Injuries of foot and ankle in front seat car occupants

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Abstract: The accident research of Hanover and (from 1999 on) Dresden registered 736 leg injuries (AIS ≥ 2) from 1983 to March 2007. 174 of these injuries (23.6 %) were fractures or dislocations of foot and ankle. 149 feet of 141 front seat car occupants in 140 cars were affected. Of these 117 were drivers, 24 were front seat passengers. The mean age of occupants was 38.5 ± 16.8 years. Ankle fractures were the most frequent injury (n = 82; 80 malleolar fractures, 2 pilon fractures). 34 fractures and dislocations affected the hindfoot (5 talus and 26 calcaneal fractures, 2 subtalar dislocations and 1 subtotal amputation) , 16 to midfoot (4 navicular fractures, 5 cuboid fractures, 3 fractures of cuneiformia, 2 dislocations of chopart joint, 1 subtotal amputation, and one severe decollement) and 39 the forefoot (metatarsal fractures). Open fractures were seldom seen (2 malleolar fractures, 1 metatarsal fracture). Both feet were injured in 10 cases. 33 occupants (23.4 %) were polytaumatic had a polytrauma, 17 of them died. 81 percent of the occupants were belted. The cars were divided in pre EuroNCAP (year of manufacture 1997 and older) and post EuroNCAP cars (year of manufacture 1998 and newer). Most of the foot injuries were seen in pre EuroNCAP cars. Most of the occupants sat in compact cars (40 drivers and 9 front seat passengers) and large family cars (27 drivers and 7 co-drivers). 49 of 140 accidents occurred on country roads, 26 on main roads and 13 on motorways. The crash direction was mostly frontal. Generally were found no differences of delta v- and EES-level between the injured foot regions, but divided into pre- and post-EuroNCAP cars there was a tendency to higher delta v- and EES-levels in newer cars. The frequency of foot injuries increased linearly with increasing delta v-level; but above delta v-level of 55 km/h the linear increase only was seen in pre-EuroNCAP cars, post-EuroNCAP cars showed no further increase of injuries. The footwell intrusion showed no difference between the injured foot regions but pre-EuroNCAP cars had a tendency to higher footwell intrusion. There were no differences in footwell intrusion between the car types. Only 29 of 174 fractures or dislocations of foot were seen in post-EuroNCAP cars, the predominate number of these injuries (n = 145) were noticed in pre-EuroNCAP cars. A lower probability of long-term impairment was found in post-EuroNCAP cars for equal delta v levels, using the AIS2008 associated Functional Capacity Index (FCI) for the foot region.

Introduction: The lower extremity is the second most frequently injured anatomical region after the head, on an AIS2+ level. Although leg injuries are rarely as life threatening as head injuries, they can result in long-term disability and impairment. Therefore the social costs due to these non-fatal injuries are high. Fractures and dislocations of foot and ankle amount to one third of leg injuries AIS ≥ 2, so they are the most frequent leg injury in car crashes. Ankle fractures amount to 11.1 % of operated injuries. The constant improvement of passive safety of cars led to a better survival of trauma, so the outcome of foot injury often is decisive for long term disability. Although current restraint systems greatly reduce the risk of occupant injury, protection of these systems is not very effective for lower limbs as compared to that offered for head and chest [1; 2].

Material and methods: Retrospective analysis of GIDAS (German in-depth accident study)-database from 01/1983 to 03/2007. Fractures und dislocations of foot and ankle AIS ≥ 2 were registered. The foot was divided into hindfoot, midfoot and forefoot. CDC-level (collision deformation characteristics), delta v- and EES (energy equivalent speed)-level and footwell intrusion were registered. The cars were grouped into vehicle segments. The vehicle age was split binary into pre-EuroNCAP (up to 1997 inclusive) and post-EuroNCAP (1998 and newer). The injury causing assembly, road class, weather conditions and crash opponent were also registered. Injuries were scaled using AIS90/98, AIS2005/2008 and FCI. The Polytrauma criterion was ISS >= 16.

Results: A total of 11,255 fractures and dislocations of the lower extremity were registered by accident research Hanover and Dresden in the period from 1983 till March 2007. 10,519 of them were AIS 0 and AIS 1 injuries. 736 leg injuries were classified as AIS ≥ 2 (AIS 2+). 135 accidents with 141 front occupants with ankle/foot injury AIS 2+ were registered. In these accidents 140 cars were damaged, 89 men and 51 women were injured; in one case sex was not registered. Mean age of those injured was 38.5 ± 16.8 years (range 15 to 83 years). 117 drivers were faced with 24 co-drivers. These occupants had 174 fractures, 149 feet were suffered. Finally 23.6 % of leg injuries AIS ≥ 2 were fractures and dislocations of foot and ankle.

	Left Foot		Right Foot**	
Driver	63	42,9%	59	40,1 %
Front seat passenger	10	6,8 %	15	10,2 %

Table 1: Distribution of fractures and dislocations of foot and ankle to left and right foot
** In two cases side not registered

Injured foot region	Driver injury		Front seat passenger injury	
Ankle	69	40,3 %	13	7,6 %
Hindfoot	32	18,7 %	2	1,2 %
Midfoot	14	8,2 %	2	1,2 %
Forefoot	29	17,0 %	10	5,8 %

Table 2: Number of fractures and dislocations of foot and ankle
In 3 Cases the exact location of injury was not coded.

The following single injuries could be analyzed:

Foot region	n	Pre-EuroNCAP	Post-EuroNCAP
Ankle: Malleolar fractures	80	65	15
- open	2	1	1
- dislocation fractures	6	5	1
Pilon fractures	2	2	
Hindfoot: Talus fractures	5	4	1
- dislocation fractures	2	2	
subtalar dislocations	2	2	
- open	1		
Calcaneal fractures	26	22	4
subtotal amputation	1	1	
Midfoot: Chopart joint dislocations	2	2	
Naviculare Fractures	4	3	1
Cuboid fractures	5	5	
Cuneiforme fractures	3	3	
subtotal amputations	1	1	
Decollement	1	1	
Forefoot: Metatarsal fractures	39	31	8
- open	1	1	

Table 3: Fractures and dislocations of different anatomic regions of foot and ankle

Both feet were injured in 10 cases (9 from it in pre-EuroNCAP cars). Different anatomic regions in one foot were injured in also 10 cases (also 9 from it in pre-EuroNCAP cars). 33 occupants (23.4 %) suffered polytraumatic injuries, 17 of them died. 81 percent of occupants were belted.

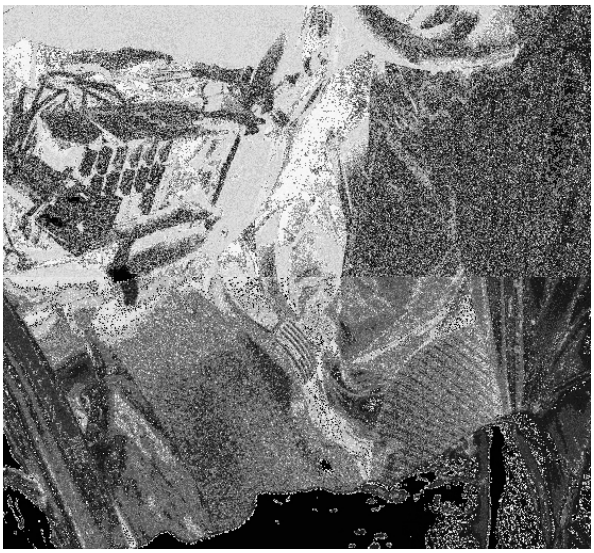

Figure 1: Typical foot pinch by intrusion of floor panel and pedals.

Fractures and dislocations of foot and ankle mostly happened in compact cars, followed by small cars and large cars. The participated cars are shown in the following table:

Car segment	**Driver**		**Front seat passenger**	
Small cars	30	21,4 %	2	1,4 %
Compact cars	40	28,6 %	9	6,4 %
Large cars	27	19,3 %	7	5,0 %
Executive cars	13	9,3 %	4	2,8 %
other	3	2,1 %	1	0,7 %
Luxury cars	2	1,4 %	0	
Sport coupes	1	0,7 %	1	0,7 %

Table 4:
Front row vehicle occupants with foot and/or ankle injury by vehicle market segment.

33 % of cars were equipped with front airbags. The Front airbags deployed in 30 percent of cases. 19 Accidents were in built up areas, the majority, 121 (86.4 %), occurred in rural areas. With 35% of the cases country roads were the most frequent road type, followed by federal roads (18.6 %) and motorways (9.3 %). In 26.4 % of the cases a street type was not coded. More than half of the accidents occurred during daylight hours (58.6 %), 13.6 % at dusk and 27.1 % at night. In 77,1% of the cases the weather conditions were dry, in 18.6 % it was rainy, and in 2.9 % snowfall was documented at the time the accident occurred. Every other car (n = 70) collided with a car, 22 cars (15.7 %) collided with 2 and more cars. 48 of the accidents were single vehicle accidents (34.3 %).

Most of the accidents were frontal impacts:

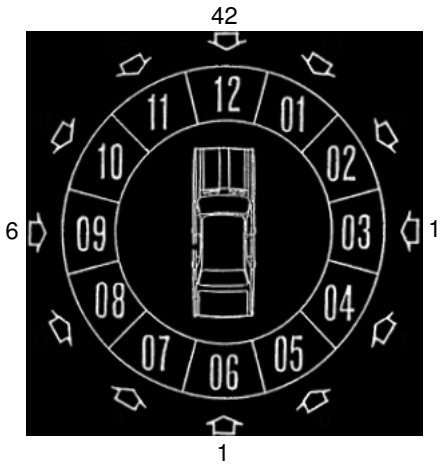

Figure 2:
Impact direction of car with injured front seat occupant.

The part of the car which leading caused the injury was registered: 31.8 % of fractures and dislocations of foot and ankle of drivers were caused by the pedals, 25.9 % by bulkhead and 17.6 by bottom side of dashboard.

Delta v and EES levels showed no differences between the anatomic foot regions (EES not showed):

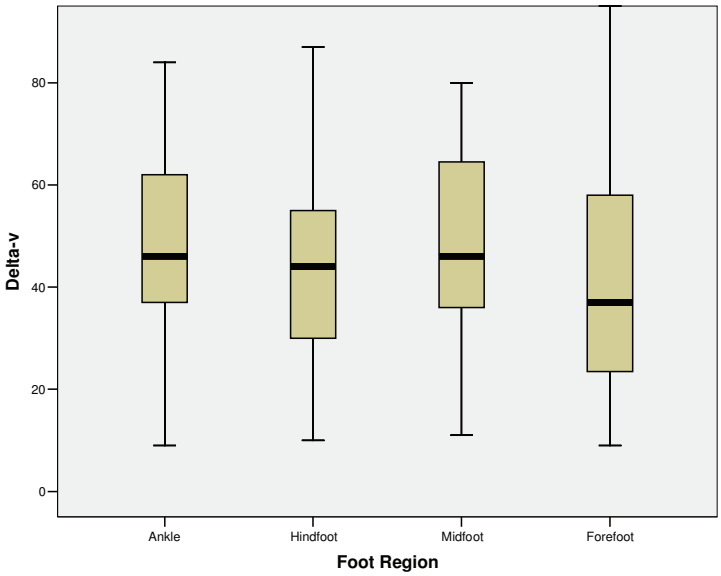

Figure 3:
Injuried foot region vs. delta v [km/h]
Differences are not statistically significant.

The separated analysis of newer (post-EuroNCAP) and older (pre-EuroNCAP) cars showed a tendency to higher delta v-levels of injuries of ankle, hind- and midfoot in newer cars, but in forefoot there was a tendency to the opposite direction, though the findings were not statistically significant.

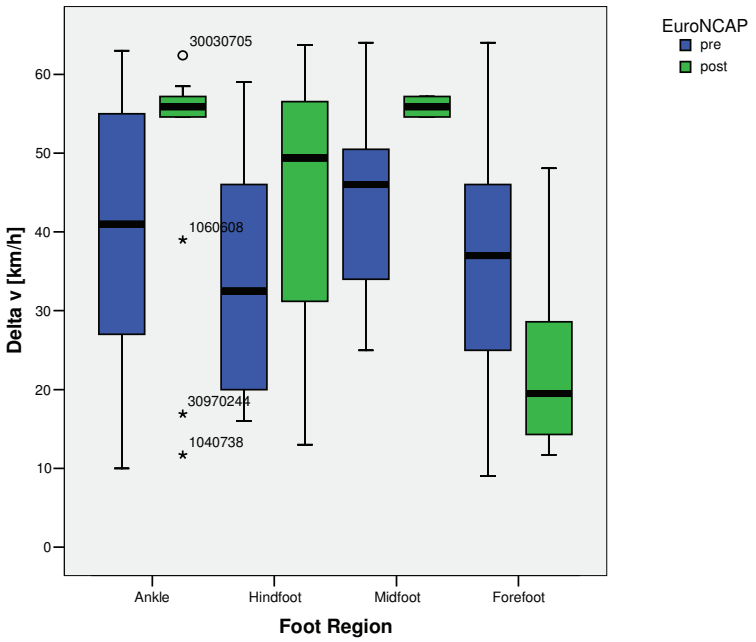

Figure 4:
Delta v [km/h] vs. injured foot region for pre- and post-EuroNCAP cars.
Differences are not statistically significant.

There was also a tendency to higher footwell intrusion levels in fractures or dislocations of ankle and midfoot in post-EuroNCAP cars:

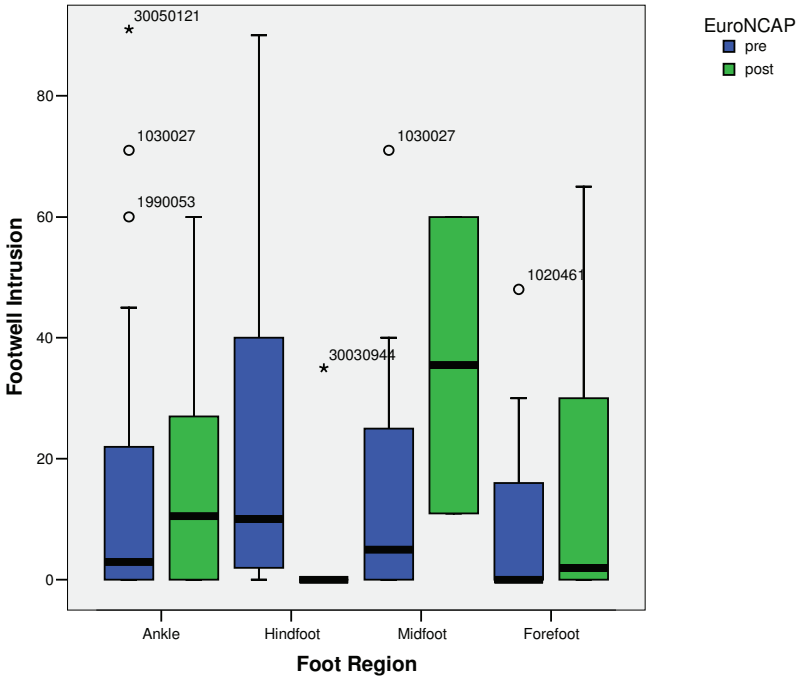

Figure 5:
Footwell intrusion (cm) vs. injured foot region in pre- and post-EuroNCAP cars.
Differences are not statistically significant.

Higher intrusion levels were noted with increasing delta v levels in a part of injuries, but several injuries occurred without footwell intrusion despite of relatively high delta v level:

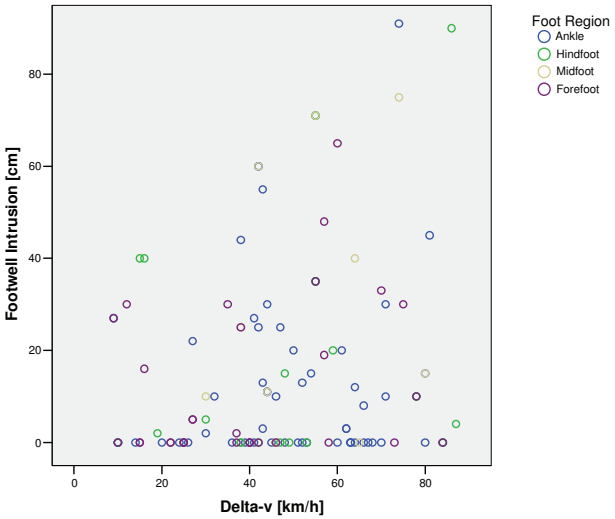

Figure 6:
Injured Foot region by footwell intrusion [cm] and delta v [km/h].

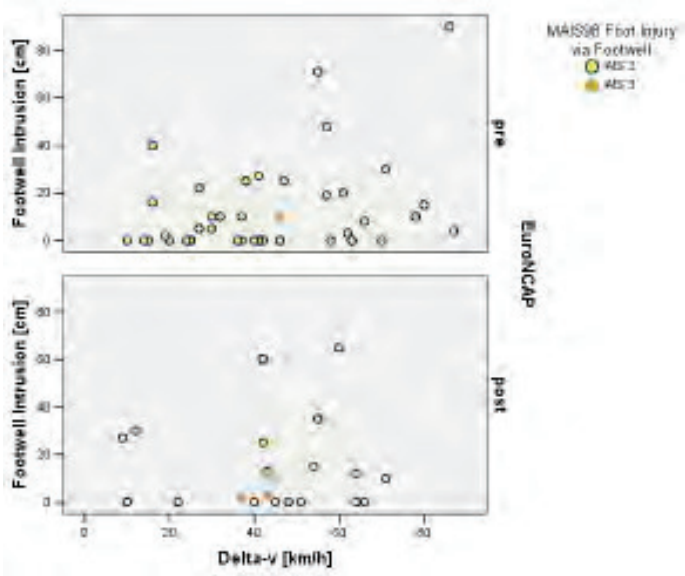

Figure 7:

AIS-coded foot injuries vs. footwell intrusion [cm] and delta v [km/h] for pre- and post-EuroNCAP cars.

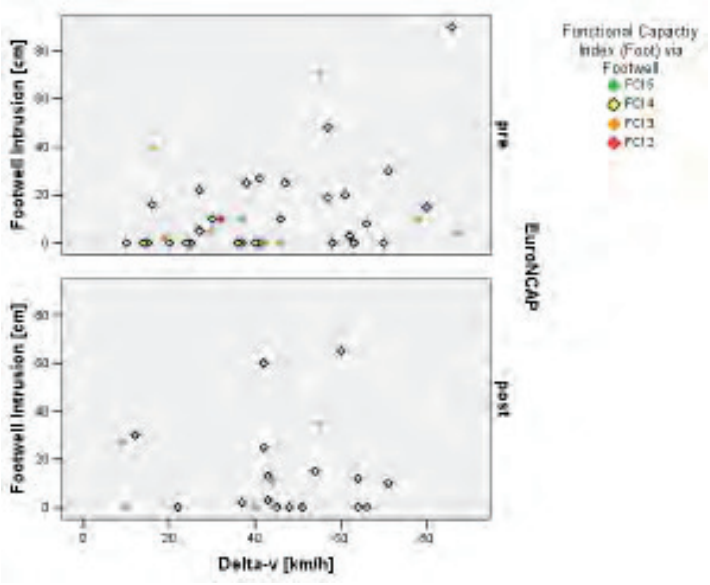

Figure 8:
FCI coded foot injuries vs. footwell intrusion [cm] and delta v [km/h] for pre- and post-EuroNCAP cars.

In older cars a linear increase of frequency of foot injury with increasing delta v level was registered; in newer cars no increase of frequency of foot injury above a delta v-level of 60 km/h was noted:

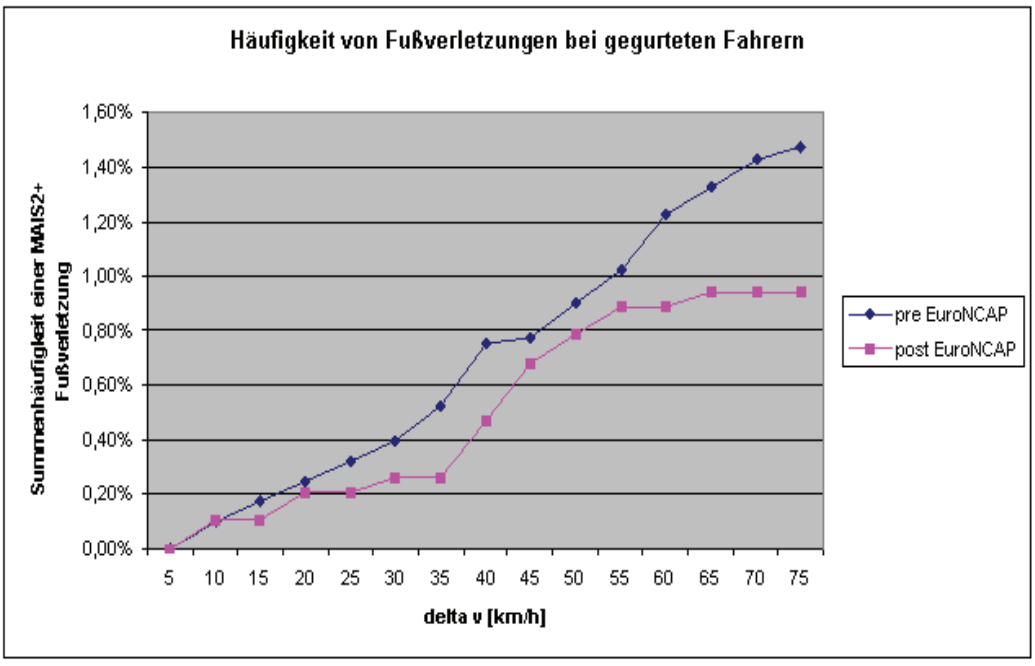

Figure 9: Cumulative frequency of foot injuries in dependency of delta v level. Pre- and Post-EuroNCAP cars. Injury orientated description.

Discussion: 174 Fractures and dislocations of feet and ankle were registered by GIDAS research project during a period of 26 years. These injuries represent 24 % of AIS 2+ leg injuries. In previous analyses foot and ankle injuries amounted to 34 %.[3] As described earlier[2, 4] ankle fractures were the most frequent injuries, followed by fractures of metatarsalia. Midfoot fractures (n = 16) were a rarity. Hindfoot injuries, among them 26 calcaneal fractures, were registered in 34 cases, in earlier analyses[3, 5] 15 to 32 percent of foot and ankle fractures were calcaneal fractures. 117 drivers and 24 front seat passengers suffered a fracture or dislocation of foot and ankle. This corresponse with most

other investigators who report a 75% higher incidence on drivers than on front seat passengers,[2, 7, 8] while some investigators found a more balanced relationship between front seat occupants.[6] Most of the documented injuries occured in older, pre-EuroNCAP, cars. Serious injuries with severe soft tissue damage like ankle dislocation fractures, subtalar dislocations or subtotal amputations were seen nearly exclusively in pre-EuroNCAP car occupants. Nearly 25 % of occupants were classed as polytraumatic patients (ISS >=16), half of these patients died within 30 days of the accident. It has been previously postulated that lower extremity injuries have a dominant influence on the outcome of the patient.[9]
Half of the cars were small and compact cars (table 4), this could be a hint as to the role of the size of the footwell in the genesis of injury, but one also has to take into account that small and compact cars are the predominant cars on German roads and thus tend to feature prominently in accident statistics. There was no difference in footwell intrusion between the anatomic regions, in ankle and forefoot injuries almost no intrusion was registered. The role of footwell intrusion in genesis of foot and ankle injuries is inconsistent to that described by other investigators: Begeman and Pattimore noted a footwell intrusion in 75 – 96 % of their cases,[2, 10] other investigators found no intrusion in up to 32 % of foot and ankle injuries.[11–14] There was a tendency to higher intrusion levels in post-EuroNCAP cars, especially in midfoot fractures and dislocations; In these cars a higher intrusion depth was necessary in order to cause an injury. An increasing delta v-level is often linked to a higher footwell intrusion, therefore the injury risk also increases[15]. This tendency was primarily found in fractures and dislocations of ankle and forefoot (figure 6). Nearly all injuries occurred in frontal impacts (81 cars), in 19 cases the feet of drivers were injured in the left side impacts. In other studies more than half of foot and ankle fractures were observed in frontal collisions.[16–18] The speed parameter delta v and EES did not show significant differences between the injured foot regions (figure 3 and 4), formerly reported levels (delta v in calcaneal fractures of 49 km/h[5]) were not reached. The AIS98 coding of foot injuries does not show a significant difference in the injury severity for pre and post-EuroNCAP cars (figure 7), while the FCI based injury coding does (figure 8). Figure 9 shows a linear increase of frequency of injuries with increasing delta v level for pre-EuroNCAP cars, but in post-EuroNCAP cars there is no increase above delta v level of 60 km/h. Finally newer (post-EuroNCAP) cars offer a better prevention for foot and ankle compared with older (pre-EuroNCAP) cars.

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