Lumbar Spine Injuries in front seat occupants in frontal collisions leading to Long-Term Consequences.

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Abstract Lumbar Spine injuries frequently lead to long term consequences (LTC), although no single injury classification system completely captures LTC. The study developed an approach to ranking the risk and frequency of occurrence of injuries with LTC in road traffic collisions (RTC), using the example of lumbar spine injuries to passenger car front seat occupants in frontal collisions. Multiple complementary classification systems are used, including the Abbreviated Injury Scale (AIS©), the associated predicted Functional Capacity Index (pFCI) and the latest disability weights (DW), to identify injuries with high risk of LTC. Analysis of three in-depth crash databases (France: VOIESUR, Germany: GIDAS, United Kingdom: RAIDS) on the frequencies of different lumbar spine injuries to male and female car front seat occupants in frontal collisions was performed on an injury and occupant level. Considering injury severities, risks of long-term consequences, and frequencies of lumbar spinal injuries in frontal collisions of front seat occupants of cars, the most relevant injuries seem to be lumbar musculoskeletal strains and sprains, as well as lumbar vertebral body fractures (minor compressions). By taking AIS severity and pFCI from real-world collision data, and integrating DW, priorities for injury prevention focused on mitigating LTC are recommended.

Keywords Frontal collisions, Long-Term Consequences, Lumbar spine injuries, occupants, prevention priorities.

I. INTRODUCTION

In general, a stable passenger compartment and occupant restraint systems (i.e. safety belts and airbags) protect car occupants well in frontal impacts. Crash test dummies, as regularly used for the assessment of passive vehicle safety, measure loads applied to the dummy in a crash and thus enable injury assessments to be made, particularly in the head, neck, thorax and femur regions of the body.

However, the market launch of new vehicle (safety) technologies and the possibility of virtually assessing potential injuries using human body models (HBMs) requires a rethink. In particular, automated driving and the expected comfort positions of users, e.g. reclining function, initially suggest an increased risk of injury to the lower spine, abdomen and lower extremities in the event of a traffic crash [1-6]. Therefore, the need to pay special attention to these areas of the body has been recognised. The need is reinforced because in frontal passenger car impacts even with upright seating positions, HBMs may nowadays not effectively assess lumbar spine injuries [1-4] and information about related potential physical long-term consequences (LTC) is rare. However, researchers and developers are confident that HBMs will also be able to evaluate these (LTC-relevant) injuries in the near future. According to Rieger et al. [4] in automotive applications, safety load limits have been successfully applied to protect passengers. For example, these load limits are dummy loading criteria with associated injury risk curves. However, according to them, there is currently no such criterion that is accepted for predicting lumbar spine injury in automotive crashes, but such a lumbar injury criterion would be helpful for evaluating the complex loading conditions and could result in the design of better safety systems [4].

While in the past, the focus was primarily on severe and fatal injuries, efforts to reduce the incidence of LTC now also address relevant injuries of a less severe nature. The present study was conducted as part of the EU-funded research project Injury Mitigation to PROmote Vision-zero Achievement (IMPROVA). The predicted Functional Capacity Index (pFCI) included in the AIS dictionary indicates a functional impairment relating to different physiological functions (not including pain and psychological consequences) that can be expected

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12 months after the injury. The range is from 1 (worst possible state) to 5 (perfect state) [7]. The advantage of the pFCI is the direct link to each AIS code [7]; however, there is only a weak relation to health outcomes in real-world [8,9]. Nevertheless, pFCI can serve as an orientation for selecting relevant injuries of severity AIS 1 and AIS 2 that have been neglected in preventive efforts up until now. In addition, expected disability from injuries as used for calculating Years Lost to Disability (YLD) and Disability Adjusted Life Years (DALYs) [10] could serve as additional criteria for prioritising these low severity injuries that lead to LTC. The Global Burden of Disease (GBD) Study and the INTEGRIS-EUROCOST project published disability weights (DW), which range from 0 to 1 (no disability to 100% disabled) [11-14]. Further, the Injury Burden Estimates Study (Injury-VIBES) measured patient reported health outcome one year after injury with measurement tools like EQ-5D-3L (EuroQuol-5 dimensions-3 levels) [15] and SF 12 (short form 12 items) [16] to calculate DW for injured patients [17]. They published DW for main diagnosis of the patients for three medical classification systems, namely the International Classification of Diseases, 10th revision (ICD-10)[18], the injury groups as defined by EUROCOST and by the GBD. The advantage lies in capturing impact on daily life and psychological LTC in addition to LTC focussing only on bodily functional losses. The disadvantage lies in the injury groups comprising a range of different injuries of different severities.

Lumbar spine (LS) injuries, such as vertebral fractures and ligament tears, are significant causes of disability for healthy individuals and can induce high socioeconomic consequences [19]. Approximately 50% of injuries ranging in severity from minor bony fractures to complex fracture dislocation may lead to disability [20]. LS injuries often lead to chronic pain and functional limitations generally affecting quality of life [21]. 27% of car occupants with permanent medical impairment (PMI) due to LS injuries still suffer from pain even several years after the injury [22]. The risk for a permanent medical impairment (rPMI) at a 10% level is 100% for AIS 4+, and for AIS 2 injuries the risk on a rPMI1% level is 50% [23].

The 18 different AIS4+ codes relating to the LS are incomplete (with preservation of some motor and/or sensory function) (pFCI 2) and complete (pFCI 1) injuries of the lumbar spinal cord, and complete injuries of the cauda equina (pFCI 1) [7]. Published mean DWs for Spinal cord lesion below neck level range from 0.296 to 0.676 [12,13,17,24]. However, no DWs specifically relating to the lumbar spinal cord are published. Road Traffic Collisions (RTCs) are a leading cause of spinal injuries [25], yet, LS injuries are not considered that common. There are no LS injuries of severity AIS 6, 18 AIS 3 injuries have a pFCI of 5, except for the cauda equina injuries with a pFCI of 4, and 34 AIS Codes of severity AIS 1 or AIS 2 all are assigned a pFCI of 5 [7]. Therefore, additional criteria are needed to rank LS injuries for preventive efforts.

For the improvement of Finite Element (FE) HBMs a prioritisation of which structures in the lumbar spine to improve first might be helpful. A special interest is put on lumbar spinal injuries like disk rupture/compression, vertebral body fracture, fractures of the posterior part of the vertebrae, cord/canal compromise or ligament ruptures. A key research question was which of these different injuries or injury types that often only show an AIS severity value between 1 and 3, need to be prevented to reduce LTC.

Most research on the incidence and prevalence of road traffic injuries use the AIS© as the preferred severity scale. In-depth crash databases worldwide use the AIS system in their records. The AIS severity number used in Road Traffic Injury Research ranks the severity of an injury on a scale from 1 to 6, acknowledging lethality, but also energy dissipation, impairment, tissue damage, treatment, and quality of life [7]. As there is already functional estimation of the consequences of each AIS coded injury as given by the pFCI, if each AIS code had also an associated disability weight in addition to the pFCI, a transfer to LTC that not only relate to physical functioning could be gained. Within the IMPROVA Project an attempt to map DW to AIS Codes was started. For the following study questions, the preliminary results of the mapping are applied to the LS injuries, to discuss potential additional knowledge gain:

- Will additional insight be gained by taking DW in addition to AIS and pFCI into account, when prioritising lumbar spine injuries?
- What are the most frequently occurring LS injuries in front seat occupants (FSO) of cars in frontal impacts, and will the frequency and ranking be changed, if focus is set on LTC?

II. METHODS

First, a ranking of lumbar spine injuries as defined by AIS 2015 by their LTC potential was attempted by theoretical considerations. Second, a data analysis of real-world crash data was performed to identify the most frequently occurring LS injuries in frontal car occupants in frontal crashes. The theoretical considerations are taken into account to discuss the focus of preventive efforts.

Data preparation based on literature regarding Lumbar Spine injuries with LTC by AIS, pFCI, and DW

Health related outcomes had been collected from patients, with both treatment in and out of hospital, having been assigned to injury groups as defined by ICD-10 (A), EUROCOST (B), and GDB (C), to calculate mean disability weights that were published in 2016 [17], see TABLE I.

TABLE I
PUBLISHED "MEAN NEW DISABILITY WEIGHTS (95%CI)" AT 12 MONTHS POST-INJURY BY INJURY GROUPS AND HOSPITAL STAY – LUMBAR SPINE RELATED [17]

ID	INJURY GROUPS	Mean DW (95%CI)
A	ICD-10 code; Diagnosis	
A1	S34.1; Other injury of lumbar spinal cord*	0.328 (0.216 to 0.440)
A1	S32.0; Fracture of lumbar vertebra	0.187 (0.156 to 0.219)
A2	S33.5; Sprain and strain of lumbar spine**	0.097 (0.066 to 0.128)
A2	S33.0; Traumatic rupture of lumbar intervertebral disc	0.147 (0.063 to 0.232)
B	Nature-of-injury group EUROCOST	
B1	Spinal cord injury	0.333 (0.296 to 0.370)
B1	Fracture/dislocation/strain/sprain of vertebrae/spine	0.170 (0.155 to 0.186)
B2	Fracture/dislocation/strain/sprain of vertebrae/spine	0.112 (0.086 to 0.138)
C	Injury category GBD	
C1	Spinal cord lesion below neck level	0.356 (0.300 to 0.411)
C1	Fracture of vertebral column	0.168 (0.152 to 0.183)
C2	Fracture of vertebral column	0.113 (0.038 to 0.187)

A New disability weights for the primary diagnosis codes of the International Statistical Classification of Diseases (ICD-10), as derived from the responses of patients, from six injury cohorts,
A1 who were admitted to hospital
A2 who presented at emergency departments but were not admitted to hospital
B New disability weights for the nature-of-injury groups used by EUROCOST, as derived from the responses of patients, from six injury cohorts,
B1 who were admitted to hospital
B2 who presented at emergency department but were not admitted to hospital
C New disability weights for each of the injury categories used in the Global Burden of Disease 2013 study, as derived from the responses of patients, from six injury cohorts,
C1 who were admitted to hospital
C2 who presented at emergency department but were not admitted to hospital
*S34.1- Other injury of lumbar spinal cord includes:
S34.10 complete paraplegia/laceration of lumbar spinal cord
S34.11 incomplete paraplegia/laceration of lumbar spinal cord
S34.18 Other injury of lumbar spinal cord
**S33.5 Sprain and strain of lumbar spine includes:
S33.50 Sprain and strain of lumbar spine nfs
S33.51 Sprain and strain of lumbosacral juncture and its ligaments

In IMPROVA, AIS Codes were mapped to each of the injury groups as defined by ICD-10 (A), EUROCOST (B), and GDB (C), see TABLE VI in the Appendix for lumbar spine AIS Codes. This was done by one expert opinion to test practicability of this methodological approach and is therefore subject to discussion and improvement. In some classification systems there are obviously no apt injury groups for an AIS Code (e.g. no injury group for spinal cord injuries is offered in the GBD systematic applied to out of hospital patients (C2)). In this first step however, AIS Codes were also mapped to injury groups that were not perfectly fitting but were the closest within the classification system. In a second step, for each AIS Code only acceptably fitting injury groups from the six different medical classification systems were kept. The decision on taking the data of patients with in-hospital treatment or not into account was also done by expert assignment (e.g. B1 or B2 for fracture), which is also subject to discussion and improvement. For most AIS codes a different number of injury groups remained that was used for calculating a weighted average of the published mean DW (weighted by number of patients each contributing to the different published mean DW values). By considering AIS severity number, pFCI, and weighted average mean DW a ranking of LS injuries by LTC relevance is performed for AIS3- injuries (TABLE VII in Appendix).

AIS Codes not fitting at all to any of the injury groups after the second step received the weighted averaged DW based on their AIS and pFCI value within the LS (for AIS Codes 610601.2, 610602.2, 610699.1, and 630099.9). The average DW for the body region Lumbar Spine by AIS and pFCI are pictured in Fig 1 in the Appendix.

In-depth Crash data analysis to detect frequent LS injuries for front seat occupants in cars in frontal collisions

For this analysis, the data from the in-depth databases of France (VOIESUR), Germany (GIDAS), and Great Britain (RAIDS) was studied.

Vehicle Occupant Infrastructure Road User Safety Study (VOIESUR) was a French research project focusing on road accidents that occurred in 2011. It includes approximately 8,500 injury crashes derived from in-depth analyses of police reports (including medical reports) involving accidents where at least one person was injured, with inclusion criteria covering all fatal accidents nationwide, all injury accidents in the Rhône region, and a random 5% sample of other injury accidents nationwide. Each accident was thoroughly described across three domains: vehicles, road users (and their injuries), and infrastructure. The sampling design is stratified and supported by weighting factors to ensure national representativeness. Injuries were initially coded using AIS 98 and later mapped to AIS 2015.

Since 1999, the German In-Depth Accident Study (GIDAS) project has performed in-depth investigation of traffic collisions from a purely scientific perspective, aiming to achieve a sustainable improvement in road safety. Around 2,000 road traffic collisions with personal injury are investigated on-scene each year, with up to 3,000 characteristics each. The sampling strategy is regionally based and randomised to support national representativeness. GIDAS captures a wide range of data, including environmental, technical, medical, and psychological information, as well as long-term outcomes. Injuries are documented by AIS 2015; older cases coded by AIS 2005 update 2008 have been translated to AIS 2015.

Road Accident In-Depth Studies (RAIDS) study is the UK’s in-depth road traffic collision data collection programme. Running since 2013, it includes a mix of live-scene investigations and retrospective analyses based on vehicle examinations and police reports, capturing all road users (including uninjured participants), but with a deliberate focus on more severe collisions and occupants of newer vehicles. Data can be scaled to national representativity using weights based on STATS19 national police reported data. At the time of analysing the data for this report, there were 6,979 collision participants included (includes all road user types including pedestrians and uninjured). Fully anonymised injury descriptions are provided by participating hospitals and injuries are coded by AIS 2015; older cases coded by AIS 2005 update 2008 have been translated to AIS 2015.

The following criteria have been used to select the appropriate cases for this analysis: Belted front row occupants of age > 12 years, with LS injuries (defined by Unique Numerical Identifier (UNI) of the AIS Code, first digit of UNI =6 and 4th digit of UNI =6 (included in addition is 630099.9: Injuries to the lumbar spine NFS)), that were sitting in M1 vehicles with Year of Registration from 2004 on, involved in a frontal collision (car must travel forward and is hit from at the front / hits an object with the front), but not having had rollovers or multiple impacts.

The year of homologation was preferred, but availability restrictions led to the decision to use registration year. Depending on database frontal crashes were selected by use of e.g. 11/12/1 o’clock or impact zones. Children up to 12 years would need additional analyses due to the use of child restraints. Therefore, the age restriction was chosen. N1 vehicles were excluded to avoid biases in the analysis due to any geometrical differences of the seat, steering wheel configuration and finally the sitting posture of drivers and front seat passengers compared to M1 vehicles. Fatalities within 30 days of the crash were excluded as the focus was on injuries with LTC after at least 12 months. Multiple impacts including rollover before or after frontal impact were excluded as coding rules and variable availability in the three databases differs. If the lumbar spine injury cannot be attributed to the requested injury-inducing frontal impact (may it be the first or second or most severe) it will change the results and potential conclusions drawn from the analyses.

Analyses on injury and on occupant level have been performed separate for males and females according to SAGER guidelines (Sex and Gender Equity in Research) [26]. Anthropometric differences might contribute to different injuries leading to LTC, and the development of preventive measures for LS injuries by using injury predictions of FE HBMs should start with utilising the apt male or female model, in case differences show up.

A first analysis aims at the frequency distribution of Lumbar spine (LS) AIS Codes on injury and occupant level. For a second analysis an attempt is made to relate a disability weight to a LS injury patient with multiple injuries as coded by AIS. "Mean new DW" with 95%ile CI were published for injury groups of the patients' principal diagnosis [17]. A need for defining the "principal diagnosis" was solved by selecting the injury with the highest AIS severity number. Only those casualties were kept in that sample, that had their MAIS (also) in the Lumbar Spine. The underlying assumption is that the published DW relate to patients with the same injury pattern as in our samples, meaning: with the same main diagnosis, the co-occurring injuries will show the same distribution, and the patients in our sample will show the same disability after 12 months, if they have the same main diagnosis. This is just an approximation, as the patient samples were only in 32.2% from transport-related injury, completed by mostly other blunt trauma, including falls, and in our sample the focus is on passenger car occupants in frontal impacts. Further, the patients in our sample might have suffered from an injury of the same AIS severity in another body region in addition, and might have been treated under that co-occurring principal diagnosis. The DWs are multiplied by the number of patients affected for ranking the "burden" within the databases. The second analysis therefore aims at the frequency distribution of LS AIS Codes on injury and occupant level for those patients with MAIS occurring in the LS.

III. RESULTS

Lumbar Spine injuries with LTC by AIS, pFCI and DW

The AIS Codebook 2015 offers 72 different AIS codes related to Lumbar Spine injuries, covering injuries of the Spinal Cord and Cauda equina, Vertebrae, Nerves/Sacral plexus, Ligaments, Discs, Muscles, but no Vessels or Skin. The severity values range from 1 to 5, the pFCI ranges from 5 to 1. AIS Codes with an associated pFCI 3 do not exist for the LS. The AIS Codes that fit to the different injury groups with published DW are listed in Appendix TABLE VI. In TABLE VII for AIS 3- Codes the calculated weighted average DW are listed.

From theoretical considerations and literature, priorities for prevention efforts to reduce LTC of LS injuries are presented in decreasing order:

- Lumbar Spinal cord injuries (AIS up to 5, pFCI down to 1, DW of 0.328)
- Lumbar Vertebral body fractures (AIS 2 to AIS 3, pFCI 5, DW 0.187)
- Lumbar Disc rupture (AIS 3, pFCI 5, DW 0.147)
- Fractures of posterior part of lumbar vertebrae (AIS 1 to AIS2, pFCI 5, DW 0.113)
- Lumbar Strains/sprains (AIS 1, pFCI 5, DW 0.097)

Lumbar Spine injuries in real-world crash data for front seat occupants in cars in frontal collisions

Results for male FSO, see TABLE II.

The VOIESUR data contained 23 male FSO that had 25 single injuries to the Lumbar Spine. Most frequently (n=8, 35%) the diagnosis of lumbar strain was present. Also, in the GIDAS data of 57 patients with 82 single LS injuries most frequently (n=30, 53%) the diagnosis of lumbar strain (640678.1 - Spinal muscle strain, acute) was found. In the RAIDS data, however, of 64 patients with 104 single LS injuries only 15 (22%) suffered from lumbar strain.

The VOIESUR data contain five patients (22%) with fractures without further specification (not further specified (nfs)) of the fracture (in GIDAS one (2%), in RAIDS twelve (18%)), four (17%) show Lumbar vertebral body fractures nfs (GIDAS five (9%), RAIDS 16 (24%)).

In RAIDS most frequently fractures of at least one transverse process were seen in 20 patients (29%) (VOIESUR three (13%) GIDAS eleven (19%)). The GIDAS data document seven (12%) patients with Lumbar vertebral body fractures with minor compression (VOIESUR only one (4%), RAIDS two (3%)).

TABLE II

FREQUENCY DISTRIBUTIONS OF LS INJURIES IN MALE FRONT SEAT OCCUPANTS

AIS Code	pFCI	n(injuries)	%(injuries)	n(persons)*	%(persons)*
VOIESUR data					
640678.1	5	8	32%	8	35%
650630.2	5	5	20%	4	17%
650616.2	5	5	20%	5	22%
650620.1	5	4	16%	3	13%
650612.3	5	1	4%	1	4%
650634.3	5	1	4%	1	4%
650632.2	5	1	4%	1	4%
total number of injuries, and persons*		25	100%	23	
GIDAS data					
640678.1	5	30	37%	30	53%
650620.1	5	25	30%	11	19%
650632.2	5	8	10%	7	12%
650630.2	5	5	6%	5	9%
630099.9	9	2	2%	2	4%
650602.2	5	2	2%	1	2%
650618.1	5	2	2%	2	4%
650634.3	5	2	2%	2	4%
650636.3	5	2	2%	2	4%
650603.3	5	1	1%	1	2%
650640.3	5	1	1%	1	2%
650616.2	5	1	1%	1	2%
650617.2	5	1	1%	1	2%
total number of injuries, and persons*		82	100%	57	
RAIDS data					
650620.1	5	44	42%	20	29%
650616.2	5	18	17%	12	18%
650630.2	5	18	17%	16	24%
640678.1	5	15	14%	15	22%
650632.2	5	3	3%	2	3%
650617.2	5	3	3%	2	3%
650604.2	5	1	1%	1	1%
650634.3	5	1	1%	1	1%
650636.3	5	1	1%	1	1%
total number of injuries, and persons*		104	100%	68	

*multiple injuries possible

Colours: lumbar strain: blue; vertebra fracture nfs: orange; vertebral body fracture - nfs: grey, – minor compression: green; transverse process fracture: lilac

By reducing the sample to male casualties with their MAIS (also) occurring in the LS, being potentially their principal diagnosis, the following changes can be seen (TABLE III).

In the VOIESUR data 15 male FSO (MAIS = LSMAIS) with 15 single injuries to the Lumbar Spine most frequently (eight, 53%) show the diagnosis of lumbar strain. In GIDAS of 45 casualties with 46 LS injuries now 60% (n=27) are affected by lumbar strain, and in RAIDS (with 46 patients with 59 LS injury codes) the share rises to 28% (n=13). In RAIDS most frequently patients with Lumbar vertebral body fractures nfs are seen (n=15, 33 %) (VOIESUR two (13%), GIDAS three (7%)). In GIDAS six (13%) show Lumbar vertebral body fractures with minor compression (VOIESUR and RAIDS each one). Patients with fractures of at least one transverse process are seen less frequently (VOIESUR one (7%), GIDAS two (4%), RAIDS five (11%)).

By multiplying the weighted average DW with the number of affected patients, the highest burden of injury can be assigned to lumbar strain (in VOIESUR and GIDAS data), and Lumbar vertebral body fractures nfs in RAIDS.

TABLE III
FREQUENCY DISTRIBUTION OF LS INJURIES IN MALE FRONT SEAT OCCUPANTS WITH MAIS = LSMAIS

AIS Code	pFCI	n(injuries)	%(injuries)	n(persons)*	%(persons)*	Weighted average DW	n(persons) x Weighted average DW
VOIESUR data:							
640678.1	5	8	53%	8	53%	0.097	0.776
650616.2	5	2	13%	2	13%	0.170	0.341
650630.2	5	2	13%	2	13%	0.171	0.342
650612.3	5	1	7%	1	7%	0.170	0.170
650620.1	5	1	7%	1	7%	0.154	0.154
650632.2	5	1	7%	1	7%	0.166	0.166
total number of injuries, and persons*		15	100%	15			
GIDAS data:							
640678.1	5	27	59%	27	60%	0.097	2.619
650632.2	5	7	15%	6	13%	0.166	0.998
650630.2	5	3	7%	3	7%	0.171	0.513
630099.9	9	2	4%	2	4%	0.187	0.374
650620.1	5	2	4%	2	4%	0.154	0.308
650634.3	5	2	4%	2	4%	0.171	0.342
650603.3	5	1	2%	1	2%	0.163	0.163
650636.3	5	1	2%	1	2%	0.171	0.171
650640.3	5	1	2%	1	2%	0.171	0.171
total number of injuries, and persons*		46	100%	45			
RAIDS data:							
640678.1	5	13	22%	13	28%	0.097	1.261
650630.2	5	17	29%	15	33%	0.171	2.565
650616.2	5	11	19%	9	20%	0.170	1.534
650620.1	5	11	19%	5	11%	0.154	0.770
650617.2	5	3	5%	2	4%	0.171	0.342
650604.2	5	1	2%	1	2%	0.162	0.162
650632.2	5	1	2%	1	2%	0.166	0.166
650634.3	5	1	2%	1	2%	0.171	0.171
650636.3	5	1	2%	1	2%	0.171	0.171
total number of injuries, and persons*		59	100%	46			

*multiple injuries possible
Colours: lumbar strain: blue; vertebra fracture nfs: orange; vertebral body fracture - nfs: grey, – minor compression: green; transverse process fracture: lilac

Results for female FSO, see TABLE IV.

In VOIESUR 26 female FSO with 42 single injuries to the Lumbar Spine most frequently (n=10, 38%) show the diagnosis of lumbar strain. This is also the most frequent diagnosis in GIDAS with 25 (50%) of 50 female FSO with 64 single injuries to the LS, and in the RAIDS data with 18 (38%) of 47 female FSO with 63 single injuries to the LS. In VOISEUR nine (35%), in GIDAS eight (16%), and in RAIDS eleven (23%) show Lumbar vertebral body fractures nfs.

IN GIDAS seven female FSO (14%) show vertebral fractures with minor compression; in VOIESUR six (23%) and in RAIDS eight (17%) show fractures without further specification of the fracture. In VOIESUR four (15%) show fractures of at least one transverse process, in GIDAS six (12%), and in RAIDS eight (17%).

TABLE IV
FREQUENCY DISTRIBUTION OF LS INJURIES IN FEMALE FRONT SEAT OCCUPANTS

AIS Code	pFCI	n(injuries)	%(injuries)	n(persons)*	%(persons)*
VOIESUR data:					
640678.1	5	10	24%	10	38%
650620.1	5	10	24%	4	15%
650630.2	5	10	24%	9	35%
650616.2	5	8	19%	6	23%
650618.1	5	3	7%	1	4%
650632.2	5	1	2%	1	4%
total number of injuries, and persons*		42	100%	26	
GIDAS data:					
640678.1	5	25	39%	25	50%
650620.1	5	11	17%	6	12%
650630.2	5	10	16%	8	16%
650632.2	5	8	13%	7	14%
650616.2	5	5	8%	4	8%
630099.9	9	2	3%	2	4%
650605.3	5	1	2%	1	2%
650602.2	5	1	2%	1	2%
650604.2	5	1	2%	1	2%
total number of injuries, and persons*		64	100%	50	
RAIDS data:					
640678.1	5	18	29%	18	38%
650620.1	5	17	27%	8	17%
650630.2	5	13	21%	11	23%
650616.2	5	9	14%	8	17%
650632.2	5	2	3%	2	4%
650618.1	5	2	3%	1	2%
650617.2	5	1	2%	1	2%
650634.3	5	1	2%	1	2%
total number of injuries, and persons*		63	100%	47	

*multiple injuries possible
Colours: lumbar strain: blue; vertebra fracture nfs: orange; vertebral body fracture - nfs: grey, – minor compression: green; transverse process fracture: lilac

By reducing the sample to female casualties with their MAIS (also) occurring in the LS, being potentially their principal diagnosis, the following changes can be seen (TABLE V).

In the VOIESUR data 17 female FSO (MAIS = LSMAIS) with 19 single injuries to the Lumbar Spine most frequently (n=9, 53%) show the diagnosis of lumbar strain. This is also the most frequent diagnosis in GIDAS with 23 (59%) of 39 female FSO with 43 single injuries to the LS, and in the RAIDS data with 14 (52%) of 27 female FSO with 37 single injuries to the LS. In VOIESUR four (24%), in GIDAS six (15%), and in RAIDS five (19%) female FSO with MAIS=LSMAIS show Lumbar vertebral body fractures nfs.

In GIDAS five (13%) show Lumbar vertebral body fractures with minor compression. In the VOIESUR data three (18%) and in RAIDS four (15%) show fractures without further specification of the fracture. IN GIDAS one female FSO shows fractures of each one transverse process of two vertebra, and in RAIDS three show fractures of at least one transverse process.

By multiplying the weighted average DW with the number of affected patients, the highest burden of injury can be assigned to lumbar strain (in all three databases) followed by nfs vertebral body fractures (650630.2).

TABLE V
FREQUENCY DISTRIBUTION OF LS INJURIES IN FEMALE FRONT SEAT OCCUPANTS WITH MAIS = LSMAIS

AIS Code	pFCI	n(injuries)	%(injuries)	n(persons)*	%(persons)*	Weighted average DW	n(persons) x Weighted average DW
VOIESUR data:							
640678.1	5	9	47%	9	53%	0.097	0.873
650616.2	5	5	26%	3	18%	0.170	0.511
650630.2	5	4	21%	4	24%	0.171	0.684
650632.2	5	1	5%	1	6%	0.166	0.166
total number of injuries, and persons*		19	100%	17			
GIDAS data:							
640678.1	5	23	53%	23	59%	0.097	2.231
650630.2	5	7	16%	6	15%	0.171	1.026
650632.2	5	5	12%	5	13%	0.166	0.832
630099.9	9	2	5%	2	5%	0.187	0.374
650620.1	5	2	5%	1	3%	0.154	0.154
650605.3	5	1	2%	1	3%	0.147	0.147
650602.2	5	1	2%	1	3%	0.163	0.163
650604.2	5	1	2%	1	3%	0.162	0.162
650616.2	5	1	2%	1	3%	0.170	0.170
total number of injuries, and persons*		43	100%	39			
RAIDS data:							
640678.1	5	14	38%	14	52%	0.097	1.358
650616.2	5	5	14%	4	15%	0.170	0.682
650620.1	5	9	24%	3	11%	0.154	0.462
650630.2	5	5	14%	5	19%	0.171	0.855
650618.1	5	2	5%	1	4%	0.154	0.154
650632.2	5	1	3%	1	4%	0.166	0.166
650634.3	5	1	3%	1	4%	0.171	0.171
total number of injuries, and persons*		37	100%	27			

*multiple injuries possible
Colours: lumbar strain: blue; vertebra fracture nfs: orange; vertebral body fracture - nfs: grey, – minor compression: green; transverse process fracture: lilac

IV. DISCUSSION

In non-fatal real-world crashes from France, Germany, and UK for frontal collisions of front seat passengers most frequently lumbar strains are reported, followed by fractures of lumbar vertebra and transverse processes, followed by minor compression or not further specified vertebral body fractures, both for males and females. Differences between datasets might be biased largely by the case collection or database sampling criteria, coding habits, the share of drivers and front seat passengers, and medical information quality of the different datasets rather than the actual country of origin. Especially the RAIDS data is biased towards more severely injured patients.

Lumbar spinal cord injuries (SCI), showing high severity and LTC, were not found in the real-world data of frontal collisions of front seat occupants given the selection criteria (e.g. excluding fatalities). Literature reports traumatic lumbar SCI as rare events, with a share between 11% and 26% [27,28] of all SCI in the lumbar region, and approximately 30% to 40% of all SCI to be caused by traffic accidents [27-29]. In general, the need to improve FE HBMs in frontal impacts towards predicting lumbar SCI is of low priority as a countermeasure to reduce the long-term consequences of lumbar spine injuries from RTC.

In addition, Chance fractures occurred only in low numbers. Chance fractures (650640.3) or major compression "burst" fractures (650636.3) of lumbar vertebra seem to occur in at maximum 4% of the occupants with LS injuries (based on at least two males in the GIDAS data; in RAIDS data major compression fractures were found twice in men and once in women). Chance fractures are typically caused by seatbelt restraint during high-energy crashes, particularly head-on collisions. The mechanism involves excessive flexion of the spine around the seatbelt as a fulcrum, creating a distraction force that transmits along the spinal column [30]. They have a high association with intra-abdominal injuries, occurring in up to 50% of cases and in a similar fashion to wedge fractures, typically happen at the junction between the thoracic and lumbar spine (T12-L2). Several risk factors such as osteoporosis, high-speed collisions, poor seatbelt positioning have been found to increase the likelihood of wedge fractures [31]. However, it needs to be considered, that especially in the VOIESUR data up to 35% (in RAIDS 23%) of the females show vertebral body fractures nfs, that is, they are not further specified, and in 24% and 28% (RAIDS 20% and 17%) of the females with LS injury those were among the most severe injuries of the patients. Usually, the documentation of injuries is assumed to be of higher quality if the injury was more severe. Only under this assumption, the not further specified vertebral body fractures might more likely be minor compressions and not major compressions, although this is not known for certain. Axial compression fractures occur when bones in the spine are bent forward and are crushed or collapsed due to excessive downward pressure. This can be a common outcome in frontal impacts where the driver or occupant is propelled forward. Tang et al. (2020) indicates that design features intended to prevent submarining can also led to increased lumbar spine forces, thereby raising the risk of fracture [32].

Frequently occurring LS injuries in the data were fractures of the lumbar vertebra, unfortunately often not further specified. If fracture of the vertebral body was known, frequently it was not documented as minor or major compression. A study by Nolet et al. (2020) found that individuals who sustained lumbar fractures in RTCs are 2.7 times more likely to develop chronic low back pain compared to those without such injuries [33]. The long-term consequences of vertebral fractures depend on the type and severity of the fracture, how nerves respond, as well as the effectiveness of pain management [34]. While stable compression fractures may heal with treatment, they can still lead to chronic pain and kyphotic deformity (abnormal concave or convex curvature of the spine) in some individuals [21]. In some cases without surgical stabilisation, severe fractures may lead to life-long persistent pain, stiffness and functional limitations [25]. The AIS severity for minor compression vertebral body fracture is AIS 2, for major compression, and for major compression involving the posterior element it is AIS 3. All of the vertebral body fractures are assigned a pFCI of 5. Literature shows high risk of LTC, and the DW for lumbar vertebra fractures (ICD-10) was given with 0.187 (0.156 to 0.219) [17]. In the future, with reclined sitting postures, a higher share of compression fractures is expected [1,3,5,6].

While the DWs for disc injuries are worth being concerned about, there was very little evidence of these injuries occurring for car occupants in frontal impacts. Disc ruptures occurred only in low numbers (one women in the GIDAS data). Also Kent et al. (2023) report only 0.010 to 0.888 per 10.000 occupants exposed to motor vehicle collisions [25]. Intervertebral discs mimic shock absorbers and sit between vertebral bodies. These are not directly prone to injury despite high forces experienced in RTCs, as the disc is almost never the first structure to be injured in impact loading unless it is highly flexed and compressed [25]. Disc herniation (seen in one man in the GIDAS sample) can compress nearby nerve roots (seen in one woman in the GIDAS sample) leading to radicular pain, neurological deficits, and chronic low back pain. This is reflected by (weighted averaged) DWs of 0.163 and 0.147.

The AIS Codes for fractures of the spinous or one transverse process show AIS severity 1, the lamina, pedicle, and facets have AIS severity 2, all of the codes receive a pFCI of 5. A weighted average DW of 0.154 was calculated for them. In the data especially transverse process fractures were seen, yet, those were not the most severe injuries for these persons in most cases. The AIS Coding rules will obscure bilateral transverse process fractures, as the code for multiple fractures of one vertebra is to be chosen in these cases. However, only one man in GIDAS and two men and one woman in the RAIDS data show this code for multiple vertebra fractures. Fractures of the transverse process seem to occur more frequently in persons with additional injuries of higher AIS severity. As long-term consequences of transverse process fractures are not addressed specifically in literature it seems that they might not have to be prioritised in prevention efforts.

Lumbar strain injuries were most frequently seen in the data, especially in those, who had their most severe injury in the lumbar spine. That they are common in RTC was also reported by [36]. Kent et al. report rates between 108 and 151 per 10.000 occupants exposed to motor vehicle collisions [25]. These injuries can result in localised pain, muscle spasm, and restricted range of motion. While many individuals with these injuries recover within weeks or months, a subset develops chronic pain and disability. The mechanisms underlying the transition from acute to chronic pain in these cases are complex and may involve factors such as psychological distress, maladaptive coping mechanisms, and persistent inflammation [37]. Lumbar distortion in rear-end impacts can be induced by comparable mechanisms like for whiplash injury and in conjunction with whiplash [38]. In approximately 40% [39] of people that suffer from whiplash, an additional lumbar sprain/strain or distortion is seen. For frontal impacts, the mechanisms should be comparable to the Whiplash associated disorders (WAD) in frontal impacts, and a tight lap-belt might increase eccentric contraction of lumbar muscles or injury-inducing motions between vertebra [40-42].

Despite the AIS assigning no functional loss at 12 months after injury (pFCI 5), the DWs for lumbar strain and sprain, disc rupture, and fractures show that after 12 months patients are still suffering from disability due to these injuries [17].

The answer to the first research question in general is no, as the AIS already captures long-term consequences in their severity score. Obviously lumbar spinal cord injuries with permanent impairment should be prevented anyway as being severe injuries and having a high DW. When focussing on AIS3- additional insight can be gained only for the AIS1 injuries (all with pFCI 5) to strengthen the assumption that fractures show higher LTC risk and severity compared to Lumbar strain. Only when taking the frequencies of injuries in real-world data into account additional considerations are enabled by DWs. The answer to the second research question is yes and no. As no AIS4+ injuries are found in the data, a need to improve FE HBM towards those seems not to be given when focusing on LTC. To focus on disc ruptures or major compressions and Chance fractures (all AIS3 and high DWs) is also not supported by the data; however, as a lot of NFS fractures (AIS2, potentially obscuring AIS3 injuries) are documented, they should not be forgotten. AIS1 and AIS2 vertebral body fractures should be addressed according to frequencies and DW. Taking only injury frequencies in real-word data into account the focus should be set on lumbar strain prevention. On a population basis, combining frequencies and DWs, also the lumbar strain comes into focus. This is even pronounced when assuming the LS injury to be the most severe injury for the patient by reducing the sample to MAIS occurring in the LS.

Limitations

The three databases differ in their case mix, especially by crash years and crash severity, the available injury documentation per case and the injury coding. This rather explains the different level of detail of injury codes, and the differences in the found LS injuries. Still, the numbers of many LS AIS Codes found in the three databases were too low to draw final conclusions. Many AIS Codes were found only once. Therefore, a weighting procedure to national levels was not performed as this would over- or underestimate those seldomly documented injuries and injuries not found at all under the given selection criteria would be neglected by extrapolation. Yet, as also from literature there do not seem to be a lot of lumbar spinal cord injuries in frontal crashes, the focus on AIS3- injuries could be justified. In the future a check with other databases such as CISS could be an option to check with weighted results for the US to see if frequencies of LS injuries differ. The theoretical approach leading to the ranking of LS related AIS Codes in TABLE VII showed more granularity compared to only ranking by AIS and pFCI. Still, many AIS Codes relating to the LS end up with the same DW as there were only limited and not exhaustive numbers of injury groups covering a wide range of AIS Codes. Different mapping rules (more or less stringent matching, keeping all or choosing only one injury group) did not lead to big changes (not shown). However, due to the approach of in any case choosing injury groups from different classification systems neither compatible between each other nor with the AIS systematic, obviously the presented average DW values are no true values. EUROCOST and GBD injury groups do not differentiate between thoracic and lumbar vertebral fractures (see TABLE I), therefore the actual value for the lumbar parts might be higher or lower, (usually more chronic low back pain is reported than thoracic back pain as an LTC). Those injury groups do not cover traumatic disc herniation. No direct mapping was possible for sacral plexus and nerve root injuries; for those AIS Codes the unspecific “nerve injury” from the EUROCOST systematic was applied. Yet, those codes were not found in the crash data. In general, the results could have been discussed with literature relating to LTC only and would have led to the same conclusions. Further limitations are, that the Injury Vibes study ignores patients with recovery within three months, and an assessment of LTC was followed-up only until 12 months. Trajectories of LTC after 12 months however are highly individual [43-46]. There might be an option to calculate the burden of injury for aggregated samples, by grouping patients to injury groups first, and then calculating the burden for e.g. the sample of frontal occupants in frontal crashes, still this would be a challenge due to incompatibility of injury groups with AIS Codes. Yet, this was not of interest for the research question at hand. To rank lumbar spinal injuries as coded by AIS by their potential LTC, the calculated weighted average mean DW could have added information in addition to AIS and pFCI, however, only to be considered for careful discussion. The latest DW specifically addressing injuries were published in the Injury-Vibes Study, utilising patient data from the years 2001 up to 2011 without a specific focus neither on road traffic casualties nor on front occupants in frontal crashes. Further effort and improvement should not be put into the presented method, which is limited by relying on decisions based on expert opinion twice, the wide injury groups and the DWs taken from a sample with potentially different injury pattern. Instead, new data should be collected for RTC casualties with injuries coded by AIS, which is aimed at by the IMPROVA project.

V. CONCLUSION

The potential burden of lumbar spine injuries in frontal collisions of front seat occupants of cars might be highest due to lumbar strains for both males and females when the focus of prevention shifts from fatalities and severe injuries to AIS3- injuries with LTC. The pFCI seems to insufficiently identify injuries of lower AIS severity with LTC that are otherwise identified via DWs, indicating need to resolve inconsistencies in scaling approaches. The approach to map AIS Codes to DW must be seen as a first attempt to get started, and future studies and surveys are strongly recommended. In terms of population socioeconomic benefit, it might be indicated to focus on lumbar strain and vertebral body fractures. FE HBM improvement might start with these frequently occurring injuries leading to LTC.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

1. Tushak SK, Donlon PJ, et al. (2022) Failure tolerance of the human lumbar spine in dynamic combined compression and flexion loading. Journal of biomechanics, 135: 111051.

2. Draper D, Newell N, Masouros S, Peldschus S (2021) Multiscale Validation of Multiple Human Body Model Functional Spinal Units. Journal of biomechanical engineering, 143(4): 041011

3. Boyle KJ, Reed MP, Zaseck LW, Hu J (2019) A Human Modelling Study on Occupant Kinematics in Highly Reclined Seats during Frontal Crashes, Proceedings of the International Research Council on the Biomechanics of Injury Conference, Ircobi 2019, IRC-19-43, Florence, Italy

4. Rieger LK, Shah A, et al. (2024) Subject-Specific Geometry of FE Lumbar Spine Models for the Replication of Fracture Locations Using Dynamic Drop Tests. Annals of biomedical engineering 52(4):816–831.

5. Richardson R, Jayathirtha M, et al. (2020) Thoracolumbar spine kinematics and injuries in frontal impacts

with reclined occupants. Traffic injury prevention, 21sup1:66-71.

6. Rawska K, Gepner B, et al. (2019) Submarining sensitivity across varied anthropometry in an autonomous driving system environment. Traffic injury prevention, 20sup2:123-127.

7. Association for the Advancement of Automotive Medicine (2018) Abbreviated Injury Scale: 2015 Revision (6 ed.)., Chicago, IL.

8. Palmer CS, Cameron PA, Gabbe BJ (2020) Comparison of revised Functional Capacity Index scores with Abbreviated Injury Scale 2008 scores in predicting 12-month severe trauma outcomes. Injury prevention : journal of the International Society for Child and Adolescent Injury Prevention 26 (2):138–146.

9. Schluter PJ, Neale R, Scott D, Luchter S, McClure RJ (2005) Validating the functional capacity index: a comparison of predicted versus observed total body scores. The Journal of trauma 58 (2):259–263.

10. Murray CJL, Lopez AD (1996) The Global Burden of Disease: A Comprehensive Assessment of Mortality and Disability from Diseases, Injuries and Risk Factors in 1990 and Projected to 2020. Harvard School of Public Health,

11. Haagsma JA, Graetz N, et al. (2016) The global burden of injury: incidence, mortality, disability-adjusted life years and time trends from the Global Burden of Disease study 2013. Injury prevention : journal of the International Society for Child and Adolescent Injury Prevention 22 (1):3–18.

12. Haagsma JA, Maertens de Noordhout C, et al.(2015) Assessing disability weights based on the responses of 30,660 people from four European countries. Population health metrics 13:10.

13. Haagsma JA, Polinder S, et al. (2012) Improved and standardized method for assessing years lived with disability after injury. Bulletin of the World Health Organization 90 (7):513–521.

14. Polinder S, Haagsma J, Panneman M, Scholten A, Brugmans M, van Beeck E (2016) The economic burden of injury: Health care and productivity costs of injuries in the Netherlands. Accident; analysis and prevention 93:92–100.

15. Devlin NJ, Brooks R (2017) EQ-5D and the EuroQol Group: Past, Present and Future. Applied health economics and health policy 15 (2):127–137.

16. Ware J, Kosinski M, Keller SD (1996) A 12-Item Short-Form Health Survey: construction of scales and preliminary tests of reliability and validity. Medical care 34 (3):220–233.

17. Gabbe BJ, Lyons RA, et al. (2016) Disability weights based on patient-reported data from a multinational injury cohort. Bulletin of the World Health Organization 94 (11):806–816C.

18. Organization WH (2019) International Classification of Diseases Tenth Revision (ICD-10). Sixth Edition edn., Geneva

19. Sundgren PC, Philipp M, Maly PV (2007) Spinal trauma. Neuroimaging clinics of North America 17 (1):73–85.

20. Rajasekaran S, Kanna RM, Shetty AP (2015) Management of thoracolumbar spine trauma: An overview. Indian journal of orthopaedics 49 (1):72–82.

21. Rao RD, Berry CA, Yoganandan N, Agarwal A (2014) Occupant and crash characteristics in thoracic and lumbar spine injuries resulting from motor vehicle collisions. The spine journal : official journal of the North American Spine Society 14 (10):2355–2365.

22. Stigson H, Boström M, Kullgren A (2020) Health status and quality of life among road users with permanent medical impairment several years after the crash. Traffic injury prevention 21 (sup1):S43–S48.

23. Malm S, Krafft M, Kullgren A, Ydenius A, Tingvall C (2008) Risk of permanent medical impairment (RPMI) in road traffic accidents. Annals of advances in automotive medicine Association for the Advancement of Automotive Medicine Annual Scientific Conference 52:93–100

24. Salomon JA, Haagsma JA, et al. (2015) Disability weights for the Global Burden of Disease 2013 study. The Lancet Global health 3 (11):e712–723.

25. Kent R, Cormier J, et al. (2023) Spinal injury rates and specific causation in motor vehicle collisions. Accident; analysis and prevention 186:107047.

26. Heidari S, Babor TF, de Castro P, Tort S, Curno M (2016) Sex and Gender Equity in Research: rationale for the SAGER guidelines and recommended use. Research integrity and peer review, 1:2.

27. Barbiellini Amidei C, Salmaso L, Bellio S, Saia M (2022) Epidemiology of traumatic spinal cord injury: a large population-based study. Spinal cord 60 (9):812–819.

28. Barriga-Martin A, Perez-Ruiz P, et al. (2025) Epidemiology of traumatic spinal cord injury in Spain: A ten-year analysis of trend of clinical and demographic characteristics. J Spinal Cord Med 48 (5):884–890.

29. Lu Y, Shang Z, et al. (2024) Global incidence and characteristics of spinal cord injury since 2000–2021: a systematic review and meta-analysis. BMC medicine 22 (1):1–13.

30. Fouda Mbarga N, Abubakari A-R, Aminde LN, Morgan AR (2018) Seatbelt use and risk of major injuries sustained by vehicle occupants during motor-vehicle crashes: a systematic review and meta-analysis of cohort studies. BMC Public Health 18 (1):1413.

31. Koay J, Davis DD, Hogg JP (2025) Chance Fractures. In: StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK536926/

32. Tang L, Zheng J, Hu J (2020) A numerical investigation of factors affecting lumbar spine injuries in frontal crashes. Accident; analysis and prevention 136:105400.

33. Nolet PS, Emary PC, Kristman VL, Murnaghan K, Zeegers MP, Freeman MD (2020) Exposure to a motor vehicle collision and the risk of future back pain: A systematic review and meta-analysis. Accident; analysis and prevention 142:105546.

34. Beaudoin FL, Kessler RC, et al. (2021) Pain after a motor vehicle crash: The role of socio-demographics, crash characteristics and peri-traumatic stress symptoms. European journal of pain (London, England) 25 (5):1119–1136.

35. Müller CW, Otte D, et al. (2014) Vertebral fractures in motor vehicle accidents - a medical and technical analysis of 33,015 injured front-seat occupants. Accident; analysis and prevention 66:15–19.

36. Laberge-Nadeau C, Bellavance F, Messier S, Vézina L, Pichette F (2009) Occupant injury severity from lateral collisions: a literature review. Journal of safety research 40 (6):427–435.

37. MacNeela P, Doyle C, O'Gorman D, Ruane N, McGuire BE (2015) Experiences of chronic low back pain: a meta-ethnography of qualitative research. Health psychology review 9 (1):63–82.

38. Fast A, Sosner J, Begeman P, Thomas MA, Chiu T (2002) Lumbar spinal strains associated with whiplash injury: a cadaveric study. American journal of physical medicine & rehabilitation 81 (9):645–650.

39. Beattie N, Lovell ME (2010) Can patients with low energy whiplash associated disorder develop low back pain? Injury 41 (2):144–146.

40. Kent R, Forman J (2025) Disc Injury and Spine Loads in Low-to-Moderate-Severity Frontal Impacts. Ann Biomed Eng 53 (10):2689-2700.

41. Minton RM, P.A.; Pitcher, M.; Galasko, CSB. (1998) LOWER BACK AND NECK STRAIN INJURIES: THE RELATIVE ROLES OF SEAT ADJUSTMENT AND VEHICLE SEAT DESIGN. 16th ESV Conference, Enhanced Safety of Vehicles, Windsor, Ontario, Canada, May 31-June 4, 1998

42. Richards DC, M.; Raasch, C.; Pierce, J.; Steffey, D.; Ostarello, A. (2006) INCIDENCE OF THORACIC AND LUMBAR SPINE INJURIES FOR RESTRAINED OCCUPANTS IN FRONTAL COLLISIONS. PROCEEDINGS of 50th ANNUAL Conference ASSOCIATION FOR THE ADVANCEMENT OF AUTOMOTIVE MEDICINE, October 16-18, 2006

43. Gabbe BJ, Simpson PM, et al. (2016) Return to Work and Functional Outcomes After Major Trauma: Who Recovers, When, and How Well? Annals of surgery 263 (4):623–632.

44. Harcombe H, Langley J, Davie G, Derrett S (2015) Functional status following injury: what recovery pathways do people follow? Injury 46 (7):1275–1280.

45. Holbrook TL, Anderson JP, Sieber WJ, Browner D, Hoyt DB (1999) Outcome after major trauma: 12-month and 18-month follow-up results from the Trauma Recovery Project. The Journal of trauma 46 (5):765–771; discussion 771–773.

46. Polinder S, van Beeck EF, et al. (2007) Functional outcome at 2.5, 5, 9, and 24 months after injury in the Netherlands. The Journal of trauma 62 (1):133–141.

VIII. APPENDIX

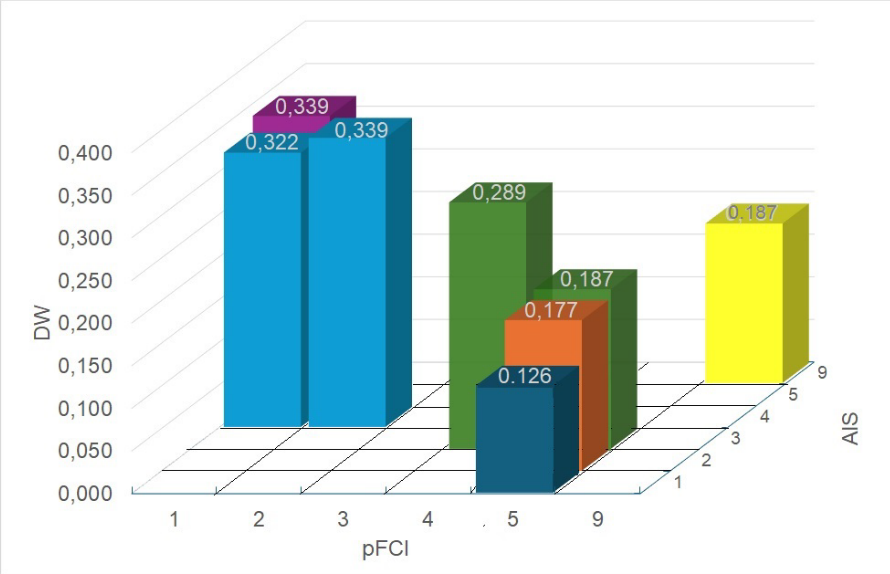

Fig. 1. weighted average values of mean disability weights by AIS severity and pFCI for AIS Codes relating to the lumbar spine.

TABLE VI
Mean new Disability weights (95%CI) At 12 months post-injury by injury groups [17] and AIS Codes matching to Injury Group – lumbar Spine related

Injury Groups with associated DW	mean DW (95% CI)	AIS-Codes 2015 fitting into injury group (multiple fits possible)	pFCI 2015
A1 - Fracture of lumbar vertebra	0.187 (0.156 to 0.219)	610604.3	5
		610608.3	5
		630606.2	5
		630610.2	5
		650616.2	5
		650617.2	5
		650618.1	5
		650620.1	5
		650622.2	5
		650624.2	5
		650626.2	5
		650630.2	5
		650632.2	5
		650634.3	5
		650636.3	5
		650640.3	5
		650698.9	9
A1 - Other injury of lumbar spinal cord	0.328 (0.216 to 0.440)	610600.3	5
		610610.4	2
		610612.4	2
		610613.4	2
		610614.4	2
		610616.4	2
		610618.4	2

		610620.5	1
		610622.5	1
		610623.5	1
		610624.5	1
		610626.5	1
		610628.5	1
		630600.2	5
		630620.3	4
		630622.3	4
		630623.3	4
		630624.3	4
		630626.3	4
		630628.3	4
		630630.4	1
		630632.4	1
		630633.4	1
		630634.4	1
		630636.4	1
		630638.4	1
A2 - Sprain and strain of lumbar spine	0.097 (0.066 to 0.128)	640678.1	5
		640684.1	5
A2 - Traumatic rupture of lumbar intervertebral disc	0.147 (0.063 to 0.232)	610603.2	5
		630603.2	5
		630623.3	4
		630633.4	1
		650605.3	5
		650699.2	5
B1 - Fracture/dislocation/strain/sprain of vertebrae/spine	0.170 (0.155 to 0.186)	610603.2	5
		610604.3	5
		610606.3	5
		610608.3	5
		630603.2	5
		630606.2	5
		630608.2	5
		630610.2	5
		650600.2	5
		650602.2	5
		650603.3	5
		650604.2	5
		650609.2	5
		650610.2	5
		650612.3	5
		650616.2	5
		650617.2	5
		650630.2	5
		650632.2	5
		650634.3	5

		650636.3	5
		650640.3	5
B1 - Spinal cord injury	0.333 (0.296 to 0.370)	610600.3	5
		610610.4	2
		610612.4	2
		610613.4	2
		610614.4	2
		610616.4	2
		610618.4	2
		610620.5	1
		610622.5	1
		610623.5	1
		610624.5	1
		610626.5	1
		610628.5	1
		630600.2	5
		630620.3	4
		630622.3	4
		630623.3	4
		630624.3	4
		630626.3	4
		630628.3	4
		630630.4	1
		630632.4	1
		630633.4	1
		630634.4	1
		630636.4	1
		630638.4	1
B2 - Fracture/dislocation/strain/sprain of vertebrae/spine	0.112 (0.086 to 0.138)	610603.2	5
		610604.3	5
		610606.3	5
		610608.3	5
		630603.2	5
		630606.2	5
		630608.2	5
		630610.2	5
		650600.2	5
		650602.2	5
		650603.3	5
		650604.2	5
		650609.2	5
		650610.2	5
		650618.1	5
		650620.1	5
		650622.2	5
		650624.2	5
		650626.2	5

		650632.2	5
C1 - Nerve injury	0.191 (0.078 to 0.305)	630600.2	5
		630602.2	5
		630603.2	5
		630604.2	5
		630606.2	5
		630608.2	5
		630610.2	5
		630612.2	5
		630614.3	4
		630620.3	4
		630622.3	4
		630623.3	4
		630624.3	4
		630626.3	4
		630628.3	4
		630630.4	1
		630632.4	1
		630633.4	1
		630634.4	1
		630636.4	1
		630638.4	1
		630660.2	5
		630662.2	5
		630664.2	5
		630666.3	4
		630668.2	5
		630699.2	5
C1 - Spinal cord lesion below neck level	0.356 (0.300 to 0.411)	610600.3	5
		610610.4	2
		610612.4	2
		610613.4	2
		610614.4	2
		610616.4	2
		610618.4	2
		610620.5	1
		610622.5	1
		610623.5	1
		610624.5	1
		610626.5	1
		610628.5	1
C1 - Fracture of vertebral column	0.168 (0.152 to 0.183)	650616.2	5
		650617.2	5
		650630.2	5
		650632.2	5
		650634.3	5
		650636.3	5

		650640.3	5
C2 - Fracture of vertebral column	0.113 (0.038 to 0.187)	650616.2	5
		650618.1	5
		650620.1	5
		650622.2	5
		650624.2	5
		650626.2	5
		650632.2	5

TABLE VII
LUMBAR SPINE RELATED MAIN DIAGNOSIS BY AIS CODE AND EXEMPLARY CALCULATED WEIGHTED AVERAGE OF MEAN NEW DISABILITY WEIGHTS (95%CI) AT 12 MONTHS POST-INJURY– SORTED BY DECREASING AIS SEVERITY NUMBER (AIS3-), RISING PFCI AND DECREASING DW

AIS-Code 2015	AIS Severity number	pFCI 2015	weighted average DW
630620.3	3	4	0.324
630622.3	3	4	0.324
630624.3	3	4	0.324
630626.3	3	4	0.324
630628.3	3	4	0.324
630623.3	3	4	0.311
630614.3	3	4	0.191
630666.3	3	4	0.191
610600.3	3	5	0.339
610604.3	3	5	0.189
610608.3	3	5	0.189
650634.3	3	5	0.171
650636.3	3	5	0.171
650640.3	3	5	0.171
650612.3	3	5	0.170
650603.3	3	5	0.163
610606.3	3	5	0.162
650605.3	3	5	0.147
630600.2	2	5	0.324
630602.2	2	5	0.191
630604.2	2	5	0.191
630612.2	2	5	0.191
630660.2	2	5	0.191
630662.2	2	5	0.191
630664.2	2	5	0.191
630668.2	2	5	0.191
630699.2	2	5	0.191
610601.2	2	5	0.177
610602.2	2	5	0.177
650617.2	2	5	0.171
650630.2	2	5	0.171
650616.2	2	5	0.170
650632.2	2	5	0.166
630606.2	2	5	0.166
630610.2	2	5	0.166

650600.2	2	5	0.163
650602.2	2	5	0.163
630608.2	2	5	0.162
630603.2	2	5	0.162
650604.2	2	5	0.162
650609.2	2	5	0.162
650610.2	2	5	0.162
610603.2	2	5	0.161
650622.2	2	5	0.154
650624.2	2	5	0.154
650626.2	2	5	0.154
650699.2	2	5	0.147
650618.1	1	5	0.154
650620.1	1	5	0.154
610699.1	1	5	0.126
640678.1	1	5	0.097
640684.1	1	5	0.097
630099.9	9	9	0.187
650698.9	9	9	0.187

*weighted average is based on varying number of apt injury groups depending on individual AIS Code, taking into account the number of patients that contributed to the according DWs per Injury group