CISS data: Of the 31,431 (79 unweighted) belted and non-ejected front-seat occupants with serious spine injuries and spinal degeneration, 45% (14,278 weighted/18 unweighted) had a history of prior surgery including implant/fusion, 37% (11,538 weighted/21 unweighted) of osteopenia/osteoporosis, and 33% (10,346 weighted/7 unweighted) had both. There were no other variables to help discriminate the type of prior surgery or location of the surgery. The cases were then reviewed to provide additional insight.

CISS case 2018-17-52 shows an example of multiple prior surgeries in low-to-moderate crash severity. The case involved a 56-year-old female lap-shoulder belted in a 2009 Ford Focus compact sedan. The rear of the Focus was struck by the front of a 2011 GMC C/K (large) pickup, resulting in a +23 km/h delta V (CDC: 06BDEW03). The Focus was pushed off the roadway and travelled into a ditch. Its front then struck the ground (delta V: -14 km/h, CDC: 12FYMW01). The obese (BMI:32.3 kg/m^2) driver sustained a L3 compression fracture injury (AIS 3). The injury's causation was characterized with two potential scenarios, with the most probable being pelvis interaction with the lap belt and seat cushion during the frontal impact event and the other possible scenario being interaction with the seatback in the rear impact event. The driver had a history of three prior back surgeries, which were listed as a contributing factor for the L3 compression fracture. No other injuries were noted. Figure 3 shows the damage to the front and rear of the vehicle. There was minimal evidence of seat loading in the case.

12FYMW01, delta V: 14 km/h
06BDEW03, delta V: 23 km/h

Fig. 3. Multiple prior surgeries in low-to-moderate crash severity (CISS case 2018-17-52).

CISS case 2020-73-71 provides an example of complex medical history in a relatively minor severity crash resulting in a significant injury outcome (Fig 4). This case involves a 77-year-old male belted in the driver seat of a 2006 Ford Escape compact utility vehicle. The vehicle crossed the opposite lane and departed the roadway. Its front contacted several trees. The most significant impact was close to the vehicle centreline with a barrier equivalent speed of -19 km/h. The frontal airbag deployed. The driver sustained a major compression fracture of the L2 vertebra (AIS 3). The injury's causation was characterized as pelvis interaction with the lap belt and seat cushion producing compression in the lower spine. The occupant was hospitalized for six days and died due to prior medical conditions (fatal – ruled disease). The occupant had a history of osteoporosis or osteopenia, musculoskeletal implant, surgery/fusion, impaired coagulation, and degenerative spinal condition. The medical records indicated demineralization of portions of the inferior endplate of L2 and severe osteopenia of the L3 vertebra, which were noted as relevant to the injury causation.

5 frontal impacts, CDC: 12FDEW01, BES: 11.8 mph (19 km/h)

Fig. 4. Older occupant with serious spine injury and a complex medical history involved in a low-speed frontal impact (CISS case 2020-73-71).

CIREN data: Of the 82 belted and non-ejected front-seat occupants with serious spine injuries, 18 had a history of spine degeneration. Of those, two had DISH, two had AS, and one had both. A discussion of the three cases with DISH follows (CIRENIDs 704, 916, and 892).

CIREN case 704 is representative of a serious outcome involving an older occupant with DISH in a moderate rear impact. The case involved a 74-year-old male (180 cm, 140 kg) in a 2017 GMC Yukon XL large utility vehicle. The Yukon was struck in the rear by a 2010 Ford Fusion intermediate sedan. The impact resulted in a +28 km/h delta V according to the event data recorder. Figure 5 shows the vehicle damage and interior. The seat remained upright with minimal seat deformation. The head restraint shows signs of occupant loading.

The radiology records showed multiple fractures including a T5 oblique fracture with anterior distraction (1 cm) of the anterior fragment (AIS 3), T5-6 facet joint fracture with widening of the bilateral facet intervals, a nondisplaced fracture of the right T5 pars interarticularis, a displaced fracture of the T5 spinous process with ossified interspinous ligament, nondisplaced left T5 and T6 transverse process fractures, and a nondisplaced fracture of the L1 right mamillary process (AIS 2). Figure 4 shows select radiology with annotations. Severe canal stenosis was observed at the T5 level from retrolisthesis of the posterior fracture fragment. Comorbidities included obesity (BMI: 43.2 kg/m^2), multilevel spondylosis with anterior bridging osteophytes consistent with DISH, and fusion of the bilateral sacroiliac joints, which may represent sequelae of an inflammatory arthropathy. DISH and spine osteophytes can stiffen the spine and make the joints brittle, increasing the vulnerability to fracture-dislocation during spine loading. The spinal injury causation was attributed to the interaction between the occupant's shoulders and thoracic spine and the seatback with the spinal condition being a contributing factor.

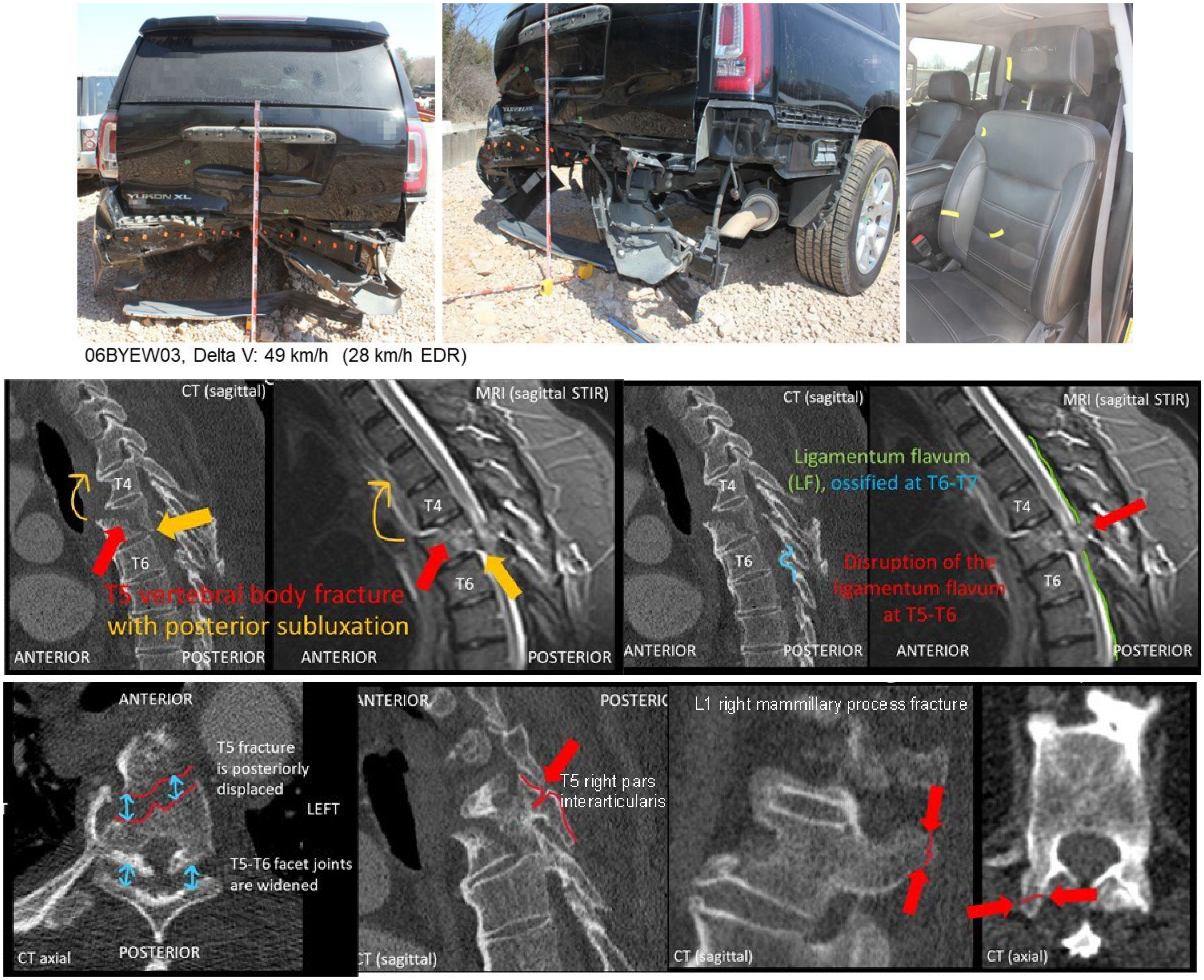

Fig. 5. Older occupant with serious spine injury and DISH involved in a moderate rear impact (CIRENID 704).

CIREN case 916 is representative of a serious outcome with an older occupant with DISH, AS, and osteoporosis in a side impact. The case involved a 79-year-old male (175 cm, 91 kg) driver of a 2018 Chevrolet Equinox compact utility vehicle. The left side of the vehicle was struck by the front of a 2016 Ford Mustang two-door (delta V: +42 km/h). The Equinox yawed counter clockwise after impact and its left front fender contacted the left side of the Mustang (minor impact). The driver sustained sixteen bilateral rib fractures (AIS 3), a left pneumothorax, a pneumomediastinum, and minor left lung contusions, T3 (AIS 3) and T11 (AIS 2) dislocations, a minor T11 endplate fracture, and L1-4 transverse process fractures, likely resulting from the tandem loading of the thorax through the backrest-mounted side airbag and into the intruding door. The occupant's AS and DISH were considered contributing factors in the spinal injury causation scenarios. Figure 6 shows the vehicle and select radiology images.

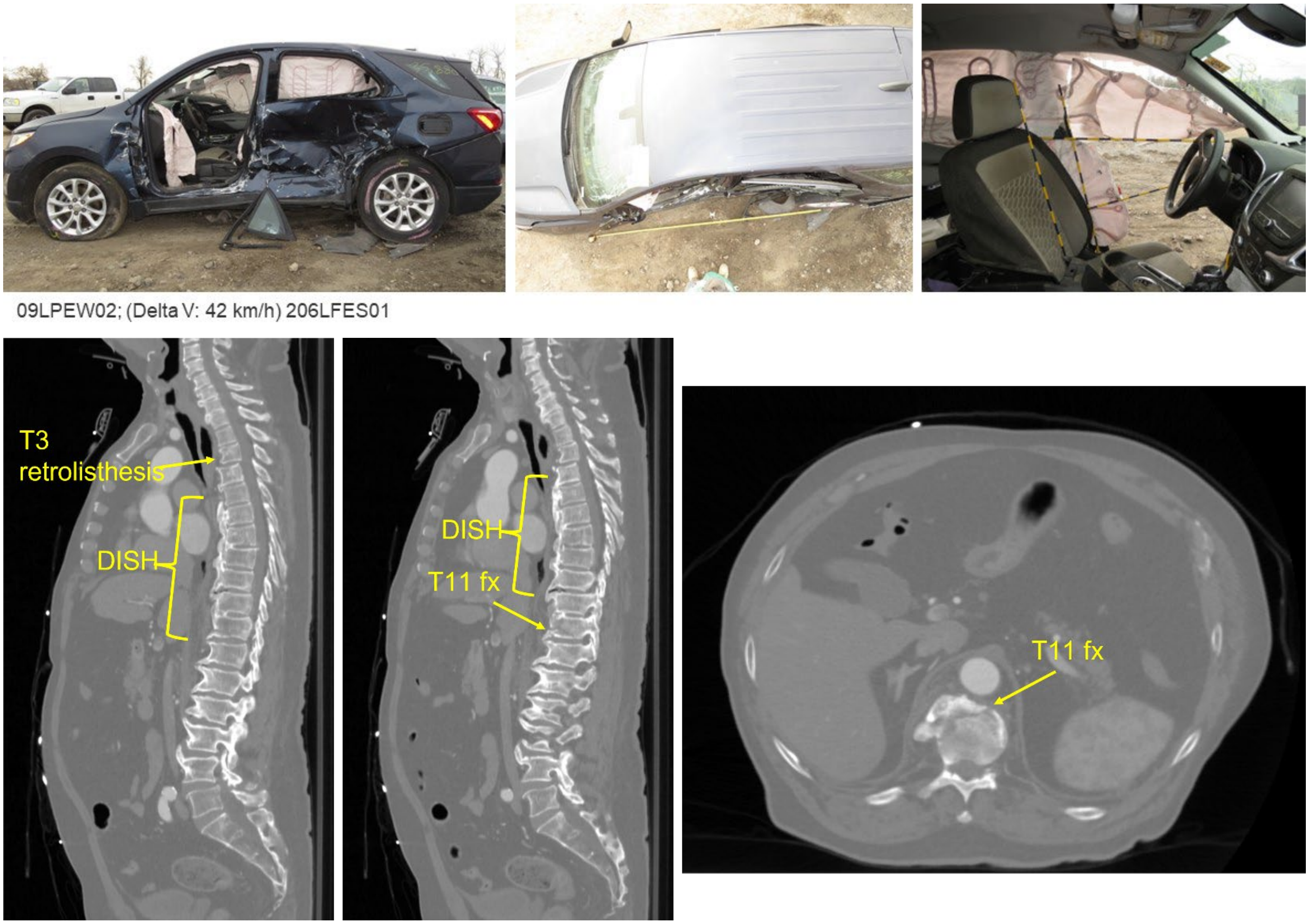

Fig. 6. Older occupant with serious spine injury and DISH and AS involved in a side impact (CIRENID 916).

CIREN case 892 is representative of a serious outcome with an older occupant with DISH in a multi-event crash with rollover. Other comorbidities included osteopenia/osteoporosis, coronary artery disease, atherosclerosis, hypertension, and active chemotherapy. The case involved a 79-year-old female (168 cm, 68 kg) driver of a 2019 Nissan Rogue compact utility vehicle. The vehicle departed the left side of the roadway. Its front struck a guy-wire of a utility pole (event 1). It then crossed a driveway while slightly airborne. The front of the vehicle struck an embankment (Event 2, most significant event), yawed counter clockwise, tripped on the ground and rolled three quarter turns as it yawed (Event 3). The roll was interrupted, as the vehicle rolled back onto its wheels and its undercarriage landed on a speed limit sign (Event 4). Figure 7 shows the vehicle's frontal damage.

The driver's most severe injuries included a L5 burst fracture (AIS 3) and an occipital basilar skull fracture. Other spinal injuries included a T7 minor compression fracture, left C6 facet fracture, left C7 pedicle fracture, L4 minor compression fracture, as well as a minor laceration to the left vertebral artery. The T7 minor compression fracture was attributed to a contact with the occupant's seat cushion during Event 2. The L5 burst fracture and L4 minor compression fracture were attributed to contact with both the seat cushion and lap belt during Event 2. Fracture to the occipital basilar skull, left C6 facet, left C7 pedicle, and associated vertebral artery laceration are possibly due to contact with the left roof side rail or B-pillar during Event 3. Decreased bone quality and DISH likely contributed to the skeletal spine outcome.

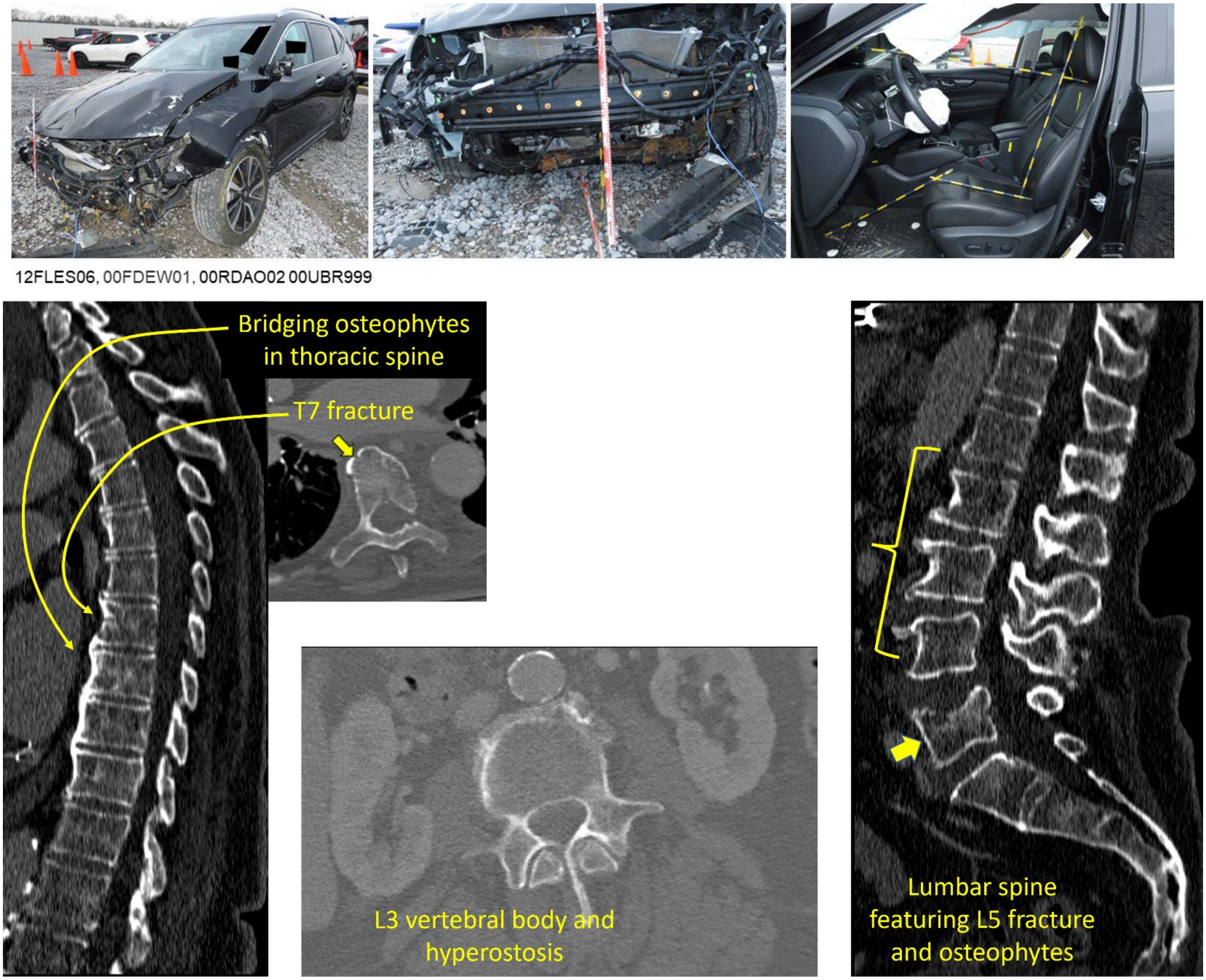

Fig. 7. Older occupant with serious spine injury and history of DISH involved in a complex crash with rollover (CIRENID 892).

CIREN case 694 is another example of spine degeneration and prior surgeries in a moderate frontal crash severity. It involves a 72-year-old male driver (175 cm, 94 kg), lap-shoulder belted in a 2019 Nissan Frontier pickup struck by a 2020 Ford Mustang two-door. Figure 8 shows the case vehicle's damage and interior resulting from the 30 km/h total delta v. The radiology records show a C7 vertebral body fracture (AIS 2) extending into the C7 posterior elements with a right C6-7 facet joint dislocation (AIS 3), a comminuted sternal body fracture, a T1 minor compression fracture with mild anterior height loss, multiple anterior rib fractures bilaterally, and fractures of the L1 and L4 left transverse processes. Figure 8 shows the case subject's prior C4-C7 anterior spinal fusion, with superimposed C6 and C7 fractures, resulting in subluxation of the bilateral C6-C7 facet joints, locked on the right, and perched on the left. There were chronic multilevel degenerative changes, resulting in severe left C3-C4/C4-C5/C5-C6 neuroforaminal narrowing, impinging upon the left C4, left C5 and left C6 nerve roots, with associated effacement of the left C3-C4 lateral recess and moderate spinal canal stenosis. The injury pattern is consistent with neck flexion, likely occurring with the head translation relative to the restrained torso. The injury analysis narrative indicated *Given the low severity of this crash, it's unlikely that the cervical spine fracture injuries would have occurred had this fusion and associated spine degeneration not been present*.

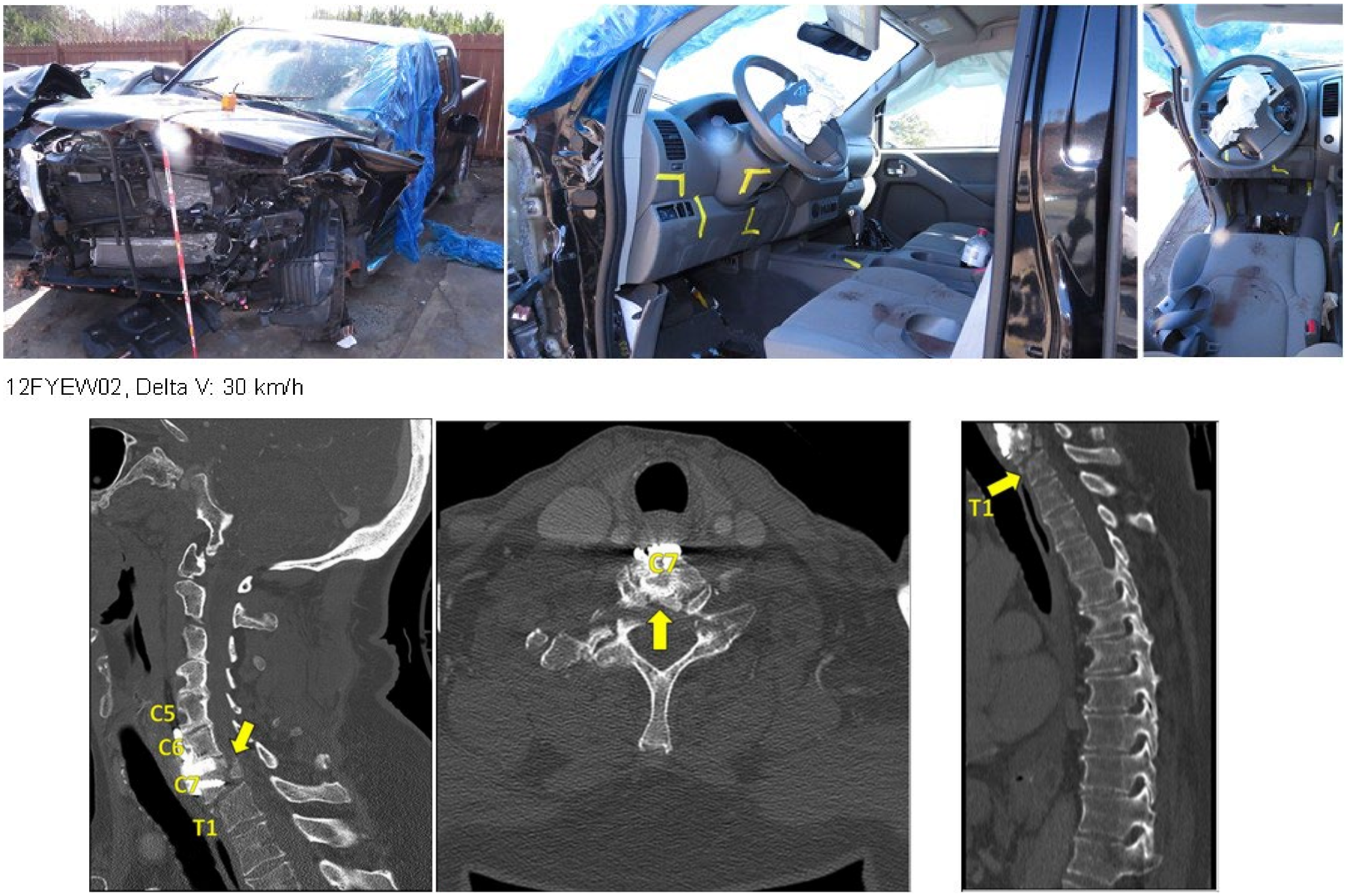

Fig. 8. Older occupant with serious spine injury and history of stenosis and prior cervical surgery involved in a moderate frontal impact (CIRENID 694).

IV. Discussion

The anatomical, biomechanical, and physiological characteristics of the spine are important to consider when assessing injury mechanisms in motor vehicle crashes. Changes in spine tissue properties can influence the mechanical behaviour of the spine during loading and result in lower tolerance to injury. A better understanding on how spine degeneration influences injury outcomes has gained interest in recent years. Prevalence of spine injuries has been assessed. Most studies are often based on small samples [1-3]. This study is a first to report on the prevalence of spine degeneration using a large sample of crash data. The results indicate that spine degeneration was observed in 9.6% of exposed front seat occupants involved in light vehicle crashes. It was documented in 63.2% of occupants with serious spine injuries.

Spine degeneration was most commonly documented among seriously injured occupants in the lumbar area, followed by the thoracic spine. It was also more frequent in females than in males, consistent with prior literature. For example, Parenteau et al. [5] analysed US Medicare data and reported that a higher prevalence of degenerative spine diagnoses, including spine curvature, spondylitis, osteoporosis, and disc degeneration in females compared to males. The exception was DISH, which was more prevalent in males.

The average age of occupants sustaining serious spinal injuries was 1.5-times higher with spinal degeneration as a comorbidity than without based on the CISS data. The association between age and spine degeneration is well-documented [6]. Zhou et al. [7] observed a decrease in injury tolerance with age due to lower bone strength. In this study, the injury rate was determined as the ratio of occupants with serious injury and/or fatality (MAIS 3+F) and exposed occupants (MAIS 0+F). The rates were not adjusted. A Chi-square was used to compare the relative risks. To assess the effect of age, a logistic model was developed using the SURVEYLOGISTIC procedure to compare the difference in injury rate between occupant with and without spine degeneration. The logistic model controlled for potential differences and confounding effects associated with age and sex. The logistic analysis results showed that the overall injury rates (MAIS 3+F) were statistically different when controlling for age (<.0001).

Spine degeneration can be a very broad term. The cases with serious spine injury and degeneration were reviewed from the CISS and CIREN databases. In most CISS cases, there was no information on the specific type of spine degeneration. Some spine degeneration information could however be found in the injury causation details. For example, CISS case 2020-52-107 indicated that the occupant had *congenital cervical kyphosis*. To better understand the type of spine degeneration and how it can affect the injury mechanism, CIREN cases were examined. CIREN cases provide more in-depth medical information, including radiology. CIREN data cannot be used to determine field relevancy since case selection is a purposive sample. Figure 5 shows injury proximity relative to the region of spine degeneration for CIRENID 704. The case illustrates how spine degeneration, such as DISH, can stiffen the spine and increase vulnerability. The occupant in CIRENID 916, who was subjected to a side impact similar in nature and severity to a US NCAP moving deformable barrier test, sustained serious spinal injuries most certainly influenced by DISH and AS. The sagittal view of the spine demonstrates the extent of the DISH, which likely affected overall spine flexibility and response to the lateral loading.

The case review indicates that spine degeneration can lead to serious outcomes even with minor trauma exposure, consistent with prior literature [8]. For example, the CIRENID 704 involved a +29 km/h delta V rear plane impact. The risk of serious injury should be low at that crash severity as indicated by sled test responses falling below the Injury Assessment Refence Value (IARV) [9]. Yet, in the CIREN case, the condition produced serious injury in the spine. The decrease in tolerance for individuals with spine degeneration has been documented [10]. Viano et al. [11] identified a new injury mechanism for spinal fracture-dislocation in older occupants with spinal degeneration in rear crashes. The authors observed that the fracture/dislocation injuries occurred in rear impacts when the occupant's calcified spine tried to straighten along the relatively upright seatback with the high and forward head restraint; some occurred at low crash severity. Viano and Parenteau [12] argued the need for yielding seats to diminish the risk of spine injury in frail occupants who are older and/or have a history of spine degeneration. However, there is a continuous debate when selecting optimal designs due to the complexity of crash and individual characteristics. A yielding seat may not yield optimal results for all circumstances.

The effects of prior surgery were also observed in this study. For example, spinal fusion is a surgical procedure that rigidly connects two or more vertebrae. It can alter the normal biomechanics of the spine by eliminating fused segment mobility and/or altering load paths, resulting in elevated loading of the adjacent joints and segments. Spinal fusion can also lead to spinal degeneration. Adjacent Segment Degeneration or ASD refers to the development of degenerative changes at the next mobile segment above or below spinal fusion. About a quarter of individuals develop ASD within five years after surgery, making them more vulnerable to injury. CISS case 2018-17-52 and CIRENID 694 illustrate the effect of surgical hardware stiffening the spine and resulting in serious spine injury even with minor crash severity. One additional case, not part of the study given the occupant's unbelted status, has been summarized in Appendix B. It involves a 50-year-old male driver with a history of cervical stenosis in a 20 km/h frontal crash. The airbags did not deploy. He sustained serious spine injuries resulting in quadriplegia. The case highlights the potential for serious injury outcomes in a minor event when the occupant has a history of spine degeneration, as previously discussed in the literature.

One notable limitation of this study is the availability of comorbidity data in CISS cases. Comorbidities are only coded for injured occupants whose medical records document the presence of a captured condition. The prevalence of a comorbidity in the exposed population, which includes uninjured occupants, will therefore be underrepresented. Further, some seriously injured occupants may not have a comorbidity recorded if available documentation did not indicate its presence. There is also a possibility a spinal condition may not be recorded if acute care documentation and imaging do not include the spine when no spinal injury is suspected. Although CIREN cases contain extensive medical details, the lower overall case count and selection process limit statistical analysis. Finally, this study does not include an examination of outcomes for occupants with spinal degeneration who did not sustain serious spinal injury. No comparisons in injury outcome were attempted between crashes of similar severity for occupants with and without certain conditions.

V. Conclusions

Occupants with spine degeneration have higher risk of serious injury. An analysis of US field data indicated that spinal degeneration was a common comorbidity in cases with serious spinal injury. There was a strong association between age and presence of spine degeneration coded in the CISS data. The radiology review from selected CIREN cases shows that injury location was dependent on the region of spine degeneration, highlighting their association. Degenerative spine conditions, such as DISH, can stiffen the spine and make it more vulnerable to crash loading, even among restrained occupants in minor severity crashes. Some cases demonstrated the influence of prior spinal fusion surgery, which was also found to relate to the location of injury. This study demonstrates the importance of documenting occupant comorbidities in field crash data systems given their potential for influencing occupant injury tolerance.

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Appendix A

TABLE AI

FRONT-SEAT OCCUPANTS WITH AND WITHOUT SPINE DEGENERATION BY CRASH TYPE AND INJURY SEVERITY

Crash Type	***MAIS Category***	Unwgt	***Incidence*** Weighted	SE	***MAIS 3+F %*** Rate	SE	***95th CL %*** Lower	Upper
			All first row occupants					
Total	3+F	919	199,123	25,354	1.60	0.18	1.22	1.99
	0+F	13,689	12,416,823	1,000,125	-	-	-	-
Front	3+F	473	92,639	12,762	1.35	0.17	1.01	1.70
	0+F	7,186	6,857,672	624,623	-	-	-	-
Side	3+F	201	51,510	12,587	1.67	0.33	0.98	2.36
	0+F	3,332	3,079,649	336,405	-	-	-	-
Rear	3+F	35	10,487	4,331	1.00	0.43	0.10	1.91
	0+F	1,185	1,044,771	81,656	-	-	-	-
Rollover	3+F	165	30,058	6,970	4.15	1.01	2.04	6.26
	0+F	1,181	723,772	68,510	-	-	-	-
			without spine degeneration (NO)					
Total	3+F	582	112,190	10,505	2.27	0.20	1.85	2.70
	0+F	6,613	4,936,098	512,199	-	-	-	-
Front	3+F	289	51,469	6,752	1.90	0.23	1.42	2.38
	0+F	3,413	2,710,024	306,347	-	-	-	-
Side	3+F	124	24,762	5,499	2.11	0.27	1.56	2.66
	0+F	1,528	1,173,131	157,065	-	-	-	-
Rear	3+F	19	6,443	4,145	1.86	1.25	0.00	4.46
	0+F	524	347,036	54,417	-	-	-	-
Rollover	3+F	113	15,711	2,943	3.66	0.75	2.08	5.23
	0+F	771	429,481	52,455	-	-	-	-
			with spine degeneration (YES)					
Total	3+F	312	83,365	18,408	15.9	3.0	9.6	22.2
	0+F	1,353	524,722	54,081	-	-	-	-
Front	3+F	170	38,788	6,982	16.0	2.4	10.9	21.1
	0+F	719	242,358	32,652	-	-	-	-
Side	3+F	71	26,229	11,110	17.8	6.6	4.0	31.6
	0+F	298	147,427	18,352	-	-	-	-
Rear	3+F	15	4,028	1,988	7.2	4.6	0.0	16.9
	0+F	110	55,706	20,247	-	-	-	-
Rollover	3+F	49	13,767	5,783	23.2	5.4	12.0	34.5
	0+F	173	59,225	15,344	-	-	-	-

Total includes other, missing, and unknown data

TABLE AII

SERIOUSLY INJURED (MAIS 3+F) FRONT-SEAT OCCUPANTS WITH SERIOUS SPINE INJURIES AND WITH AND WITHOUT CODED SPINE DEGENERATION

Spine degeneration	Unwgt	***Incidence*** Weighted	SE	***Occ w/ AIS 3+ spine %*** Rate	SE	***95th CL %*** Lower	Upper
Yes	79	31,431	11,512	6.0	2.0	1.87	10.11
No	75	18,295	3,645	0.37	0.08	0.21	0.54
*Total**	154	49,726	13,272	0.40	0.10	0.19	0.62

* Total includes other, missing, and unknown data

TABLE AIII

SERIOUS SPINE INJURIES TO LAP-SHOULDER BELTED FRONT-SEAT OCCUPANTS BY SPINE REGION, SEX, AGE, CRASH TYPE AND SPINE DEGENERATION STATUS

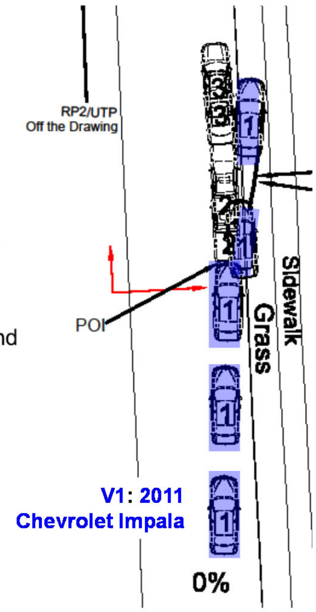
	AIS 3-6 spine injury						
	Unweighted data			Weighted data			
	Spine degeneration						
Spine Region	*No*	*Yes*	*Total*	*No*	*Yes*	*Total*	Freq.
Overall	84	91	175	21,511	35,835	57,347	100%
Males	46	44	90	12,429	7,858	20,287	35%
Females	38	47	85	9,083	27,977	37,060	65%
Mean age (yrs)	-	-	-	45	69	60	-
Front	32	44	76	6,814	15,661	22,475	-
Side	11	13	24	1,940	12,874	14,815	-
Rear	10	5	15	3,892	510	4,403	-
Rollover	21	27	48	3,803	6,626	10,429	-
Other/unk	10	2	12	5,062	165	5,226	-
Cervical	34	22	56	7,325	3,222	10,546	18.4%
Males	16	12	28	4,426	1,147	5,573	53%
Females	18	10	28	2,899	2,075	4,974	47%
Mean age (yrs)	-	-	-	44	73	53	-
Front	12	9	21	3,335	2,418	5,753	-
Side	8	3	11	1,510	218	1,728	-
Rear	1	3	4	71	118	188	-
Rollover	9	7	16	826	468	1,293	-
Thoracic	23	24	47	7,138	10,798	17,936	31.3%
Males	14	10	24	3,388	2,905	6,293	35%
Females	9	14	23	3,750	7,893	11,643	65%
Mean age (yrs)	-	-	-	44	61	54	-
Front	9	10	19	2,175	4,582	6,757	-
Side	1	5	6	77	1,535	1,612	-
Rear	4	1	5	1,762	84	1,846	-
Rollover	7	8	15	2,630	4,597	7,227	-
Lumbar	27	45	72	7,048	21,816	28,864	50.3%
Males	16	22	38	4,615	3,806	8,421	29%
Females	11	23	34	2,434	18,009	20,443	71%
Mean age (yrs)	-	-	-	46	72	66	-
Front	11	25	36	1,304	8,661	9,964	-
Side	2	5	7	354	11,121	11,474	-
Rear	5	1	6	2,060	309	2,369	-
Rollover	5	12	17	347	1,561	1,908	-

Shaded cells indicate <10 unweighted cases

Appendix B

50 yo Male Driver in a 20 km/h Frontal Impact

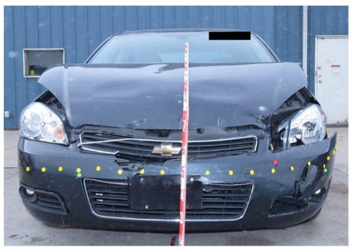
Unbelted, no airbags

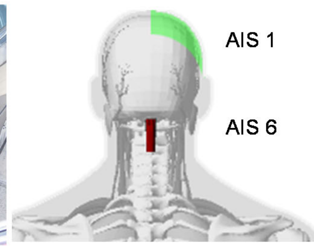


Injury

- Scalp contusion, subgaleal hematoma (AIS 1)
- Cervical spinal cord injury, motor and sensory complete, includes complete cord transection syndrome (AIS Grade A) C3 and above without fracture (AIS 6)

Driver is now quadriplegic. Paralysis below the nipple line. Driver had severe canal stenosis at C3-C4 and ossification of posterior longitudinal ligaments noted at C3-C4 and C5-6. The driver also had a fractured osteophyte of the posterior longitudinal ligament. Cervical spinal cord compression. Driver underwent surgery and had posterior lateral fusion C2-T1 with bilateral C4, C5 lateral mass screws and pars articularis C2 screws, pedicle screws at C7, T1 and C3-6 laminectomy





12FDEW02, delta V: 20 km/h
12LYMS02, delta V: Moderate

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