Pelvic and femoral injuries in car-to-pedestrian accidents

Corina Klug, Martin Weinberger, Ernst Tomasch, Florian Feist, Wolfgang Sinz,
Hermann Steffan, Thomas Kinsky, Franz Roth, Norbert Praxl, Benjamin Buenger

Abstract Among pedestrian safety tests, the upper legform to bonnet leading edge test procedure has been regularly criticised for being neither biofidelic nor relevant.

In this study, the injuries to the femur and the pelvis in pedestrian-vehicle accidents are re-examined in terms of pedestrian, vehicle and impact parameters. Pedestrian accidents of four European in-depth databases (German, Austrian, French and Swedish) were analysed.

In total, 2,405 AIS 2+ and 978 AIS 3+ injuries were analysed. The relative frequency of pelvic combined with upper femoral injuries ranged from 2% to 15% depending on the underlying data set. Less than 4% of all AIS 2+ and AIS 3+ injuries were caused by the bonnet leading edge area. A high proportion (70-88%) of pelvic injuries cannot be assigned to the bonnet leading edge directly. Older people and females showed higher odds of suffering pelvic injuries. Among modern cars with year of market introduction after 2000, Small MPVs & Superminis have higher odds for pelvic injuries than Large & Small Family Cars. It has to be investigated, which measures are most effective in reducing pelvic and upper femoral injuries for the relevant population of pedestrians.

Keywords: *pedestrian safety tests, upper legform to bonnet leading edge test, femur, pelvis*, *accident analysis.*

I. INTRODUCTION

The pedestrian safety testing methodology was initially developed by EEVC (European Enhanced Vehicle-Safety Committee) working groups. It consists of three subsystem tests: headform to bonnet test; upper legform to bonnet leading edge (ULF-BLE) test and lower or upper legform to bumper test.

Since the pedestrian safety test procedures were published in the 1990s, the ULF-BLE test has been frequently criticised as not being representative of the real-world accident scenario or the injury mechanisms in pedestrian-to-vehicle accidents [1–4].

The ULF-BLE test never became mandatory in European regulations but was conducted for monitoring purposes and consumer information tests (Euro NCAP). In 2013/2014, Euro NCAP discussed modifications to the test procedure. However, the aim of short-term improvement restricted the amount of possible modifications. Essentially, the impact location and speed were changed for the updated test protocol of January 2015 (v8.0).

Various studies analysing pedestrian accidents were published within the past years. Most statistical analysis are based on the GIDAS (German In-Depth Accident Study) [1, 5–8] or PCDS (Pedestrian Crash Data Study of the NHTSA) databases [7],[9],[10]. Lower extremities are commonly summarised in one group (according to AIS body regions), without distinction of pelvic, femoral, knee or lower thigh injuries.

Comparison of studies is often difficult because of inconsistent boundary conditions: observed time period, country, applied filtering, injury severity. This is shown exemplarily in Fig. 1. The proportion of pedestrians suffering pelvic injuries varies from 0.7%, based on GIDAS [11] (when only injuries caused by the BLE with an impact speed <40 km/h were considered, i.e. injuries addressed by current Euro NCAP ULF-BLE test), to 10.4%, based on PCDS (considering all injury sources and impact velocities). The relative frequency of pelvic injuries is highly dependent on the injury severity considered and varies from 2% of all AIS 3+ injuries (based on ABIDA [12]) to 14.9% of all injuries from pedestrian accidents in GIDAS [6].

C. Klug (tel: +43 316 873 30329, e-mail: corina.klug@tugraz.at) and M. Weinberger are doctoral students, E. Tomasch, F. Feist and W. Sinz are postdoc researchers and Professor H. Steffan is head of the Vehicle Safety Institute (VSI) at Graz University of Technology in Austria. T. Kinsky, B. Buenger (Opel), F. Roth (Audi) and N. Praxl (PDB) are representatives of the ACEA Task Force Pedestrians.

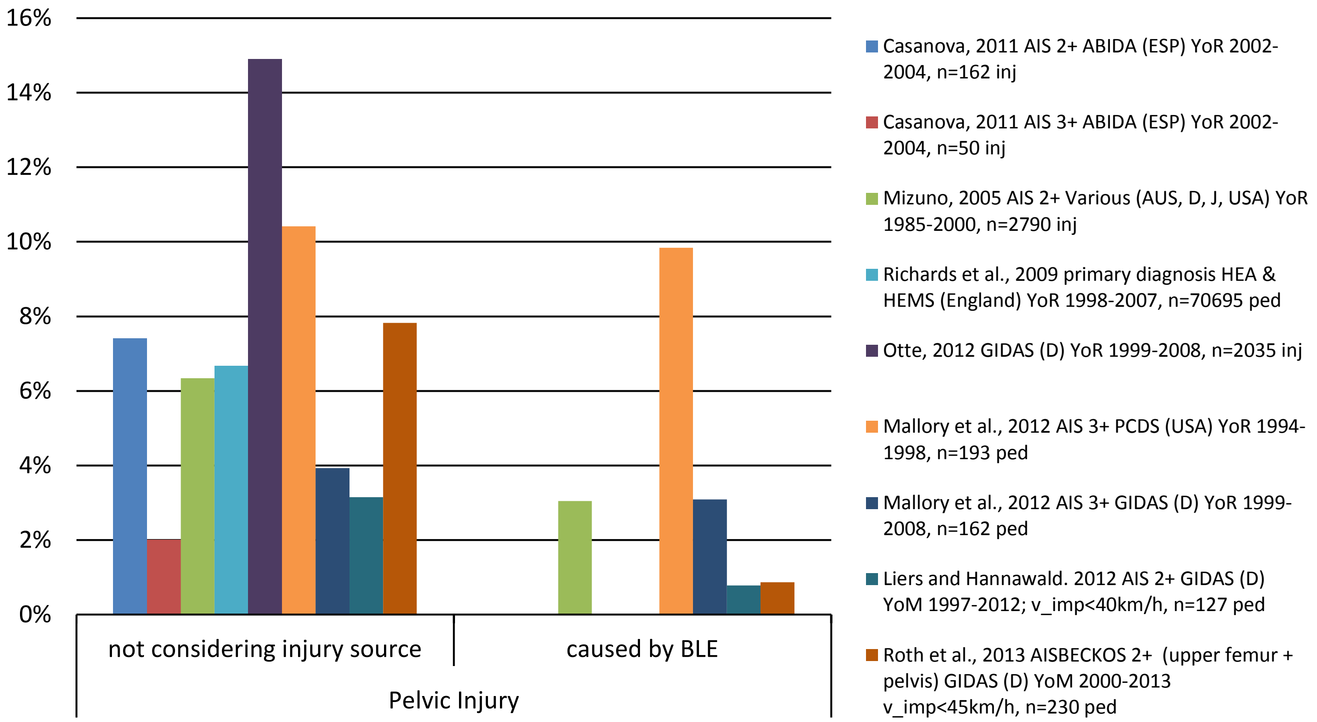

Fig. 1. Relative frequency of pelvic and pelvic/upper femoral combined injuries based on different studies [1],[6],[7],[11–14], referring to the total number of injuries (inj) or the total number of injured pedestrians (ped). Data sets differ in terms of year of recording (YoR), injury severity, country and filter criteria.

Several risk factors associated with pelvic and femoral injuries have been reported in literature: age and gender of the pedestrian, vehicle geometry and impact speed,

Demetriades et al. [15] found within a trauma registry study that pelvic fractures were significantly more common for elderly pedestrians (6.8% for pedestrians younger than 14 years compared to 9.8% for 65+ years). Also, gender [16],[17] and pedestrian body height [18],[19] were found to influence impact kinematics and the risk of sustaining pelvic injuries.

Vehicle geometry is another influencing factor. Snedeker et al. [2] found that “safer” cars could be identified by geometric measures. They concluded that, based on Post Mortem Human Surrogate (PMHS) tests and simulations with THUMS, “low bonnet leading edge height, large bonnet edge radius, moderate bumper lead, and high bumper edge height would practically rule out the possibility of a femoral fracture in primary lateral impact of a 50th percentile male pedestrian at impact velocities less than 40 km/h”. SUVs generally have a high bonnet leading edge and are therefore likely to directly strike the pelvis or the thigh of the pedestrian, leading to a higher likelihood of pelvis and femur fractures compared to small sedans. Kikuchi et al. [20] used PCDS data to show that fractures of the pelvis occurred around three times more often with SUVs than with passenger cars.

Another discussion point is the injury source, i.e. the area of the vehicle accountable for pelvic injuries. Mallory et al. [7] analysed injury sources from the GIDAS and PCDS databases. The majority of AIS 3+ injuries of both data sets were attributable to bumper/valance and bonnet surface. In PCDS most of the pelvic injuries were caused by the BLE (19) followed by the bonnet surface (10), while in GIDAS six injuries were associated with the bonnet surface and only five with the BLE. In total, the BLE was found to be the injury source of 4% of all AIS 3+ injuries in GIDAS, and 13% in PCDS. Liers and Hannawald [11] analysed the ability to address upper leg and pelvic injuries in geometrically modern vehicles (YoM (Year of market introduction) > 1997). Therefore, only accidents meeting the Euro NCAP accident scenario were filtered: only 30% of all MAIS 2+ pedestrian accidents were found to meet the filter criteria (frontal impact with M1 vehicle and collision speed ≤ 40 km/h). They found a decreasing relevance of the BLE as the injury-causing part and low benefit of Euro NCAP tests in this area. Conflicting aims with other body regions were registered in the case of hip impacts. Only one upper leg/pelvis AIS 2+ injury caused by the BLE was found in the database, out of 127 frontal pedestrian accidents involving new vehicles (YoM > 1997).

The purpose of the present study was to find key parameters based on accident analysis that are relevant (high relevance or high odds) for pelvic and upper femoral injuries, which should be taken into account in future analysis and possible improved pedestrian safety regulatory.

II. METHODS

Pedestrian accidents found in four European in-depth databases were analysed: GIDAS (German In-Depth Accident Study [21]), ZEDATU (Austrian central database for in-depth analysis of road accidents [22]), EDA (French in-depth accident study of LAB - Laboratory of Accidentology and Biomechanics [23]) and V_PAD (Volvo Cars Pedestrian Accident Database [24]). Query tables were prepared and were filled in by VUFO Dresden (Traffic Accident Research Institute of the TU Dresden) with GIDAS data, CEESAR (European Centre of Studies on Safety and Risk Analysis) with EDA data, VCC (Volvo Car Corporation) with V_PAD data and VSI TU Graz (Vehicle Safety Institute of Graz University of Technology) with ZEDATU data. The different databases use an on-the-spot and retrospective accident investigation approach. The data from the scene are used to reconstruct the accidents, taking skid marks and damage patterns into account.

The following filter criteria were defined for the analysis of this study.

- Pedestrian was impacted by the vehicle front.
- Vehicle is forward moving.
- Striking vehicle is a passenger car or van.
- Pedestrian was upright (not lying) prior to the impact.
- Vehicle was previously undamaged.
- Pedestrian was struck only by one vehicle.
- Information on both pedestrian and vehicle is available in the database.
- Pedestrian suffered an AIS 2+ injury

Template cross tables were developed, including the parameters shown in Table I. Parameters that were taken for the presented analysis in this paper are written in bold. AIS 98 injury codes were used because this increases sample size compared to AIS 2005 (more cases coded in AIS 98 available). The template cross tables were filled in with the data from the different countries. The cross tables were then combined and analysed.

The lack of information on raw data (the authors only had information according to the cross tables) meant that only simple statistical methods could be applied. Therefore, 2x2 contingency tables were analysed in order to compare two parameters. Odds ratios (OR) were calculated and statistical tests (Chi Squared Test, if all expectancy values were greater than 5, or Fisher test otherwise) were carried out in order to prove significance. Statistical significance was defined when the p-value (p) was less than 0.05.

TABLE I
ANALYSED PARAMETERS

Car	*Pedestrian*
Year of market introduction (YoM)	**Age**
Vehicle type	**Gender**
Impact speed (v_imp)	Height
Geometric parameters	Weight
Impact location on the car (Collision Deformation Classification)	Movement pre-crash (running, walking, standing)
	Walking direction
	Injuries (AIS 98 codes)

Mean values (e.g. analysis of impact speed) were tested for significant differences, using two-sample Student's T-Tests. Normal distribution was assumed for calculation of confidence intervals. Pooled mean values (μ) and standard deviations (σ) from different databased were calculated with the following equations:

$$\mu_{total} = \frac{\mu_1 * n_1 + \mu_2 * n_2}{n_1 + n_2} \quad (1)$$

$$\sigma_{total} = \sqrt{\frac{\sigma_1{}^2 * (n_1 - 1) + \sigma_2{}^2 * (n_2 - 1)}{n_1 + n_2 - 2}} \quad (2)$$

where n is the sample size (number of injuries) and index 1 and 2 represent the two data sets to be combined.

For the classification of vehicles, the types defined in the EC-funded project APROSYS (Advanced Protection Systems) were used: Large MPVs & 1-Box; Large & Small Family Cars; Small MPVs & Superminis; and SUVs. To check that the APROSYS classification is still valid for modern cars, several modern vehicle shapes were assigned to the categories. Modern vehicle shapes still match the average shapes found in APROSYS and the categories were found to be still valid. The geometric parameters included in the UN R127 protocol were also analysed: bonnet leading edge height (BLEH), bumper lead (BL), and bumper height (BH).

In total, 2,405 AIS 2+ injuries were analysed, including 987 AIS 3+ injuries and associated parameters of Table I. The injuries encoded in AIS 98 were combined to body regions, as shown in Table VI in the Appendix. The body region "pelvis combined" includes injuries that are addressed by the BLE-ULF test, including injuries of the pelvis and the upper femur.

Trends that were found for the full data set (combining all databases) were compared with trends of GIDAS, because this database was most representative and most data was available.

In an exemplary case-by-case study GIDAS cases, where modern (YoM≥2000) cars were involved, were checked for plausibility, impact speed, pedestrian age and injury causing parts.

III. RESULTS

The relative frequency of pelvic injuries is variable in the various data sets (Fig. 2). The body region "pelvis combined" was not included in the V_PAD data and it was therefore equated to "pelvis".

The relative frequency of pelvic combined injuries among all injuries (AIS 2+), ranges from 1.5% of all AIS 3+ injuries (EDA) to 13% of all AIS 3+ injuries (ZEDATU). In GIDAS, 7% of all AIS 2+ and 6% of all AIS 3+ injuries could be assigned to the body region pelvis combined. To analyse the relative frequency, the entire V_PAD data set was used. For the detailed analysis, only data were used for which detailed information was available (reconstructed cases).

The composition of data was not homogenous for different groups of YoM. This is shown in Fig. 3. The amount of ZEDATU data was slightly increasing. Detailed V_PAD data was mainly available for modern cars. Therefore, a comparison of old and modern cars was analysed with GIDAS data only, to prevent biasing.

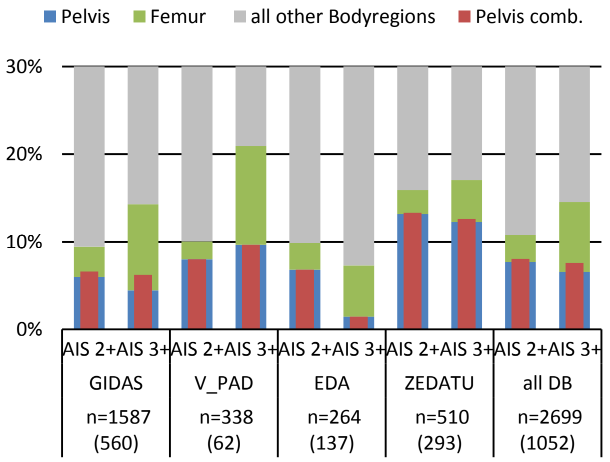

Fig. 2. Overall relative frequency of pelvic injuries in various databases. n=number of AIS 2+ (AIS 3+) injuries; All DB= whole dataset

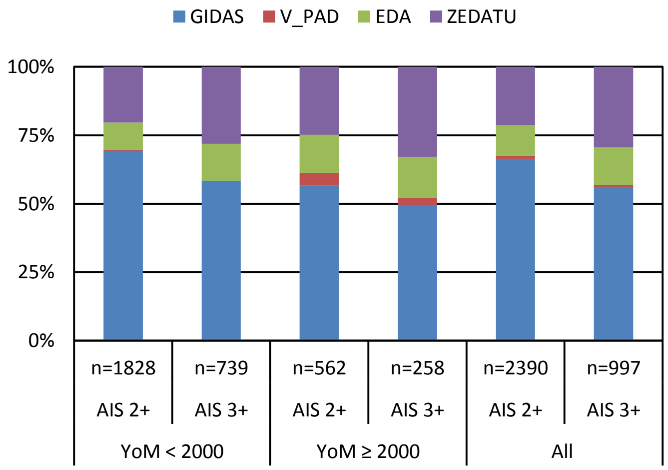

Fig. 3. Proportion of all injuries for differing years of market introduction of cars (for V_PAD only injuries where detailed information was available were used)

The number of injuries according to the year of market introduction (YoM) also varied in the databases (Fig. 4 and Fig. 5), e.g. in GIDAS, the proportion of pelvic combined injuries was 4.6% of all AIS 3+ injuries for cars with YoM < 2000 and 11.7% for cars with YoM ≥ 2000.

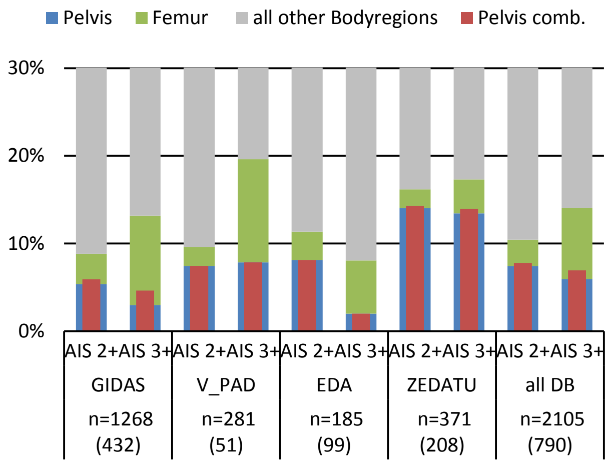

Fig. 4. Relative frequency of pelvic injuries for cars with YoM < 2000. n=number of AIS 2+ (AIS 3+) injuries; All DB= whole data set

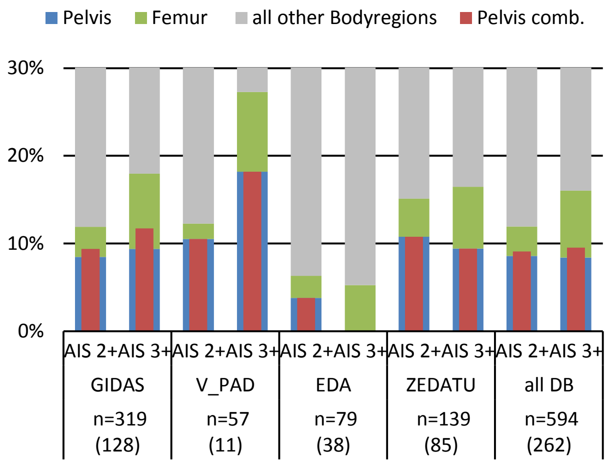

Fig. 5. Relative frequency of pelvic injuries for cars with YoM ≥ 2000. n=number of AIS 2+ (AIS 3+) injuries; All DB= whole data set

Pedestrian Parameters

The mean age (μ) of pedestrians with injuries to the pelvis combined region was statistically significantly higher than for all other injuries (see Table II). This trend was found in GIDAS as well as in the whole data set. In the whole data set more than 50% of the pelvic combined AIS 2+ and 3+ injuries happened to pedestrians older than 70 years (Fig. 6). In GIDAS (Fig. 7) this parentage was slightly less, but still 44% of AIS 2+ and 46% of AIS 3+ injuries in the body region pelvis combined happened to elderly pedestrians (70+). Pedestrian younger than 50 years made up less than 24% of all AIS 2+ and AIS 3+ pelvic combined injuries in both datasets.

TABLE II
PEDESTRIAN AGE

Data set		*Summary of all DB*				*GIDAS*			
		AIS 2+		*AIS 3+*		*AIS 2+*		*AIS 3+*	
Body region		Pelvis comb.	All others	Pelvis comb.	All others	Pelvis comb.	All others	Pelvis comb.	All others
Number of injuries (n)		190	2280	73	958	105	1557	35	547
	μ	61.32	51.35	65.29	52.96	59.00	50.46	65.00	53.30
Age	σ	23.98	25.66	20.33	27.87	25.00	26.07	19.00	29.51
	p	**<0.001**		**<0.001**		**0.001**		**0.021**	

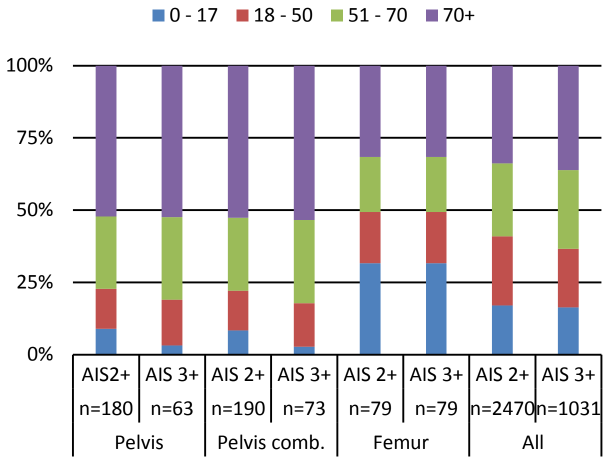

Fig. 6. Analysis of pedestrian age (whole data set)

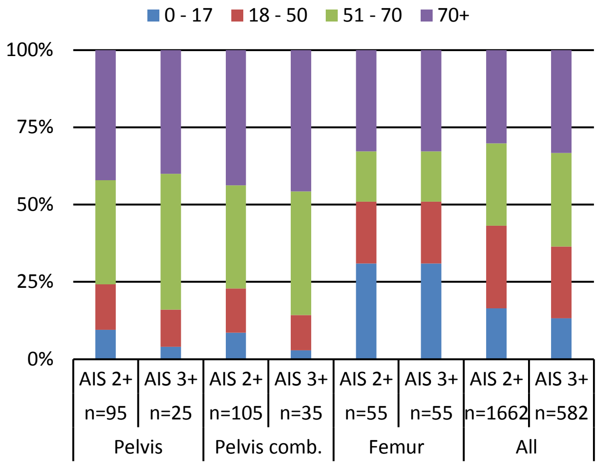

Fig. 7. Analysis of pedestrian age (GIDAS)

Pelvic injuries are more often associated with females than with males (Fig. 8 and Fig. 9). For the whole data set, the odds for females were 1.7 and 1.8 times higher for pelvic ($p = 0.0003$) and pelvic-femur combined ($p = 0.0001$) AIS 2+ injuries (Table III) than for males.

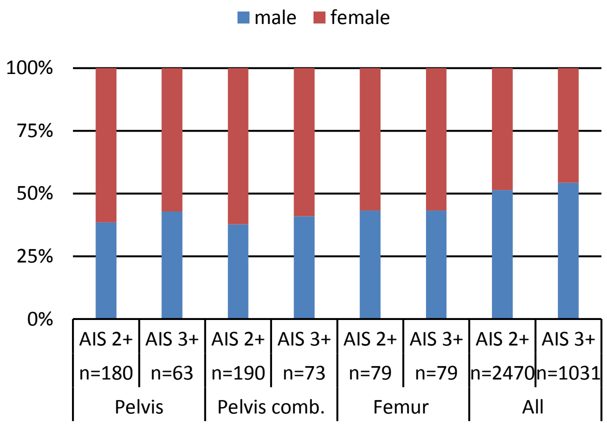

Fig. 8. Gender distribution of pedestrians (whole data set)

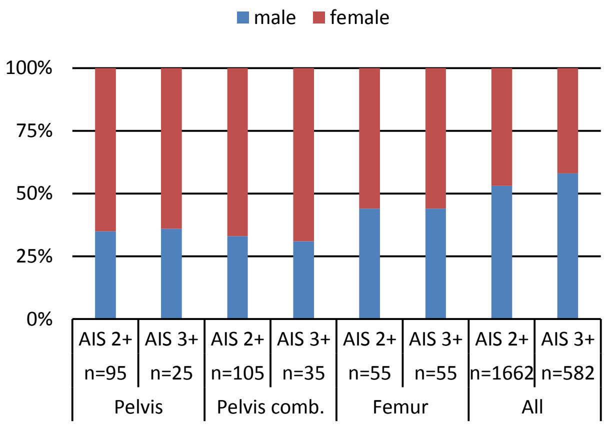

Fig. 9. Gender distribution of pedestrians (GIDAS)

TABLE III
GENDER OF INJURED PEDESTRIANS (WHOLE DATA SET)

		AIS 2+			*AIS 3+*		
		Pelvis	*Pelvis comb.*	*Femur*	*Pelvis*	*Pelvis comb.*	*Femur*
female vs. male	*OR*	1.774	1.815	1.416	1.634	1.775	1.634
	p	**<0.001**	**<0.001**	0.130	0.060	**0.019**	**0.036**

Most injuries in all databases were caused by vehicles of the categories Large & Small Family Car (62%) and Small MPV & Supermini (31%). There were nearly no cases in the data sets used for this study in which SUVs or roadsters were involved.

The proportion of pelvic injuries caused by Small MPVs & Superminis has increased compared to Large & Small Family Cars. Before 2000, 75% of pelvic combined AIS 2+ (62.5% of AIS3+) injuries in the data set were attributable to Large & Small Family Cars and only 22% to Small MPVs & Superminis (29% of AIS3+). Analysing injuries that were caused by cars with YoM after 2000, 67% of the pelvic combined AIS 2+ (65% of AIS3+) injuries occurred in accidents with Small MPVs & Superminis and 33% with Large & Small Family Cars (30% of AIS 3+). Because Small MPVs & Superminis were associated to only 36.5% of all AIS 2+ injuries, this results in significant higher odds for this vehicle category for modern cars. This is shown in Table IV – OR >1 indicate higher odds for Large & Small Family Cars.

TABLE IV
COMPARISON OF THE VEHICLE TYPES LARGE & SMALL FAMILY CARS(1) VS. SMALL MPVS & SUPERMINIS(2)
(WHOLE DATASET)

		AIS2+ injuries		*AIS3+ injuries*	
	YoM	*<2000*	*≥2000*	*<2000*	*≥2000*
All injuries	*n*	1130(1)/498(2)	300(1)/194(2)	435(1)/210(2)	135(1)/93(2)
Pelvis	*OR*	1.712	0.308	1.1972	0.284
	p	**0.015**	**<0.001**	0.6244	**0.006**
	n	101(1)/27(2)	16(1)/30(2)	27(1)/11(2)	7(1)/15(2)
Pelvis comb.	*OR*	1.531	0.248	1.037	0.284
	p	0.046	**<0.001**	0.914	**0.006**
	n	101(1)/30(2)	13(1)/30(2)	30(1)/14(2)	7(1)/15(2)
Femur	*OR*	1.105	0.637	1.2250	0.669
	p	0.756	0.372	0.536	0.437
	n	35(1)/14(2)	8(1)/8(2)	35(1)/14(2)	8(1)/8(2)

Injury Source

Fig. 10 shows that for the whole data set most pelvic combined injuries could be assigned to the bonnet surface (37% of AIS 2+ and 48% of AIS 3+), followed by the BLE (28% of AIS 2+ and 23% of AIS 3+). 17%-18% of pelvic combined injuries could not be assigned to a single injury source. The analysis of GIDAS data alone showed a similar trend (Fig. 11), but the percentage of injuries that were caused by the bonnet surface was lower and those not attributable to single surface one's were higher. The percentage of injuries that were directly attributable to the BLE was similar (30% of AIS 2+ and 22% of AIS 3+ injuries) to the whole data set.

Considering all AIS 2+ injuries, the BLE was assigned to 4% of AIS 2+ and AIS 3+ injuries over the whole data set and 3% of AIS 2+ and 2% of AIS 3+ injuries of the GIDAS data set.

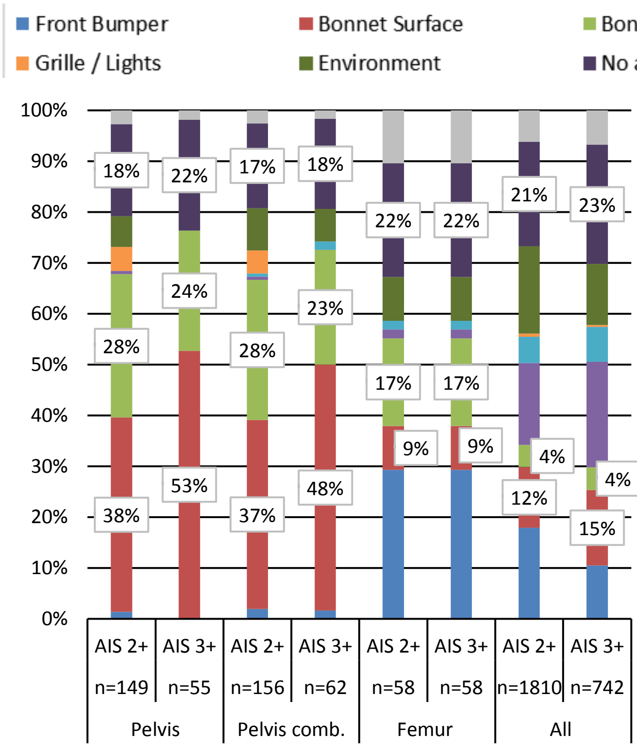

Fig. 10. Injury sources for based on whole data set

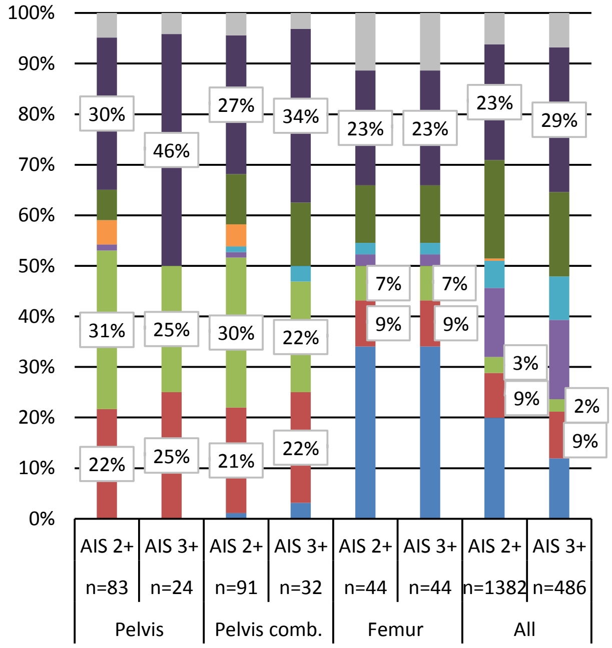

Fig. 11. Injury sources based on GIDAS

Fig. 12 shows that 55% of AIS 2+ and 42% of all AIS 3+ injuries assigned to the BLE were within the body region pelvis combined. For the bonnet surface, injuries of this body region make up 27% of all AIS 2+ and AIS 3+. When analysing only GIDAS data, a similar trend shows up: 61% of AIS 2+ and 58% of AIS 3+ injuries caused by the BLE were pelvis combined injuries and only 16% of the injuries caused by the bonnet surface were in the body region pelvis combined.

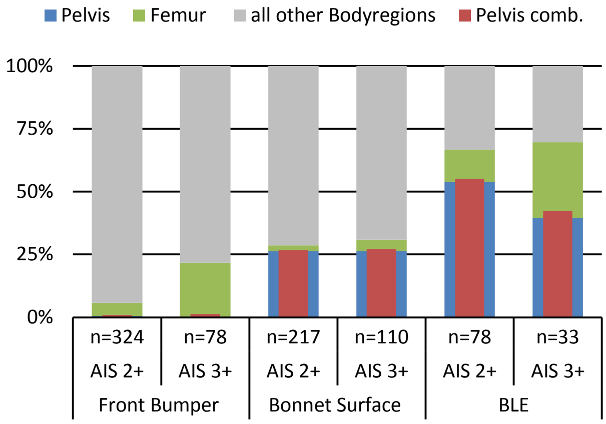

Fig. 12. Relative frequency of pelvic injuries among all injuries of one injury source based on whole data set

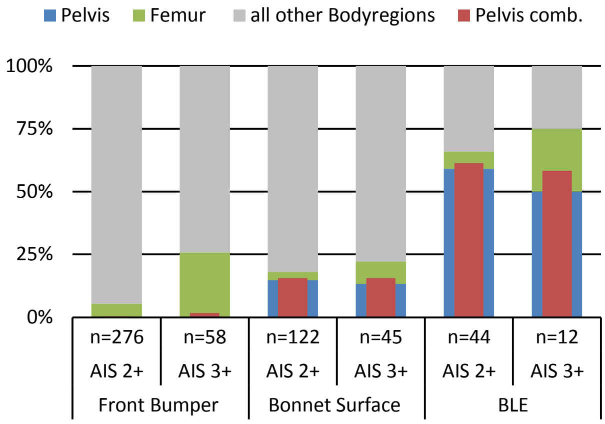

Fig. 13. Relative frequency of pelvic injuries among all injuries of one injury source based on GIDAS

Impact Location

Fig. 14 indicates that about 30% pelvic and femoral injuries were caused when the pedestrian was hit on the right side (R0 and R1 – see Fig. 18 in the Appendix for explanation of the CDC coding) from the driver's perspective (sitting on the left side of the car). For the whole data, set most of the damage to the car was found on the right outer side (1/4 of the overall width of the vehicle from the right side excluding the longitudinal beam [25]). This was found to be a general trend for all injuries. No significant differences among all injuries were found. Fig. 15 shows that 27% of AIS 3+ injuries in GIDAS and 38% of AIS 3+ injuries of the whole data set in the body region pelvis combined were assigned to the wings of the car (R0 or L0).

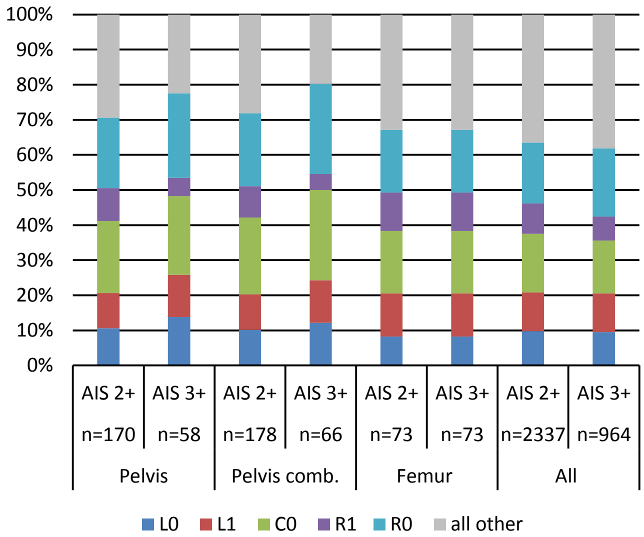

Fig. 14. Impact locations on the car according to SAE J224 [26] Collision Deformation Classification (CDC) based on whole data set

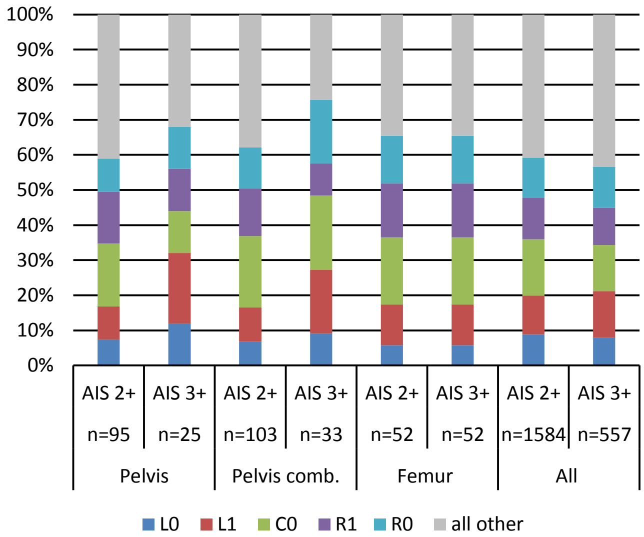

Fig. 15. Impact locations on the car according to SAE J224 [26] Collision Deformation Classification (CDC) based on GIDAS data

Comparison of old and modern cars based on GIDAS data

In the GIDAS database, the odds of AIS 3+ pelvic injuries caused by Large & Small Family Cars slightly decreases for cars with YoM ≥ 2000. The proportion of pelvic combined injuries was 7% of all AIS 2+ injuries in the GIDAS data set for cars with YoM < 2000, decreasing to 6% for cars with YoM ≥ 2000. However, no statistical significance was found. Vehicles of the category Small MPVs & Superminis showed a different trend. The proportion of pelvic injuries among all AIS 2+ injuries jumped from 3% to 18%. Odds ratios and p-values are shown in Table V and significances are highlighted. Odds ratios >1 indicate higher odds for modern cars.

TABLE V
COMPARISON OF MODERN(1) VERSUS OLD(2) CARS (GIDAS)

		AIS 2+ injuries		*AIS 3+ injuries*	
Vehicle Type		*Small MPVs & Superminis*	*Large & Small Family Cars*	*Small MPVs & Superminis*	*Large & Small Family Cars*
All injuries	*n*	95(1)/ 374 (2)	192(1)/ 782(2)	27(1)/ 142(2)	89(1)/ 254(2)
Pelvis	*OR*	6.052	0.623	12.075	1.447
	p	**< 0.001**	0.220	**< 0.001**	0.517
	n	17(1)/ 13(2)	8(1)/ 51(2)	71)/ 4(2)	4(1)/ 8(2)
Pelvis comb.	*OR*	5.216	0.819	7.93	1.886
	p	**< 0.001**	0.558	**0.001**	0.266
	n	17(1)/ 15(2)	11(1)/ 54(2)	7(1)/ 6(2)	7(1)/ 11(2)

To find reasons for the differing trends of these two vehicle types, geometric parameters were analysed: Fig. 16 shows the mean values of the geometric measures for all AIS 2+ injuries. There were only ten AIS 2+ injuries (no pelvic or femoral) included in the data set that occurred with Large & Small Family Cars with YoM > 2005. Therefore no geometric analysis was possible for those. Bonnet leading edge height (BLEH) was significantly different before 2000 (p < 0.001). A significant difference of bumper height (BH) was found between the two vehicle categories for all time periods analysed (p < 0.001 for YOM < 2000; p = 0.002 for YoM 2000–2004). Bumper lead (BL) differed significantly for cars with YoM between 1997 and 1999 (p < 0.001) and 2000 and 2004 (p = 0.02). The mean values of all AIS 2+ injuries and pelvis, pelvis combined and femur AIS 2+ injuries did not differ significantly.

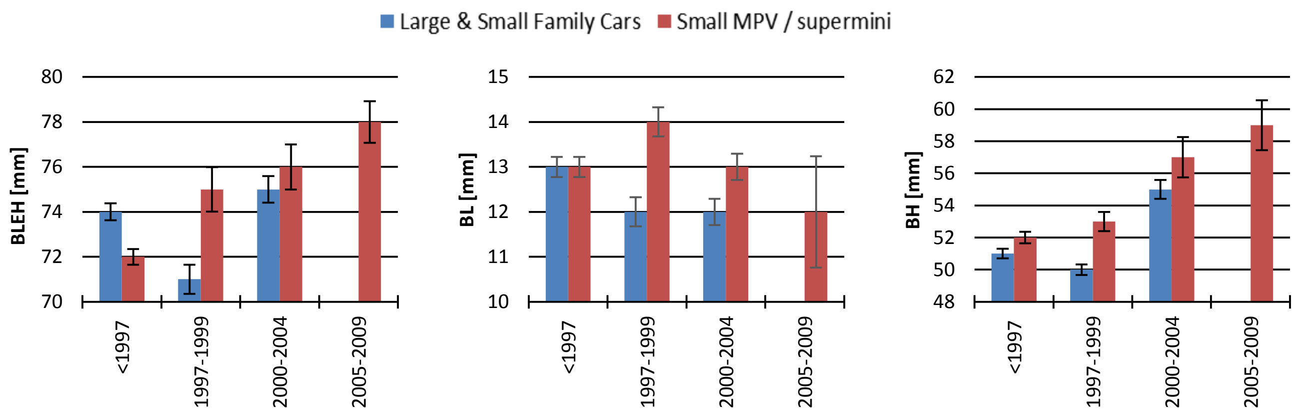

Fig. 16. Analysis of geometric parameters of vehicles of the category Large & Small Family Cars (n=677, 146, 180) and Small MPVs & Superminis (n=283, 99, 61, 40) for differing YoM (whiskers show 95% confidence intervals – normal distribution assumed)

The impact speed of cars in accidents involving a pedestrian with pelvic injuries found for Large & Small Family Cars was higher than for Small MPVs & Superminis for all YoM when all AIS 2+ injuries were considered (p = 0.008, 0.014, < 0.001 for YoM < 1997, 1997–1999 and 2000–2004, respectively – see Table VII in Appendix). Significant differences of the impact speeds are highlighted in Table VII and P values are specified for the comparison with all injuries (e.g. pelvis AIS 2+ vs. all AIS 2+) and for the comparison of Large & Small Family Cars vs. Small MPVs & Superminis.

Results of case-by-case study

Statistical analysis can only be used to a limited extent due to the small number of cases in total. In order to obtain a useful active field for a passive test, it is necessary to supplement statistical analysis with case-by-case studies. Fig. 17 shows the totality of GIDAS accidents with the criterion of injury severity "Pelvis combined" over the impact speed with the usefully addressable cases identified. No maximum age limit addressable by passive measures was applied.

In total 23 cases from GIDAS were identified where vehicles with YoM ≥ 2000 were involved and pelvic combined injury occurred (11 Small MPVs & Superminis and 12 other vehicle types)

- In eight cases the injuries could not be assigned to the bonnet leading edge or bonnet surface.(resulted from glancing blow, ground impact or overrun)
- For two cases the coding was not plausible (wrong vehicle classification and injury source, pedestrian was stuck between two cars)
- In three cases the injury causing part was the bonnet surface, an area which is already addressed by the child head impactor test.
- In all five remaining cases where Small MPVs & Superminis were involved, the pedestrians were older than 70 years (three females and two males).
- In the four remaining cases of Large & Small Family Cars one pedestrian was 89 and the others were younger (two females aged 59 and one 9 year old girl).
- The pelvic injury of one 81 year old pedestrian was associated to the grill of an SUV.

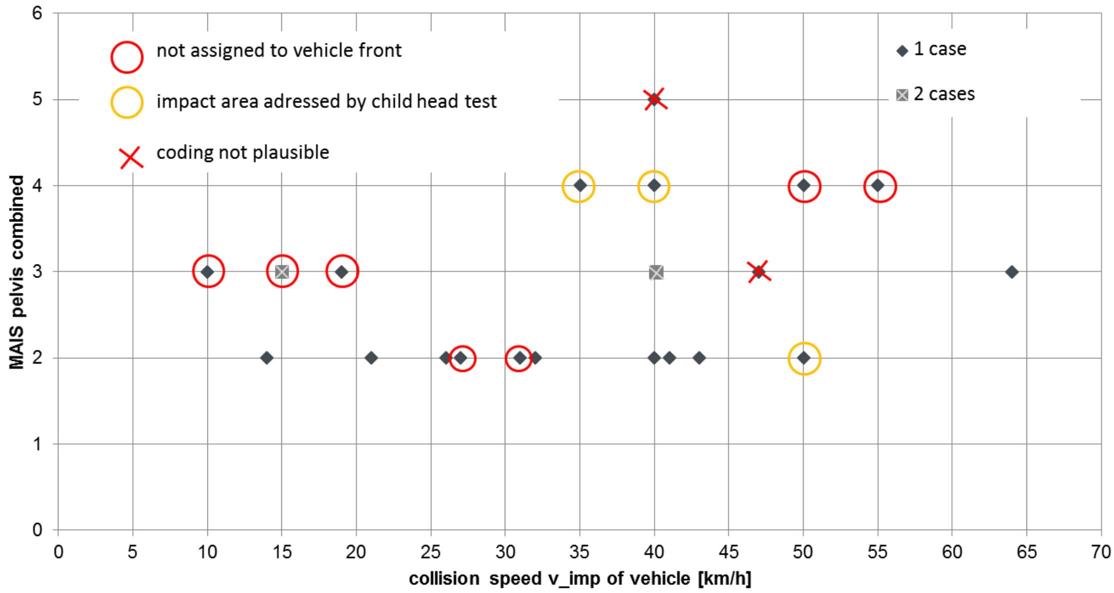

Fig. 17. Case-by-case analysis of GIDAS data for cases with modern cars (YoM≥2000)

IV. DISCUSSION

In general, the relative frequency of pelvic injuries was found to be in the range published in other studies shown in Fig. 1: 1.5% (EDA) to 13% (ZEDATU).

The analysis of accident data underlies a variety of limitations, as follows:

- This study includes only data from four European countries.
- There was no access to the raw data, i.e. mean values, standard deviation, etc. were provided in cross table templates.
- When only GIDAS data were used, sample sizes for some analysis are quite small
- Combining databases is challenging because accident databases were not comparable in some aspects.

V_PAD and ZEDATU accident databases are retrospective databases, while EDA and GIDAS record the accidents on scene. ZEDATU includes only cases where at least one accident victim was fatally injured.
- Analysis were therefore carried out with the whole data set and GIDAS data only to double-check if the same trends showed up.
- Higher significances are gained when combining the databases. This seems feasible because databases showed comparable trends.

The number of cases involving modern cars (YoM ≥ 2000) was generally low. A possible reason for this is that modern cars offer a better protection for pedestrians and therefore produce fewer injuries. It also takes some time until modern cars can be found in the statistics. The higher odds of modern Small MPVs & Superminis compared to older ones could be caused by the decreasing number of total AIS 2+ and AIS 3+ injuries for cars with later YoM.

Reasons for increasing odds of Small MPVs & Superminis compared to Large & Small Family Cars might be found in changes in geometry of the latter or in the decreasing number of pelvic injuries for the first.

Pedestrians in advanced years were not excluded from the data set and all impact velocities were included. The study showed higher Odds for pelvic injury for elderly (70+) pedestrians and females. Other studies showed a similar trend [15–17]. The outcome of the case-by-case analysis indicated that pelvic injury is mainly an issue of elderly pedestrians or at glancing impacts. It seems questionable how many of these injuries could be prevented by passive safety measures.

Outlook

The potential reduction of pelvic and femoral injuries has to be proven in future research. Can the cases that showed-up in the accident analysis be addressed by passive safety measures? Is reducing the impact speed (e.g. with Active Emergency Breaking (AEB) systems) more effective?

Trends found in the accident analysis will be further analysed by carrying out FE simulations using human body models. It will be studied if the pelvic injury risk attributed to “modern” and “older” cars is caused by geometric or structural changes. Furthermore, the reasons for a higher pelvic injury risk among women will be investigated. It is open to question if this is a result of the smaller size of females, or due to anatomical reasons, or simply because of different age distribution between male and females.

A high proportion of pelvic injuries (21%-37% of AIS 2+ and 22%-48% of AIS 3+) were assigned to the bonnet area. The lower bonnet area is tested with a child headform impactor. It thus has to be investigated if a target conflict for preventing pelvic and head injuries is caused by bonnet designs meeting this test. Also, it has to be investigated, which measures are most effective in reducing pelvic injuries for the relevant population of pedestrians.

V. CONCLUSIONS

The study led to the following conclusions:

- A high proportion of pelvic-combined injuries were caused by the bonnet area or were not attributable to a single source. 22-30% of pelvic injuries were assigned to the BLE.
- Despite the differences between the accident data of four different European databases the number of injuries assigned to the BLE appears to be low: In total not more than 4% of all AIS 2+ and AIS 3+ injuries were assigned to the BLE area.
- A high proportion of pelvic-combined injuries (27-38%) were assigned to the sides (wings) of the vehicle front – an area that is not tested in the ULF-BLE test.
- The relative frequency of pelvic injuries ranges from 1.5% of all AIS 3+ injuries (EDA) to 13% of all AIS 2+ injuries (ZEDATU). In GIDAS 6% of all AIS 2+ and AIS 3+ were assigned to the body region pelvis-combined.
- Among modern cars (YoM ≥ 2000), Small MPVs & Superminis seem to have higher odds for pelvic injuries than Large & Small Family Cars. This will be investigated more thoroughly by means of numerical simulations.
- Females sustain pelvic and femoral injuries more frequently than males.
- Older people (70+ years) showed higher odds for suffering pelvic injuries.
- The case-by-case study indicated that it is challenging to address pelvic injuries in car to pedestrian

accidents because for most of the cases the pedestrian was either very old and thus fragile, or the injury resulted from a glancing impact.

VI. ACKNOWLEDGEMENTS

The authors would like to thank ACEA (European Automobile Manufacturers' Association) for providing the funding for the study. Furthermore, we would also like to thank VUFO, CEESAR and VCC for providing the accident data.

VII. REFERENCES

[1] Roth, F., Schenk, T. and Coulongeat, F. Pelvis and Upper Leg Injuries: Potential from the View of Integrated Safety. *Praxiskonferenz Fußgängerschutz*, 2013, Bergisch Gladbach.

[2] Snedeker, J.G., Walz, F.H., Muser, M.H., Lanz, C. and Schroeder, G. Assessing femur and pelvis injury risk in car-pedestrian collisions: comparison of full body PMTO impacts, and a human body finite element model. *The 19th ESV Conference Proceedings*, 2005, NHTSA, Washington, D.C., USA.

[3] Lubbe, N., Hikichi, H., Takahashi, H. and Davidsson, J. Review of the EURO NCAP Upper Leg Test. *The 22nd ESV Conference Proceedings*, 2011,

[4] Hardy, B.J., Lawrence, G.J.L., Knight, I.M., Simmons, I.C.P., Carroll, J.A., Coley, R. et al. A study of possible future developments of methods to protect pedestrians and other vulnerable road users. 2007 Mar, TRL Limited. Report No.: UPR/VE/061/07.

[5] Otte, D. and Haasper, C. Technical parameters and mechanisms for the injury risk of the knee joint of vulnerable road users impacted by cars in road traffic accidents. *Proceedings of IRCOBI Conference*, 2005, Prague, Czech Republic.

[6] Otte, D., Jänsch, M. and Haasper, C. Injury protection and accident causation parameters for vulnerable road users based on German In-Depth Accident Study GIDAS. *Accident Analysis & Prevention*, 2012, 44(1):149–53.

[7] Mallory, A., Fredriksson, R., Rosen, E. and Donnelly, B. Pedestrian Injuries by Source: Serious and Disabling Injuries in US and European Cases. *Annals of Advances in Automotive Medicine / Annual Scientific Conference*, 2012, 56:13–24.

[8] Fredriksson, R. Priorities and Potential of Pedestrian Protection - Accident data, Experimental tests and Numerical Simulations of Car-to- Pedestrian Impacts [Doctoral Thesis]. 2011, KTH, [Stockholm].

[9] Takahashi, Y., Kikuchi, Y., Konosu, A. and Ishikawa, H. Development and validation of the finite element model for the human lower limb of pedestrians. *Stapp Car Crash Journal*, 2000, 44:335–55.

[10] Roudsari, B.S., Mock, C.N. and Kaufman, R. An evaluation of the association between vehicle type and the source and severity of pedestrian injuries. *Traffic Injury Prevention*, 2005, 6(2):185–92.

[11] Liers, H. and Hannawald, L. Benefit estimation of the EuroNCAP pedestrian rating concerning real-world pedestrian safety. 2009 Mar, VUFO, Dresden.

[12] Guerra Casanova, L.J. Analysis of the Key Parameters in Pedestrian Safety Assessment for the European Vehicle Fleet Using Multibody and Finite Element Mathematical Models [Doctoral Thesis]. 2011, E.T.S.I. Industriales (UPM).

[13] Mizuno, Y. Summary of IHRA Pedestrian Safety WG Activities (2005) - Proposed Test Methods to Evaluate Pedestrian Protection Afforded by Passenger Cars. 2005,

[14] Richards, D.C., Cookson, R.E., Cuerden, R.W., Davies, G. and Rutter, H. Prioritising pedestrian injury prevention based on frequency and cost. *Proceedings of IRCOBI Conference*, 2009, York, United Kingdom.

[15] Demetriades, D., Murray, J., Martin, M., Velmahos, G., Salim, A., Alo, K. et al. Pedestrians injured by automobiles: relationship of age to injury type and severity. *Journal of the American College of Surgeons*, 2004, 199(3):382–7.

[16] Starnes, M.J., Hadjizacharia, P., Chan, L.S. and Demetriades, D. Automobile versus Pedestrian Injuries: Does Gender Matter? *The Journal of Emergency Medicine*, 2011, 40(6):617–22.

[17] DeSantis Klinich, K. and Schneider, L. Biomechanics of Pedestrian Injuries Related to Lower Extremity Injury Assessment Tools: A Review of the Literature and Analysis of Pedestrian Crash Database. 2003 Sep, Alliance for Automobile Manufacturers. 92 Report No.: UMTRI-2003-25.

[18] Subit, D.Q., Kerrigan, J., Crandall, J., Fukuyama, K., Yamazaki, K., Kamiji, K. et al. Pedestrian-vehicle interaction: kinematics and injury analysis of four full scale tests. *Proceedings of IRCOBI Conference*, 2008, Bern, Switzerland

[19] Serre, T., Lalys, L., Bartoli, C., Christia-Lotter, A., Leonetti, G. and Brunet, C. Child pedestrian anthropometry: evaluation of potential impact points during a crash. *Accident Analysis & Prevention*, 2010, 42(6):1943–8.

[20] Kikuchi, Y., Takahashi, Y. and Mori, F. Full-Scale Validation of a Human FE Model for the Pelvis and Lower Limb of a Pedestrian. 2008 Apr, SAE International, Warrendale, PA. Report No.: 2008-01-1243.

[21] Otte, D., Krettek, C., Brunner, H. and Zwipp, H. Scientific Approach and Methodology of a New In-Depth-Investigation Study in Germany so called GIDAS. *Proceedings of the 18th ESV Conference*, 2003, Nagoya, Japan.

[22] Tomasch, E. and Steffan, H. ZEDATU (Zentrale Datenbank tödlicher Unfälle in Österreich) – A Central Database of Fatalities in Austria. *Reports on the ESAR-Conference*, 2006, Hannover.

[23] Ferrandez, F. and Brenac, T. L’étude détaille d’accidents orientée vers la sécurité primaire: méthodologie de recueil et de pré-analyse. 1995, Presses de l’Ecole Nationale des Ponts et Chaussées.

[24] Lindman, M., Jakobsson, L. and Jonsson, S. Pedestrians interacting with a passenger car; A study of real world accidents. *Proceedings of IRCOBI Conference*, 2011, Krakow, Poland.

[25] "DaCoTa Manual - CDC4". Internet: [http://dacota-investigation-manual.eu/English/1054] [05/28/2015]

[26] SAE International. SAE Standard J224: Collision Deformation Classification. 2011,

VIII. APPENDIX

TABLE VI
DEFINED BODY REGIONS (AIS 98 CODES)

Femur	Pelvis	Pelvis combined
851800.3 – fracture NFS	852600.2 - pelvis	852600.2 - pelvis
851801.3 – open/displacement/comminuted	852602.2 – closed/undisplaced	852602.2 – closed/undisplaced
851804.3 - condylar	852604.3 – open/displacement/comminuted	852604.3 – open/displacement/comminuted
851808.3 - head	852606.4 – substantial deformation and displacement	852606.4 - substantial deformation and displacement
851810.3 - intertrochanteric	852608.4 - blood loss <= 20%	852608.4 - blood loss <= 20%
851812.3 - neck	852610.5 – blood loss >= 20%	852610.5 – blood loss >= 20%
851814.3 – shaft	852800.3 – sacroilium	852800.3 – sacroilium
851818.3 - subtrochanteric	853000.3 – symphysis pubis	853000.3 – symphysis pubis
851822.3 - supracondylar		851808.3 – femur head
		851810.3 - intertrochanteric
		851812.3 – femur neck

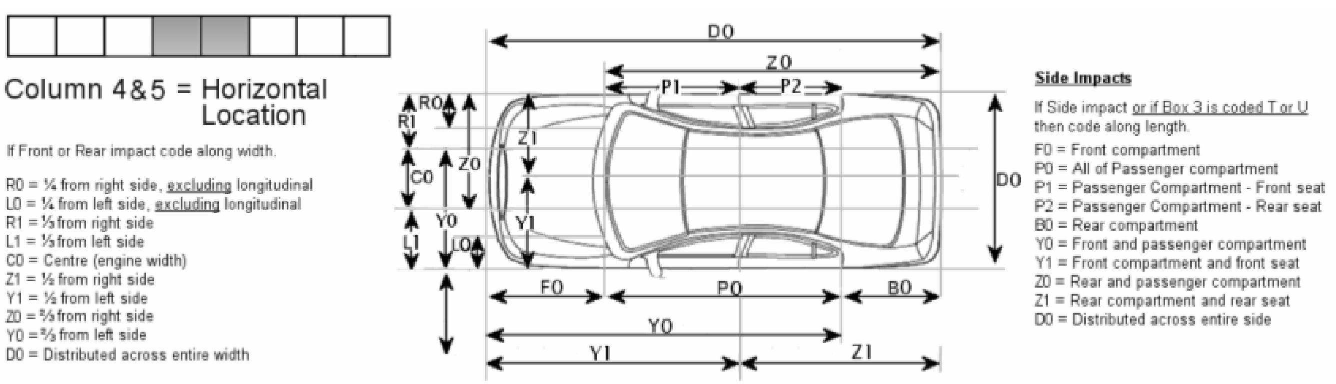

Fig. 18. Impact location according to 4th and 5th digit of CDC [25]

TABLE VII
COMPARISON OF IMPACT VELOCITIES (GIDAS)

	YoM	Impact speed (v_imp) in km/h	Pelvis AIS 2+	Pelvis AIS 3+	Pelvis comb. AIS 2+	Pelvis comb. AIS 3+	Femur AIS 2+	Femur AIS 3+	All AIS 2+	All AIS 3+
Large & Small Family Cars	< 1997	μ	45	51	45	50	42	42	46	55
		σ	18	9	17	9	15	15	22	26
		n	42	5	45	8	20	20	644	221
		p (vs. All Injuries)	0.770	0.730	0.770	0.590	0.420	**0.030**	-	-
		p (vs. Small MPV / Supermini)	0.437	0.163	0.293	0.911	0.018	**0.018**	**0.008**	**0.013**
	1997–1999	μ	40	35	40	35	35	35	31	39
		σ	9	9	9	9	9	9	14	14
		n	9	3	9	3	6	6	138	33
		p (vs. All Injuries)	0.060	0.630	0.060	0.630	0.490	0.510	-	-
		p (vs. Small MPV / Supermini)	0.475	1.000	0.475	1.000	0.573	0.573	**0.014**	0.267
	2000–2004	μ	48	50	39	35	23	23	55	63
		σ	8	10	16	19	21	21	28	29
		n	8	4	11	7	5	5	180	88
		p (vs. All Injuries)	0.482	0.376	0.063	**0.014**	**0.012**	**0.003**	-	-
		p (vs. Small MPV / Supermini)	**0.016**	0.320	0.750	0.686	0.104	0.104	**<0.001**	**0.005**
Small MPV / Supermini	< 1997	μ	40	67	39	51	28	28	42	48
		σ	22	19	21	22	13	13	18	18
		n	11	2	13	4	10	10	277	105
		p (vs. All Injuries)	0.720	0.142	0.560	0.746	**0.016**	**0.001**	-	-
	1997–1999	μ	35	35	35	35	31	31	35	36
		σ	4	4	4	4	0	0	9	8
		n	2	2	2	2	2	2	97	37
		p (vs. All Injuries)	1.00	0.86	1.00	0.86	0.53	0.39	-	-
	2000–2004	μ	37	41	37	41	47	47	35	40
		σ	8	6	8	6	0	0	13	6
		n	8	2	8	2	3	3	55	13
		p (vs. All Injuries)	0.675	0.830	0.675	0.830	0.118	0.069	-	-