Lower Extremity Injuries in Car Crashes, focusing the Foot, Ankle and Leg

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Abstract With the purpose to contribute to further understand influencing factors and mechanisms for lower extremity injuries from car crashes, the current study investigated lower extremity protection over the years in relation to car design advancements, using two well-controlled car model samples.

The overall efficiency of the car design advancements for the driver was shown to be approximately in average 60% for overall AIS2+ lower extremity injury risk (0.9% vs. 0.4%), as well as for AIS2+ foot, ankle and leg injury risk (0.6% vs. 0.2%). This confirmed that the car advancements were successful. They were relevant for both females and males, providing substantial injury reduction for both sexes and with no distinguishable injury risk difference in the newer car model group.

Foot, ankle and leg injuries are highly related to frontal impacts and front-seat occupants. A case-by-case analysis on the foot, ankle and leg injuries in the newer car model group showed that they are diverse with several influencing factors and that they can occur even at lower impact severity and without foot well intrusion. They were not specifically related to sex nor occupant size, instead the feet positions and the impact dynamics were likely more influential.

Keywords Ankle, Car crashes, Foot, Frontal impacts, Lower extremities

I. INTRODUCTION

Lower extremity injuries in passenger car crashes, and specifically injuries to the foot, ankle and leg, have attained increased attention in recent years. Forman *et al.* [1], who studied restrained occupants in frontal impacts in NASS CDS, reported that females were at greater risk of AIS2+ injury compared to males, with the greatest sex-related effect on injury risk occurring in the lower extremities. Using the same database and controlling for crash and vehicle differences, Brumbelow and Jermakian [2] found that the odds of a female driver sustaining a lower extremity injury remained nearly three times that of a male driver, while no sex-related injury difference for non-extremity body regions. In a follow-up study using frontal crashes with event data recorder information, Brumbelow [3] further emphasised the importance of accounting for vehicle type and crash difference between females and males when seeking to compare relative injury risk. They also concluded that compatibility improvements will be an important part of addressing higher risks in females. In another study, Brumbelow [4] investigated driver and crash factors and concluded that efforts to reduce female lower extremity injuries in frontal crashes should consider the higher risk associated with BMI, which was unique to female, in addition to precrash braking, which however was not unique for females.

Lower extremity injury risk in car crashes is not a new research topic. In the 1960s, Nahum *et al.* [5] examined 186 vehicle occupants and identified speed of impact, car weight and occupant age as influencing factors. States [6] reported on cases in which foot and ankles were injured by crushing due to entrapment in the pedals, by torsional forces applied between the foot and the knee and by axial loading, in addition to intrusion by engine displacement and floor elevation. Begeman and Prasad [7] performed experiments on dorsiflexion caused by impact loading to the bottom of the foot inspired by the earlier studies.

During the 1990s, several research groups around the world performed in-depth crash investigations to study influencing factors and to identify injury mechanisms [8-12]. Morgan *et al.* [8] examined 480 in-depth cases from NASS and structured the mechanisms into descriptions of how the foot/ankle interacted with the interior of the vehicle. All these interactions included occupant loading through the limbs, also adding parameters such as intrusion, entrapment between floor and instrument panel, contact with the pedals or the floor, in addition to

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foot trapped under pedals. Intrusion in the footwell area as an influencing factor has been shown by several studies [11][13-15], also showing that intrusion adds on to the effect of the crash severity. Even in crashes with small or no footwell intrusion, injuries below the knee were seen, pointing out the importance of the crash severity and timing on vehicle's change in velocity and the rate and timing of intrusion if any [16], and suggesting that padding in the footwell could help reduce peak loads [17]. Otte *et al.* [15] identified a mechanism of degree of support and slip-off mechanism of the foot, which could occur in less severe crashes, in which there was no intrusion.

Summarising the published mechanisms and their relation to the different types of fractures, Forsell *et al.* [18] complemented with a study on foot, ankle and leg injuries in frontal car crashes including real-world data, simulations and crash tests. Real-world crashes involving Volvo 700 and 900 models were studied overall as well in an in-depth study on 20 cases with occupants sustaining AIS2+ ankle injuries. General design guidelines were specified in the following areas: geometry, acceleration, pedals and intrusion. These guidelines were also transformed into internal design targets, which were adhered to in the development of Volvo cars since then.

The current study serves to contribute to further understand influencing factors and mechanisms behind injuries to the lower extremities during car crashes, partly by relating to the learnings from [18] and partly to provide insights related to current cars. Specially, one objective was to investigate lower extremity protection over the years in relation to car design advancements, using a sample of car models for which the design advancements are well known, and for which the crash data has been collected in a consistent way over the years. In addition, a second objective was to study factors influencing AIS2+ foot, ankle and leg injuries in current cars, including occupant, car and crash characteristics, to better understand underlying mechanisms.

II. METHODS

This study comprised of two analyses: one statistical analysis and one case-by-case analysis. In the statistical analysis, one part included a comparison of two well-controlled groups of Volvo cars. The newer car model group included cars with design advancements based on the design guidelines as described by [18]. Injury risks with respect to overall maximum AIS2+ injury (MAIS2+), maximum lower extremity AIS2+ injury (LX2+) and maximum foot/ankle/leg AIS2+ injury (FAL2+) were studied in relation to the older car model group. The other part included analyses of the newer car model group with respect to driver characteristics, for all crash types and for frontal impacts specifically.

The case-by-case analysis included the occupants with FAL2+ injuries in the newer car model group to study influencing factors in current cars. For some of these cases, reference cases were identified and included in the analysis to provide further understanding of the complexity of these incidents. These reference cases offer examples of similar crashes without FAL2+ injuries. The reference cases were selected based on comparable car types and car deformations. A summary of each FAL2+ and reference case can be found in the Appendix.

The Data

The Volvo Cars Traffic Accident Database (VCTAD) includes data from road traffic crashes occurring in Sweden involving Volvo cars since 1970. Currently, the dataset covers crashes occurring until 2021, with a total of 50,950 cars involving 83,840 occupants. Volvia (If P&C Insurance) provides notification for cars involved in crashes with estimated repair costs exceeding a certain threshold. All Volvo cars are insured with Volvia for at least the first three years after registration. Photos and technical details of the cars are sent to Volvo Cars' Accident Research Team. The Volvo Cars team sends out a detailed questionnaire to the owner of the car to gather information about the crash, the car and the occupants. The information covers the circumstances of the crash, e.g. weather, road conditions, posted speed limits, sequence of events, and collision objects. Examples of occupant data are age, sex, stature, weight, seat position, restraint use, and injury status. The response rate, which has varied over the years, is currently approximately 30%. In addition, the fatally injured cases are enriched with information from governmental investigations. With the approval from injured occupants, their medical records are requested and coded by a physician within the Volvo Cars Team, in line with the Abbreviated Injury Scale (AIS) code book. Based on the photos of the damaged car, and information about the crash from the questionnaire, experts from the Volvo Cars team code the deformation of the car in line with the SAE Standard J224 Collision Deformation Classification (CDC) [19].

For the present study two data sets were extracted from VCTAD. Both data sets were used in the statistical analysis, while only the newer car model group dataset was used in the case-by-case analysis. The selection included seatbelt restrained occupants, aged 13 years and older, exposed to any type of crash in two different car model groups. The newer car model group represented car model platforms/generations in which the learnings summarized in [18] were addressed. The older car model group included a selection of earlier car models, developed just prior to those in the newer car model group. The learnings include design guidelines to help keep the footwell area intrusion extent and acceleration low and focus on the evenness of the footwell area, including pedal design [18]. Since car models from different platforms/generations may overlap, the actual car model years (MY) in the two car model groups overlap. However, all cars in the newer car model groups belong to platforms/generations that were introduced 1999 and later. The newer car model group included all such Volvo cars e.g. Volvo S60/80/90, V70/90, XC60/70/90 of MY 1999-2022; in total 13,925 drivers, 3,721 front-seat passengers and 1,422 rear-seat passengers. They were involved in crashes from 1999 to 2021. The older car model group included mainly Volvo 850 and 900 models of MY 1991-2005, in crashes occurring from 1990 to 2021. In total 8,647 drivers, 2,654 front-seat passengers and 1,205 rear-seat passengers are in the older car model group.

With the objective to study potential influencing factors, the case-by-case analysis served the purpose to provide additional insights from real-world case analyses beyond what the coded data in databases can provide. In total, 26 drivers and 10 front-seat passengers with FAL2+ injuries were included in the case-by-case analysis study. These are all, but seven, cases in the newer car model group sustaining FAL2+ injuries. Seven cases were excluded due to extreme crash severity and car deformations making the FAL2+ injury mechanism of secondary interest. In addition, for 13 of the cases one or two reference cases were found and included in the analysis. The reference cases were selected based on being of same car platform/generation, and with similar car deformation (based on the CDC deformation coding and photo comparison) and relevant course of event. For those without reference case it was difficult to find a relevant match, mainly due to rare crashes, such as multiple crashes, frontal impacts preceded by run-off road sequences and infrequent high-severity crashes.

The Analysis

The injury risk comparisons made between the two car model groups served the purpose of understanding whether the design advancements had been effective overall, as well as for female and male, respectively. In addition, influencing factors such as crash types, and occupant characteristics were studied focusing drivers in the newer car model group. This was done for all crash types and for frontal impacts separately.

Injury risk was calculated and defined as the ratio of the number of injured occupants in an analysis category by the total number of occupants in that category. This means that it represents the average injury risk for occupants in crashes within the collection criteria of VCTAD, i.e. crashes with Volvo cars in Sweden above a defined severity threshold. In the current study, statistical significance is defined by non-overlapping 95% confidence intervals when comparing two analyses categories. The 95% confidence intervals are also included in the graphs, when relevant. Injury reducing effect (efficiency) is defined as the injury risk in the newer car model group in relation to the injury risk in the older with 95% confidence limits (C_L,C_U).

The cases in the case-by-case analysis were analysed based on detailed information on the injury, the occupant, the car and the crash, focusing mechanisms, interaction patterns and influencing factors. The reference cases were used for comparison to the matched FAL2+ injured case, to provide further support in understanding potential influencing factors.

III. RESULTS

All Crash Types

Figures 1(a)-(b) show MAIS2+, LX2+ and FAL2+ injury risks for all drivers and front-seat passengers, comparing the two car model groups. The injury risks are statistically significant lower for drivers in the newer car model group as compared to the older car model group, for MAIS2+ (3.8% vs. 2.4%), as well as for LX2+ (0.9% vs. 0.4%) and FAL2+ (0.6% vs. 0.2%). This corresponds to an overall (MAIS2+) injury reducing effect of the car design advances between the newer and older car model groups by 36% with the confidence limits (C_L,C_U)=(26%, 45%), while 62% (46%-73%) and 60% (38%-75%), respectively, for LX2+ injuries and the subset of FAL2+ injuries. Statistically significant lower overall (MAIS2+) injury risks are seen for front-seat passengers too (4.1% vs. 2.5%), while the confidence intervals are overlapping for LX2+ and FAL2+ injuries. When separating females and males, the same injury risk trends between the two car model groups are seen for the drivers, including statistically significant lower risks of MAIS2+ and LX2+ injuries for both sexes, while with respect to FAL2+ injuries only statistically significant for the males. Separating the front-seat passengers by sex is not meaningful, due to few males and especially few males with FAL2+ injuries.

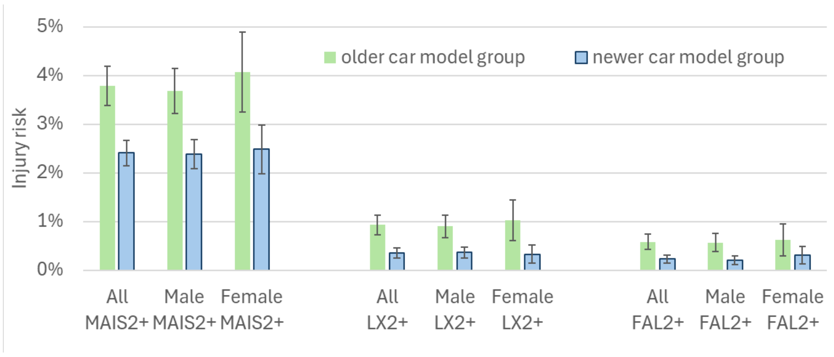


Fig. 1(a). Injury risks (including 95% confidence intervals) for MAIS2+, LX2+ and FAL2+ for all drivers, and males and females separately, in older and newer car model year groups, all crash types.

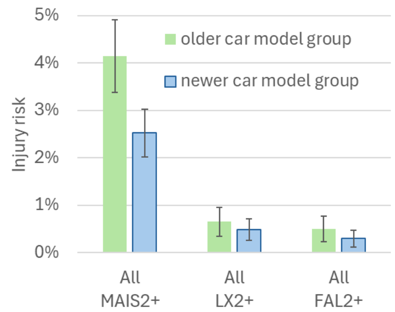
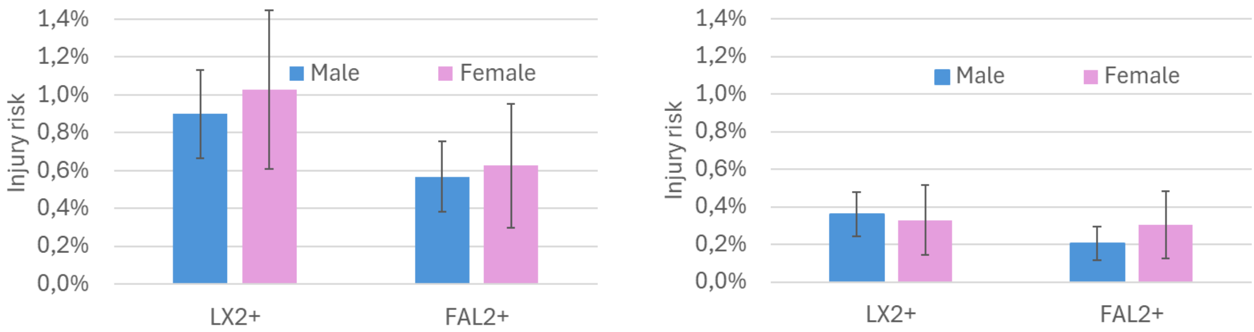


Fig. 1(b). Injury risks (incl. 95% conf. intervals) for MAIS2+, LX2+ and FAL2+ for all front-seat passengers, all crash types.

The injury risks are low overall. Among the 13,844 drivers in the newer car model group with known injury outcome, 49 sustained LX2+ injuries, of which 32 were injured to the foot, ankle or leg. Of these 32 FAL2+ injured drivers, six also sustained AIS2+ injuries to the knee, thigh or hip (KTH2+). Among the 3,684 front-seat passengers, 18 sustained LX2+ whereof 11 with FAL2+. One of these also sustained KTH2+. None of the 1,409 rear- seat passengers sustained a FAL2+ injury.

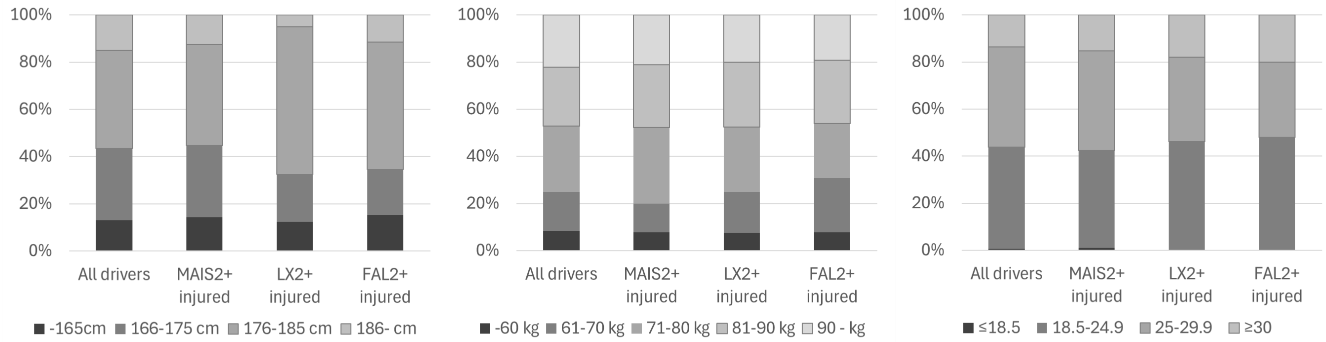
Figure 2 provides an extract from Figure 1(a) on LX2+ and FAL2+ injury risks to enable easier comparison between females and males, for respective car model group.



(a) Older car model group (b) Newer car model group

Fig. 2. LX2+ and FAL2+ injury risks (including 95% confidence intervals) comparing males and females, all crash types.

Figure 3 shows distribution of driver characteristics in the newer car model group for all crash types. The driver's stature, weight and BMI are grouped and presented for all drivers and the subsets of MAIS2+, LX2+ and FAL2+ injured drivers. No clear trends can be seen. Figure 3(a) shows a small shift in distribution towards taller occupants both with respect to LX2+ and FAL2+ injured drivers as compared to the other two groups, however not for the tallest group (186 cm and taller). No trend for FAL2+ injured for increased weight is seen, rather the opposite (Figure 3(b)). Although there might seem like a relatively higher share for the obese group for the FAL2+ in Figure 3(c), there are only seven in that group, making the shares uncertain.



(a) Stature (b) Weight (c) BMI

Fig. 3. Distributions of driver characteristics for all drivers (N=12,504) and the subgroups of the drivers sustaining MAIS2+ injuries (N=293), LX2+ injuries (N=39) and FAL2+ injuries (N=25), in the newer car model group, all crash types.

The crash type distributions for all drivers and for the drivers sustaining MAIS2+ injuries, in addition to the subsets of LX2+ and FAL2+ injured drivers, are shown in Figure 4. The distribution of LX2+ injured drivers deviates from the trend of all drivers as well as MAIS2+ injured drivers. Additionally, while LX2+ injured drivers are mainly seen in frontal impacts, they are also seen as results of several other crash types, although those with FAL2+ are predominately found in frontal impacts. Among the 32 FAL2+ injured drivers, all were exposed to a frontal impact or a multiple crash which included a forward impact component.

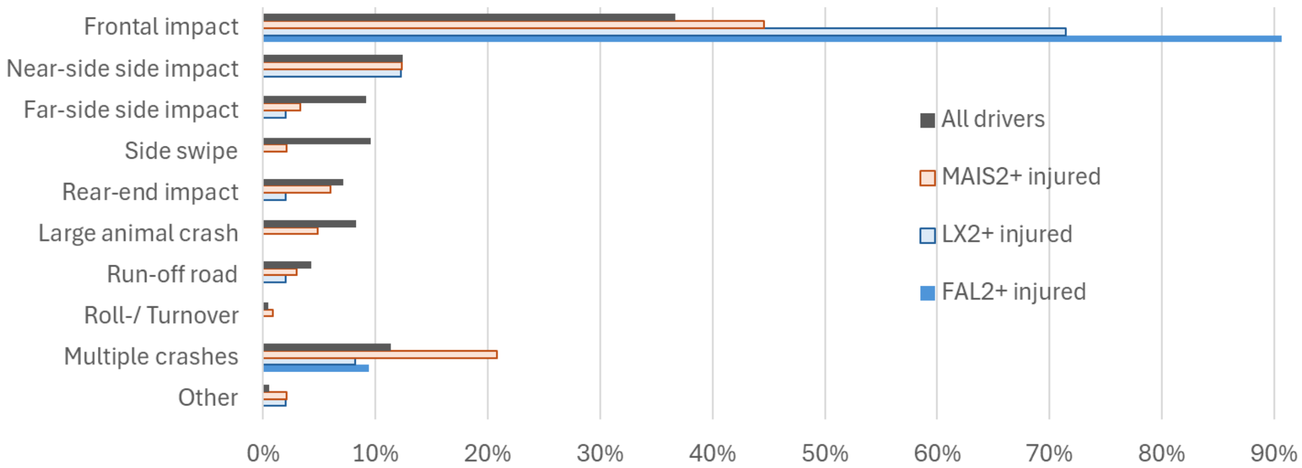


Fig. 4. Distribution of crash types comparing all drivers (N=13,911), all drivers with MAIS2+ injuries (N=332), drivers with LX2+ injuries (N=49), and those with FAL2+ injuries only (N=32), the newer car model group.

Frontal Impacts

MAIS2+, LX2+ and FAL2+ injuries for the drivers and front-seat passengers in frontal impacts are shown in Figures 5(a)-(b), comparing the two car model groups. It follows the same trend as for all crash types, including statistically significant difference for all drivers, and male drivers separately, in all three categories MAIS2+, LX2+ and FAL2+ injured.

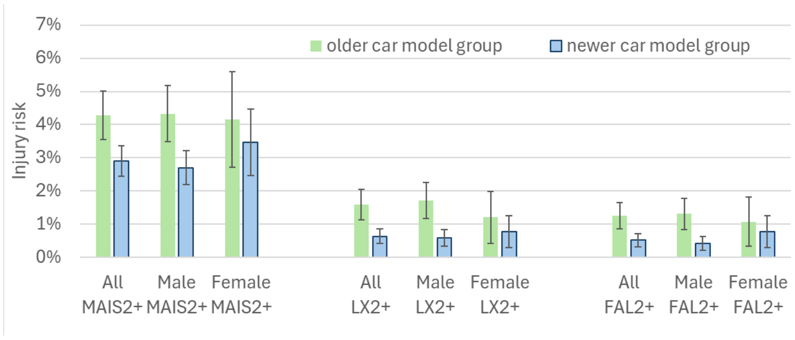


Fig. 5(a). Injury risks (including 95% confidence intervals) for MAIS2+, LX2+ and FAL2+ injured, for all drivers, and males and females separately, comparing older and newer car model groups, frontal impacts.

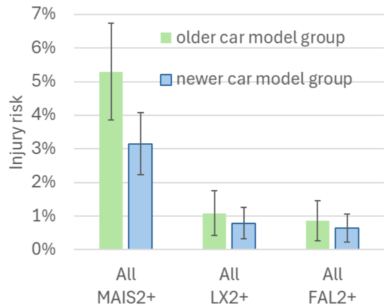
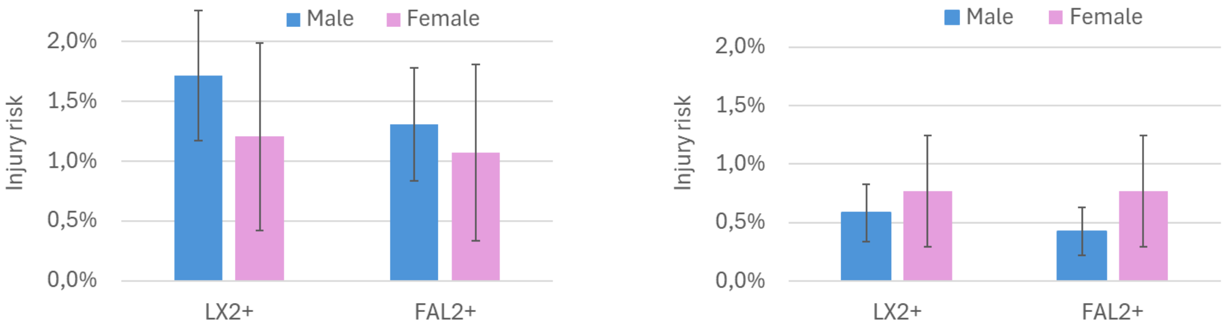


Fig. 5(b). Injury risks (incl. 95% conf. intervals) for MAIS2+, LX2+ and FAL2+ injured, for front-seat passengers, frontal impacts.

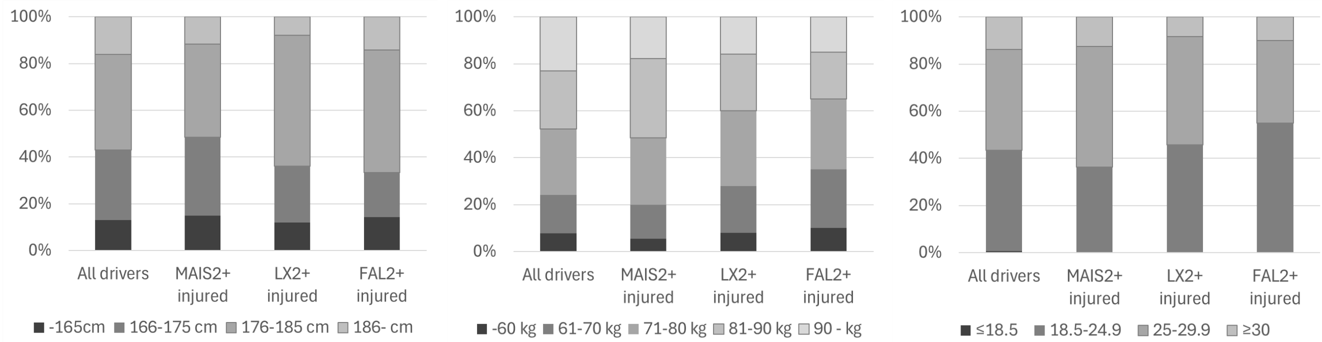
Figures 6(a)-(b) provide an extract from Figure 5(a) on LX2+ and FAL2+ injury risks to enable easier comparison between females and males, for respective car model groups.



(a) older car model year groups (b) newer car model year groups

Fig. 6. LX2+ and FAL2+ injury risks (including 95% confidence intervals) comparing males and females, frontal impacts

The distribution of driver characteristics in the newer car model group for those exposed to frontal impacts are plotted in Figures 7(a)-(c). The driver's stature, weight and BMI are grouped and presented for all drivers and the subsets of MAIS2+, LX2+ and FAL2+ injured drivers. The stature distribution for this frontal impact subset (Figure 7(a)) is similar to when all crash types were included (Figure 3(a)). The weight distribution for the frontal impact subset shows a trend towards relatively fewer of higher weight among the FAL2+ injured, with a share of approximately 35% who weighs more than 80kg, as compared to a share of approximately 50% for all drivers and the group of MAIS2+ injured (Figure 7(b)). With respect to BMI, 55% of the FAL2+ injured drivers are of normal BMI (18.5-24.9), this is a larger share than for all drivers, as well as the MAIS2+ and LX2+ injured subsets (Figure 7(c)).



(a) Stature (b) Weight (c) BMI

Fig. 7. Distributions of driver characteristics for all drivers (N=4,562) and the subgroups of the drivers sustaining MAIS2+ injuries (N=127), LX2+ injuries (N=24) and FAL2+ injuries (N=20), in newer car model groups, frontal impacts.

Foot, Ankle and Leg AIS2+ (FAL2+) Injuries

In total, 43 occupants among the 19,068 occupants in the 13,925 crashes in the newer car model group sustained one or more FAL2+ injuries. There were 32 FAL2+ injured drivers and 11 FAL2+ injured front-seat passengers. All driver cases were exposed to different types of frontal impacts or a multiple crash in which all cases included a frontal component. While most FAL2+ injured front-seat passenger cases followed this pattern, there were exceptions. One case was a driver-side side-impact, and another was a multiple crash with a driver-side small-overlap frontal impact followed by a rollover.

After excluding the seven cases due to extreme crash severity and car deformation, the regions and types of injuries for the remaining 26 FAL2+ injured drivers and the 10 FAL2+ injured front-seat passengers are summarised in Tables I-III. Details on the individual FAL2+ cases are available in Appendix. The reference cases for eight of the driver cases and 5 of the front-seat passenger cases are available in Appendix as well, numbered "ref-" and the number of the matched FAL2+ injured case.

TABLE I
LIMB AND REGIONS OF THE FAL2+ INJURIES TO THE DRIVERS AND FRONT-SEAT PASSENGERS

<table>
<tr><th></th><th></th><th>Foot</th><th>Ankle</th><th>Leg (tibia/fibula)</th><th>Total</th></tr>
<tr><td rowspan="7">Drivers</td><td rowspan="2">Right limb only</td><td>2</td><td>2</td><td>7</td><td rowspan="2">12</td></tr>
<tr><td></td><td colspan="2">1 with both ankle and leg</td></tr>
<tr><td>Left limb only</td><td>2</td><td>5</td><td>1</td><td>8</td></tr>
<tr><td rowspan="4">Both limbs</td><td>1</td><td>1</td><td>0</td><td rowspan="4">5</td></tr>
<tr><td colspan="2">1 right ankle, and left foot</td><td rowspan="3"></td></tr>
<tr><td colspan="2">1 right foot, and left ankle</td></tr>
<tr><td colspan="2">1 right foot + ankle, and left foot</td></tr>
<tr><td rowspan="3">Front-seat passengers</td><td>Right limb only</td><td>2</td><td>2</td><td>1</td><td>5</td></tr>
<tr><td>Left limb only</td><td>2</td><td>1</td><td>1</td><td>4</td></tr>
<tr><td>Unknown limb</td><td colspan="2"></td><td>1</td><td>1</td></tr>
</table>

While all the 10 front-seat passengers were injured in one limb only, 5 of the 26 drivers sustained FAL2+ injuries to both limbs (Table I). For the drivers, a relatively higher proportion of the FAL2+ injuries were seen for the right limb, in total 17 as compared to 13. Twelve of these 17 drivers applied the brake at time of impact, while five of them indicated they did not, or it was likely that they had not. The injury types for these two categories are summarised in Tables II-III.

While the drivers mainly sustained their leg fractures distally or midshaft (Table II), the two fibula-injured front-seat passengers (with known fracture location) both sustained their fractures close to the knee (Table III). One of them was exposed to the multiple crash and also sustained an AIS2+ knee injury on her other limb (case 36, Appendix), while the other was in a frontal impact (case 28, Appendix). The one with an unspecified leg injury was involved in the side impact and hence not exposed to a forward crash component (case 32, Appendix).

TABLE II
TYPES OF FAL2+ INJURIES TO THE DRIVER

<table>
<tr><th></th><th>Foot</th><th>Ankle</th><th>Leg (tibia/fibula)</th><th>Total</th></tr>
<tr><td rowspan="4">Right limb, braking</td><td>2 metatarsals</td><td>1 medial malleolar</td><td>1 proximal tibia</td><td rowspan="4">12</td></tr>
<tr><td>1 talus and metatarsal</td><td>1 lateral malleolar</td><td>4 distal or midshaft tibia/fibula</td></tr>
<tr><td colspan="2">1 combined metatarsal and medial mall.</td><td></td></tr>
<tr><td></td><td colspan="2">1 combined medial malleolar and distal tibia</td></tr>
<tr><td rowspan="2">Right limb, no braking</td><td>1 talus</td><td>2 lateral malleolar</td><td>1 midshaft tibia and fibula</td><td rowspan="2">5</td></tr>
<tr><td>1 cuneiform + talus</td><td colspan="2"></td></tr>
<tr><td rowspan="3">Left limb</td><td>1 talus</td><td>3 medial malleolar</td><td>1 unspecified</td><td rowspan="3">13</td></tr>
<tr><td>4 metatarsals</td><td>1 lateral malleolar</td><td rowspan="2"></td></tr>
<tr><td></td><td>3 bimalleolar</td></tr>
<tr><td>Unknown limb</td><td>1 metatarsal</td><td colspan="2"></td><td>1</td></tr>
</table>

TABLE III
TYPES OF FAL2+ INJURIES TO THE FRONT-SEAT PASSENGERS

	Foot	Ankle	Leg (tibia/fibula)	Total
Right limb	1 calcaneus	1 bimalleolar	1 proximal fibula	5
	1 talus	1 trimalleolar		
Left limb	1 talus	1 pilon	1 proximal fibula	4
	1 unspecified			
Unknown limb			1 unspecified	1

When analysing the crash configurations of the cases with FAL2+ injuries in the case-by-case analysis (Appendix), it is obvious that many factors contribute. There is no clear correlation between fracture type and direction of impact, nor car body deformation. As an example, the car deformation patterns for the 13 drivers who sustained malleolar fractures were not consistent with type of malleolar fracture (medial vs. lateral), or which ankle, nor braking or not. However, it can be noted that the three bimalleolar fractured ankles were all left ankles. Looking at these three cases, two of them may have some footwell intrusion due to local deep front deformation close, while the third most likely did not. The course of events varied between the three as well; run-off-road and impact to embankment (case 9), impact into narrow object (case 17) and distributed high-severity frontal impact (case 26).

The overall severity of the crash varied widely from low-moderate severity, such as cases 1, 5, 27 and 31, to very high crash severity, such as cases 21, 25 and 26 (Appendix). The influence of footwell intrusion was not seen as a main factor in the current study, since only in a limited number of the FAL2+ injured cases footwell intrusion likely occurred.

Case 25 was a head-on collision of very high severity, with a delta-V of 100km/h. The male driver sustained injuries to several body regions, see Appendix. His most severe injuries were AIS3 injuries to the head, neck artery, lungs and right femur. The two AIS2 talus fractures, one for each foot, were of different kinds. The right foot sustained the collum tali fracture as described by Pettersson *et al.* [20]. Such fracture requires tensed muscles, which corresponds to the hard braking and his tensed muscles in the right limb. In addition, he sustained a fracture of the right third metatarsal bone, which could be a result of the same mechanism, but also influenced by how the foot was placed on the pedal. The right femur fracture was caused by compressive loads while also loading into the knee airbag, confirming the high loads through his right limb. His left foot was likely positioned on the footrest, since the talus fracture in that foot indicated that the foot did not have full support during the whole crash but rotated off the footrest.

When pairwise analysing the cases in Appendix, it is difficult to see a specific trend between the injured cases and the corresponding FAL2+ non-injured reference cases. For example, case 2 and its reference both were braking with the same brake pedal design. It is likely to stipulate that the exact position and hence support by the brake pedal differed, causing the ankle of the driver of case 2 into an eversion due to body loading.

In case 4 and its two reference cases, none of the drivers were braking, hence it is difficult to know where their feet were placed initially as well as during the event. They were all exposed to a run-off-road event, which also may have positioned their feet differently.

IV. DISCUSSION

The current study covers several decades. The rationale is that the cars included in this study underwent a design focus on foot, ankle and leg injury protection during the 1990s. The learnings from Forssell *et al.* [18] were implemented into the car models which are referred to as the newer car model group. As shown in Figure 1, the injury risks for occupants in this group as compared to the older car models were statistically significant lower for LX2+ injuries as well as for FAL2+ injuries. This leads to the overall conclusion that the protection principles, broken down in design guidelines as described by [18] and implemented into the cars, were effective. When extracting frontal impacts only, the same conclusions apply (Figure 5). Figures 1 and 5 also show that the principles identified and the design advancements made were relevant for both females and males. The current study shows that by addressing the needs of the people in real traffic, focusing the principles of protection, improvements can be made irrespectively variation in occupant sizes and sex. The working process for this is further described in [21] and covers beyond what standardized tests do.

In the current study, there were only FAL2+ injured in the front seat in the newer car model group. Among the 1,409 rear-seat passengers included there was no one sustaining FAL2+ injuries. With the low injury risks in this study, making it sensitive to singular cases, it is difficult to draw any firm conclusions. Nevertheless, it is in line with another recent study, in which foot, ankle and leg injuries were few in the rear seat [1].

The case-by-case analysis confirmed prior studies with respect to a large variety of influencing factors and the overall injury mechanism of body loading through the limbs. In several cases, knee abrasions or other injuries confirmed knee loading. Since the cars in the current study had less intrusion overall, as compared to the studies from the 1990s, other factors were shown more of interest. The foot injuries were primarily from two main mechanisms; metatarsal fractures indicating a dorsiflexion mechanism, and heel bone fractures related to high body loading. The ankle injuries included malleolar fractures of different degrees and sides, resulting from a combination of low-energy eversion/inversion type of mechanisms and high-energy body loading with twisting. For foot and ankle injuries, the evenness of the surface under the foot was essential. This applied to both the initial surface and the dynamic surface caused by intrusion, in those cases applicable. It was then also influenced by the interplay of body load and intruding structure, in addition to potential knee loading. Fractures to the tibia and/or fibula occurred mainly for the drivers. They occurred in situations both with and without intrusion and in varied direction of impact. Some of them were classified as open fractures, indicating a hard local impact. Some reported injuries attributed to “pedal impact”, although difficult to confirm. Nevertheless, it indicated that the driver noticed the pedal afterwards, suggesting it was a potential impact point.

Some differences between drivers and front-seat passengers were seen with respect to distribution of injuries. For instance, in this dataset non-knee impact related leg injuries were seen only in drivers. In addition, some fracture types were specifically related to harsh braking combined with tensed muscles (case 25 right ankle, Appendix), while some are related to lateral stability (case 25 left ankle, Appendix) and plantar stability (case 6 and 22, Appendix). These injuries could have been influenced by intrusion of the footwell area, the behaviour of the pedals during the crash, but also by the occupant kinematics at impact. One of the front-seat passengers who sustained right bimalleolar fractures reported that he was sitting with his right limb over his left at time of impact (case 31, Appendix). Another front-seat passenger, who sustained a left foot fracture, reported that the injury was caused by a non-attached object (cabin heater) in the footwell area (case 33, Appendix). Hence, although the front-seat passengers do not face challenges with the pedals, they may encounter other challenges.

Many factors may influence FAL2+ injury occurrence. Sitting posture and feet placement are among those, but they are difficult to collect and investigate from real-world crashes retrospectively and thus difficult to analyse. Although drivers have a more controlled sitting posture and seat position, it is yet difficult to know where their feet are placed at time of impact and where their knees are in relation to potential knee impact areas. However, some insights can be gained by analysing those who were identified as braking, whereby assuming that their right foot was placed on the brake pedal. Within this group there were a variety of fracture types, including the foot, the ankle as well as the leg (Table II). This indicates that the exact placement of the foot on the pedal, obviously together with the dynamic event of force directions, body load and potential footwell/pedal intrusion, influences the outcome. This emphasises the importance of addressing a range of measures such as evenness and to reduce acceleration by measures addressing body load, footwell/pedal design and intrusion. These measures should apply to all areas where feet may be placed. In modern cars, an increased variation will likely be seen for the drivers’ right foot position too, due to speed support systems, such as adaptive cruise control, in addition to electric cars’ one-pedal-drive functionality.

With respect to occupant characteristics, several studies have shown that female drivers had a higher likelihood of below-knee injuries than males, e.g., [1-2][22-23]. Studies have also shown an increased risk with higher body weight [23] and that higher BMI correlated to higher foot/ankle injury risks [24][4]. Rudd [22] reported that occupants shorter than 164 cm are twice as likely to sustain leg (tibia/fibula) injuries than those of stature 164-186 cm, and female occupants shorter than 164 cm were at significantly higher risk of foot/ankle and leg injuries than males in the same height range. While sex is reported as an influencing factor for LX2+ and FAL2+ injury risks in several studies, this was not seen in the current study (Figures 2 and 6). One of the main differences from prior studies is the homogenic dataset on car models in the current study. The differences in results may be related to the challenges by other studies to exclude additional influencing factors in their datasets, but it could also be that the car models in the current dataset have been developed based on a real-world crash based working process, including the awareness of such complexity as summarised in [18]. With respect to other occupant characteristics, the trends for stature, weight and BMI were not evident in the current study, especially when all crashes were included. However, for drivers in frontal impacts, some difference in distribution with respect to weight and BMI could be observed between the sub-group of LX2+ injured in relation to all drivers as well as the MAIS2+ injured. Figures 7(b)-(c) show a trend towards higher distribution for lower weight and lower BMI, which contrasts with prior studies. However, the numbers are small in the current study and the graphs should be interpreted carefully. The case-by-case analyses, including the comparison to reference cases, helped to shed light on the complexity and multitude of influencing factors. For example, although there are some match-case comparisons in which the female was injured (e.g. cases 5, 7, 27 and 28, Appendix), there are other where the opposite is seen (e.g. cases 4 and 11, Appendix).

Few studies have included all crash types when exploring this topic. The focus of FAL2+ injuries has mainly been on frontal impacts. The current study supports that focus, since the vast majority of the FAL2+ injured occupants were exposed to a frontal impact or multiple crashes which also included a frontal component. Nevertheless, including all crash types provided a widened perspective and contributed to the understanding of the range of potential mechanisms for FAL2+ injuries. The mechanism of body loading turns out to be the main mechanism, confirming prior studies, e.g. [8][15]. The mechanisms of the foot and ankle injuries were all relevant to body loading. So were most of the distal tibia/fibula fractures sustained by the drivers, especially those at higher severity and in combination with heel and ankle injuries. While some of them could be related to direct hard impacts to pedals intruding, or the foot slipping off the pedal impacting another pedal, the body loading would still be a part of the mechanism. The exceptions are those with proximal leg injuries (mainly front-seat passengers), for which an impact mechanism, similar to as for knee injuries, is the most likely injury mechanism. In crash tests, the crash test dummies are sometimes observed to swing their feet upwards in a frontal impact, mainly in the passenger seats. While the current study cannot confirm if such kinematics occur in reality, the results do not support this kinematics being injurious to the foot, ankle or leg.

Limitations include that the analysis was partly based on self-reported data, such as information on braking. There was also a variation in the quality of the data for the case-by-case analysis. For some cases only the standard information for the dataset was available, while some cases were also part of an in-depth investigation dataset, for which extensive information, including interviews with the driver and tear-down and read-out of the vehicle and more, were available. However, even with this in-depth information, it is still difficult to know the exact seat position, nor how the limbs were positioned, in addition to the feet placement and movement during the crash. The medical reports, including radiology information, were essential for the mechanism analyses. They were available for all cases, except six.

This data is based on one car brand and crashes in one country only. Thereby the data is difficult to generalise. From that perspective this may be perceived as a limitation, however with the objective and focus of this study, a well-controlled car model set was a prerequisite. The results show that the principles as stated in [18] can help towards improved protection of AIS2+ injuries below the knees, and that it will protect both females and males. The injury risk estimation should also be treated in the perspective of the limitations of the sampled selection of cases in this database and should not be generalized to absolute estimates of the injury risk posed for all car occupants within category of analysis.

A strength in the current study is the homogenic group of cars and for which the design is well known. The two vehicle groups were set to distinguish between two major levels of car design, within the area of focus. Other studies in the area include a larger variety of cars, which then also likely influence the outcome when comparing differences with respect to other factors such as occupant characteristics.

The variety of influencing factors and their spread in real world crashes was large, even if limiting to focus frontal impacts and front-seat occupants. Addressing FAL2+ injuries from a car manufacturer’s perspective was doable. Figures 1 and 5 show the progress that can be made by first studying the mechanisms based on real-world data, identifying the influencing factors, summarised into protection principles and addressed in car development. This was achieved using a variety of methods and design guidelines. However, addressing FAL2+ injuries from a standardised test assessment perspective is more difficult, and will require new thinking and novel ways going beyond the standardised testing with crash test dummies in limited sizes and with singular seat positions and sitting postures. The feet positions influence the injury risks as well as types of injury. It is also a fact that passengers, and even drivers, place their feet in varied places. In the current dataset, approximately 60% of the drivers were braking prior to the crash, meaning that they had their right foot placed on the brake pedal. In standardized tests, the crash test dummy's foot is positioned on the gas pedal. Adding to this is the growing number of cars equipped with speed support systems allowing the right foot of the driver to be placed in even more different positions.

V. CONCLUSION

Injury risks for occupants in the group of car models with car design advancements addressing foot, ankle and leg injuries were shown significantly lower than for the prior car models. Lower risks were observed for both LX2+ and FAL2+ injuries. Consequently, the protection principles, broken down in design guidelines as described by Forssell *et al.,* (1996) and implemented into the cars, were effective. Additionally, the identified principles and the design advancements made based on those, were relevant for both females and males, with no distinguishable sex differences in injury outcome.

The study confirms prior findings that countermeasures need to address several aspects, including footwell geometry, pedal design, intrusion and acceleration management. Overall injury mechanisms for FAL2+ injuries are body load into the feet, in some cases also with knee interaction with instrument panel. While footwell intrusion may contribute to these injuries, the evenness in the supportive surface under the feet appears to have more influence.

FAL2+ injuries are diverse with several influencing factors, they were not seen specifically related to sex nor occupant size, instead the feet positions and the dynamics in the impact were likely more influential. FAL2+ injuries are highly related to frontal impacts and front-seat occupants.

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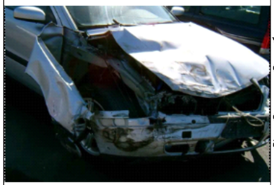
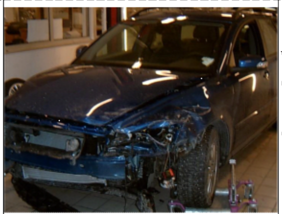
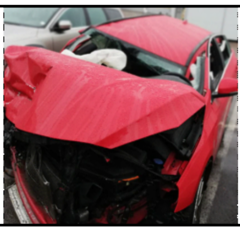
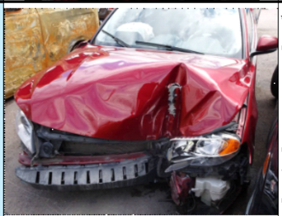
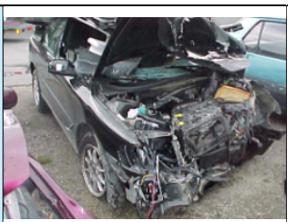
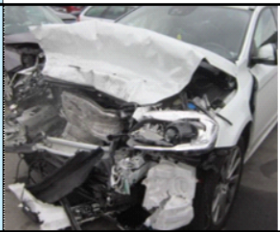
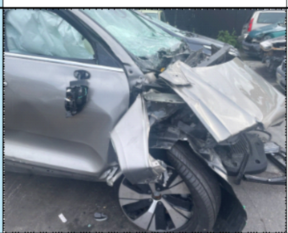
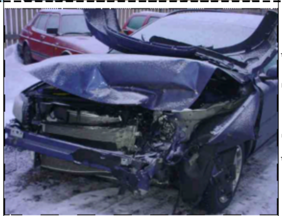
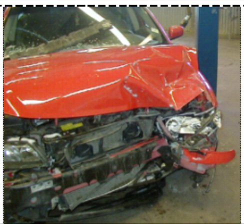
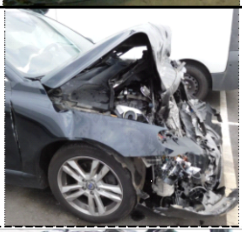
VII. APPENDIX

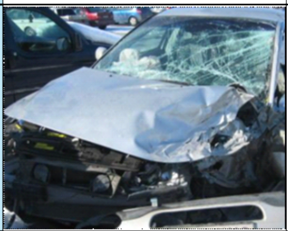
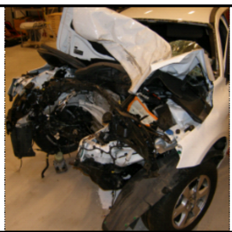
1		**Volvo V70-01** CDC:02FZEW40 Oblique head-on collision with a heavy truck	**Driver** Male, 51y 183cm, 87kg MAIS2 Action: braking	**Left foot:** Metatarsale II fracture, AIS2 *Mech: forced dorsiflexion*	N/A	Abrasion left foot, AIS1 + Neck and right shoulder pain, AIS1
1-ref		**Volvo V70-04** CDC:01FZEW40 Oblique frontal-impact to a passenger car	**Driver** Male, 32y 194cm, 98kg MAIS1 Action: no braking	N/A	N/A	Abrasion knees and fingers, AIS1
2		**Volvo S60-01** CDC:11FYEW35 Oblique head-on collision with a heavy truck	**Driver** Female, 56y 167cm, 54kg MAIS2 Action: braking	N/A	**Right ankle:** Medial malleolar fracture, AIS2 *Mech: forced eversion of the ankle*	Hematoma right knee, AIS1 Abrasion left knee, AIS1 + AIS1 injuries head, face chest and spine
2-ref		**Volvo V70-04** CDC:11FYEW35 Oblique frontal-impact into left side of a truck	**Driver** Female, 54y 170cm, 80kg MAIS1 Action: braking	N/A	N/A	Neck pain
3		**Volvo S60-04** CDC:12FYEW70 Head-on collisions with a passenger car	**Driver** Male, 54y 189cm, 93kg MAIS2 Action: Braking	N/A	**Right leg:** Open midshaft fibula and tibia fractures, AIS2 *Mech: interaction with pedals*	No other injuries
3-ref		**Volvo XC70-04** CDC:12FYEW70 Head-on collisions with a passenger car	**Driver** Male, 70y 179cm, 74kg MAIS1 Action: Braking	N/A	N/A	Left toe injury, AIS1
4		**Volvo V70-02** CDC:12FCEN70 Run-off road and impact with a tree	**Driver** Male, 39y 178cm, 70kg MAIS2 Action: no, drowsy	N/A	**Right leg:** Comminuted spiral fracture distal tibia + Compound midshaft fibula fracture, AIS2 *Mech: combined axial and rotation loads*	No other injuries
4-ref1		**Volvo V70-01** CDC:12FCEN50 Run-off road and impact with a tree	**Driver** Male, 39y 186cm, 100kg MAIS1 Action: no, distracted	N/A	N/A	Right knee luxation, AIS1 Left hand fracture, AIS1
4-ref2		**Volvo V70-04** CDC:12FCEN60 Run-off road and impact with a tree, slippery road	**Driver** Female, 23y 164cm, 75kg MAIS1 Action: tried to brake and steer	N/A	N/A	Hematoma knees, torso and right hand, AIS1 Pain in shoulder, neck and back, AIS1

5		**Volvo S60-09** CDC:11FYEW30 Oblique head-on collision with a passenger car	**Driver** Female, 64y 167cm, 63kg MAIS2 Action: braking	N/A	**Right ankle and leg:** Medial malleolar fracture, AIS2 + distal tibia fracture, AIS2 *Mech: high body load and forced eversion of the ankle*	+ Torso, wrist and head pain, AIS1
5-ref		**Volvo S60-02** CDC:11FYEW40 Oblique frontal impact into the side of a passenger car	**Driver** Male, 58y 178cm, 83kg MAIS1 Action: braking	N/A	N/A	Torso hematoma, AIS1 Face pain, AIS1
6		**Volvo C30-07** CDC:11FLEN50 Skidding and impact to a tree	**Driver** Female, 21y 169cm, unkn. weight MAIS2 Action: braking	N/A	**Right foot:** Metatarsal II-IV fractures, AIS2 *Mech: forced dorsiflexion*	No other injuries
6-ref		**Volvo V50-07** CDC:11FLEW45 Offset frontal impact into rear of a passenger car	**Driver** Female, 43y 164cm, 90kg MAIS1 Action: braking	N/A	N/A	Right knee hematoma and neck strain, AIS1
7		**Volvo XC60-19** CDC:12FYEW40 Head-on collision with a passenger car	**Driver** Female, 45y 175cm, 78kg MAIS2 Action: braking to standstill	N/A	**Right leg:** Distal tibia fracture, complete articular, AIS2 *Mech : high body load*	Right hip hematoma, AIS1 + Face and hand injuries, AIS1
7-ref		**Volvo XC90-18** CDC:12FDEW40 Head-on collision with a passenger car	**Driver** Male, 63y 186cm, 75kg MAIS2 Action: braking	N/A	N/A	Rib fractures, AIS2 Left arm laceration, AIS1
8		**Volvo V70-02** CDC:12FYEW45 Frontal impact into a tractor trailer	**Driver** Male, 45y 178cm, 95kg MAIS2 Action: braking	N/A	**Right leg:** Tibia and fibula fractures, 5 cm from ankle, AIS2 *Mech: high body load and pot. interaction with pedals*	+ Left hand abrasion, AIS1
9		**Volvo S60-01** CDC:01FREW50 Run-off road and impact with embankment / drain pipe	**Driver** Female, 52y 165cm, 67kg MAIS2 Action: no braking	**Left ankle:** Bimalledar fractures, AIS2 *Mech: high body load and twisting of ankle*	**Right ankle:** Lateral malleolar fracture, AIS2 *Mech: forced eversion of the ankle*	Left knee contusion, AIS1 Pelvis fracture, AIS2 + Sternum fracture, AIS2
10		**Volvo S80-01** CDC: 12FYEW80 Run-off road and frontal impact to fundament and guard rail, likely simultaneously	**Driver** Male, 24y 174cm, 65kg MAIS3 Action: braking	N/A	**Right leg:** Open tibia fracture 15 cm from ankle, AIS3 *Mech: combined axial and rotation loads*	+ Left clavicle hematoma, AIS1

11		**Volvo XC70-00** CDC:12FZEW20 Head-on collision with a pssenger car	**Driver** Male, 69y unknown size MAIS3 Action: no braking	**Left ankle:** Medial malleolar fracture, AIS2 *Mech: forced eversion of the ankle*	N/A	+ Lumbar spine fracture, AIS3
11-ref		**Volvo XC70-04** CDC:12FZEW20 Head-on collision with a passenger car	**Driver** Female, 26y 169cm, 59kg MAIS1 Action: no braking	N/A	N/A	Torso pain, AIS1 Neck stretch, AIS1
12		**Volvo V70-03** CDC: 10LFEW10 CDC: 12FDEW20 Multiple impact with a side and a frontal impact, unknown sequence	**Driver** Male, 64y 176cm, 90kg MAIS3 Action: no braking	**Left ankle:** Lateral malleolar fracture, AIS2 *Mech: forced inversion of the ankle*	N/A	+ Head injuries, AIS1-3
13		**Volvo V70-04** CDC: 12FDEW60 Spinned and impacted a road fence	**Driver** Male, 19y 177cm, 69kg MAIS2 Action: unknown	**Left ankle:** Medial malleolar fracture, AIS2 *Mech: forced eversion of the ankle*	N/A	+ Clavicle fracture, AIS2 Lung contusion, AIS2 Concussion, AIS1
14		**Volvo S80-02** CDC: 12FCEN110 Run-off road followed by interaction with a tree along the left side, and a frontal impact to another tree.	**Driver** Male, 33y 185cm, 79kg MAIS4 Action: no braking	**Left ankle:** Medial malleolar fracture, AIS2 *Mech: forced eversion of the ankle*	**Right foot:** Talus fracture, AIS2 *Mech: high body loads*	Knee abrasions, AIS1 + Lung rupture, AIS4 AIS1 injuries chest, face and elbow
15		**Volvo V40-16** CDC: 06BDEW40 CDC: 12FCEW20 Multiple collision. Rear-end impact followed by a frontal impact into a statue in a round-about	**Driver** Female, 79y 164cm, 84kg MAIS4 Action: no braking		**Right ankle:** Lateral malleolar fracture, AIS2 *Mech: forced inversion of the ankle*	Thigh contusions, AIS1 + Spine fractures, AIS3 Torso injuries, AIS1-4
16		**Volvo V60-14** CDC: 01FYEW85 Run-off road and impact towards a brickwall	**Driver** Male, 58y 180cm, 98kg MAIS3 Action: no braking	**Left foot:** Metatarsal fracture, AIS2 *Mech: forced dorsiflexion*	N/A	Abrasion right foot, AIS1 Contusion right knee, AIS1 + Head injuries, AIS2-3 Rib fractures, AIS3
17		**Volvo V70-13** CDC: 12FCEN50 Laterally squeezed between truck and a wire crash barrier followed by a frontal impact to a narrow object	**Driver** Female, 66y unknown size MAIS2 Action: no braking	**Left ankle:** Bimalleolar fractures, AIS2 *Mech: high body load and twisting of ankle*	N/A	Laceration left ankle, AIS1 + Clavicle and wrist, AIS1
18		**Volvo V70-07** CDC: 01F..... Run-off road, through a fence and impacted a parked truck trailer	**Driver** Male, 51y 180cm, 110kg MAIS2 Action: no braking	**Ankle:** Fracture AIS2	Unknown limb	+ Face fractures, AIS2

19		**Volvo V70-01** CDC:12FYEW70 Frontal impact into the side of a passenger car	**Driver** Male, 38y 188cm, 82kg MAIS2 Action: braking	**Left foot:** Metatarsale fracture, AIS2 *Mech: forced dorsiflexion*	**Right foot and ankle:** Metatarsale II-IV fractures, AIS2 Medial malleolar fracture, AIS2 *Mech: forced eversion and dorsiflexion*	+ Concussion, AIS2 Clavicle fracture, AI2
20		**Volvo V70-04** CDC:11FYEW35 Front left corner impact to a caravan's front	**Driver** Female, 58y unknown size MAIS2 Action: no braking	N/A	**Right foot:** Cunieforme fracture and metatarsales fracture, AIS2 *Mech: leg entrapment*	Right tibia condyle fracture, AIS2 Right knee abrasion, AIS1
21		**Volvo XC60-17** CDC:01FDAW80 Head-on collision with a large pickup	**Driver** Male, 51y 184cm, 140kg MAIS3 Action: braking	N/A	**Right leg:** Proximal tibia fracture AIS2 *Mech: knee load*	Right femur fracture, AIS3 Pelvis fracture, AIS2 + Head, chest, upper extremity and spine injuries, AIS1-3
22		**Volvo XC60-16** CDC: 12FDEW40 Head-on collision with a jeep	**Driver** Male, 30y 180cm, 90kg MAIS2 Action: braking	N/A	**Right foot:** Metatarsal fractures, AIS2 *Mech: forced dorsiflexion*	Right knee contusion, AIS1 + AIS1 injuries torso, right wrist and right forearm
23		**Volvo V40CC-14** CDC: 12FYEW80 Head-on collision with a small commercial van	**Driver** Male, 44y 180cm, 80kg MAIS3 Action: braking	**Left foot:** Metatarsal II and III fractures, AIS2 *Mech: forced dorsiflexion*	**Right ankle:** Lateral malleolus fracture, AIS2 *Mech: forced inversion of the ankle*	+ Lumbar spine fracture, AIS3 Thumb pain, AIS1
24		**Volvo V50-08** CDC: 11FYEW85 Head-on partial overlap collision with a heavy truck	**Driver** Male, 34y 185cm, 85kg MAIS3 Action: braking	**Left leg:** Tibia/fibula fracture, unspec, AIS2 *Mech: unknown*	N/A	Right ankle abrasion, AIS1 Pelvis ring fracture, AIS2 + Injuries to head, liver, wrist, AIS1-3
25		**Volvo XC40-21** CDC: 12FDEW100 Head-on collision with a small commercial van in very high speed	**Driver** Male, 48y 177cm, 72kg MAIS3 Action: braking	**Left foot:** Talus fracture, AIS2 *Mech: dorsalextension / pronation*	**Right foot:** Talus fracture, AIS2 Metatarsal fracture III, AIS2 *Mech: high axial loads and tensed muscles*	Right femur fracture, AIS3 + Injuries to head, neck, lungs, abdomen and wrists, AIS1-3
26		**Volvo S60 - 20** CDC: 12FDEW60 Front impact at high speed into the rear of a standstill tow truck	**Driver** Female, 30y 158cm, 59kg MAIS3 Action: no braking	**Left ankle:** Bimalleolus fracture, AIS2 *Mech: high body load and twisting of ankle*	N/A	Right ankle sprain, AIS1 Leg lacerations, AIS1 Right patella fracture, AIS2, and laceration, AIS1 + Injuries to abdomen, lungs, both forearms, neck pain, AIS1-3

27		**Volvo S80-09** CDC:01FZEW50 Oblique head-on collision with a passenger car	**Front seat passenger** Female, 58y 174cm, 68kg MAIS2 Action: driver steering left	N/A	**Right foot:** Calcaneus fracture, AIS2 *Mech: unknown*	No other injuries
27-ref		**Volvo V70-12** CDC:12FZEW45 Frontal impact into rear of a passenger car	**Front seat passenger** Male, uknown age unknown size MAIS0 Action: driver braking	N/A	N/A	Uninjured
28		**Volvo V50-07** CDC:12FYEW50 Frontal impact into rear of a passenger car	**Front seat passenger** Female, 55y 165cm, 65kg MAIS2 Action: driver no action	**Left leg:** Proximal fibula fracture, AIS2 *Mech: knee impact*	N/A	+ Pelvis and back/neck pain, AIS1
28-ref		**Volvo V50-04** CDC:12FDEW35 Frontal impact into side of a passenger car	**Front seat passenger** Male, 16y 175cm, 70kg MAIS1 Action: driver braking	N/A	N/A	Left ankle sprain, AIS1
29		**Volvo V70-06** CDC:11FYEW20 Oblique head-on collision with a passenger car	**Front seat passenger** Female, 53y 163cm, 73kg MAIS2 Action: driver braking	**Left foot:** Talus fracture, AIS2 *Mech: high body load*	N/A	Right knee contusion, AIS1 + Sternum fracture, AIS2 Contusion chest, AIS1
29-ref1		**Volvo V70-04** CDC:11FYEW30 Oblique head-on collision with a passenger car	**Front seat passenger** Female, 33y 170cm, 50kg MAIS1 Action: driver braking	N/A	N/A	Chest and neck pain, AIS1
29-ref2		**Volvo V70-04** CDC:11FYEW35 Frontal impact into the side of a truck cab	**Front seat passenger** Male, 49y 172cm, 95kg MAIS0 Action:	N/A	N/A	Uninjured
30		**Volvo V70-13** CDC:12FDEW35 Head-on collision with a passenger car	**Front seat passenger** Male, 50y unknown size MAIS2 Action: driver no action	N/A	**Right ankle:** Trimalleolar fracture, AIS2 *Mech: high body load and twisting of ankle*	No other injuries
30-ref		**Volvo V70-08** CDC:12FDEW35 Frontal impact into the side of a passenger car	**Front seat passenger** Male, 52y 174cm, 82kg MAIS1 Action: driver no action	N/A	N/A	Neck and thumb pain, AIS1

31		**Volvo S90-17** CDC:12FDEW30 Front into side of a passenger car	**Front seat passenger** Female,26y 175cm, 65kg MAIS2 Action: unknown	N/A	**Right ankle:** Bimalleolar fracture, AIS2 Sitting with right leg over left, at impact. *Mech: unknown*	Right knee contusion, AIS1
31-ref		**Volvo XC60-19** CDC:12FYEW40 Head-on collision with a passenger car	**Front seat passenger** Male,45y 186cm, 75kg MAIS1 Action: driver braking	N/A	N/A	Chest and back pain, AIS1
32		**Volvo S80-01** CDC:11LYEW20 Side impact, struck by a heavy truck	**Front seat passenger** Female,67y 161cm, 65kg MAIS2 Action: driver no action	**Leg:** Fracture AIS2	Unknown which limb	No other injuries
33		**Volvo S60-04** CDC:11FLEW70 Oblique head-on collision with a passenger car	**Front seat passenger** Female,57y 162cm, unkn weight, MAIS2 Action: driver braking	**Left foot:** Unspec fracture, AIS2 May have been hit by a non-attached object (cabin heater) *Mech: ?*	N/A	+ Rib fractures, AIS2
34		**Volvo V70-04** CDC:01FZEW40 Run-off road into a dtich and impact to a large stone	**Front seat passenger** Female,72y 162cm, 80kg MAIS3 Action: driver tried to steer up from the ditch	**Left ankle:** Pilon fracture, AIS2 *Mech: high body load*	N/A	+ Rib fractures, AIS2 Cervical spine fracture, AIS3
35		**Volvo XC60-15** CDC:12FCEN120 Run-off road and impact to a large tree	**Front seat passenger** Female,71y 168cm, 70kg MAIS4 Action: driver no action	N/A	**Right foot:** Talus fracture, AIS2 *Mech: high body load*	+ Chest injuries, AIS1-4
36		**Volvo XC90-14** CDC:12FLEW30 Small overlap head-on collision with a passenger car, whereby push down a slope, followed by a rollover event	**Front seat passenger** Female, 25y 165cm, 60kg MAIS2 Ation: N/A	N/A	**Right leg:** Proximal fibula fracture, AIS2 *Mech: knee impact*	Right knee fracture, AIS2 Ligament injuries, both knees, AIS1 + Abdominal injury, AIS2 Pelvis contusions, AIS1