INJURY MECHANISMS FOR PELVIS FRACTURES OF NEARSIDE OCCUPANTS IN LATERAL CAR IMPACTS AND INFLUENCES OF DEFORMATION CHARACTERISTICS

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ABSTRACT

Measures for an optimized protection in lateral collisions are pregnant in current car developments. For this it is important to know the injury risks and mechanisms in lateral collisions.

A review of literature shows that head, thorax and pelvis are the most injured body regions in frequency and severity. The problem of pelvic injuries is the complexity of bony structure and the different kind of fractures relating to various possibilities of traumatological treatment.

In this study 1,556 nearside seated occupants in isolated lateral collision were analyzed. 35 persons suffered pelvic fractures and 13 occupants femural fractures. The paper will describe the biomechanics of pelvic fractures including the biomechanics of femur as part of pelvic load in relation to delta-v, intrusion and vehicle deformation characteristics. The lateral deformation was measured and characteristics reproducted in a 3-dimensional view correlating to the injuries.

Protection appliances in the car, such as the safety belt, airbag and the safety steering column make driving increasingly safer. Due to this fact, fewer persons sustain injuries in the course of traffic accidents. The number of persons killed in accidents decreases the last decades continually. It has however become evident that injured persons, especially those sustaining severe or fatal injuries were involved into collisions with lateral impact (Otte - 1).

In a country such as, for instance, the Federal Republic of Germany, 6128 drivers and passengers of cars were fatally injured in 1993 (StBA - 2). This is a proportion of 61.5% of all persons killed in road traffic (fig. 1). The different collision constellations concerned in 34% with isolated and in 31% with multiple collisions including lateral impacts. Cognitions derived from figure 1 established that 65% of the persons killed were involved in lateral collision. This fact calls for immediate measures.

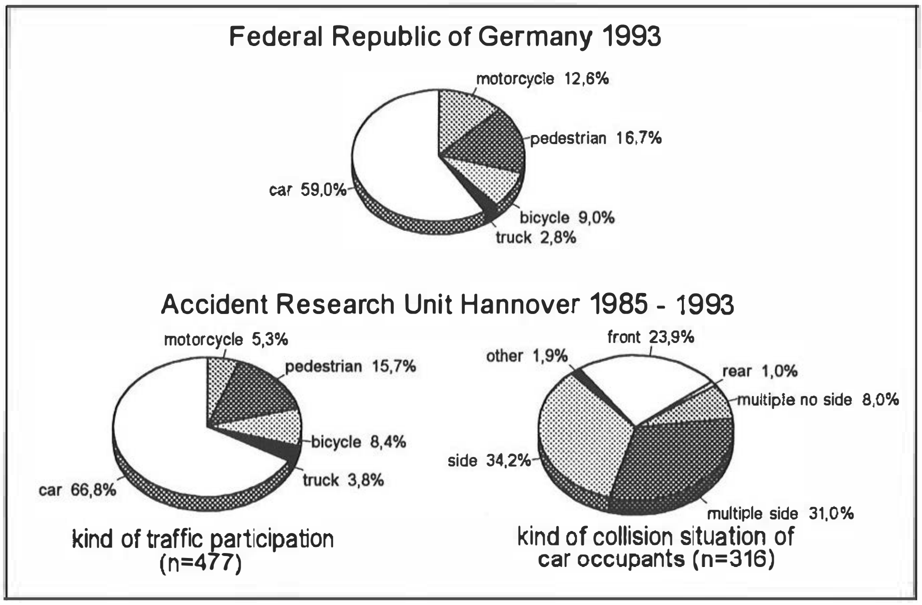


Figure 1 Kind of traffic participants of fatal injured persons in accidents as the result of official statistic Germany compared with Accident Research Unit Hannover

OBJECTIVE

The importance of lateral collisions on the one hand is shown in the statistic of severely injured occupants, on the other hand by the fact that safety devices were, up to now, mainly developed on the frontal impact protection. In lateral collisions the limited side space as well as the thin side structures of the doors do not provide an effective crumple zone. The effect of protective measures such as door bolsters and door pipes between the posts is limited. The present discussions concerning research and development aspects regard test criteria, i.e. whether a barrier contacting the door right-angled, according to ECE, or an obliquely positioned barrier, according to US-FMVSS, appear to the main objectives of future research (ETSC - 3). Further discussions exist, i.e. what influence the height of the lower barrier edge will have on the resulting injury severity. Security measures for the lateral impact are contemplated by implementation of various airbag systems, i.e. by installation on the seat (Volvo) or on the B-post, or along the upper door frame (BMW) respectively. In addition, dummies have been developed, in order to measure biomechanical force within the lateral impact (EURO-SID and US-SID). For that critical biomechanic force levels have to be investigated.

It is the objective of this study to analyse the injury mechanics of the latereral impact in real life accidents and to demonstrate under which circumstances bony injuries, especially those to the pelvis, are to be expected. The present measuring technique of the dummy requires an evaluation of the real accident situation, especially for this body region. The EURO-SID dummy proposes a possibility of measuring the forces to the pelvis. In this process, the "Pubic Symphisis Peak Force" (PSPF) is used as the critererion for the maximum force measured by a load cell at the pubic symphysis of the pelvis less than or equal to 6 KN. The US-SID exclusively measures the accelarations tri-axially with a limit of < 130 g. The US-SID and EURO-SID side-impact dummies developed up to now have no measuring points on the thighs, as it is assumed that axial forces to the thighs do not occur during lateral collisions.

The problem of pelvic injuries exists in its complexitiy of bony structure and the different kind of fractures relating to various possibilities of traumatological treatment. The paper will describe the special pelvic fractures including the biomechanics of femure as part of pelvic load in relation to Delta-v, intrusion and vehicle deformation characteristics.

DATA AT DISPOSAL

In this study 1,556 nearside seated occupants in isolated lateral collisions were analyzed, 332 of them were collided to cars, 86 to trucks and 138 occupants to objects like trees and poles. The data has been derived from traffic accidents which have been documented by a scientific team at the Accident Research Unit of the Medical University of Hannover/Germany (Otte - 4). By order of the Federal Highway Research Institute, since 1973 traffic accidents have been documented on the scene of accident and vehicle damage as well as injuries have been recorded in a data-base. Since 1985, the accident documentation has been carried out on the basis of a statistical spot-check plan and the evaluation is carried out by use of a statistical weighing procedure. Thus the established results for the injury situation of lateral collisions can be regarded as representative. Accidents from 1985 to 1993 are the basis of this study. All the Pelvic fractures in lateral car collisions were observed for the detailed analysis of the biomechanics.

INJURY SITUATION IN LATERAL IMPACTS

For the description of the injury severity the Abbreviated Injury Scale AIS (American Association of Automotive Medicine - 5) was used.

It is evident that an impact in the compartment region represents a higher injury risk than an outside impact. The nearside seated passenger faces a greater danger of injury. Only 48.5% of the nearside seated passengers remained uninjured in impacts to the compartment region (fig.2). 38.6% of the passengers received slight injuries of severity degree MAIS 1, and 12.9% MAIS 2 and higher, which are described in the following as MAIS 2+.

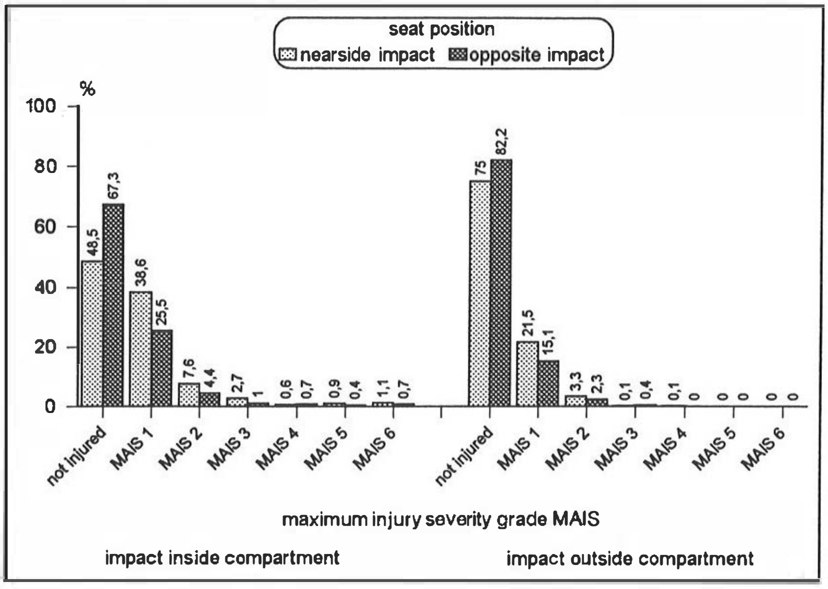


Figure 2 Maximum injury severity grades (MAIS) of car occupants of cars with isolated side impact

Two-thirds of the impact objects (62.6%) are cars (fig.3a). It was established that the lateral collision consists of three different collision types:

car as impact opponent	41%
truck as impact opponent	14%
tree/post impact object	40%

Object collisions, however, often lead to severe injury consequences (fig.3b). 40.4% of the persons with MAIS 2+ injuries were involved in lateral collisions with objects. Trucks were the collision opponents in 14.4% of the lateral collisions against the car side.

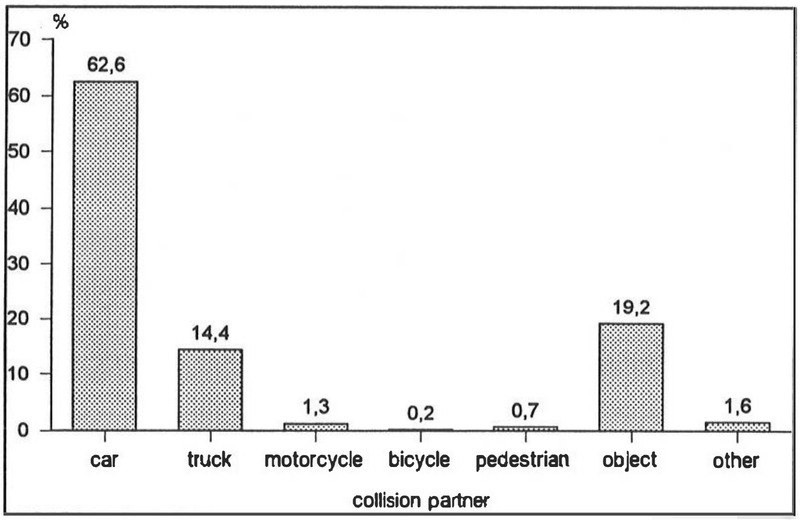


Figure 3a Collision partners of cars with injured occupants and isolated side impacts

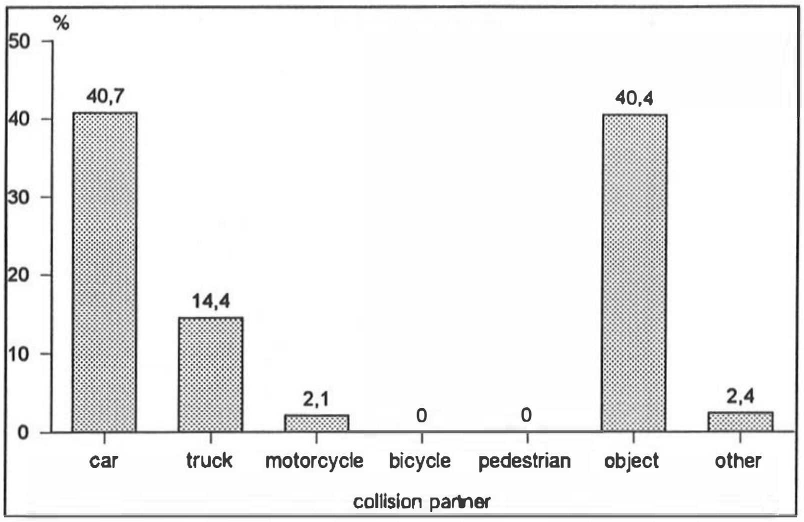


Figure 3b Collision partners of cars with injured occupants of MAIS 2+ and isolated side impacts

INJURY SEVERITY IN LATERAL COLLISIONS WITH VARIOUS COLLISION PARTIES

It was established that an impact of the vehicle side against a tree or post respectively causes the most frequent injuries and the most severe consequences to the nearside seated passengers. Table 1 shows that 93.4% of the nearside seated passengers received injuries in collisions with objects. 77.2% of them were slightly injured (MAIS 1/2), and 7.4% suffered injuries of severity degrees MAIS 5/6. In collisions with cars in comparison, only 61.3% of the persons were registered as injured, of which 95.7% incured injuries of severity degree MAIS 1/2, and 0.7% were most severely injured at MAIS 5/6.

The established injury frequencies to the various body regions vary for the various collision parties. Injuries to the various body regions range as follows: head 27.8%, thorax 21%, upper extremities 19.6%, legs 16.1% and pelvis 8.7%. It is remarkable that in object collisions the whole body is distinctly more frequently and severely traumatized, i.e. the head to a rate of 53.9%, the upper extremeties to 49.4%, the thorax to 38.1%, the lower extremeties to 38.1%, and the pelvis to 8.4%.

Pelvis injuries are established to a rate of between 8 and 9% in all collision types for all nearside seated passengers. Only the severity of pelvis injuries is often more serious in connection with the collision opponents truck and object, compared to the car impacts. 25.6% of the persons with pelvis injuries were traumatized to a rate of AIS 3/4 in the course of truck collisions, compared to 27.7% in object collisions.

	collision partner		
	car	truck	object
total	332	86	138
total body			
injured	61.3%	86.6%	93.4%
MAIS 1/2	95.7%	90.1%	77.2%
MAIS 3/4	3.4%	6.0%	13.1%
MAIS 5/6	0.7%	2.7%	7.4%
head			
injured	27.8%	55.0%	53.9%
AIS 1/2	98.8%	94.3%	79.5%
AIS 3/4	0.5%	0.8%	11.4%
AIS 5/6	0.6%	4.0%	7.1%
neck			
injured	11.0%	14.6%	19.4%
AIS 1/2	100.0%	91.0%	72.8%
AIS 3/4	-	4.6%	1.5%
AIS 5/6	-	2.1%	15.6%
thorax			
injured	21.0%	38.6%	38.1%
AIS 1/2	96.6%	85.9%	81.7%
AIS 3/4	2.3%	11.3%	12.5%
AIS 5/6	1.1%	-	2.7%
upper extremities			
injured	19.6%	32.0%	49.4%
AIS 1/2	100.0%	99.0%	89.1%
AIS 3/4	-	1.0%	10.9%
abdomen			
injured	4.9%	5.8%	9.8%
AIS 1/2	85.7%	66.9%	70.0%
AIS 3/4	9.7%	13.2%	9.6%
AIS 5/6	2.7%	7.1%	13.7%
pelvis			
injured	8.7%	9.7%	8.4%
AIS 1/2	85.2%	74.4%	61.9%
AIS 3/4	13.9%	25.6%	27.7%
AIS 5/6	-	-	-
lower extremities			
injured	16.1%	18.3%	38.1%
AIS 1/2	93.9%	94.0%	80.2%
AIS 3/4	6.1%	4.1%	18.1%

Table 1 Injury severity grades for nearside impact seated occupants in cars with isolated side collision impacted inside compartment region

TYPES OF PELVIS INJURIES

Table 2 shows the injury types incured by nearside passengers in lateral collisions, differentiated by soft-tissue injuries, fractures and inner organic injuries. The highest proportion of fractures can be established for the pelvis. The pelvis, at 8 to 9%, is generally rarely injured, but 1/3 of the pelvis injuries are fractures which are most frequent in object collisions (52%). In collisions with cars they are only caused in 28.3% of the cases.

	collision partner		
	car	truck	object
total	332	86	138
total body			
soft tissue only	67.6%	63.0%	45.6%
fracture	25.4%	23.8%	26.7%
organ	6.2%	11.3%	19.7%
fractures + organ	0.8%	1.9%	8.0%
head			
soft tissue only	87.3%	79.4%	52.1%
fracture	-	1.8%	3.7%
organ	12.7%	16.5%	35.9%
fractures + organ	-	2.3%	8.3%
neck			
soft tissue only	2.9%	9.6%	13.4%
fracture	97.1%	85.8%	81.4%
organ	-	4.6%	4.1%
fractures + organ	-	-	1.1%
thorax			
soft tissue only	78.2%	74.8%	58.5%
fracture	20.0%	22.9%	32.1%
organ	-	1.2%	1.0%
fractures + organ	1.8%	1.1%	8.4%
upper extremities			
soft tissue only	95.1%	81.9%	76.6%
fracture	4.9%	18.1%	23.4%
abdomen			
soft tissue only	74.1%	67.2%	60.0%
fracture	7.7%	17.8%	8.8%
organ	15.5%	15.0%	31.2%
fractures + organ	2.7%	-	-
pelvis			
soft tissue only	70.2%	70.3%	48.0%
fracture	28.3%	29.7%	52.0%
organ	-	-	-
fractures + organ	1.5%	-	-
lower extremities			
soft tissue only	90.4%	84.8%	66.4%
fracture	8.7%	15.2%	32.9%
fractures + organ	0.9%	-	0.7%

Table 2 Kind of injuries for nearside impact seated occupants in cars with isolated side collision impacted inside compartment region

This proves that the proportion of patients with pelvis fractures in this study is quite negligable. Only 35 persons with pelvis fractures and 13 persons with isolated thigh fractures could be included in this study. Pelvis injuries are also mechanically possible by force transmission, via the thigh and hip region. Lateral collisions may include transverse impulse directions and transverse relative movements. For this reason, persons with concurring as well as isolated hip joint fractures, luxations and femural fractures were included in the study for a detailed observation of injury mechanisms. The special collective for a detailed analysis consists of 48 persons.

Injury combinations of thigh/pelvis in lateral impacts are:

62.4%	isolated pelvic fractures	n=29
26.3%	isolated femural fractures	n=13
11.3%	pelvic and thigh fractures	n= 6
6.8%	pelvic and thigh fractures	n= 4

Patients with pelvis fractures are regarded as most seriously injured. 45% were so-called poly-traumatized. Poly-traumatization is in effect when at least three different body regions receive mortality risk injuries. 23% of the 48% of the patients with pelvis fractures died. The pelvis region is not explicitely regarded as the cause of death, this is because in 50% of the dead persons the localisation of fatal injuries were found on the head, 22% on spine, 16% on thorax, and 75% of fatal injuries could be explained as additional mortality risk factors.

40% of the patients were between 16 and 25 years old, only 14% were older than 55. These observations exclude the influence of the age factor for patients with pelvis fractures involved in lateral impacts. 61% of the patients with pelvis and thigh fractures were male and 79% were belt-protected.

Fig. 4 shows additionally established injuries to other body regions for patients with pelvis fractures. Persons injured to the pelvis by car crashes suffered injuries to the head in 41%, to the thorax in 36% and to the lower legs in 33% of the cases. Impacts with trucks or objects cause massive force influences to the whole body. The head is injured in almost all cases. 81% of the pelvis-injured persons in object impacts incure head impacts, 60% thorax and 72% impacts to the lower legs. The cervical vertebra appears to be frequently involved in lateral impacts, especially in object impacts, i.e. with 43% of all injured.

The most frequent fracture of the pelvis is the pelvic-ring fracture (32% of pelvic fractures). The pelvic-ring consists of three bony elements: both the hip-bones iliac-bone and ischial bone as well as pubic bone and rear sacrum. These elements are flexible and connected to each other by ligaments. The hip joint represents the connection to the femural bone. The front pelvis (ischium, pubic bone) consists of relatively weak developed bony structures. Fractures are most frequent here. The rear pelvis ring is strongly developed, with very strong bone and ligaments. Force transmissions to the spine are possible in these regions.

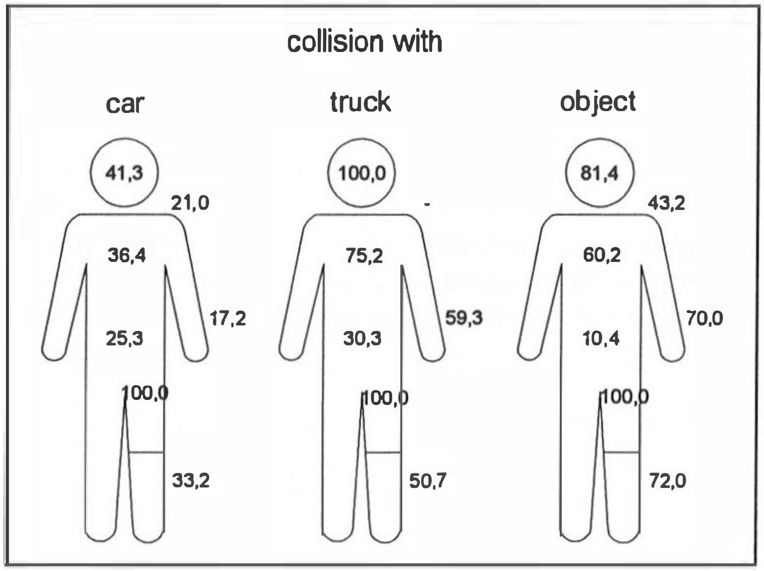
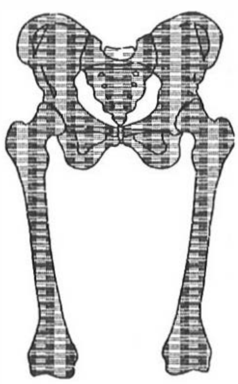


Figure 4 Car occupants with fracture of pelvis and/or upper leg, cars with isolated side impact including compartment, frequencies of injured body regions

When classifying the pelvis fractures, the following differences must be taken into consideration, definded by Tile (6) and Letournel (7):

- fractures concerned the pelvis brim and / or impaired the stability of the ring (type A)
- fractures which at least parts of the dorsal structures remained stable (type B)
- fractures which occur with a complete front and rear disconnection of the structure (type C)

For a better survey in this study, exclusively injuries of the front pelvis ring (ischium, pubic bone) and higher graded instabilities (pelvis-ring fracture) are differentiated (fig. 5). The observed pelvis-ring fractures were, as a rule, one-sided and impact-sided and were mostly front ring fractures. Ischium fractures occured to 9%, pubic bone fractures to 11%.



pelvic-ring fracture	n= 17	32%
ischial fracture	n= 5	9%
pubic fracture	n= 6	11%
hip joint	n= 5	9%
femur fracture	n= 13	20%

Figure 5 sample of often observed pelvis fractures (n = 54)

VEHICLE DEFORMATION CHARACTERISTICS WITH PELVIS FRACTURES

The deformation characteristics of each vehicle was produced by use of a matrix system. This system, which was developed and published the first time by the author, is described in the SAE paper 933126. It portrays the whole vehicle from a top view with a total of 200 identical fields. In the accident documentation all deformed fields are marked in a true-to-scale manner. This copy of the deformation pattern is stored in the computer for each accident. This method enables a convenient selection and evaluation of each case to reproduce the deformation picture by accumulated addition of all damaged fields. Fig.6 a-c show the deformation patterns for different impact objects in lateral collisions.

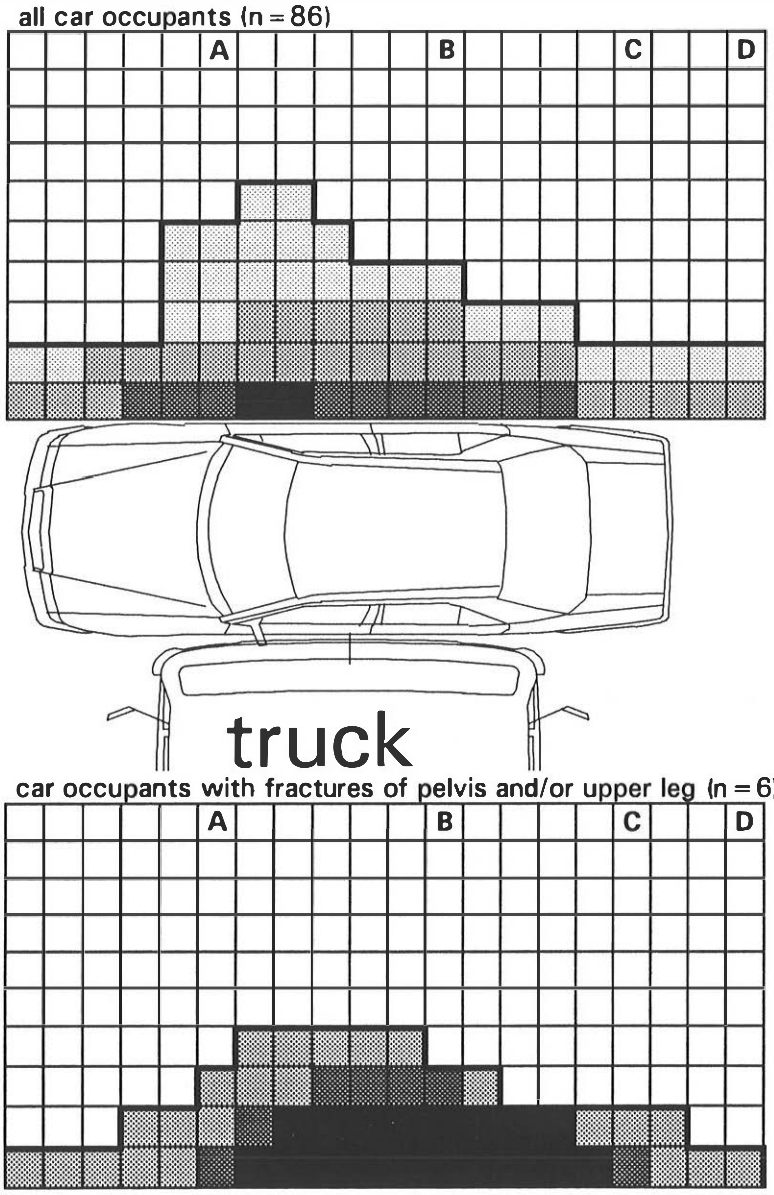


Figure 6a car occupants, cars with isolated side impact including compartment, **collision partner truck**

to 10% 10-40% 40-80% >80%

frequency of deformation of matrix fields

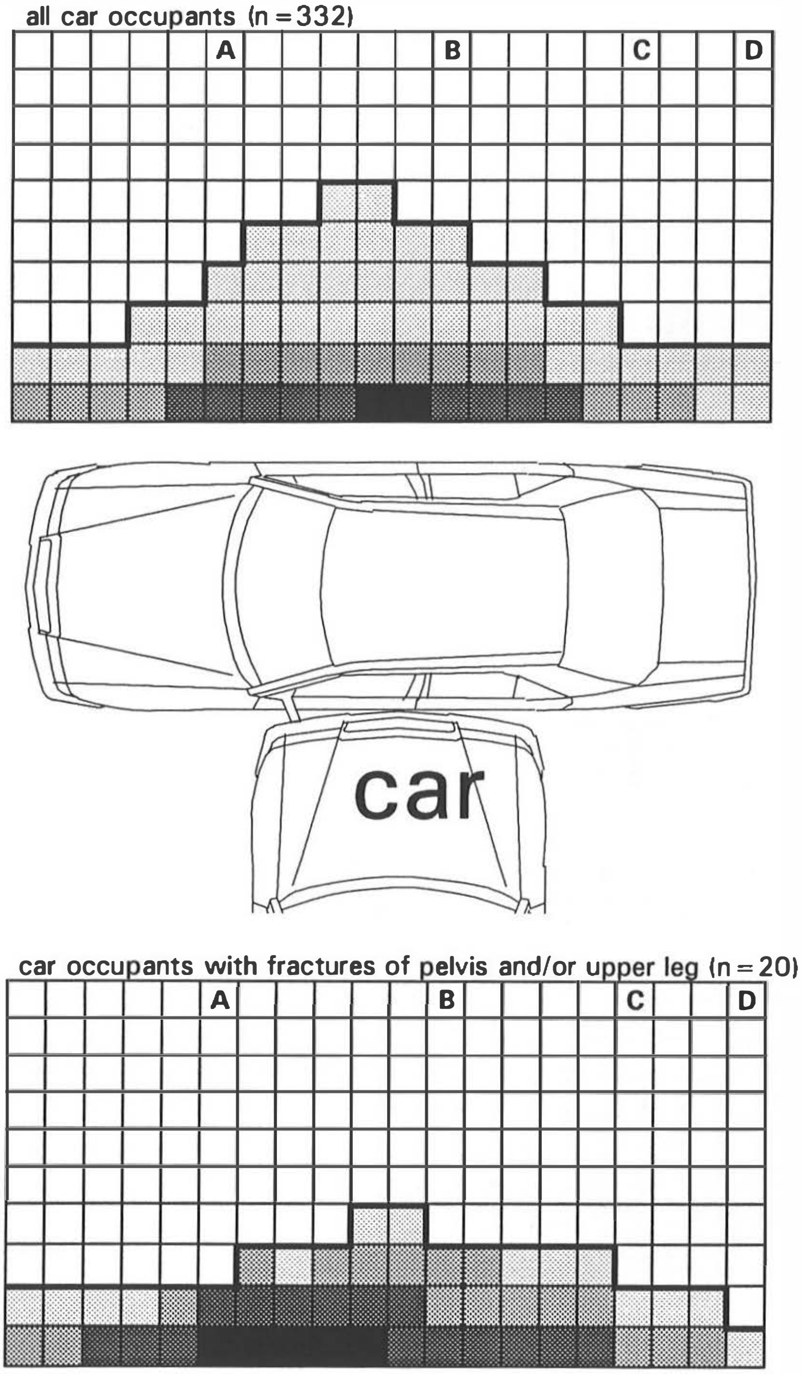


Figure 6b car occupants, cars with isolated side impact including compartment, **collision partner car**

bis 10% 10-40% 40-80% >80%

frequency of deformation of matrix fields

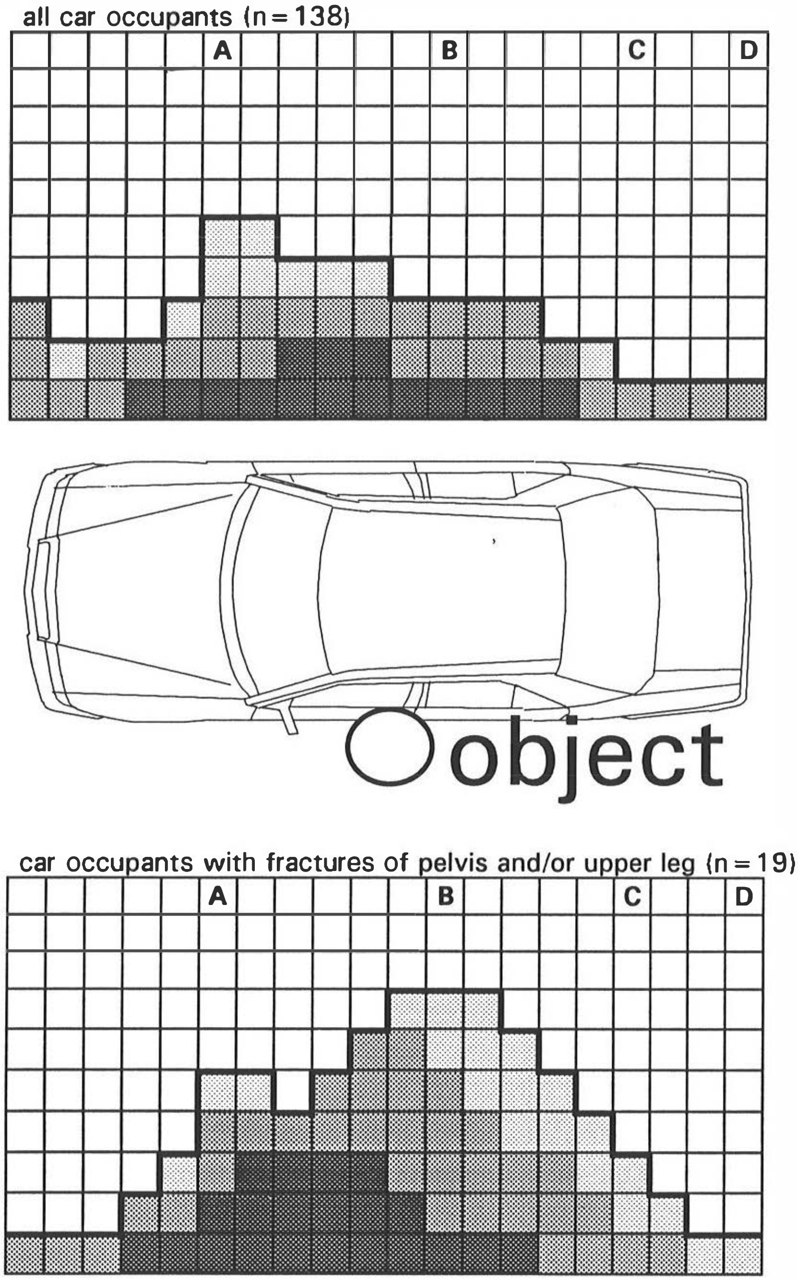


Figure 6c car occupants, cars with isolated side impact including compartment, **collision partner object**
bis 10% 10-40% 40-80% >80%
frequency of deformation of matrix fields

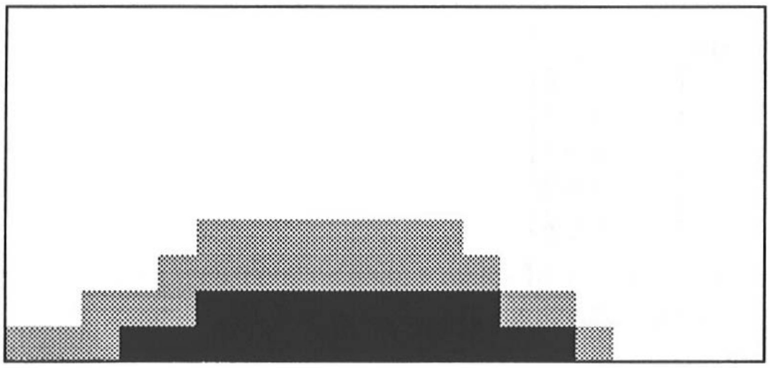
They further show the deformation patterns of car passengers with pelvis fractures. The deformation depth is clearly more penetrant for passengers with pelvis fractures.
An intrusion depth of frequently up to 10% in the direction of the vehicles transverse axis, predominantly between the A- and B-pillar, can be

established for the car of the collision opponent. On the other hand, a truck as collision opponent endures a relatively even deformation depth along the whole side of the vehicle, where as the passenger cell in the compartment near the A-pillar is deformed to a greater extent. The area from the A- to the B-pillar is damaged frequently by an intrusion depth of up to 40%. The semi-circular character of the impact-charcteristics which can frequently be established in the case of impacts with objects (fig. 6c) can also be recognised in the matrix. Deformations of up to 80% often occur between the A- and C-pillars.

Characteristic deformation marks regarding the occurance of pelvis/thigh fractures are shown in the study. Regarding the expected injury pattern, these are divided into 4 impact constellations:

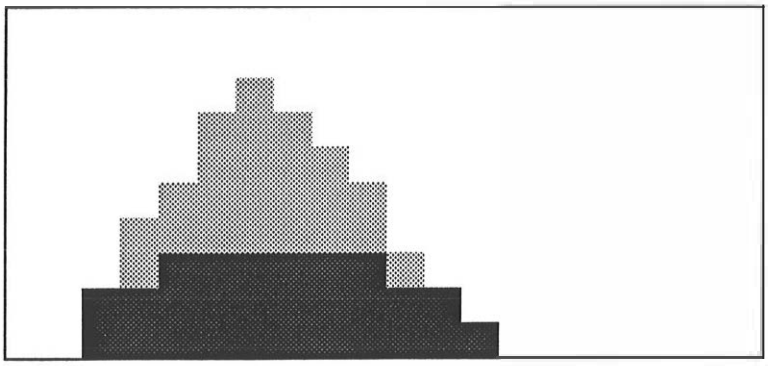
1. flat impact (car/truck) (fig. 7a)
2. post impact (object) rectangularly in the front compartment (fig.7b)
3. post impact (object) in front compartment with impulse oblique from the front (fig. 7c)
4. post impact (object) to the area of middle and rear compartment (fig.7d)

Of importance for the resulting injury of the pelvis are the impulse direction and the position of the lateral force introduction which can lead to pelvis and/or thigh injuries. The deformation characteristics for the resulting trauma sequence of the pelvis can be anticipated by the analysis of single cases. One must distinguish between the impact of a flat front structure of a car/truck (fig.7a) with a relatively even and wide range intrusion characteristic, and the other can be seen as a pole impact, with a round characteristic (fig.7b-d). Depicted in the pictures is the deformation extension of the registered maximum deformation outline for these injuries, and the collision conditions.



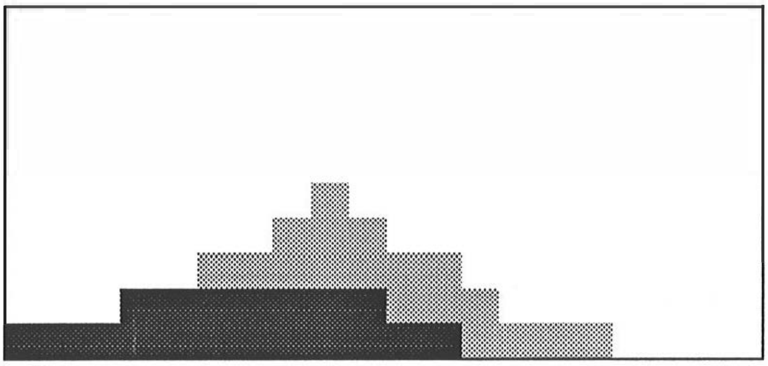
kind of pelvic fractures	
ischium fracture	n=4
pelvic girdle fracture	n=6
frontal pelvic girdle fracture	n=2
sacrum fracture	n=2
pubis fracture	n=3
sacro-iliac joint rupture	n=1

Figure 7a typical deformation matrix of cars, collision partner flat, occupants with pelvis fracture



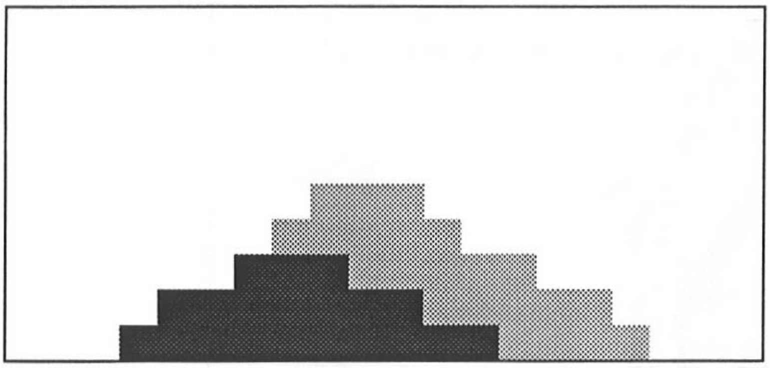
kind of fracture	
femur fracture	n=13

Figure 7b typical deformation matrix of cars, collision partner pole, occupants fracture upper leg



kind of pelvic fracture	
acetabulum fracture	n=4
pelvic girdle fracture	n=2
ala of the ilium fracture	n=1
pubis fracture	n=2
femur fracture	n=2

Figure 7c typical deformation matrix of cars, collision partner pole, occupants fracture of pelvis and upper leg (n=5)



kind of pelvic fracture	
pelvic girdle fracture	n=5
acetabulum fracture	n=1

Figure 7d typical deformation matrix of cars, collision partner pole, occupants pelvis fracture

The lateral as well as the longitudinally orientated force vector is apparent (fig. 8). Isolated femur fractures are incured when a direct impact to the thigh region occurs distinctly in front of the pelvis. As a rule, these are pole impacts. A combination of femur and pelvis fractures can be found when the impact, especially against a pole, occurs transversally from the front. Isolated pelvis fractures are found when the lateral impact to the cars involves the pelvis region.

Pelvis ring fractures occur in car as well as in object collisions. They do also often determine a transverse longitudinal axis component. All persons with pelvis fractures were exposed to high collision severity.

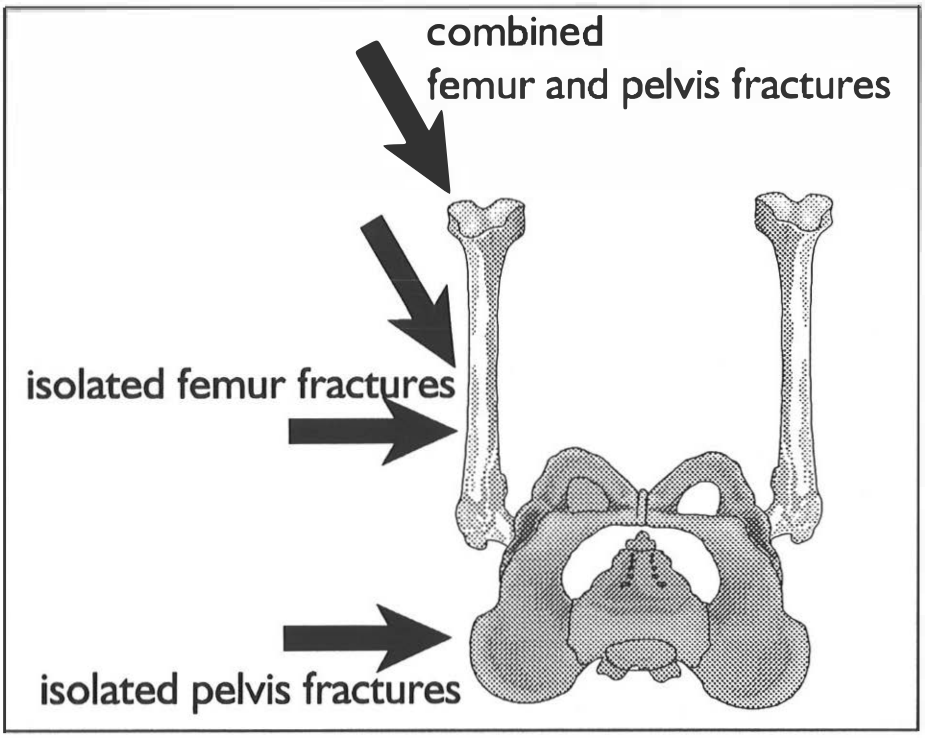


Figure 8 biomechanical load for the occurance of femur and pelvis fraktures

In 75% of the cases the speed absorption Delta-v amounted to 30 km/h, the average was 45 km/h (standard deviation =19,7). Fractures to the ischium and pubic bone as well as the pelvic brim can be regarded as direct impact traumatization. In this case the main deformation zones on the cars were situated directly laterally to the pelvis at delta-v values between 30 and 50 km/h.

CONCLUSION

The study shows that the lateral impact of the car is responsible for a high injury severity, especially for the head, but also for the thorax. Lateral impacts are very often collisions with objects which lead to a considerable intrusion of the lateral car structures. This in turn presents a very high injury risk for the head and thorax. Pelvis fractures occur in lateral impacts to a rate of 8 to 9% by car, truck and object, which is realatively seldom. They occur when a high intrusion and the impact point on the car are positioned directly lateral to the pelvis. In object impacts, injuries to the thigh and hip region must be expected. The thigh is also involved when the impact includes a transverse component of the load in longitudinal axis. This means that in lateral collisions the thigh must be regarded as a body region exposed to considerable forces.

From the results of the study, conclusions can be defined for future vehicle development and test conditions:

1. OPTIMIZED TEST CONDITIONS OF THE LATERAL IMPACT

- Measurements in the pelvis region of dummies are sufficient for crash-test conditions regarding the *simulations of car collisions* against the side of a car. The measuring of symphysis force, carried out by EURO-SID, basically appears to be more sufficient for establishing the injury threshold for the especially frequent fracture of the pelvic ring and consequently provides a suitable injury criterion. Force measuring in the thigh region does not seem to be necessary.
- Test conditions for the *simulation of truck collisions* against the side of a car do not seem to be necessary, as these are sufficiently covered by the EG as well as the US barrier test, and the frequency of pelvis injuries does not appear to be relevant.
- Only one test condition for the simulation of car-side collisions is not efficient. In view of frequency and severity, the *object impact*, especially the pole impact, is of considerable importance.
- In order to provide accident *test conditions conform to an object impact*, the pole should impact the car directly in front of the passengers pelvis, between the A and B pillar. The impact direction should include a transverse component from the front.
- In addition to the pelvis sensors, the length and transverse forces to the femure bone of the dummy's leg must be measured during an object impact.
- In EG as well as US tests the lower edge of the barrier should be situated as high as possible, in view of the fact that in real accident situations with pelvis injuries the side sill was usually under the localisation of impact point, and the passenger compartment consequently received a high positioned intrusion.

2. OPTIMIZED VEHICLE SAFETY

The following suggestions are made to improve vehicle safety in lateral impacts:

- For the prevention of a high positioned intrusion from pole impacts it is necessary to reinforce the side sill and the roof edge, in order to avoid the tilting-up of the vehicle, with the consequence of an extensive intrusion in the upper roof region, as well as an intrusion in the lower passenger region.
- As far as the side of the passenger compartment is concerned, it is necessary to temper the impact to the passengers with installation of suitable air-bags. There are systems developed which can be positioned on the seat/B-pillar/door roof edge to protect the head and the thorax and those positioned on the cross-beam/pane/A-pillar to protect the thorax and pelvis. A combination of both lateral air-bags would be a worthwhile improvement.

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