Lumbar Spine Injuries in Motor Vehicle Crashes

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I. INTRODUCTION

There were 1.35 million fatalities on roads [1] and the aim is to reduce global fatalities by 50% by 2020 [2]. Advancements in vehicle safety are driven by regulations and consumer demands [3]. However, in vehicle regulations, lumbar spine injuries are not assessed, perhaps due to a lack of information [4]. In fact, motor vehicle crashes are one of the most common causes of these injuries [5-7]. Studies [4][8-10] highlight the fact that L1 (the 20th vertebra) is the most frequently injured vertebra.

The following factors which affect lumbar spine injury (LSI) have been mentioned by the literature.

Seat belts: The 3-point belt system has reduced overall spinal injuries [11]. However, belted occupants had five times greater odds for major compression lumbar spine (MCLS) fractures than unbelted occupants [9]. In fact, the incidence rate of thoracolumbar injury scoring two or higher on the abbreviated injury scale (AIS2+) for delta-v greater than 60 km/h increased to 10.3% for the 3-point belt system and 11.3% for the 3-point belt system with airbag deployment. However, for delta-v less than 50 km/h the incidence rate for both configurations was only 0.6% [12]. Another study found that in all cases with LSI a pre-tensioner had activated during the crash [10], suggesting that the pre-tensioner, rather than the seat belt itself, was associated with the mechanism of injury.

Vehicle model year: Despite advances in restraint systems, occupants in 2000+ models have 212% greater odds of experiencing MCLS fractures in frontal collisions than those in 1990s models [9].

Age and gender: Older occupants (65+) have a higher risk of spinal injuries in frontal, side or rollover crashes [13]. A 60-year-old occupant has a 376% greater chance of experiencing an MCLS fracture in a frontal crash than a 20-year-old occupant under the same load conditions; further, females have 20% greater risk for MCLS fractures than males [9].

Vehicle type and collision type: Lumbar spine fractures were far more likely for car occupants than truck occupants, motorcyclists, pedestrians or cyclists. Further, car occupants are more likely to suffer injuries of three and higher on the maximum abbreviated injury scale (MAIS3+) in frontal collisions (51.6%) than in other collision types [14]. Overall, frontal collisions have a higher frequency of thoracolumbar vertebral fractures compared to other types [4].

Other factors, such as collision speed, opponent's vehicle type, occupant's body mass index (BMI), etc., could also have an effect. The current study has three aims: first, to describe LSI using the recent German In-depth Accident Study (GIDAS) database; secondly, to identify statistically significant factors influencing the risk of LSI; and thirdly, to make recommendations for a regulatory approach to assess lumbar spine injuries (LSIs).

II. METHODS

This study consists of descriptive and statistical analyses, both performed in R [15].

Data and Final Sample

This section describes the steps taken to obtain the final sample used to provide an overview of the crash characteristics associated with LSIs. It was performed by querying the GIDAS database released in January 2019 for accidents from 1999-2018. Cases with M1 vehicle involvement and occupants sustaining at least slight injury were selected from all completed cases. From this initial total of 22,531 occupants (Figure 1), 255 were discarded: 179 were missing sequence numbers, 64 occupants were not in the proper seat position, and 12 were missing opponent details. In addition, one occupant's injury, originally miscoded as an LSI, was manually changed to a non-LSI. (This correction was communicated to the GIDAS team and will be updated in the 2020 database release.)

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The final total was 22,276 unweighted occupants. Further, the variables were grouped by collision type (Appendix A), age in the intervals of 20 years, lumbar spine injury (Appendix B) and injury source (Appendix C).

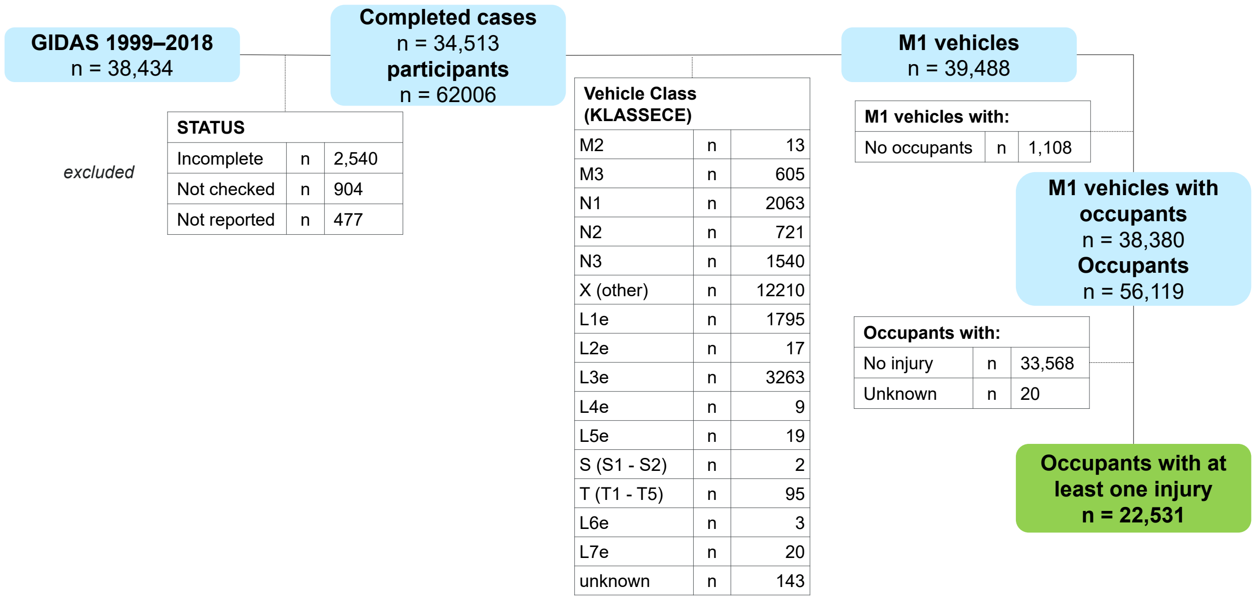

Fig. 1. Step-by-step selection criteria.

The data were weighted and normalised in accordance with the Destatis report for M1 vehicles, using injury severity (slight, serious or fatal) and occupant role (driver or passenger). The normalised weight factors for drivers were slight (1.21), serious (0.26) or fatal (0.4) and for passengers' slight (0.89), serious (1.43) or fatal (0.35). The final sample, used from here on, contains 22,228 (n=22,276) normalised-weighted occupants.

Statistical methods

The sample from the "Data and Final Sample" section was used for the statistical modelling. Occupants under age of 18 (n=1,545) or whose age, gender or both were unknown (n=308) were discarded, resulting in 20,373 (n=20,423) occupants. The predictive-mean matching (PMM) method [16] was used to impute missing values and unknowns for other predictors. Independent variables used for imputation were: accident year (for model year); driver age, driver gender, accident year, model year, number of occupants in the vehicle, and time of day [17] (for initial travelling speed); collision type, opponent body type, and severity (for collision speed); age and gender (for height and weight) were used. Finally, body mass index (BMI) was calculated.

Table I describes each of the predictors supplied to the regression model. All predictors were checked for the presence of multicollinearity using the variance inflation factor (VIF; ≤5) because when different predictors contain similar information (multicollinearity, i.e., VIF>5) the regression model is more unstable (Appendix D).

TABLE I

DESCRIPTION OF THE PREDICTORS WITH DATA TYPES

Predictors	Description	Data type
MODELYEAR	Model year of the vehicle	Continuous
NUMOFCOLL	Total number of collisions for a vehicle	Continuous
MULTICOLL	Whether the vehicle had multiple collisions (=1) or single collision (=0)	Binary
AGE	Age of occupant	Continuous
COLLISIONSPEED	Collision speed (VK) of a vehicle for the sequence under consideration	Continuous
RUNOFF	Whether the vehicle went off-road (=1) or not (=0)	Binary
SKID	Whether the vehicle skidded (=1) or not (=0)	Binary
FRONTSEATED	Occupant seated in the front row (=1) or in a rear row (=0)	Binary
BELTUSE	Occupant used seat belt (=1) or did not use a seatbelt (=0)	Binary
BUCKLEDAMAGE	Buckle for occupant seated position was damaged (=1) or undamaged (=0)	Binary
SIDEBAGDEPLOY	Any side airbag (AIRBSI, AIRBDI, AIRBTI) deployed (=1) or not deployed (=0)	Binary
BMI	Body mass index of occupant (kg/m^2)	Continuous
GENDERMALE	Male (=1) or female (=0) occupant	Binary
OPPONENTCAR	Collision partner was a car (=1) or other (=0)	Binary
COLLTYPFRONTAL	Collision type was frontal (=1) or other (=0)	Binary

The dataset was divided into *training* (80%) and *test* (20%) datasets, to train the model and then test its prediction accuracy. Normalised-weighted logistic regression was performed on the *training* dataset and the Akaike Information Criterion (AIC) and pseudo R^2 values were noted. The best model (with the lowest AIC value) was selected by stepwise backward approach. It was then tested on the *test* dataset using the k-fold cross-validation (k-fold CV) technique, and the root mean squared error (RMSE) was determined; the area under the curve (AUC) was also evaluated for the receiver operating characteristic (ROC) curve [18].

III. INITIAL FINDINGS

Descriptive Analysis

Of the 22,228 occupants, 704 had at least one LSI: 52% were female and 14% were over 60 years old. There were 139 occupants with at least one AIS2+ LSI: 61% were female and 27% were over 60. The main collision types for the 704 occupants were frontal (36%) and rear (34%). For the 139 occupants, frontal collisions alone contributed 65%, followed by side collisions (17%). The delta-v associated with the 704 occupants was 24 km/h or less for 70% of the sample. In contrast, for the 139 occupants, 70% of the sample covered a delta-v up to 49 km/h. There were 758 LSIs across the 704 occupants, with the following AIS-level distribution: 70% AIS1, 23% AIS2, 2% AIS3 and 5% unknown. The injury distribution was: 70% strain (acute, no fracture or dislocation), 23% fracture (with/without dislocation, no cord involvement), 5% other injuries, 1% nerve root or sacral plexus, and 1% disc injury. The 23% that resulted in fractures comprised: 28% no further details, 26% transverse process, 21% burst fracture, 20% minor compression, 4% major compression and 3% spinous process. The most often injured vertebra was L1 at 29% (Figure 2). Figure 3 shows that body motion (54%) and seat-backrest (27%) were the main causes of LSI.

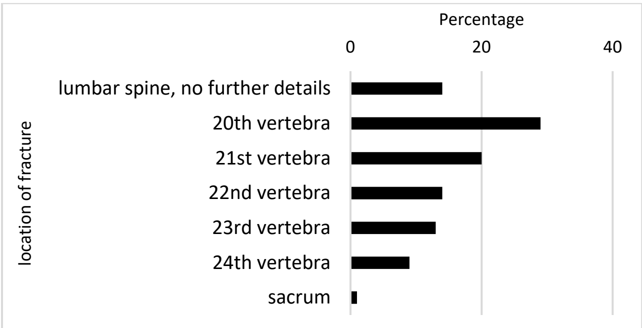

Fig. 2. Distribution of injury location for fracture with/without dislocation and no cord involvement.

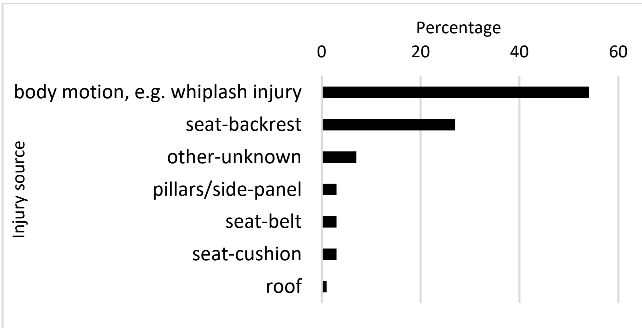

Fig. 3. Distribution of injury source for 758 lumbar spine injuries.

For all 22,228 occupants, those in newer model year (2000+) vehicles had a higher proportion of LSI. Moreover, rear-seated occupants in these vehicles had a higher proportion of LSIs compared to front-seated occupants and the proportion of LSIs for belted occupants was higher than that for unbelted occupants.

Statistical Analysis

The best model obtained by backward selection had an AIC value of 669.78 (Appendix E). Table II shows the odds ratio of predictors with a 95% confidence interval.

TABLE II
ODDS RATIO OF PREDICTORS OF AIS2+ LUMBAR SPINE INJURY

Predictors	**Odds Ratios**	**CI**	**p**
(intercept)			
AGE	1.01	1.00–1.03	**0.007**
COLLISIONSPEED	1.01	1.01–1.02	**<0.001**
SKID	1.83	1.10–3.04	**0.019**
FRONTSEATED	0.55	0.31–1.06	0.054
BELTUSE	2.17	1.06–5.26	0.055
BUCKLEDAMAGE	4.20	1.19–10.86	**0.009**
SIDEBAGDEPLOY	1.84	0.87–3.48	0.080
GENDERMALE	0.60	0.40–0.91	**0.016**
OPPONENTCAR	0.49	0.31–0.80	**0.004**
COLLTYPFRONTAL	2.03	1.33–3.16	**0.001**

The pseudo R^2 value for the best model was 0.08. Further, the area under the curve for ROC was 0.76 and the RMSE from the k-fold CV was 0.01. All predictors were statistically significant ($p<0.05$) except for side airbag deployment, seated position and seatbelt usage ($p<0.1$).

IV. DISCUSSION

Table II lists all the statistically significant factors influencing the risk of LSI. For the five risk factors, there were similarities with the literature: seat belts (usage increases the odds), age (increase in age increases the odds), gender (females have higher odds), vehicle type (car as the opponent has lower odds), and collision type (frontal collision type has higher odds). In addition, buckle damage was associated with a four times greater risk of AIS2+ LSI compared to an undamaged buckle. However, the effect of pre-tensioners or other seat belt features (load-limiters, electrical pre-tensioners, etc.) on LSI was not analysed.

In contrast to the literature [4][9], vehicle model year had worsened the model fit (increase in AIC) and thus was discarded in backward selection. However, the descriptive analysis showed that LSI is more frequent in new model year vehicles. In addition, skidding and collision speed showed greater odds for all vehicles.

Since BMI had no influence on LSI, no dummy is currently excluded due to its anthropometry for evaluating LSIs. Instrumentation should be placed in the proximity of the L1 vertebra (Figure 2). However, more work is required to understand the injury mechanisms, risk curves and thresholds for injury assessment. Finally, it is suggested that lumbar spine loads should be included in frontal crash-tests to increase occupant safety.

V. REFERENCES

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VI. APPENDIX

Appendix A

TABLE A
DEFINITION OF COLLISION TYPES USING GIDAS VARIABLES VDI1, VDI2, ROLLL AND ROLLQ

Labels	Definition
Frontal	VDI1 = 11, 12, 1 VDI2 = 1
Rear	VDI1 = 5, 6, 7 VDI2 = 3
Side	VDI1 = 2, 3, 4, 8, 9, 10 VDI2 = 2, 4
Sideswipe	VDI1 = 5, 6, 7, 11, 12, 1 VDI2 = 2, 4
Rollover	VDI5 = 4 or ROLLL != 0/999 or ROLLQ != 0/999

Appendix B

TABLE B
DEFINITION OF LUMBAR SPINE INJURY ACCORDING TO THE AIS CODES

Injury type	Injury Description	AIS98 codes
Lumbar spine injury	Cauda equina w/wo fracture/dislocation	630600.3,630602.3,630604.3,630606.3,630608.3,630610.3, 630620.3,630622.3,630624.3,630626.3,630628.3,630630.4, 630632.4,630634.4,630636.4,630638.4
	Cord contusion w/wo fracture/dislocation	640600.3,640601.3,640602.3,640604.3,640606.3,640608.3, 640610.4,640612.4,640614.4,640616.4,640618.4,640620.5, 640622.5,640624.5,640626.5,640628.5
	Cord laceration w/wo fracture/dislocation	640640.5,640642.5,640644.5,640646.5,640648.5,640650.5, 640662.5,640664.5,640666.5,640668.5
	Spinous ligament	640684.1
	Nerve root or sacral plexus	630699.2,630660.2,630662.2,630664.2,630666.3,630668.2, 630612.2,630614.3
	Strain acute no fracture or dislocation	640678.1
	Disc injury	650699.2,650600.2,650602.2,650603.3
	Dislocation -no fracture -no cord involvement	650604.2,650609.2,650610.2,650612.3
	Fracture w/wo dislocation no-cord involvement	650616.2,650618.2,650620.2,650622.3b, 650624.3b,650626.3b,650630.2,650632.2,650634.3
	Lumbar spine other injuries	617099.9,617999.9

Appendix C

TABLE C

CLASSIFICATION FOR INJURY SOURCES

General Category	Injury source
Seat-backrest	Backrest of front seat Backrest of rear seat Backrest 3rd row Backrest, further rows (bus)
Seat cushion	Seat cushion, front Seat cushion, rear Seat cushion, 3rd row
Ejected	Ejected Ejected from own vehicle Ejected, surrounding area Ejected, kinematics
Pillars/Side-panel	Upper area of A-pillar Lower area of A-pillar Upper area of B-pillar Seat belt loop, B-pillar Lower area of B-pillar Upper area of C-pillar Seat belt loop, C-pillar Lower area of C-pillar Seat belt loop, D-pillar Upper area of D-pillar Lower area of D-pillar Side panel in rear compartment Door cladding front
Runover	Run over by own vehicle Run over
Airbag	Front passenger airbag, activated Driver airbag, activated Side airbag. Activated Knee airbag [new code since 2010]
Steering	Control levers on steering column left Control levers on steering column right Steering wheel as a whole Steering wheel rim Steering wheel spokes Steering wheel hub Driver airbag, activated Steering column cover Steering column cover
Roof	Front edge of roof Roof section
Body motion, e.g. whiplash injury	Body motion, e.g. Whiplash injury
Own action, e.g. bit tongue	Own action, e.g. Bit tongue

Seat-belt	Seat-belt
Other-unknown	Unknown Windscreen from inside Top of dashboard Pedals Rear window Loose parts inside the vehicle Child restraint system Living area (camper) Collision partner Road surface, even Field, pasture

Appendix D

TABLE D
VARIANCE INFLATION FACTOR (VIF) TO CHECK MULTICOLLINEARITY (VIF>5) AMONG PREDICTORS

PREDICTORS	**VIF**
NUMOFCOLL	2.924881682
MULTICOLL	2.832118344
OPPONENTCAR	1.782108397
RUNOFF	1.670962406
SKID	1.633326737
COLLISIONSPEED	1.294170753
AGE	1.210435037
COLLTYPFRONTAL	1.130250569
BMI	1.128769796
MODELYEAR	1.126575436
SIDEBAGDEPLOY	1.084997956
GENDERMALE	1.067272446
BELTUSE	1.045898055
FRONTSEATED	1.044975506
BUCKLEDAMAGE	1.027025959

Appendix E

TABLE E
FINAL LOGISTIC REGRESSION MODEL USING STEPWISE BACKWARD SELECTION (AIC-669.78)

Coefficients	**Estimate**	**Std. Error**	**Z value**	**p**
Intercept	-6.43	0.58	-11.062	**$<2e^{-16}$**
AGE	0.014	0.005	2.687	**0.007**
COLLISIONSPEED	0.013	0.003	4.406	**$1.05e^{-05}$**
SKID	0.604	0.258	2341	**0.019**
FRONTSEATED	-0.598	0.310	-1.928	0.053
BELTUSE	0.772	0.403	1.916	0.055
BUCKLEDAMAGE	1.435	0.548	2.617	**0.009**
SIDEBAGDEPLOY	0.612	0.350	1.748	0.080
GENDERMALE	-0.504	0.210	-2.399	**0.016**
OPPONENTCAR	-0.710	0.243	-2.912	**0.003**
COLLTYPFRONTAL	0.710	0.220	3.226	**0.001**