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A Medical and Technical Analysis of Knee Injuries Focusing Vulnerable Road Users and Restrained Car Drivers in Road Traffic

Abstract

Description of road traffic related knee injuries in published investigations is very heterogeneous. The purpose of this study was to estimate the risk of knee injuries in real world car impacts in Germany focusing vulnerable road users (pedestrians, bicyclists and motorcyclists) and restrained car drivers.

The accident research unit analyses technical and medical data collected shortly after the accident at scene. Two different periods (years 1985-1993 and 1995-2003) were compared focusing on knee injuries (Abbreviated Injury Scale (AIS_{Knee}) 2/3). In order to determine the influences type of collision, direction and speed as well as the injury pattern and different injury scores (AIS, MAIS, ISS) were examined.

1.794 pedestrians, 742 motorcyclists, 2.728 bicyclists and 1.116 car drivers were extracted. 2% had serious ligamentous or bony injuries in relation to all injured. The risk of injury is higher for two-wheelers than for pedestrians, but knee injury severity is higher for the latter group. Overall the current knee injury risk is low and significant reduced comparing both time periods (27%, $p<0,0001$). Severe injuries (AIS_{Knee} 2/3) were below 1%). Improved aerodynamic design of car fronts reduced the risk for severe knee injuries significantly ($p=0,0015$). Highest risk of injury is for motorcycle followed by pedestrians, respectively. Knee protectors could prevent injuries by reducing local forces. The classically described dashboard injury was rarely identified.

The overall injury risk for knee injuries in road traffic is lower than estimated and reduced comparing both periods. The aerodynamic shape of current cars compared to older types reduced the incidence and severity of knee injuries. Further modification and optimization of the interior and exterior design could be a proper measurement. Classic described injury mechanisms were rarely identified. It seems that the AIS is still underestimating extremity injuries and their long term results.

Introduction

Description of road traffic related knee injuries is very heterogeneous. The purpose of this study was to estimate the risk of knee injuries in real world car impacts in Germany focusing vulnerable road users (pedestrians, bicyclists and motorcyclists) and restrained car drivers. With the increasing use of safety belts and availability of air bags, more occupants survive serious car crashes [14]. However, many people involved in frontal or offset crashes incur disabling lower extremity injuries [23, 22, 21]. Though lower extremity injuries are usually not life threatening, the physical and psychosocial consequences of lower extremity injuries are often long lasting. Next to the high risks subsequently high costs follow lower limb injuries [27, 18, 12]. The knee is the largest and one of the most complicated joint of the human body. Eight joint parts cooperate here and allow a limited rotation around its longitudinal axis besides extension and flexion of the lower extremity. Two cruciate and two collateral ligaments stabilize the knee passively. The menisci counterbalance the different bone surfaces. In case of an injury of the knee, one or more of these ligamental or bony elements can be injured and the probability of long-term problems is high due to the complexity [9]. In case of an crash event with a knee injury there is a high likelihood of residual long-term effects [8].

YANG [26] reported in a study using a mathematical simulation of knee movements different injury patterns of the leg. Fractures of the tibia and/or knee injuries such as ruptures of the ligaments and fractures of the condyles were frequently found in experimental studies; he mentions studies by BUNKETORP, ALDMAN, KRAMER, PRITZ and CAVALLERO [2, 10, 11, 16, 20]. Also accident analyses report knee injuries by APPEL, ASHTON and MAKI [3, 17, 4]. A study carried out in Dublin found in a post mortem investigation at the Department of Forensic Medicine, knee joint injuries in 214 out of 357 fatal pedestrian victims of

traffic accidents (60%) [25]. Although there are previous studies trying to outline distinct characteristics there is a lack of in-depth technical evaluation for preventive interventions. Most of the previous study analyzed medical, police, and/or insurance records [6, 7, 15, 5]. Under consideration of the results of previous studies with other priorities, we strongly believe that a technical in-depth crash investigation in combination with a medical data analysis is the most sufficient basis for an improvement of safety lower limb injury risk.

The purpose of this study was to analyze the incidence of road traffic knee injuries in Germany by demographic data, place and person co-ordinates and to identify clusters.

Methods

The accident research unit analyses technical and medical data collected shortly after the accident at scene. Two different periods (years 1985-1993 and 1995-2003) were compared focusing on knee injuries (Abbreviated Injury Scale (AIS_{Knee}) 2/3). In order to determine the influences type of collision, direction and speed as well as the injury pattern and different injury scores (AIS, MAIS, ISS) were examined. The vulnerable road users were distinguished as pedestrians, motorcyclists and bicyclists.

n=16563 accidents with 22804 injured persons were identified (Table 1). A total of, 11111 accidents of all traffic participants for the years 1985 to 1994 and 11693 accidents for the years 1995 to 2003 (current situation) were available. From these cohorts the injury frequency of the knee for different types of traffic participation (occupants of cars and trucks, vulnerable road users) including the slight soft tissue injuries were determined in this study.

For vulnerable road users two different groups of accident data were compared, in which a car hits a vulnerable road user: the years 1985 to 1993 (n=2739 persons), and 1995 to 2003 (n=2749 persons). The vulnerable road users were differentiated as pedestrians (n=1794), motorcyclists (n=742) and bicyclists (n=2728). Only those accidents were selected that involved cars (vans included). For the same periods restrained car drivers were selected (n=591 vs. n=525). The accidents with injuries to the knee were compared to all accidents of traffic participants.

Accident reports collected between 1985 and 2003 were carefully analyzed for knee injured road traffic participants and the following parameters: demographic data, AIS, MAIS, ISS, incidence of polytrauma, incidence of serious or severe injuries, role of traffic participation, collision speed, collision opponent, and collision type. For statistical analysis of the correlation between crash circumstances with injury severity (AIS, MAIS, ISS) a t-, Pearson- or Linear-Trend-test was used. The classification of the injury severity was executed according to AIS (American Association for Automotive Medicine 1998 [1]). The documentation was conducted using the same methodology for the whole period of data collection, which allowed for a statistical comparison of the accident structure between early cases and today. These cases were checked by an experienced surgeon based on the AIS-classification and the medical evaluation of the injury pattern and injury patterns of the knee were defined. Knee injuries examined in this study were defined from the distal femur epiphysis including condyles to the tibial head with epiphysis, as well as all ligaments including bone insertion, menisci and the patella and the soft tissue surrounding these structures. The AIS classification considers contusions and smaller soft tissue lesions as AIS 1, soft tissue injuries of a greater extent (sprains) with injuries of bursa, ligaments or menisci, patella fractures, non-compound and only slightly shifted fractures of the tibia, knee dislocations and an open joint are allocated AIS degree 2 whereas fractures of the distal femur, compound or comminute proximal tibia fractures, full posterior cruciate ligament ruptures and open ligament ruptures are classified as the highest degree of injury severity AIS 3 (Table 2). Different technical parameters were focused and examined like influence of car shape developments on injury, the severity outcome of the knee injury pattern in vulnerable road users and finding the characteristics and mechanisms of knee joint injuries. An evaluation concerning the occurring mechanics that were operative during the impact and subsequently applied to the knee unit was conducted. For this purpose, the position of the pedestrian or the cyclists that was derivable from the reconstruction of the accident was taken into account and the resulting kinematics were determined from the damage to the vehicle and the evaluated throwing motion and differentiated according to the occurring load characteristics as direct impact, bending, rotation and combinations of these. A comprehensive reconstruction of the

	total	kind of traffic participation				
		car occupant	truck occupant	motorcyclist	bicyclist	pedestrian
Year of accident 1985-1993						
Total (n)	11111	5891	401	1052	2304	1463
Head	47.7%	48.1%	51.3%	23.2%	52.3%	55.8%
Neck	19.9%	33.1%	22.2%	7.8%	4.9%	4.1%
Thorax	29.8%	37.6%	24.6%	22.5%	20.9%	22.0%
Upper extr.	37.1%	28.0%	36.9%	49.2%	47.6%	44.4%
Abdomen	8.2%	9.0%	8.1%	7.7%	6.3%	8.8%
Pelvis	10.7%	7.8%	7.4%	16.0%	12.2%	16.3%
Femur	9.2%	4.8%	7.8%	16.9%	12.1%	15.5%
Knee	23.5%	14.4%	22.0%	42.2%	31.5%	30.9%
Lower leg	16.0%	9.0%	13.0%	29.0%	20.9%	25.7%
Foot	13.2%	7.1%	7.9%	29.6%	17.2%	18.2%
Year of accident 1995-2003						
Total (n)	11693	6824	507	1227	2018	1117
Head	36.6%	35.1%	45.0%	17.0%	42.1%	52.8%
Neck	30.2%	46.7%	38.1%	7.5%	5.6%	4.9%
Thorax	27.6%	31.2%	32.9%	26.3%	20.5%	19.9%
Upper extr.	31.3%	22.4%	42.8%	45.0%	44.3%	37.4%
Abdomen	6.8%	6.7%	15.5%	6.9%	5.1%	7.4%
Pelvis	8.2%	5.0%	12.1%	14.6%	10.7%	13.4%
Femur	4.7%	2.5%	5.1%	9.4%	6.6%	8.7%
Knee	17.2%	10.0%	16.6%	36.1%	25.4%	21.8%
Lower leg	9.6%	5.0%	10.6%	17.6%	14.6%	17.6%
Foot	7.7%	3.3%	4.9%	17.6%	12.7%	14.1%

Table 1: Distribution of injuries in selected road traffic users

AIS Knee
1 Contusion
2 Soft tissue injuries incl. ligaments, menisci; patella fractures; closed, minimal displaced tibial fractures; knee dislocation; opened joint cavity
3 Fractures of the distal femur; open, displaced or multifragmentary tibial fractures

Table 2: AIS Knee (based on AIS 1998)

vehicle motion sequence and the accident severity that occurred can be determined on the basis of scaled drawings and a technical impact analysis. Accident characteristics, such as delta-v, EES or deformation depth can be correlated to the classified injury severities. The injuries were documented using independent documentation and the inspection of medical diagnosis reports and x-rays. The documentation contains graphical material and drawings of the accident traces at the site of the accident, detailed measurements of the damages to the vehicle are taken and an accident reconstruction of the motion sequence using computer aided simulation (PCcrash) is conducted. From these data the origin, the type and the extent of the injuries can be determined. The analysis of the accident mechanism and the accident load from the technical point of view is conducted in parallel, based on the analysis of technical data photographs.

Results

1.794 pedestrians, 742 motorcyclists, 2.728 bicyclists and 1.116 car drivers were extracted (Table 1).

Car occupants

After grouping in the years 1985-1993 and 1995-2003 all cases of knee injuries with a severity of AIS 2+ were separated (85-93 n=56; 95-03 n=26). The injuries during the impact and afterwards to the knee were evaluated. End position of the knees of the seated occupants that had been derived from the accident reconstruction was taken into account and the occurring kinematics were evaluated according to the resulting damages in the interior as well as the impact vector and the resulting relative

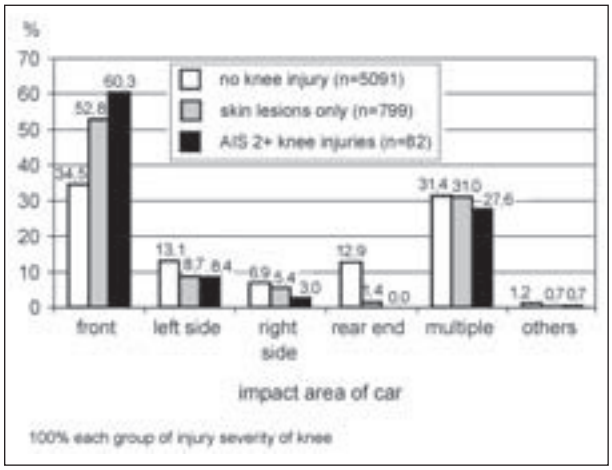

Figure 1: Impact area of restrained car drivers; n=5972 belted injured car drivers

motion of the car (Figure 1) and differentiated according to frontal and side impact it could be demonstrated that an increasing delta-v the incidence of a knee injury and the degree of severity increases.

Up to delta-v values of 50km/h the portion of knee injuries AIS 2+ could be seen in less than 6%. In frontal collisions with a delta-v of up to 20km/h only 0.6% of the drivers suffered from knee injuries AIS 2+ and 13.3% AIS 1, for delta-v from 41 to 50km/h 3.5% AIS 2+ and 25.2% AIS 1 occurred. For side impacts knee injuries of the degree of severity AIS 2+ occurred only in cases of a high accident severity with more than 40km/h delta-v, for a delta-v 41 to 50km/h they registered at 3.0%. 80% of the delta-v values of restrained drivers with knee injures AIS 2+ could be found above delta-v 30 m/h, whereas for drivers without knee injuries 80% of all collisions occurred at delta-v values of up to 40km/h. Whereas 5.1% of the passenger car drivers suffered slight knee injuries AIS 1 and 3.2% of those not injured at the knee had an overall MAIS 3+ injury severity, 54.7% of the drivers who were injured AIS 2+ at the knee suffered from injuries of a degree of severity MAIS 3 or higher. It was remarkable that persons suffering from severe knee injuries as opposed to persons with a slight knee impact trauma AIS 1 and the collective of those occupants of cars in accidents who were not injured at the knee, the proportion of so-called whiplash injuries of the neck occurred significantly less frequently (33.4%, 46.2% compared to 12.8%), whereas all other body regions were more severely injured with increasing severity of the knee injuries. The pelvis was injured four times as frequently in persons with AIS 2+ knee injuries than for passengers/drivers without knee injuries, arm and head and abdomen are injured double frequently. Three quarters of all AIS 2+ knee injured restrained car drivers suffered a fractures of the patella (32.5%) and of the head of the tibia (22.1%) as well as tendon ruptures (24.2%). Fractures of the femur condyles were found in 9.3% of the cases. Where ligament injuries were observed, the medial collateral ligament (11.2%) was affected more frequently than the lateral collateral ligament (2.2%) and the anterior cruciate ligament (10.1%) more frequently than the posterior cruciate ligament. Lateral und medial menisci were injured only in 0.8% of the cases. Severe knee injuries were connected to an intrusion into the passenger compartment. In frontal impacts of cars 43% of the vehicles of restrained drivers with AIS 2+ knee injuries showed an intrusion of the compartment and 32.7% in lateral collisions, in contrast to only 14% of those with light AIS 1 soft tissue lesions of the knee and to only 7.4% of those who were not injured at the leg (16.3% or 12% for a lateral deformation). Intrusion seems to play an important role in the occurrence of severe injuries to the knee. 70% of the cars of the persons with knee injuries AIS 2+ suffered an intrusion at delta-v above 40km/h comparing to those without intrusion where nearly 2/3 delta-v values can be seen up to 40km/h. OF car occupants having severe knee injuries AIS 2+ only 54.7% did not suffer from accompanying injuries of the lower leg, foot, thigh and pelvis. 22.8% suffered from a fracture of the thigh, 13% of the pelvis, 18.8% of the lower leg, 9.6% of the foot and ankle and 0.9% of the hip. Patella fractures are accompanied in 27.1% of the cases by femur fractures und in 18.2% by fractures of the lower leg. The area of the foot is still relatively frequently injured at 11.7%. Ligament injuries frequently also involve injuries of the lower leg or foot. Collateral ligament lesions (medial as well as lateral) were linked with pelvis injuries (30%/50%). This characterizes the extreme torsion of the foot and lower leg resulting in tensile loads in the ligament structures of the knee. Thus severe knee injuries were correlated to intrusions of the passenger compartment in 32.7% of the cases. Patella fractures, fractures of the femur condylus and tendon ruptures could be observed starting at delta-v 20km/h. While restrained car drivers without any knee injury had a mean delta-v value of 29.4km/h and those with knee soft tissue lesions AIS 1 had 37.8km/h, all kinds of knee injuries AIS 2+ occurred with higher accident severity of mean delta-v of

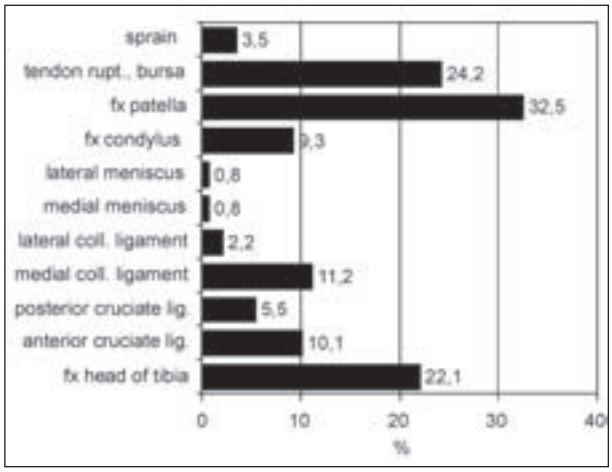

Figure 2: Knee injuries of restrained car drivers

46.1km/h (tibia plateau fracture) until mean delta-v of 60.3km/h for medial collateral ligament lesions. Remarkable seems the fact that ligament injuries of the cruciate and collateral structure of the knee higher load was responsible than for the bony fractures of the head of tibia, condylus and patella (Figure 2). A comparison of airbag and non airbag cases demonstrated a higher risk for knee injuries with airbag deployment. Especially for higher delta-v >30km/h a significant higher portion of AIS 1 knee injuries can be established by 25% for delta-v 31-40km/h and 142% for delta-v 41-50km/h.

Vulnerable road users

Highest frequency of knee joint injuries can be established for motorized two-wheelers, i.e. 42% of motorcyclists suffered knee injuries in accidents 1985-1993 compared to 36% in 1995-2003. The lowest frequency was in pedestrians, where 22% were injured at the knee in the course of accidents in 1995-2003. In case of a serious injury (AIS 2/3) for pedestrians, fractures of tibia head can often be observed (50.8%), for motorcyclists, tendon ruptures and ruptures of frontal cruciate ligament are very frequent (36.7%/20.9%).

If the investigation would be limited to bony and ligamentous injuries of the knee area, such injuries occur in less than 3%. They occur currently (1995 to 2003) at 1.2% of the pedestrians (formerly 2.6%), at 0.5% of the bicyclists (formerly 0.8%) and 1.6% of the motorized two-wheelers (formerly 1.9%).

70% of all measured impact velocities rated between 20 and 60km/h of the car, for pedestrians as well as bicyclists, whereas for patients without knee injury they rated 10 to 50km/h. For motorcyclists 70% of the determined relative velocities were found to be between 20 and 75km/h, these occurred for motorcyclists with knee injuries at 30 to 90km/h. Thus the impact speed is a dominant predictor for knee injury risk and is following in more injury severity of the whole human body. The resulting severity of the injuries of patients with knee injuries was significantly higher. Only 45.6% of the persons with knee injuries were assigned with a rate for minor injury MAIS 1 and 25.4% had a MAIS 3+ (without knee injuries 9.7%).

In case of a severe knee injury motorcyclists suffer more frequently than other road users ruptured tendons of the bursa (36.7%) and the anterior cruciate ligaments (20.9%), whereas pedestrians frequently suffer from tibia plateau fractures (50.8%) and medial ligamental lesions (20.7%). Injured bicyclists frequently show fractures of the patella (17%) and of the tibial plateau (27.2%). Injuries of the condylus, of the meniscus and the lateral ligaments were detected relatively rarely, especially for bicyclists.

Pedestrian impacts

A high risk for knee injuries arises obviously in the case of an impact of a car to the right side of a body because this situation leads to high loads to the knee elements (Figure 3). Where 32.6% of all pedestrians with no knee injuries had an impact from the right, 45% of all pedestrians who suffered from injuries to ligaments and bones of the knee were hit from the right. Such an overrepresentation was not apparent for the other sides of impact. It was differentiated if the struck sided knee was injured or the opposite one. For this analysis all laterally collided pedestrians and bicyclists with knee injuries were put together and found that sprains (86.2%), outer meniscus lesions (100%), fractures of condylus (73.7%) and of tibia head (74.8%) mostly linked with the struck side. In contrast, fractures of patella (34.4%) and medial meniscus lesions (48.6%) and tendon ruptures (40.5%) were often injured on non-struck side of the legs. It can be seen in the diagram that the highest frequent injury location for the non-struck sided knee can be registered for inner ligament lesions (31%) and for the struck side fractures of head of tibia can be seen in 40.4%.

Bicycle impacts

60.9% of all collisions between cars and bicycles resulting in an osseous/ligamentary knee injury

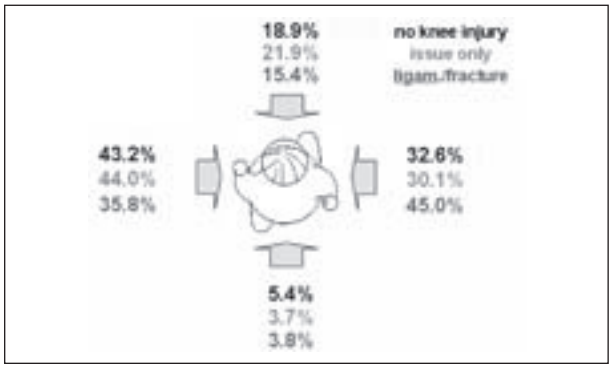

Figure 3: Impact directions of pedestrians comparing persons with and without knee injuries

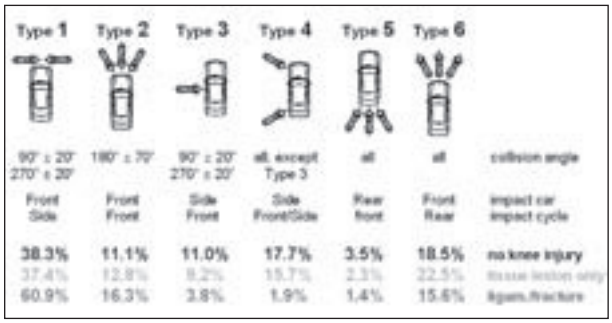

Figure 4: Collision configurations of bicycle to car impacts comparing victims with and without knee injuries

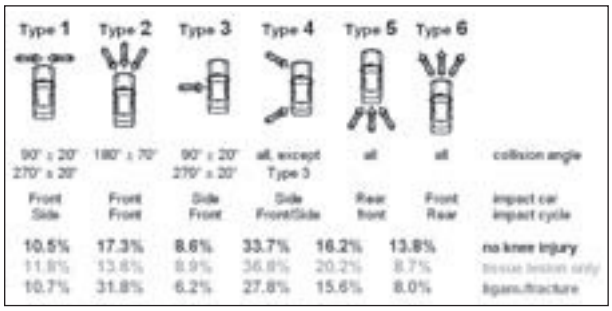

Figure 5: Collision configurations of motorcycle accidents compared victims with and without knee injuries

occur at near right angles, where the front end of the vehicle hits the side of the bicycle (Figure 4). In contrast, this type collision configuration occurs only at 38.7% of all bicyclist accidents without knee injury and in 37.4% of bicyclists with tissue lesions only.

Motorcycle impacts

For motorcyclists the angled to frontal impact of the motorcycle to the front of the car seems to be especially dangerous where osseous/ligamentous knee injuries (31.8% of all persons with knee injuries in comparison to 17.3% without knee injury) were observed (Figure 5). In contrast, the exactly perpendicular impact of a car front against the side of the motorcycle does not seem to increase the risk for knee injuries. This type of head on collisions constitutes 8.9% of all collision situations of the motorcycle driver against a car, this type of collision was also present for those 6.2% that suffered only bony of ligamentous injuries of the knee. It was apparent that for bicyclists and pedestrians the simple distortions and injuries of the outer meniscus and the outer ligaments occur at rather lower velocities, whereas motorcyclists suffer them at rather higher speeds. Injuries of the medial ligaments and tibia plateau fractures for the latter occur at lower impact speeds, however. Tendon ruptures and bursa injuries seem significantly related to higher velocities.

Mechanisms vulnerable road users

A direct impact force was responsible in 31.2%, in 9.6% bending and in 5% rotation can be seen as mechanisms (Figure 6). In 41.7% a combination of direct force plus bending could be established in

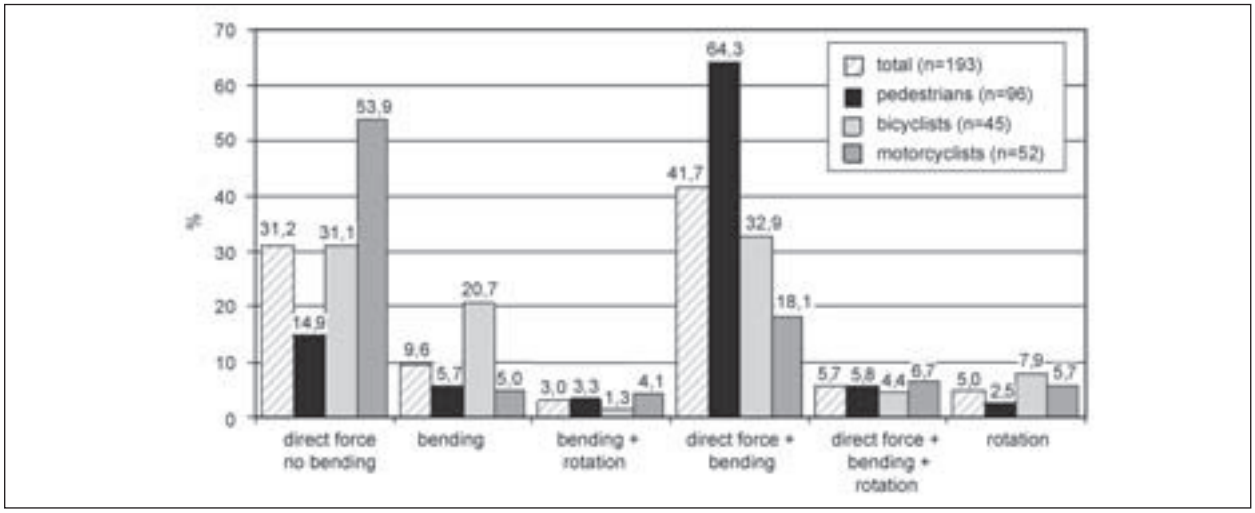

Figure 6: Mechanisms of knee injuries in vulnerable road users

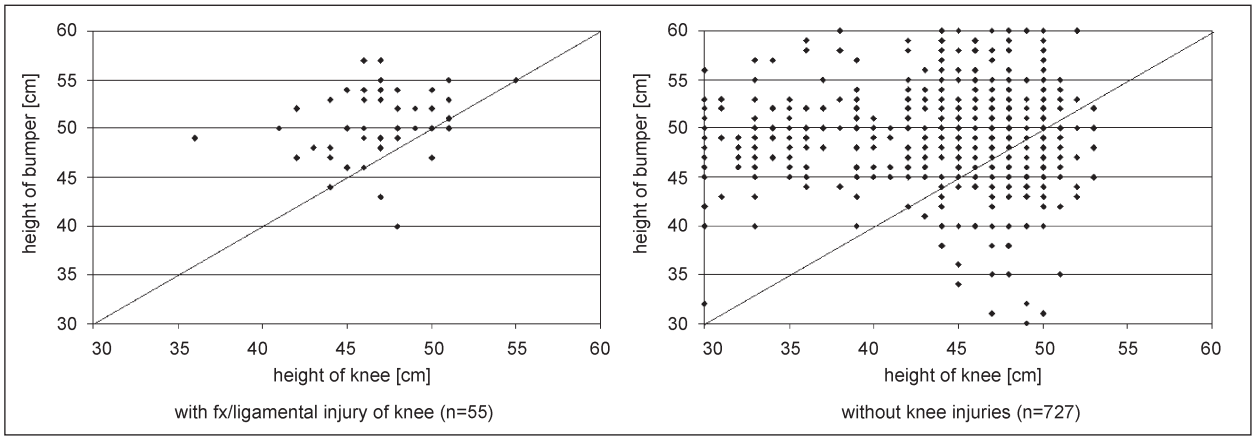

Figure 7: Bumper height and knee height for pedestrian accidents comparing persons with and without knee injuries

many cases. A difference in the collisions of the individual types of traffic participants was noted. Pedestrians frequently suffered at 64.3% from direct force and bending, whereas motorcyclists at 53.9% frequently suffered from direct force without bending. Knee injuries based on isolated rotation was in contrast detected relatively infrequently. In most of the cases rotation occurred together with bending.

It is remarkable that a lateral impact results very often in a tibia plateau fracture. This can be seen especially in car to pedestrian accidents but also in car to bicycle collisions and can be opposed to many studies, claiming that a valgus stress and an increase in force to the medial collateral ligament, which in turn then tears, occur. The analyzed mechanism for the tibia plateau fracture is related mainly to a lateral impact with bending of the ligaments. In the course of the accident, the medial collateral ligament seems to last and the increase in force seems to lead to pressure on the lateral compartment, i.e. the femur condylus is pressed on the tibial plateau while the medial collateral ligament resists, resulting in a tibia plateau fracture. Therefore 16.2% of the lateral collided cyclists with knee injuries suffered a tibia plateau fracture and 40.4% of the pedestrians suffered this kind of injury on the struck sided leg. This can be confirmed by the resulting severity of the tibia plateau fracture according to Schatzker 1 to 3 that represents two third of all kind of tibia plateau fractures.

The height of the bumper seems to have some sort of influence on the development of osseous and/or ligamentary knee injuries (Figure 7). If the bumper induces energy in the area of the knee or above it, knee injuries are extremely significant. Only few cases were found where a knee injury has occurred and the bumper was situated below the knee. 2% had serious ligamentous or bony injuries in relation to all injured. Improved aerodynamic design of car fronts reduced the risk for severe knee injuries significantly (p=0,0015).

The risk of injury is higher for two-wheelers than for pedestrians, but knee injury severity is higher for the latter group. Overall the current knee injury risk is low and significant reduced comparing both time periods (27%, p<0,0001). Severe injuries (AIS_{Knee} 2/3) were below 1%). Highest risk of injury is for motorcycles followed by pedestrians, respectively. The classically described dashboard injury was rarely identified.

Conclusion

The overall injury risk for knee injuries in road traffic is lower than estimated and reduced comparing both periods.

Most of the authors reported on risk of knee injuries for unrestrained situations. Lower limb injuries occurred to front seat occupants in more than one in three head-on crashes involving casualties. A classically mechanism described by SANDERS [24] is known as the “dashboard injury”. Axial load after contact with the instrument panel results in complex knee-femur-hip injuries. Those are patella fractures, posterior cruciate ligament ruptures, femur fractures and acetabulum fractures. It is an indicator for the degree of severity of the patients injury [19]. However although our investigation was reversed from knee injuries to correlating injuries of the femu-hip-pelvis complex we were unable to identify this injury often.

DISCHINGER [13] noticed in a US study for accidents occurring in the years 1991 to 1994 that

men suffered more frequently from factures of the pelvis and women from factures of the lower extremities. Patella fractures occurred in 2% of the drivers protected by a seat-belt, more frequently with airbags than without. People suffering from knee injuries cause the second highest costs for medical treatment today. For the emergence of knee injuries the impact situation of the vehicle plays an important role. Still, car occupants do not number among the especially risk exposed traffic participants with knee injuries. These occur especially frequently among the so-called "vulnerable road users". According to our investigation about 36% of the motorcyclists, 25% of the bicyclists and 22% of the pedestrians suffer knee injuries of the degree of severity AIS 1+, if they are victims of a traffic accident, whereas only 10% of the car occupants are thus concerned. The introduction of the safety belt, a continuously optimized safety features equipment in cars, with padding and 'defusing' of the dash board resulted in this significant reduction of the risk of knee injuries in a car.

A study carried out by TERESINSKI [25] found in a post mortem investigation at the Department of Forensic Medicine in Dublin, knee joint injuries in 214 out of 357 fatal pedestrian victims of traffic accidents (60%). He pointed out that knee injuries are frequently observed in pedestrian victims of traffic accidents and in his description of mechanisms he showed that the cross-section of tibial and femoral epiphyses bone bruises due to compression and avulsion and the bone bruises in the central tibial and femoral condyles were observed only in victims hit in an upright position. There should be a strong correlation between the side of impact on the extremities in medium sized pedestrians (from the front, back, lateral and medial side) caused by passenger cars and the mechanism of knee injuries (hyperextension, anterior dislocation of the proximal tibial epiphysis in relation to the femoral condyles, valgus and varus flexion). In the cases of very low impacts (e.g. in very tall victims hit by rapidly breaking wedge-shaped cars) or very high impact (e.g. in very short victims hit by trucks) the "reversed" complexes of injuries were found (lever principle).

The high percentage of lower extremity injuries as seen in collisions with cars demands further analysis of this type of crash scenario. The forces induced by the bumpers result in a high bending moment at the level of the knee and the proximal tibia. An alteration in design of automobile bumpers with increased padding for example or with exterior airbags may reduce the frequency and/or severity of these injuries. This allows the assumption that an optimized height design of the bumper and an optimization of the front end of the car can lead to a reduced risk of injury where a knee impact trauma is concerned.

The study showed that the motorcyclists are under risk for knee injury if a frontal direct impact to the knee occurs and based on the resulting relative motion of the human body on the bike a load is transmitted frontally to the patella following in patella fractures. Based on the following movement of the human off the bike a bending rotation mechanism is possible transmitting stress load to the ligaments on one hand. It is also possible that the tibia is forced posterior relative to the femur. The posterior cruciate ligament is usually tight when the knee is in 90 degree flexion and is therefore at high risk for disruption. The conclusions found in the course of this study can be used to improve the current computer simulation of motions and load behavior. They can also supplement the current component tests for the protection of pedestrians concerning kinematics resulting in knee injuries and finally they can also be used to include the requirements for the bicycle impact into such test regulations

However, the influence of air bags on lower extremity injuries, and in particular injuries to the knee, has not been examined effectively in previous field studies since they lacked sufficient number of air bag equipped vehicles in their real world crash dataset. Not only the knee bag or use of restraint devices in the car must be mentioned furthermore there is a need for developing technical features to protect the vulnerable road user.

Pedestrians' injuries gained attention in road crossing, whereas a large proportion of passengers who were injured inside the car passengers exists. The latter were injured while improperly seated without seat-belt protection. An estimated higher risk of knee injuries was confirmed while using motorcycles and bicycles. This study aimed at achieving an increased understanding and knowledge about the accident pattern in the traffic environment in Hannover.

This study let to some new facts about road traffic-related knee injuries. There is definitely a need to continue our observations in an in-depth study

regarding the mechanisms of accidents leading to these injuries. Strategies have to be developed to provide effective prevention. Medical and economical consequences of knee injuries in road traffic show that there is a need to enhance active and passive safety devices in road vehicles.

It can be stated that only 1.2% of the pedestrians involved in road traffic accidents, 0.5% of the bicyclists and 1.6% of motorized two-wheeler drivers were injured at the knee in the course of a collision with a car. This incidence can be called a low risk. It was also found that the risk for knee injuries was significantly lower than 10 or 20 years ago. Knee injuries are not necessarily but in general significantly related to a high impact velocity of the car, they have been observed for speeds lower than 10km/h on the one hand, but 50% occurred at speeds above 35km/h for pedestrians and above 25km/h already for accidents involving bicycles, for motorcycle accidents 50% of the relative speeds exceeded 50km/h.

Advancement in vehicular designs, with specific attention to air-bags, dashboards, and firewalls, needs to be made to reduce the incidence and magnitude of lower extremity trauma in motor vehicle accidents. Seat-belts remain the most effective restraint in the prevention of lower extremity trauma in the motor vehicle.

The study also reveals how important scientific in-depth investigations are und that the depth of information also supplies details of comprehensive injury documentation. A limitation to this study is that the population risk, taking into account time spent in each injury relevant activity is not available. This is shared by most real-world injury investigations.

The aerodynamic shape of current cars compared to older types reduced the incidence and severity of knee injuries. Further modification and optimization of the interior and exterior design could be a proper measurement. Classic described injury mechanisms were rarely identified. It seems that the AIS is still underestimating extremity injuries and their long term results.

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