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Occupant injuries in light passenger vehicles—A NASS study to enable priorities for development of injury prediction capabilities of human body models

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ABSTRACT

To prioritize how the development of mathematical human body models for injury prediction in crash safety analysis should be made, the most frequent injuries in the NASS CDS data from 2000 to 2015 were analyzed. The crashes were divided into seven types, from front to side. Non-minor injuries (AIS2+) were analyzed in two steps. In the first step, a grouping was made according to the AIS definition of body regions: head, face, neck, thorax, abdomen and pelvic contents, spine, upper extremities (including shoulder girdle) and lower extremities (including pelvis). In a second step, the body regions were divided in organs, parts of the spine, and parts of the extremities. The three most often injured anatomical structures of each body region were estimated for drivers and front seat passengers in each type of crash.

For drivers, an injury risk greater than 2.4 % was found for the lower extremities (pelvis) and the head (concussion) in side oblique near side impacts, for the head in frontal oblique near side impacts (concussion) and for the lower extremities (ankle joint) in frontal impacts. For passengers, an injury risk greater than 2.4 % was found for the thorax (lungs) in side near side impacts, for the head (concussion) in front oblique near side impacts, and for the thorax (sternum) and the upper extremities (wrist, hand) in frontal impacts.

Future development of human body models should focus on injuries to the head, thorax and the lower extremities. More specifically, it should focus on concussion in all impact directions and on rib and pelvic fractures in side near side impacts and in side oblique near side impacts.

1. Introduction

Traditionally, development and evaluation of passive vehicle safety, such as restraint systems, have been carried out by using anthropometric test dummies (ATDs) in laboratory crash testing and FE-simulations. These ATDs are developed for specific crash directions, such as the HIII and THOR for frontal collisions (Foster et al., 1977; Parent et al., 2013) and the EuroSID and WorldSID for side collisions (Neilson et al., 1985; Lowne and Neilson, 1987; Page, 2001). Furthermore, these ATDs have been developed to evaluate injury risk using regional injury criteria, for example chest deflection to evaluate the risk of thoracic injuries. In this case, different risk curves are available, representing different AIS levels. However, the injury is not related to any specific anatomical structure. Finally, these ATDs have limited ability to reproduce human kinematics in other crash directions than pure frontal and side impacts, since this is not included in the dummy calibration procedure.

In recent years, mathematical Human Body Models (HBMs) have been proposed as a complement to mechanical ATDs for development and evaluation of passive vehicle safety. The two major HBMs of today, representing average-sized males, are the Total Human Model for Safety (THUMS) AM50 (Toyota Central R&D Labs, 2018) and the Global Human Body Model Consortium (GHBMC) M50-O model (Elemance, 2018). HBMs have several advantages in comparison to the mechanical ATDs. For example, as HBMs have detailed representation of the human anatomy, the injury risk can be evaluated on tissue level in any anatomical structure included in the model. The models can enable evaluation of physical variables mechanically related to injury, e.g. energy

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and strain (Rouhana et al., 2003). Another advantage is that HBMs with proper validation have a potential to become more biofidelic for all loading modes, including oblique impacts, due to the fact that the representation of the anatomy is more realistic than in ATDs.

Another important aspect to take into consideration is the future introduction of AD (Automatic Drive) vehicles. The usage of these vehicles may change body posture, seating position and orientation of the occupants compared with today's vehicles. It is therefore important that an analysis of a database containing today's vehicles is performed with the perspective of future AD vehicles. This perspective should also include the fact that there will be a shift in crash configurations that imposes the largest injury frequency as a result of AD crash avoiding technologies. It was shown that future vehicles with crash avoidance technology can eliminate most frontal and roll-over crashes while most side and rear-end impact will remain (Klinich et al., 2016). It was also shown that four crash types will represent 85 % of all AIS2+ injury crashes in the future (Östling et al., 2019). These are: A; Head-On, B; Turn Across Path, Initial Opposite Direction, C; Turn into Opposite Direction and D; Straight Crossing Paths.

The objective of this study is therefore to provide a foundation for prioritizing further HBM development by describing the injury patterns for moderate to severe injuries of light passenger vehicle front seat occupants in frontal, oblique, and side impacts.

2. Method

The study is based on NASS/CDS data cases from years 2000 through 2015. The inclusion criteria were: car model year 2000 or later; restrained front seated occupant at least 15 years of age. The exclusion criteria were: rollover; multiple impacts; and vehicles older than or equal to 10 years at the time of impact. Weighted data were used for the analysis and cases with NASS weighting factor (RATWGT) higher than 5 000 were trimmed to 5 000 (Kononen et al., 2011).

The crash types were selected as result of a perspective of future AD vehicles by using both general area of damage (GAD1) and impact angle (DOF1) and calculating injury risk for the combinations of these two factors (SAE J224, 1980). By this choice of analysis, evaluation of alternative seating positions and the effect of crash avoidance technologies on crash configurations can be performed.

2.1. Type of crash

The crashes were divided into seven types, according to the following definitions for an occupant sitting on the left side (driver). The definitions for the right seated occupant (passenger) are mirrored compared to the definitions below. The crash types are illustrated in Fig. 1 and in Appendix B.

- Side Near Side (DOF1 = 9, GAD1 = Left)

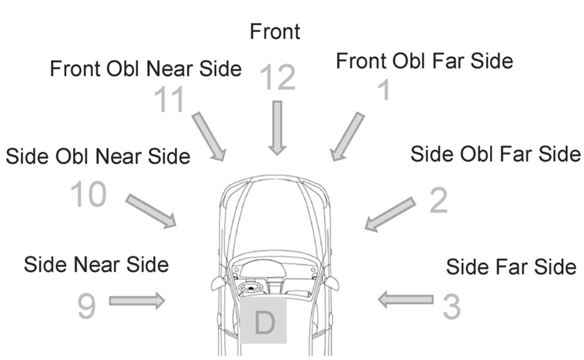


Fig. 1. Definition of crash types for an occupant sitting to the left. The definitions for an occupant sitting to the right are mirrored compared to these.

- Side Oblique Near Side (DOF1 = 10, GAD1 = Left, SHL1 = F, Y or P)
- Front Oblique Near Side (DOF1 = 11 or 12, GAD1 = Front and SHL1 = L or GAD1 = Left and SHL = F, P, Y or D)
- Front (DOF1 = 11, 12 or 1, GAD = Front, SHL1 = C, Z, Y or D)
- Front Oblique Far Side (DOF1 = 12 or 1, GAD1 = Front and SHL1 = R or GAD1 = Right and SHL = F, P, Y or D)
- Side Oblique Far Side (DOF1 = 2, GAD1 = Right, SHL1 = F, Y or P)
- Side Far Side (DOF1 = 3, GAD1 = Right)

2.2. Injuries

The analyses included only non-minor injuries (AIS2+) according to the AIS98 definitions. The injuries were analyzed in two steps. In the first step, a grouping of injuries was made according to the AIS body regions: head, face, neck, thorax, abdomen and pelvic contents, spine, upper extremities (including shoulder girdle) and lower extremities (including pelvis).

The risk of obtaining an AIS2+ injury in a specific body region in a specific type of crash was estimated as the quotient between the number of occupants who were injured in that body region in that type of crash (numerator), and the total number of occupants (injured or not), who had been involved in a crash of that specific type (denominator), as shown in Eq. 1. This risk was computed for both left seated and right seated occupants.

$$\textit{Injury risk of body part}|\textit{crash type} = \frac{\textit{No of occupants with injured body part} \mid \textit{crash type}}{\textit{All occupants} \mid \textit{crashtype}} \tag{1}$$

In a second step, each AIS body region was further divided into subgroups, like organs or organ systems, parts of the spine, and parts of the extremities. The complete list can be found in Table A1 in Appendix A. The basis for the subgroups was the 6-digit numerical identifier of the AIS98-code. However, as these codes are too detailed for the current HBMs, the codes were pooled into functional units in the following way:

- The upper extremity was divided into the following anatomical parts: the shoulder (including the scapula and the clavicle), the humerus, the elbow, the forearm, the wrist and hand (including fingers)
- The lower extremity was divided into the following anatomical parts: the hip (including the pelvis, the hip joint, and the proximal part of the femur), the femur shaft, the knee, the shaft of the lower leg, the ankle joint, and the foot (including toes).

The other body regions were divided into parts, which have or share similar types of function or are alike with respect to the effect of an injury. For example:

- The head was divided in external structures (skull bone and scalp) and internal structures (cerebrum, cerebellum, brain stem). Bleedings like epidural hemorrhage, subdural hemorrhage or subarachnoid hemorrhage were related to one of these internal structures when possible, as were diffuse axonal injuries.
- Concussion cannot be related to a specific part of the brain, why it was classified separately.
- The thorax was separated into the skeletal parts, the diaphragm, the major organs, and the major vessels.
- The abdomen and the pelvic contents were separated into the major organs and the major vessels.
- The face and the neck were separated into the skeletal parts and the organs.
- The spine was separated into the cervical spine, the thoracic spine, and the lumbar spine.

In this step, the three most frequent injuries were reported for the driver and passenger, each crash type and each body region.

Finally, to evaluate the influence of model year within the dataset (MY2000-MY2015) it was divided into two subgroups, MY2000-2006 and MY2007–2015. For this analysis, the number of crash directions were lumped reducing the number of crash directions from seven to three.

3. Results

The total number of crashes in the NASS/CDS database included 89 229 vehicles of model year 2000 through 2015. The number of cases meeting the inclusion criteria in this study was 13 114, and the number of occupants was 17 935. Of these, 12 175 occupants (9 906 drivers and 2 269 front seat passengers) were involved in crashes that could be classified in one of the seven crash types. Of these, 1 832 occupants sustained at least one moderate or more serious (AIS2+) injury. Altogether, these 1 832 occupants sustained 3262 AIS2+ injuries.

Frontal impacts caused 39 % of the casualties, 17 % were injured in frontal oblique impacts, 6 % in side oblique impacts, and 5 % in side impacts. The type of crash could not be classified in 33 % of the cases due to lack of information of any of the variables: General Area of Damage (GAD), clock direction (DOF) or horizontal location of damage (SHL).

The risk of injury to a specific body region is shown in Table 1 for drivers and passengers and for the seven crash configurations.

In drivers, the risk of head injury was at least 2 % in side near side, side oblique near side, and frontal oblique near side impacts. The risk of thoracic injury was at least 2 % in side near side and in side oblique near side impacts. The risk of injury to the upper and lower extremities was at least 2 % in frontal impacts and in side oblique near side impacts.

In passengers, the risk of head injury was at least 2 % in frontal oblique near side impacts. The risk of thoracic injury was at least 2 % in side near side and in frontal impacts. The risk of injury to the lower extremities was at least 2 % in frontal impacts.

In Figs. 2–8, the body region injury risk from Table 1 is expanded to also include the distribution of the top three ranked injuries for each body region. All injuries sum up to 100 % for each body region. However, as only the top three injuries are shown, these do not necessarily sum up to 100 %. The coloring of the occupants corresponds to the coloring in Table 1 (weighted injury risk) to highlight the body regions with highest injury risk.

For the drivers in side near side impacts, concussion was the most common injury of the head followed by subdural hemorrhage and cerebral injury (Fig. 2). For thorax, the most common injuries were rib fractures followed by injuries to the thorax cavity not further specified (NFS) and lung injuries. For the lower extremities, pelvis injuries dominated.

For passengers in side near side impacts, lungs followed by ribs and thorax cavity NFS were the most commonly injured thoracic structures.

For drivers in side oblique near side impacts, the most common head injuries were concussion followed by subdural hemorrhage and cerebral injuries (Fig. 3). For thorax, the most common injuries were rib fractures followed by injuries to the thorax cavity NFS and lung injuries. For the lower extremities, pelvis injuries dominated.

For passengers in frontal oblique near side impacts, the most common head injuries were concussion followed by subdural injuries and injuries to the skull base (Fig. 4).

For drivers and passengers in frontal impacts, the most frequent injuries to the lower extremities were ankle joint injuries followed by knee joint injuries. In addition, for the passengers, the most frequent thorax injury was sternum fractures followed by rib fractures and injuries to the thorax cavity NFS (Fig. 5).

In frontal oblique far side impacts, the injury risk was low for all body regions (Table 2). The injury risk for the different body parts was also low (Fig. 6).

For passengers in side oblique far side impacts, the most frequent injuries to the thorax were rib fractures and injuries to the diaphragm and major vessels (Fig. 7).

For passengers in side far side impacts, the most frequent injuries to the thorax were rib fractures and injuries to the thorax cavity NFS and the heart (Fig. 8).

When dividing the data into two groups: one with older vehicles MY2000-2006 (Table 2) and one with newer vehicles MY2007-2015 (Table 3) and lumping the crash directions into three groups, it can be observed that injuries to the lower extremity decreased somewhat for newer vehicles, while a clear trend cannot be observed for the other body regions.

Table 1
Weighted injury risk (AIS 2+) divided by body part and crash type for MY.2000–2015. (For interpretation of the references to colour in this table, the reader is referred to the web version of this article.)
Color coded according to risk; 0.1-0.6% ☐ 0.6-1.2% ☐ 1.2-1.8% ☐ 1.8-2.4% ☐ 2.4-3.0% ☐

3.0-3.6% ☐

		Head	Face	Neck	Thorax	Abdomen	Spine	Ux	Lx
Driver	Side NS	2.3%	0.1%	0.0%	2.0%	1.1%	1.0%	0.9%	1.8%
	Side Obl NS	2.8%	0.1%	0.0%	2.0%	0.5%	0.9%	2.2%	3.0%
	Frontal Obl NS	2.5%	0.1%	0.0%	0.9%	0.2%	0.6%	1.2%	1.6%
	Frontal	1.1%	0.1%	0.1%	1.6%	0.5%	0.8%	2.0%	2.6%
	Frontal Obl FS	0.8%	0.2%	0.0%	1.4%	0.1%	0.1%	1.7%	0.4%
	Side Obl FS	1.5%	0.0%	0.0%	1.4%	0.1%	0.4%	0.4%	1.6%
	Side FS	1.0%	0.1%	0.0%	0.5%	0.2%	0.3%	0.2%	0.5%
Pass	Side NS	1.8%	0.0%	0.0%	2.6%	1.6%	0.6%	0.0%	1.6%
	Side Obl NS	0.6%	0.0%	0.0%	1.7%	1.0%	0.2%	1.1%	1.3%
	Frontal Obl NS	2.6%	0.6%	0.0%	1.1%	0.6%	0.2%	1.1%	1.4%
	Frontal	0.9%	0.1%	0.0%	3.0%	0.5%	0.8%	2.6%	2.2%
	Frontal Obl FS	0.2%	0.0%	0.0%	0.4%	0.5%	0.1%	0.9%	0.2%
	Side Obl FS	1.9%	0.2%	0.0%	1.9%	0.4%	0.6%	0.4%	1.0%
	Side FS	0.8%	0.0%	0.0%	1.5%	0.1%	0.3%	0.2%	0.7%

Region	Passenger	%	Driver	%
Head	Subdural	53	Concussion	53
	Vault	18	Subdural	27
	Base	17	Cerebrum	13
Up. Ext	-	-	Shoulder	69
	-	-	Forearm	14
	-	-	Wrist, Hand	10
Thorax	Lungs	56	Ribs	57
	Ribs	21	Thorax cavity NFS	20
	Thorax cavity NFS	14	Lung	18
Spine	Cervical	87	Lumbar	54
	Thoracic	13	Cervical	37
	Cervical	-	Thoracic	6
Abdom.	Spleen	89	Spleen	51
	Liver	11	Liver	27
	-	-	Kidney	11
L. Ext.	Pelvis	96	Pelvis	88
	Femur Shaft	3	Lower leg NFS	5
	Ankle joint	1	Ankle Joint	2

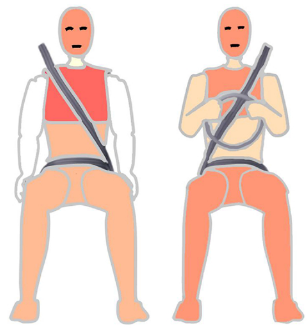


Fig. 2. The most common injuries in side near side impacts.

4. Discussion

In this study, the injured body regions and the specific injuries were analyzed and graded based on injury risk. The AIS98 system was used for injury classification, due to the fact that this was used for cases during 2000-2010. The frequency of the crash types was not taken into account. For example, the risk of an AIS2+ injury in frontal impacts was lower or equal to that in near side impacts for all body regions. However, as the number of frontal impacts was much greater (40 %) than in near side impacts (5 %), the number of AIS2+ injuries sustained in frontal impacts was much greater than in near side impacts. If the focus of the study had been the most frequently injured body regions, the results would have been concussive head injury, forearm injury, rib fractures, and injuries to the lower leg and foot sustained in frontal impacts. The frequency of injuries can be found in Appendix C. Since only the top three injuries were shown, there is a risk that an injury with a relatively high frequency can be missed. The injuries with the fourth highest frequency represented 10–16 % of the injuries for respective load case and body region. However, all these injuries were present among the top three injuries for other load cases or positions. Thus, no injuries important for HBM development were missed.

In recent studies it was shown that the exposure can shift as vehicles become more automated. In a study by Klinich et al. (2016), the authors estimated that future vehicles with comprehensive crash avoidance technology can eliminate most frontal and roll-over crashes, while most side and rear-end impacts will remain, thus shifting the AIS2+ injury producing load cases towards side impacts. In another study, estimating the potential influence of all future advanced driver assistance systems (ADAS) on future crash scenarios, four crash scenarios will represent 85 % of all AIS2+ injury crashes (Östling et al., 2018). These four crash scenarios are: A. Head-On; B. Turn Across Path, Initial Opposite Direction; C. Turn into Opposite Direction; and D. Straight Crossing Paths. For these crash configurations, the most common injuries in the future are estimated to be located to the head, thorax, and spine. However, these crash scenarios are not directly related to the crash types of this study.

Taking the expected future shift into account, this study suggests that the future development of human body models should focus on injuries seen in near side impacts. The anatomical structures and injuries that primary should be addressed are brain injuries (concussion), rib fractures and pelvis fractures. To address concussion, detailed brain models have already been developed (Kleiven, 2007; Sahoo et al., 2014). These models assess brain injuries by means of physical parameters such as stress or strain. Based on the stress or strain values, the risk of concussion is predicted using a brain tissue risk function. These models have been able to predict concussion by modelling various types of head impact resulting in concussion (Kleiven, 2007; Sahoo et al., 2014) and appear to be applicable tools to assess brain injuries. However, as concussion cannot be related to a specific part of the brain, the HBMs should also include the brain stem and part of the spinal cord.

It was shown that the risk of an occupant to sustain rib fractures in a frontal impact can be predicted by the strain in the ribs (Iraeus and Lindquist, 2015). Fracture prediction using strain is independent of loading direction. However, validation of the human body model has to be expanded to include oblique and side loading before the model can predict rib fracture, regardless of the direction of impact. In addition,

Region	Passenger	%	Driver	%
Head	Concussion	58	Concussion	57
	Subdural	32	Subdural	24
	Cerebrum	9	Cerebrum	8
Up. Ext	Shoulder	98	Shoulder	73
	Arm NFS	2	Wrist, Hand	19
	-	-	Forearm	6
Thorax	Ribs	76	Ribs	63
	Lung	12	Lung	17
	Thorax cavity NFS	6	Thorax cavity NFS	15
Spine	Thoracic	54	Lumbar	91
	Cervical	46	Cervical	7
	Lumbar	-	Thoracic	2
Abdom.	Spleen	42	Spleen	79
	Kidney	30	Liver	13
	Liver	16	Kidney	5
L. Ext.	Pelvis	72	Pelvis	78
	Ankle joint	27	Lower leg NFS	10
	Other	1	Knee Joint	6

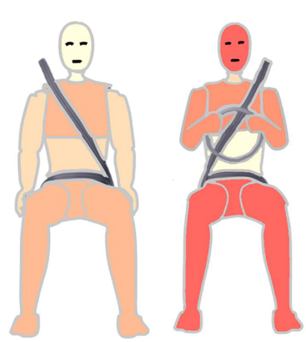
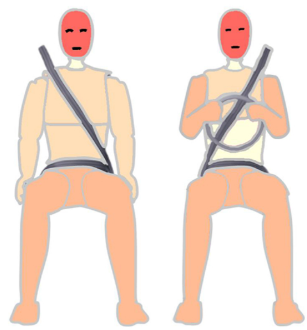


Fig. 3. The most common injuries in side oblique near side impacts.

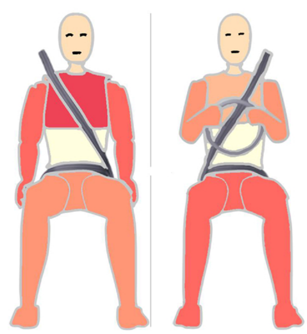
Passenger		%
Head	Concussion	74
	Subdural	19
	Base	3
Up. Ext	Shoulder	48
	Wrist, Hand	21
	Forearm	17
Thorax	Ribs	45
	Lung	26
	Thorax cavity NFS	13
Spine	Lumbar	47
	Cervical	42
	Thoracic	10
Abdom.	Spleen	42
	Bladder	23
	Liver	14
L. Ext.	Pelvis	44
	Lower leg NFS	16
	Ankle joint	14



Driver		%
Head	Concussion	83
	Subdural	8
	Cerebrum	5
Up. Ext	Forearm	41
	Wrist, Hand	29
	Shoulder	22
Thorax	Ribs	45
	Sternum	40
	Thorax cavity NFS	9
Spine	Lumbar	50
	Cervical	46
	Thoracic	3
Abdom.	Spleen	37
	Mesentery	25
	Liver	21
L. Ext.	Pelvis	39
	Ankle Joint	14
	Lower leg NFS	10

Fig. 4. The most common injuries in frontal oblique near side impacts.

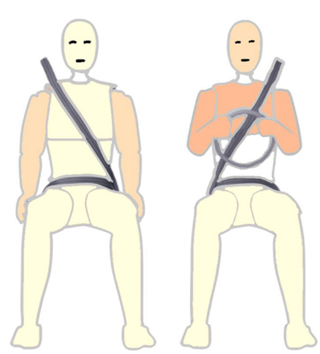
Passenger		%
Head	Concussion	76
	Subdural	12
	Cerebrum	4
Up. Ext	Wrist, Hand	46
	Forearm	30
	Shoulder	16
Thorax	Sternum	54
	Ribs	34
	Thorax cavity NFS	8
Spine	Lumbar	54
	Cervical	29
	Thoracic	17
Abdom.	Spleen	73
	Mesentery	14
	Liver	6
L. Ext.	Ankle joint	31
	Knee joint	24
	Lower leg NFS	18



Driver		%
Head	Concussion	75
	Subdural	16
	Cerebrum	4
Up. Ext	Forearm	44
	Wrist, Hand	34
	Shoulder	14
Thorax	Sternum	43
	Ribs	37
	Lung	12
Spine	Lumbar	60
	Cervical	30
	Thoracic	10
Abdom.	Liver	49
	Spleen	32
	Kidney	6
L. Ext.	Ankle Joint	26
	Knee Joint	20
	Foot	19

Fig. 5. The most common injuries in frontal impacts.

Passenger		%
Head	Subdural	69
	Concussion	29
	Cerebrum	2
Up. Ext	Forearm	63
	Humerus	17
	Shoulder	17
Thorax	Ribs	72
	Sternum	19
	Thorax cavity NFS	8
Spine	Lumbar	83
	Thoracic	14
	Cervical	2
Abdom.	Kidney	73
	Spleen	26
	Bowl	1
L. Ext.	Ankle Joint	73
	Knee Joint	7
	Lower Leg Shaft	7



Driver		%
Head	Concussion	92
	Subdural	4
	Cerebrum	3
Up. Ext	Wrist, Hand	56
	Forearm	21
	Shoulder	20
Thorax	Ribs	74
	Lung	15
	Sternum	10
Spine	Thoracic	40
	Lumbar	38
	Cervical	21
Abdom.	Liver	80
	Mesentery	10
	Kidney	6
L. Ext.	Knee Joint	46
	Ankle Joint	22
	Pelvis	18

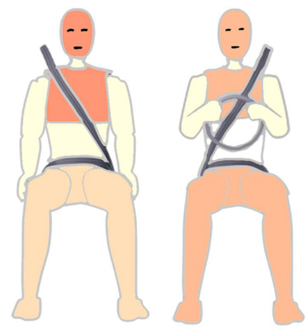
Fig. 6. The most common injuries in frontal oblique far side impacts.

the increased injury risk from combined loading of the chest such as simultaneous load on the chest from the front and side can be accounted for.

Few published studies exist with similar scope as the current study. However, in a NASS-CDS 2000–2011 study of restrained occupants, it was found that the lower extremity had the highest risk of AIS2+ injury (24.6 %), followed by the upper extremity (16.0 %), thorax (12.4 %), head (7.6 %), spine (4.6 %), abdomen (3.4 %) and face (0.6 %) (Weaver et al., 2015). These results are similar to that of the current study if exposure is also considered, or in other words, these are the body parts most commonly injured in frontal impacts. Another study on the Mortality Risk Ratio (MRR), which measures the mortality associated with injuries, showed that the most common AIS2+ head injury was unconsciousness less than one hour (AIS2) with a mortality risk of < 0.1 % (Weaver et al., 2013). The most common AIS2+ lower extremity injury was a closed pelvis fracture (AIS2) and the most common AIS2+ abdominal injury was a spleen laceration (AIS2), both with a MRR of 6–7 %. The most common AIS2+ chest injury was a unilateral lung contusion (AIS3) with an MRR of 6.4 %.

In order to get a dataset large enough to analyze according to the

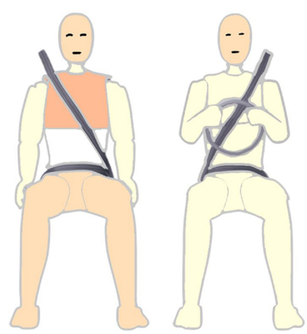
Passenger		%
Head	Subdural	50
	Concussion	49
	Base	1
Up. Ext	Forearm	56
	Shoulder	33
	Wrist, Hand	11
Thorax	Ribs	98
	Diaphragm	1
	Major Vessels	1
Spine	Lumbar	79
	Cervical	14
	Thoracic	8
Abdom.	Spleen	83
	Kidney	15
	Liver	2
L. Ext.	Knee Joint	40
	Pelvis	25
	Femur Shaft	12



Driver		%
Head	Concussion	84
	Subdural	9
	Cerebrum	6
Up. Ext	Wrist, Hand	47
	Shoulder	27
	Forearm	24
Thorax	Ribs	93
	Lung	5
	Thorax cavity NFS	2
Spine	Lumbar	97
	Thoracic	2
	Cervical	1
Abdom.	Spleen	48
	Liver	41
	Kidney	11
L. Ext.	Knee Joint	30
	Ankle Joint	22
	Lower leg NFS	14

Fig. 7. The most common injuries in side oblique far side impacts.

Passenger		%
Head	Concussion	86
	Cerebrum	4
	Vault	3
Up. Ext	Shoulder	71
	Humerus	29
	-	-
Thorax	Ribs	78
	Thorax cavity NFS	19
	Heart	2
Spine	Lumbar	100
	-	-
	-	-
Abdom.	Kidney	22
	Liver	22
	Bowl	19
L. Ext.	Pelvis	99
	Hip Joint	1
	-	-



Driver		%
Head	Concussion	49
	Subdural	21
	Base	11
Up. Ext	Shoulder	60
	Humerus	34
	Forearm	5
Thorax	Ribs	44
	Thorax cavity NFS	27
	Lung	20
Spine	Cervical	51
	Lumbar	49
	-	-
Abdom.	Kidney	52
	Liver	32
	Spleen	13
L. Ext.	Pelvis	87
	Knee Joint	12
	Hip Joint	1

Fig. 8. The most common injuries in side far side impacts.

Table 2

Weighted injury risk (AIS 2+) divided by body part and crash type for MY.2000–2006. (For interpretation of the references to colour in this table, the reader is referred to the web version of this article.)

Color coded according to risk; 0.1-0.6% ☐ 0.6-1.2% ☐ 1.2-1.8% ☐ 1.8-2.4% ☐ 2.4-3.0% ☐

		Head	Face	Neck	Thorax	Abdomen	Spine	Ux	Lx
Driver	Side NS incl. obl.	2.5%	0.2%	0.0%	2.3%	0.9%	1.0%	1.8%	2.7%
	Frontal incl. obl.	1.0%	0.1%	0.0%	1.3%	0.4%	0.4%	1.7%	2.4%
	Side FS incl. obl.	1.8%	0.1%	0.0%	1.1%	0.2%	0.4%	0.4%	1.4%

Table 3

Weighted injury risk (AIS 2+) divided by body part and crash type for MY.2007–2015. (For interpretation of the references to colour in this table, the reader is referred to the web version of this article.)

Color coded according to risk; 0.1-0.6% ☐ 0.6-1.2% ☐ 1.2-1.8% ☐ 1.8-2.4% ☐ 2.4-3.0% ☐

		Head	Face	Neck	Thorax	Abdomen	Spine	Ux	Lx
Driver	Side NS incl. obl.	2.7%	0.0%	0.0%	1.3%	0.7%	1.3%	0.8%	1.6%
	Frontal incl. obl.	2.0%	0.1%	0.2%	1.8%	0.3%	1.3%	2.1%	1.3%
	Side FS incl. obl.	0.1%	0.0%	0.0%	0.7%	0.0%	0.3%	0.2%	0.6%

method in this study, vehicles all way back to model year 2000 were included. Year 2000 was chosen as Euro NCAP was phased in from 1997 to 2000 (van Ratingen et al., 2016). Euro NCAP was driving significant modifications to the vehicle structures and safety systems. As passive safety is gradually progressing, some of the injuries seen in early 2000 cars might not be present in modern cars. Due to the fact that no clear trend was observed when the weighted data was divided into two groups the complete data set was considered valid for the complete model year span used in the analysis.

For drivers, the head followed by the thorax were the most frequently injured body regions. The most common head injuries were concussion and subdural hemorrhage. The most common thoracic injuries were related to the ribs, the lungs and the thorax cavity NFS. For passengers, the thorax followed by the head were the most frequently injured body regions. The most common thoracic injuries were related to the lungs, the ribs and the sternum. The most common head injuries were concussion and subdural hemorrhage.

The GHBMC head model was validated for head impacts by means of real world head impacts (Mao et al., 2013). However, tissue level criteria were only proposed for head fracture and brain contusion. Criteria for concussion and subdural hemorrhage were not assessed by Mao et al. (2013). The GHBMC detailed human body occupant model (M50-O; Ver. 4.4) was used to study rib failure prediction differences when examined deterministically and probabilistically (Guleyupoglu et al., 2018). However, the capability to predict the risk of rib fracture, sternum fracture or lung injury with the GHBMC model was not validated. Therefore, the current study can be used for prioritizing development of the injury prediction capability of the GHBMC and other human body models.

To develop more valid human body models, further studies should be made, which include data that have a great influence on the accident outcome such as the crash severity, the age of the occupant, and the properties of the restraint system.

5. Limitations

The major limitation of the study is the low number of cases and injuries in some crash types, which gives uncertainties in the risk estimation and for the distribution of specific injuries. This is particularly the case for passengers. In the unweighted database, there were 146 passengers with head injuries in near side impacts of which 21 sustained a concussion. With so few cases, the weighting of the results can change the risk estimates as well as the order of the most frequent injuries significantly. However, for the boxes with high risk: head, thorax, upper and lower extremity, the number of raw injury counts was high, which leads to stable risk evaluations. For the top ten boxes for the driver, the box with least number of cases was the upper extremity box for side oblique near side with 39 cases. It was considered enough for reliable risk estimation.

In addition, there is also an uncertainty in risk estimation related to the NASS/CDS inclusion criteria. The risk estimates in this study are computed and based on the NASS inclusion criteria. This means that the vehicle has to be towed away from the scene of the crash. Different levels of crash severity for different load cases can be necessary for it to be a tow away crash and included in the NASS database. That can result in that one crash direction can be overrepresented over another in the risk estimation.

Another limitation is that AIS1 injuries were excluded. One reason for this is that AIS1 injuries are underreported in the NASS database, because many of those with only AIS1 injuries never seek hospital care, and they are therefore not included in the NASS database. However, in future studies AIS1+ injuries resulting in long term consequences should be included.

6. Conclusions

Taking the predictions for future crash scenarios of AD vehicles into account, the HBM body regions which should be focused on is the head, the thorax and the lower extremities in side impacts, and the specific injuries are concussion, rib and pelvic fractures. For non-AD vehicles injuries to the lower extremities, like knee and ankle joint injuries, are also in focus.

CRediT authorship contribution statement

Bengt Pipkorn: Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Project administration. **Johan Iraeus:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Visualization. **Mats Lindkvist:** Methodology, Resources. **Pradeep Puthan:** Formal analysis, Visualization. **Olle Bunketorp:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A1
Body regions and parts of region/types of injury used in the analyses.

Head
A External (bone, scalp)
A.1 Vault
A.2 Base
B Cerebrum
B.1 Epidural hemorrhage
B.2 Subdural hemorrhage
B.3 Contusion/Laceration/Subarachnoid hemorrhage
B.4 Diffuse axonal injury
C Cerebellum
C.1 Epidural hemorrhage
C.2 Subdural hemorrhage
C.3 Contusion/Laceration/Subarachnoid hemorrhage
C.4 Diffuse axonal injury
D Brain stem
E Concussion
F Cranial nerve
G Vessel
H Massive destruction
Face
Mandible, Temporomandibular joint
Nose, Maxilla, Orbit, Zygomaticus
Organ (Ear, Eye, Optic nerve, Tongue)
Neck
Major vessel
Cranial Nerve (Phrenic nerve)
Organ (Esophagus, Larynx, Pharynx, Salivary gland, Thyroid gland, Trachea, Vocal cord)
Thorax
Major vessel
Diaphragm
Esophagus
Heart
Lung, pleura
Trachea and main Bronchus
Ribs
Sternum
Abdomen
Major vessel
Bladder
Bowl
Genital
Kidney, Ureter
Liver, Gallbladder
Mesentery, Omentum
Pancreas
Spleen
Stomach
Spine
Cervical spine
Thoracic spine
Lumbar spine
Upper Extremity
Shoulder girdle (Including Scapula, Clavicle)
Humerus
Elbow joint
Forearm (Radius shaft, Ulna shaft)
Wrist, Hand
Lower Extremity
Pelvis
Hip joint (Including Femur proximal segment)
Femur shaft
Knee (Including Femur distal segment, Tibia/Fibula proximal segment)
Lower leg (Tibia/Fibula shaft)
Ankle (Including Tibia/Fibula distal segment, Talus)
Foot

Appendix B

See Fig. B1.

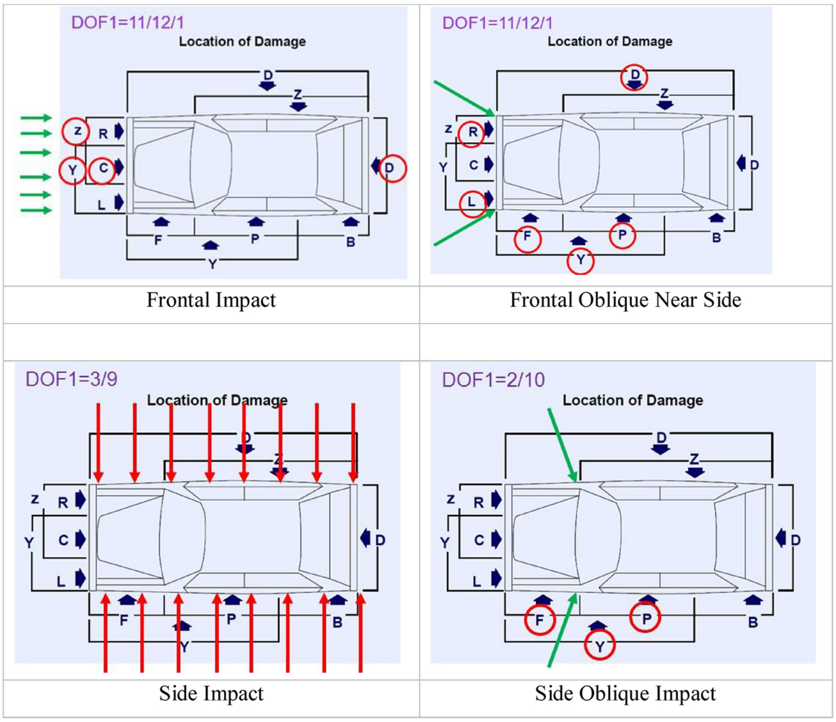

Fig. B1. Filtering criteria for each load case as per Collision Deformation Classification (SAE J 224 standard)". The green arrows show the selected loading directions. Red arrows indicate all the loads/crashes from the respective directions (here both sides). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Appendix C

See Table C1.

Table C1
Weighted Frequency of Injured Body Regions (AIS 2+) and Crash Configurations.

		Head	Face	Neck	Thorax	Abdomen	Spine	Ux	Lx
Driver	Side NS	4557	286	0	3986	2213	2054	1790	3696
	Side Obl NS	5344	216	0	3902	999	1683	4137	5671
	Frontal Obl NS	10422	438	22	5532	1143	3740	7566	10090
	Frontal	27377	3174	1917	37940	11687	19167	48752	54462
	Frontal Obl FS	4660	995	0	3548	411	546	5369	2603
	Side Obl FS	2724	0	0	2434	100	688	695	2922
	Side FS	1436	139	0	708	296	415	333	772
Pass	Side NS	715	0	8	1020	617	231	0	645
	Side Obl NS	206	0	0	629	379	71	408	456
	Frontal Obl NS	2800	635	0	1224	665	223	1233	1503
	Frontal	4063	428	94	13230	2100	3387	6192	9728
	Frontal Obl FS	274	0	0	481	578	61	1117	288
	Side Obl FS	682	71	0	712	149	220	156	349
	Side FS	428	20	0	748	28	136	127	364

HEAD

Frontal Impact	**Driver**	**Passenger**
Base Fractures	4420	621
Brain Stem	2340	1195
Cerebrum Contusion/Intracerebral Injury	14004	1810
Cerebrum Diffuse Axonal Injury	235	338
Concussion	247127	37691
Cranial Nerve	1707	0
Epidural Injury	69	0
Massive Destruction	144	0

(continued on next page)

Table C1 (*continued*)

HEAD		
Not classified	202	0
Scalp	121	0
Subdural Injury	53532	5956
Vault Fractures	5322	1775
Hematoma NFS	147	0
Cerbebellum Contusion/Intracerebellar Injury	217	0
Cerbebellum Contusion/Intracerebellar	26	0
Vessel	28	4
Frontal Oblique Far Side	**Driver**	**Passenger**
Cerebrum Contusion/Intracerebral Injury	1400	82
Concussion	47074	1009
Subdural Injury	2050	2376
Vault Fractures	291	0
Frontal Oblique Near Side	**Driver**	**Passenger**
Concussion	89396	23335
Subdural Injury	14498	5967
Cerebrum Contusion/Intracerebral Injury	9529	835
Vault Fractures	2940	0
Base Fractures	1350	973
Brain Stem	614	193
Hematoma NFS	223	141
Scalp	163	141
Not classified	96	0
Cranial Nerve	125	0
Epidural Injury	78	0
Cerbebellum Contusion/Intracerebellar Injury	5	0
Side Impact Far Side	**Driver**	**Passenger**
Base Fractures	2630	158
Brain Stem	65	0
Cerbebellum Contusion/Intracerebellar Injury	0	56
Cerebrum Contusion/Intracerebral Injury	2137	227
Cerebrum Diffuse Axonal Injury	19	0
Concussion	11803	4559
Cranial Nerve	86	0
Epidural Injury	16	0
Subdural Injury	4940	118
Vault Fractures	2194	178
Side Impact Near Side	**Driver**	**Passenger**
Base Fractures	149	4317
Brain Stem	523	116
Cerbebellum Contusion/Intracerebellar	4	0
Cerbebellum Contusion/Intracerebellar Injury	4	0
Cerebrum Contusion/Intracerebral Injury	8225	83
Cerebrum Diffuse Axonal Injury	505	0
Concussion	34370	2995
Hematoma NFS	404	0
Massive Destruction	0	16
Subdural Injury	17596	13588
Vault Fractures	3047	4726
Side Oblique Far Side	**Driver**	**Passenger**
Base Fractures	0	72
Brain Stem	89	72
Cerbebellum Contusion/Intracerebellar	0	10
Cerebrum Contusion/Intracerebral Injury	2099	0
Concussion	30527	5826
Cranial Nerve	102	0
Subdural Injury	3411	5943
Vault Fractures	55	0
Side Oblique Near Side	**Driver**	**Passenger**
Base Fractures	1214	0
Brain Stem	1639	0
Cerbebellum Contusion/Intracerebellar	46	0
Cerebrum Contusion/Intracerebral Injury	6182	191
Cerebrum Diffuse Axonal Injury/Concussion	177	0
Concussion	45083	1217
Subdural Injury	19039	676
Vault Fractures	5826	0
FACE		
Frontal Impact	**Driver**	**Passenger**
Face Laceration	1706	0
Mandible	642	0
Maxilla	2721	847
Nose	5904	423

(*continued on next page*)

Table C1 (*continued*)

FACE		
Orbita	5501	2312
Organ	140	0
Other	63	0
Tempomandibular joint	1721	254
Zygoma	1126	0
Not Available	22	0
Frontal Oblique Far Side	**Driver**	**Passenger**
Organ	0	0
Other	0	0
Mandible	0	0
Maxilla	8053	0
Nose	25	0
Orbita	599	0
Tempomandibluar joint	0	0
Zygoma	0	0
Face Laceration	0	0
Frontal Oblique Near Side	**Driver**	**Passenger**
Organ	0	0
Other	0	0
Mandible	110	0
Maxilla	1983	4570
Nose	246	0
Orbita	1125	1488
Tempomandibluar joint	0	0
Zygoma	171	3369
Face Laceration	68	235
Side Impact Far Side	**Driver**	**Passenger**
Organ	0	0
Other	198	0
Mandible	0	0
Maxilla	0	178
Nose	697	0
Orbita	594	237
Tempomandibluar joint	0	0
Zygoma	0	99
Face Laceration	0	0
Side Impact Near Side	**Driver**	**Passenger**
Organ	0	0
Other	0	0
Mandible	0	0
Maxilla	597	0
Nose	0	0
Orbita	2146	0
Tempomandibular joint	11	0
Zygoma	505	0
Face Laceration	0	0
Side Oblique Far Side	**Driver**	**Passenger**
Organ	0	0
Other	0	0
Mandible	0	21
Maxilla	0	551
Nose	0	0
Orbita	0	0
Tempomandibluar joint	0	0
Zygoma	0	0
Face Laceration	0	306
Side Oblique Near Side	**Driver**	**Passenger**
Organ	0	0
Other	0	0
Mandible	215	0
Maxilla	646	0
Nose	0	0
Orbita	380	0
Tempomandibluar joint	0	0
Zygoma	0	0
Face Laceration	403	0
NECK		
Frontal Impact	**Driver**	**Passenger**
Hyoid Fracture	417	339
Laceration	1707	0
Organ	27	94
Vessel	89	0
Frontal Oblique Near Side	**Driver**	**Passenger**

(*continued on next page*)

Table C1 (*continued*)

NECK		
Hyoid Fracture	87	0
Laceration	0	0
Organ	29	0
Vessel	0	0
Side Impact Near Side	**Driver**	**Passenger**
Hyoid Fracture	0	33
Laceration	0	0
Organ	0	0
Vessel	0	0
THORAX		
Frontal Impact	**Driver**	**Passenger**
Diaphragma	3037	329
Esophagus	59	0
Esphagus	13	0
Heart	4786	65
Lungs	66500	6771
Major Vessels	3368	218
Rib Fractures	198739	62111
Sternum Fractures	234341	99663
Thoracic Cavity Injury NFS	28995	14854
Trachea and Main Bornchus NFS	25	245
Frontal Oblique Far Side	**Driver**	**Passenger**
Major Vessels	0	0
Diaphragma	291	0
Esophagus	0	0
Heart	0	0
Lungs	6919	0
Thoracic Cavity Injury NFS	0	682
Trachea and Main Bornchus NFS	0	0
Rib Fractures	35085	6014
Sternum Fractures	4809	1611
Frontal Oblique Near Side	**Driver**	**Passenger**
Major Vessels	293	1205
Diaphragma	2004	1043
Esophagus	0	0
Heart	623	317
Lungs	15516	7914
Thoracic Cavity Injury NFS	7581	3896
Trachea and Main Bornchus NFS	0	0
Rib Fractures	31646	13408
Sternum Fractures	15664	2232
Side Impact Far Side	**Driver**	**Passenger**
Major Vessels	205	0
Diaphragma	86	0
Esophagus	0	0
Heart	760	168
Lungs	2877	140
Thoracic Cavity Injury NFS	3948	2090
Trachea and Main Bornchus NFS	0	0
Rib Fractures	6407	8595
Sternum Fractures	124	0
Side Impact Near Side	**Driver**	**Passenger**
Major Vessels	447	607
Diaphragma	1308	95
Esophagus	39	0
Heart	122	544
Lungs	12415	9075
Thoracic Cavity Injury NFS	14054	2300
Trachea and Main Bornchus NFS	21	0
Rib Fractures	39460	3427
Sternum Fractures	1539	90
Side Oblique Far Side	**Driver**	**Passenger**
Major Vessels	0	62
Diaphragma	0	120
Esophagus	0	0
Heart	0	0
Lungs	1565	10
Thoracic Cavity Injury NFS	629	0
Trachea and Main Bornchus NFS	0	0
Rib Fractures	29379	8469
Sternum Fractures	69	0
Side Oblique Near Side	**Driver**	**Passenger**
Major Vessels	625	191

(*continued on next page*)

Table C1 (*continued*)

THORAX		
Diaphragma	494	0
Esophagus	0	0
Heart	436	94
Lungs	10452	1082
Thoracic Cavity Injury NFS	9134	563
Trachea and Main Bornchus NFS	0	0
Rib Fractures	37694	6683
Sternum Fractures	1173	202
ABDOMEN		
Frontal Impact	**Driver**	**Passenger**
Bladder	1153	0
Bowl	5074	1357
Genitials	304	0
Kidney	6887	388
Liver	53471	1421
Major Vessels	606	24
Mesentery	5194	3508
Not classified	32	0
Other	62	0
Pancreas	1285	8
Spleen	34904	18270
Stomach	8	155
Frontal Oblique Far Side	**Driver**	**Passenger**
Bladder	0	0
Bowl	61	24
Genitials	0	0
Kidney	259	1891
Liver	3361	0
Major Vessels	0	0
Mesentery	416	0
Pancreas	0	0
Spleen	112	680
Stomach	0	0
Frontal Oblique Near Side	**Driver**	**Passenger**
Bladder	817	1259
Bowl	0	598
Genitials	0	0
Kidney	929	70
Liver	2181	767
Major Vessels	113	35
Mesentery	2576	352
Pancreas	0	0
Spleen	3873	2335
Stomach	0	0
Other	0	193
Side Impact Far Side	**Driver**	**Passenger**
Bladder	53	0
Bowl	0	168
Genitials	0	0
Kidney	802	196
Liver	495	196
Major Vessels	0	0
Mesentery	0	140
Pancreas	0	56
Spleen	198	140
Stomach	0	0
Side Impact Near Side	**Driver**	**Passenger**
Bladder	452	0
Bowl	1097	0
Genitials	204	0
Kidney	2839	0
Liver	6908	810
Major Vessels	668	0
Mesentery	107	0
Pancreas	348	0
Spleen	13302	6536
Stomach	21	0
Other	84	0
Side Oblique Far Side	**Driver**	**Passenger**
Bladder	0	0
Bowl	0	0
Genitials	0	0
Kidney	183	324

(*continued on next page*)

Table C1 (*continued*)

ABDOMEN		
Liver	696	41
Major Vessels	0	0
Mesentery	0	0
Pancreas	0	0
Spleen	802	1853
Stomach	0	0
Side Oblique Near Side	**Driver**	**Passenger**
Bladder	283	0
Bowl	152	0
Genitials	40	0
Kidney	552	717
Liver	1543	389
Major Vessels	155	15
Mesentery	13	242
Pancreas	37	0
Spleen	9125	1006
Stomach	0	0
Not classified	10	0
SPINE		
Frontal Impact	**Driver**	**Passenger**
Brachial Flexus	78	0
Cervical Spinal Cord	658	49
Thoracic Spinal Cord	239	9
Cervical Disc Injury	407	0
Cervical Dislocation	1038	819
Cervical Vertebral Fracture	58861	8935
Thoracic vertebral Fracture	20143	5650
Lumbar Disc Injury	1034	0
Lumbar Vertebral Fracture	123710	18440
Frontal Oblique Far Side	**Driver**	**Passenger**
Thoracic vertebral Fracture	954	403
Lumbar Vertebral Fracture	479	2360
Lumbar Dislocation	435	0
Cervical Vertebral Fracture	293	67
Cervical Dislocation	216	0
Frontal Oblique Near Side	**Driver**	**Passenger**
Cervical Disc Injury	2582	0
Cervical Dislocation	84	0
Thoracic Vertebral Fracture	1580	49
Lumbar Vertebral Fracture	24461	718
Thoracic Spinal Cord	0	108
Cervical Vertebral Fracture	19874	643
Side Impact Far Side	**Driver**	**Passenger**
Thoracic Spinal Cord	43	0
Cervical Vertebral Fracture	5661	0
Lumbar Vertebral Fracture	5455	1493
Side Impact Near Side	**Driver**	**Passenger**
Thoracic Spinal Cord	77	0
Cervical Disc Injury	438	0
Thoracic Vertebral Fracture	1628	99
Lumbar Vertebral Fracture	13689	0
Cervical Spinal Cord	0	8
Cervical Vertebral Fracture	3071	669
Side Oblique Far Side	**Driver**	**Passenger**
Cervical Dislocation	88	0
Thoracic Vertebral Fracture	415	184
Lumbar Vertebral Fracture	15146	1817
Cervical Vertebral Fracture	0	312
Side Oblique Near Side	**Driver**	**Passenger**
Thoracic Spinal Cord	21	97
Cervical Dislocation	171	0
Thoracic Vertebral Fracture	755	0
Lumbar Dislocation	21	0
Lumbar Vertebral Fracture	31383	0
Cervical Spinal Cord	0	8
Cervical Vertebral Fracture	2316	73
Not Available	10	0
UPPER EXTRIMITIES		
Frontal Impact	**Driver**	**Passenger**
Arm Fracture Forearm	1088	0
Arm Fracture NFS	32236	8199

(*continued on next page*)

Table C1 (*continued*)

UPPER EXTRIMITIES		
Elbow Joint	38	0
Forearm Fracture	251931	38177
Hand	673	0
Humerus Fracture	13277	1792
Other	1191	170
Shoulder	78552	20173
Wrist Joint	195791	13367
Not Available	111	0
Frontal Oblique Far Side	**Driver**	**Passenger**
Arm Fracture Forearm	13	0
Arm Fracture NFS	1964	0
Elbow Joint	0	0
Forearm Fracture	20331	6677
Hand	**203**	**0**
Humerus Fracture	997	1757
Other	0	0
Shoulder	18898	1751
Wrist Joint	9081	307
Frontal Oblique Near Side	**Driver**	**Passenger**
Arm Fracture Forearm	1666	0
Arm Fracture NFS	1861	1412
Elbow Joint	0	0
Forearm Fracture	30251	2357
Hand	**0**	**0**
Humerus Fracture	4673	703
Other	445	0
Shoulder	17273	6748
Wrist Joint	22479	2893
Not Available	77	0
Side Impact Far Side	**Driver**	**Passenger**
Arm Fracture Forearm	167	0
Arm Fracture NFS	72	0
Elbow Joint	0	0
Forearm Fracture	0	0
Hand	0	0
Humerus Fracture	1212	318
Other	**0**	**0**
Shoulder	2138	780
Wrist Joint	0	0
Side Impact Near Side	**Driver**	**Passenger**
Arm Fracture Forearm	0	0
Arm Fracture NFS	0	0
Elbow Joint	0	0
Forearm Fracture	2730	0
Hand	0	0
Humerus Fracture	1340	0
Other	21	0
Shoulder	13342	0
Wrist Joint	1993	0
Side Oblique Far Side	**Driver**	**Passenger**
Arm Fracture Forearm	0	0
Arm Fracture NFS	0	0
Elbow Joint	0	0
Forearm Fracture	1651	2264
Hand	0	0
Humerus Fracture	161	0
Other	0	0
Shoulder	1855	1347
Wrist Joint	3215	428
Side Oblique Near Side	**Driver**	**Passenger**
Arm Fracture Forearm	0	0
Arm Fracture NFS	0	75
Elbow Joint	0	0
Forearm Fracture	2799	0
Hand	0	0
Humerus Fracture	750	0
Other	0	0
Shoulder	33170	4312
Wrist Joint	8490	0
LOWER EXTRIMITIES		
Frontal Impact	**Driver**	**Passenger**
Ankle Joint	150288	29341
Femur NFS	7540	544

(*continued on next page*)

Table C1 (*continued*)

LOWER EXTRIMITIES		
Femur Shaft	33553	4365
Foot	114310	4999
Hip Joint	12378	1874
Knee Joint	146318	22019
Lower Leg NFS	108101	16422
Lower Leg Shaft	24867	4352
Not Available	582	259
Other	12210	602
Pelvis	64397	8904
Frontal Oblique Far Side	**Driver**	**Passenger**
Ankle Joint	5358	1743
Femur NFS	0	0
Femur Shaft	423	0
Foot	581	140
Hip Joint	1614	44
Knee Joint	11258	177
Lower Leg NFS	276	0
Lower Leg Shaft	114	175
Not Available	0	0
Other	468	0
Pelvis	4413	113
Frontal Oblique Near Side	**Driver**	**Passenger**
Ankle Joint	18703	3358
Femur NFS	1914	0
Femur Shaft	6354	655
Foot	10712	1655
Hip Joint	5444	606
Knee Joint	12341	2416
Lower Leg NFS	14090	3744
Lower Leg Shaft	4566	641
Not Available	0	0
Other	8380	51
Pelvis	53059	10383
Side Impact Far Side	**Driver**	**Passenger**
Ankle Joint	0	0
Femur NFS	0	0
Femur Shaft	0	0
Foot	0	0
Hip Joint	108	140
Knee Joint	992	0
Lower Leg NFS	0	0
Lower Leg Shaft	0	0
Not Available	0	0
Other	0	0
Pelvis	7186	9312
Side Impact Near Side	**Driver**	**Passenger**
Ankle Joint	1535	139
Femur NFS	957	0
Femur Shaft	823	421
Foot	0	0
Hip Joint	338	0
Knee Joint	1349	0
Lower Leg NFS	4154	0
Lower Leg Shaft	1083	0
Not Available	0	0
Other	0	0
Pelvis	74962	15076
Side Oblique Far Side	**Driver**	**Passenger**
Ankle Joint	9182	551
Femur NFS	131	0
Femur Shaft	3215	589
Foot	1137	0
Hip Joint	2858	0
Knee Joint	12350	1961
Lower Leg NFS	5713	551
Lower Leg Shaft	3693	0
Not Available	0	0
Other	1831	0
Pelvis	1290	1201
Side Oblique Near Side	**Driver**	**Passenger**
Ankle Joint	2399	2175
Femur NFS	60	0
Femur Shaft	2558	0
Foot	0	0
Hip Joint	563	0

(*continued on next page*)

Table C1 (*continued*)

LOWER EXTRIMITIES		
Knee Joint	6263	3
Lower Leg NFS	11056	0
Lower Leg Shaft	296	0
Not Available	10	0
Other	776	100
Pelvis	86191	5914

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