Biomechanics of Impacts to the Legs of Motorcyclists and Constructional Demands for Leg Protectors on the Motorcycle

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Abstract

This study was carried out for analysing the injury situation of legs in motorcycle accidents and to find possibilities for an optimized leg protection with constructional equipments on the machine.

Concerning this, each injury was analyzed with type of injury, localisation and severity AIS and correlated to the impact situation with impact direction, impulse angle, load and characteristics of kinematic behaviour. 258 motorcyclists collided to cars and injured on legs could be analyzed in detail.

In the study accidents with and without a fairing on the cycle used in todays praxis for aerodynamical aspects are analyzed. A benefit of leg protection could be established with fairings but a higher risk for head and thorax injuries would be expected.

The biomechanical mechanisms were analyzed in relation to impact angles and loads. The relative speed between cycle and car are responsible for the injury occurance. In the study the correlation of injury severity and relative impulse were pointed out. Especially foot injuries are frequent and these have an high importance for economical costs. The study describes these costs on the base of ICS.

In the study demands for efficient devices are discussed and accident situations described in which a special leg protector on the cycle could have the best benefit and how it looks like.

1. Introduction

As the statistic shows, the driving of motorcycles is getting much safer today. While only 10 years ago, 72000 motorcyclists were injured every year in road traffic in the German Federal Republic, there were only 36000 injured in 1992 (StBA - 1). This means a reduction of 50%, while the number of motorcycles continuously increased during this period. In comparison, all groups of traffic participants show an increase in the number of injured, with the exception of the pedestrians. Devices, such as crash helmets and protective clothes, inclusive the newly developed special protectors inside the clothes, without a doubt contribute towards this improvement in the injury situation. Only 10 years ago, the number of crash helmet wearers amounted to only 70% (Otte - 2), but was raised now to 99% (Meyer - 3). Protection clothes are still not generally used. 70 to 80% of motorcyclists only wear protective clothing which do necessarily cover the whole body. 60% of those use protective gloves and 53% boots.

Accident analyses show that the crash helmet is responsible for a considerable reduction of head injuries. Approximately 70% of motorcyclists without helmets received head injuries. Of those with helmets these were only 40% (Otte et al - 4). Latest investigations established only 20% with head injuries. There is, however, no reduction apparent for the leg region. Today as well as in the past, more than 70% of the motorcyclists received injuries mostly of injury severity degree AIS 2/3 and these are fractures. In these cases, protection combinations do not provide sufficient safety, especially when they do not have a plate inserted their protective devices (Otte - 5). Due to the extremely high local energy effect, the lower extremities often receive fractures with severe muscle distruction and primary vessel-/nerve lesions, with consequent considerable soft-tissue injuries. This may lead to a so-called compartment syndrom or bone-/soft-tissue suppurations and, consequently to the loss of extremities (Kalbe et al - 6). Injuries to the tibia can cause considerable therapeutic problems, due to the thin soft-part coating of the bone and critical proceed of the blood supply.

Efforts for better protection of the motorcyclists' legs also include technical modifications on the cycle, the so-called leg protectors. Sakamoto (7) describes in his paper 'Research History of Motorcycle Leg Protection' that the first developments were already achieved by Bothwell in the late 60's and early 70's, with accessory bars fixed in the region of the engine. This should prevent the trapping of legs between the motorcycle and the opposing vehicle. The bar construction used was improved by Bothwell during the following years, i.e. it was pulled further around the side. In 1979, Bothwell developed the so-called 'leg shield affairing devices', semi-circular shaped shield constructions, fairing the tibia in front and side. Investigations by Chinn with a 'hard leg protector' fixed in front of the knees, did show in dummy tests that these are absolutely sufficient to reduce the force to the leg region. No unfavourable influence of the total body movement was observed either. Bothwell, on the other hand stated that the knee impact caused a higher rotation and that the head would not fly upward over the collision partner, but was at a greater risk for an impact with the opposing vehicle. Basing on this cognition, further tests were made by Bartol and Chinn, with so-called force-absorbing leg protectors. In 1978, the United Kingdom suggested a National Draft Specification (UKDS for Motorcycle Leg Protectors) (TRL - 8) to which leg protection can be designed to achieve this objective, this contained: external and internal knee force absorbing regions, a structure supporting these two regions and affairing enclosure realized by a primary impact element, riged support element, knee element, knee protector element, leg lateral retention, smooth outer contour. The industry has conducted its own research programs during this period (Rogers - 9).

Several UKDS leg protector designs were evaluated in full scale crash tests by TRL and by the motorcycle industry, with generally opposite results.

In crash tests, it was established that by protection of the legs, the injury risk for head and upper body clearly increases (Rogers), and that by impact inside the leg protector, an increase in leg fractures can also be observed (Chinn - 10). An International Leg Protector Seminar in 1991 Paris led to the conclusion that an international accepted crash dummy and research test methodology were necesseray before further measurements on the two-wheelers could be pursured. Sporner (11) on the other hand recommended the use of knee protectors or knee pads, intended to raise the head above the opposing vehicle roof structure. It is considered that these objectives seem to be in conflict.

The general conclusion out of many discussions seem to have been that often there were benefits for the legs, but sometimes there were disadvantages for the head and chest.

It is the objective of the study to analyse documented accidents, collected in detail by the Accident Research Unit Hannover, for the purpose to evaluate a possible advantage of leg protectors. Demands on the future construction of leg protectors can be made through analyses of accidents, i.e. under which collision conditions, collision angle, collision constellations, the legs are most frequently and most severely traumatised. This appears to be possible, on the one hand by comparing analyses of motorcycles with and without protective fairing, on the other hand, by critical evaluation of incuring injuries in the leg region and their biomechanics in motorcycle accidents.

2. Data base

2.1 Description

A total of 496 accidents of motorcyclists were documented, during the years from 1985 to 1992, by a team of scientists, including technicians and medical staffs (Otte - 12). The evaluation was made by a statistical weighting procedure and a random sampling plan, basing on a comparison of data established by the team, with those of the National Statistic of all accidents inside the investigation region. With this method, the result can be regarded as representative.

The evaluation of the injuries is made in accordance with the AIS scaling system (American Association for Automotive Medicine - 13). The collision situation is established by a detailed accident reconstruction, on the basis of photogrammetric true-to-scale accident drawings, as well as a mathematical reconstruction procedure of the impact-mechanic analysis. 258 motorcyclists suffered injuries of the legs. These will be analysed in detail within the framework of this study.

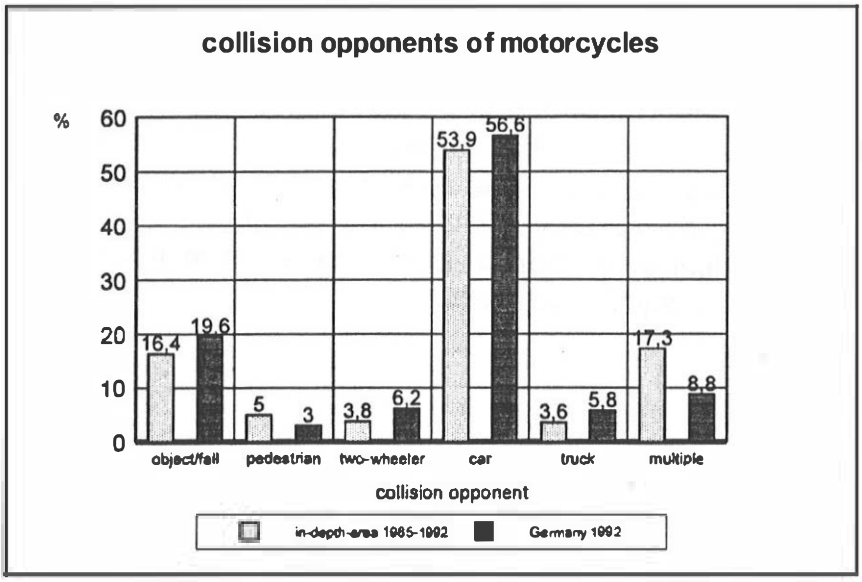
2.2 Evaluation concepts

Some of the todays motorcycles are already supplied with a protective fairing against aero-dynamic influences. These special devices are called „fairings". In the accident situation this construction can already lead to an injury reduction. Within the framework of this study, it will be differentiated between accidents with motorcycles, with and without leg fairings.

Basically, the similar contrahental distribution of the 136 with leg fairing equipped motorcycles and the 360 without fairing is shown. More than 50% of the motorcycles are involved in collisions with cars.

Of these, approximately one fifth each were solo accidents or impacts with more than one solid collision objects respectively. A good correlation between the investigation collective and the distribution of accidents in the German Federal Republic became evident here (fig. 1).

Fig. 1 Distribution of collision opponents of 496 motorcycle accidents - correlation between research area and situation in the whole country of Federal Republic of Germany



In order to establish the possible protective effect of leg protectors, in a second stage of the analysis leg injuries were described differentiated by type, severity and localisation. Injury mechanisms were analysed. Exclusively collisions of motorcycles with a car or solo accidents by falls, or collisions with solid objects respectively are included in the analysis. Collisions with trucks, however were not included, in view of the fact that various types of impact and injury mechanisms would have to be considered, which would make the evaluation of the protective effect of leg protectors difficult. In this second phase of the study exclusively cases without motorcycle protectors were observed.

3. Injury situation of the legs

The injury severity of the legs is improved by leg protection (tab. 1). 33.7% of the persons with leg fairings remained without injuries to the legs, but only 28.3% of those without fairings. This is apparent by the low proportion of 14.2% of fractures, compared with 23.0% of persons without fairings.

Tab. 1 Injury situation of legs (severity AIS, kinds and causes)

	total		leg fairings on motorcycle with		without	
total	496	100%	136	100%	360	100%
severity of leg injuries						
not injured legs	148	29.8%	46	33.7%	102	28.3%
AIS 1	265	53.3%	76	55.6%	189	52.5%
AIS 2	59	11.8%	9	6.6%	50	13.8%
AIS 3	22	4.5%	5	3.6%	18	4.9%
AIS 4	1	0.2%	0	0.2%	1	0.2%
kind of leg injuries						
soft tissue isolated	271	79.1%	74	85.8%	196	77.0%
fracture	78	20.9%	16	14.2%	62	23.0%
cause of leg injuries						
impact (car or object)	162	48.6%	47	51.9%	124	47.5%
fall	127	35.4%	31	34.7%	87	35.7%
combined fall and impact	59	16.0%	12	13.4%	47	16.8%

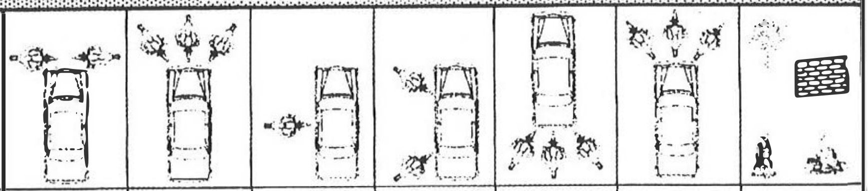
This trend of lower fracture risk with fairings is visible in all collisions with cars, or in solo accidents, but also for various collision types (tab. 2).

Based on classifications from earlier studies by Otte et al (14), the accident situation of the motorcyclist was illustrated with 7 collision types, depending on the angle position between motorcycle and car longitudenal axis.

Collision types 1 and 2 show the impact of a motorcycle with a car front. Collision types 3 and 4 show the impact with the side of a car, while collision type 5 shows the frontal collision of a cycle to the rear end of a car and type 6 shows the driving-up of a car on the motorcycle. Collision type 7 demonstrates the solo accident or the collision with other rigid objects respectively. The legs get most frequently injured in an impact with the car front (KT - type 1/2). Only 7.1% without fairings remained uninjured here. In the relatively dangerous collision to the side of a car in which normally the whole body especially the regions upwards are under exposal risk, 28.4% of the cyclists without fairings, remained without injuries to the legs. With fairings similar the same percentage 31,4% were injured. The injury severity too is especially high with type 1/2: 21.3% AIS 2 and 9.3% AIS 3. With leg fairings, however, as a rule fractures occured in less frequency, with mostly dominance in collision types 3/4 with 21,8% without fairings compared to 8,9% with fairings. This proves the drive-up accident of the motorcyclist not to be of such serious consequence for the legs. The injury severity is here often of a lighter type. With leg fairings more than 80% of the injuries are as a rule of severity degree AIS 1.

The analysis of the injured body regions head and thorax shows a basically high injury risk in solo and object accidents (collision type 7), which is relatively independent of the presence of fairings (tab. 3). 18.1% of the motorcyclists without protective elements on the motorcycle suffered head injuries, 22.8% injuries to the thorax. 19.3% of the motorcyclists with fairings suffered head injuries, and 25.9% injuries of the thorax.

Tab. 2 Injury situation of legs (severity, kinds and causes) for different collision types

	collision-types of two-wheelers						
							
	1	2	3	4	5	6	7
impact point on collision partner (clockwise)	11 12 01		08 09 10	02 03 04	05 06 07	11 12 01	
classification of collision-angles (degree)	90 ±20 270	180 ±69	90 ±20 270	180 ±69 0	0 ±69	0 ±69	

	collision type			
	type 1/2	type 3/4	type 5/6	type 7
total	17	33	20	19
severity of leg injuries				
injured	63.9%	68.6%	88.4%	56.5%
AIS 1	80.8%	88.9%	97.3%	65.5%
AIS 2	8.0%	7.3%	-	26.0%
AIS 3	11.3%	3.8%	2.7%	8.4%
AIS 4	-	-	-	-
kind of leg injuries				
soft part only	80.8%	91.1%	89.2%	73.9%
fracture	19.2%	8.9%	10.8%	26.1%
cause of leg injuries				
impact (car or object)	46.4%	58.7%	63.0%	24.5%
fall	37.9%	27.9%	26.3%	59.7%
both fall and impact	15.7%	13.3%	10.8%	15.8%
existing leg fairings				

	collision type			
	type 1/2	type 3/4	type 5/6	type 7
total	45	88	54	62
severity of leg injuries				
injured	92.9%	71.6%	84.7%	64.9%
AIS 1	69.4%	78.4%	78.6%	67.9%
AIS 2	21.3%	14.1%	20.6%	25.1%
AIS 3	9.3%	7.4%	0.8%	7.0%
AIS 4	-	-	-	-
kind of leg injuries				
soft part only	71.1%	78.2%	82.0%	75.4%
fracture	28.9%	21.8%	18.0%	24.6%
cause of leg injuries				
impact (car or object)	46.5%	64.6%	48.7%	20.4%
fall	30.2%	16.6%	40.4%	65.8%
both fall and impact	23.3%	18.8%	10.9%	13.8%
without leg fairings				

Tab. 3 Injury situation of head and thorax (severity, kinds and causes) for different collision types

		collision type			
	total	type 1/2	type 3/4	type 5/6	type 7
total	89	17	33	20	19
severity head injuries					
injured	19.3%	21.5%	17.0%	13.7%	27.3%
AIS 1	11.1%	8.7%	9.2%	13.7%	13.9%
AIS 2	5.8%	9.4%	3.0%	-	13.4%
AIS 3	0.4%	2.3%	-	-	-
AIS 4	1.8%	-	4.7%	-	-
AIS 5	-	-	-	-	-
AIS 6	0.2%	1.2%	-	-	-
severity thorax injuries					
injured	25.9%	34.0%	25.1%	11.3%	35.4%
AIS 1	15.1%	18.7%	19.4%	7.0%	13.1%
AIS 2	8.4%	15.3%	4.6%	-	17.8%
AIS 3	1.9%	-	1.1%	2.1%	4.5%
AIS 4	0.5%	-	-	2.2%	-
AIS 5	-	-	-	-	-
AIS 6	-	-	-	-	-
existing leg fairings					

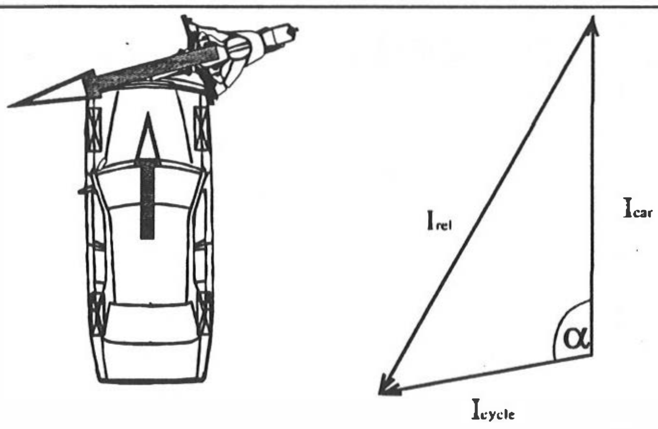
		collision type			
	total	type 1/2	type 3/4	type 5/6	type 7
total	249	45	88	54	62
severity head injuries					
injured	18.1%	15.0%	14.8%	16.2%	26.6%
AIS 1	11.2%	7.8%	9.7%	12.3%	14.8%
AIS 2	5.7%	6.4%	5.1%	3.3%	8.0%
AIS 3	0.3%	-	-	0.6%	0.6%
AIS 4	0.5%	0.8%	-	-	1.4%
AIS 5	-	-	-	-	-
AIS 6	0.4%	-	-	-	1.8%
severity thorax injuries					
injured	22.8%	12.4%	24.8%	17.4%	32.4%
AIS 1	16.0%	6.6%	18.5%	15.9%	19.3%
AIS 2	4.7%	3.8%	4.0%	1.5%	9.1%
AIS 3	1.2%	1.2%	1.6%	-	1.9%
AIS 4	0.5%	-	0.7%	-	0.8%
AIS 5	0.2%	0.8%	-	-	-
AIS 6	0.3%	-	-	-	1.3%
without leg fairings					

This can be pointed out for all different kinds of collision types. Head and thorax injuries can be seen for motorcyclists with leg protection. Especially in collision types 1/2 34% of drivers with leg fairings suffered injuries to the thorax, with fairings, these were only 23.4%. For the thorax as well as for the head, a change in the moving kinematic is observed with leg protectors.

4. Load level

For the comparison test of both investigated collectives, with and without fairings on the cycle, it is important to know whether the load caused by collision energy is approximately similar for both collectives. It is difficult to define from accident analyses the real force to the leg region. The collision speed of the motorcycle is partly decisive for the resulting energy in the collision phase. The injury to the leg depends on the collision angle of both colliding vehicles and also on the speed of the collision partners. These considerations often lead in the motorcycle analyses to the assumption of relative speed. By the vectorial addition of the speed a vector results from both speed proportions which not necessarily correspond in direction and size with the effective load to the motorcyclist. From the impact-mechanical point of view, it seems to be better to exclusively compare the resulting impulse from the impulse analyses. This is, however, very difficult to construct, in view of the not exactly defined running-out phase from the numerous motorcycle analyses. Therefore, for this study we chose a starting point for an impulse contemplation and evaluate a so-called relative impulse from the vectorial addition of both impulses (mass x speed) of motorcycle and collision partner (fig. 2).

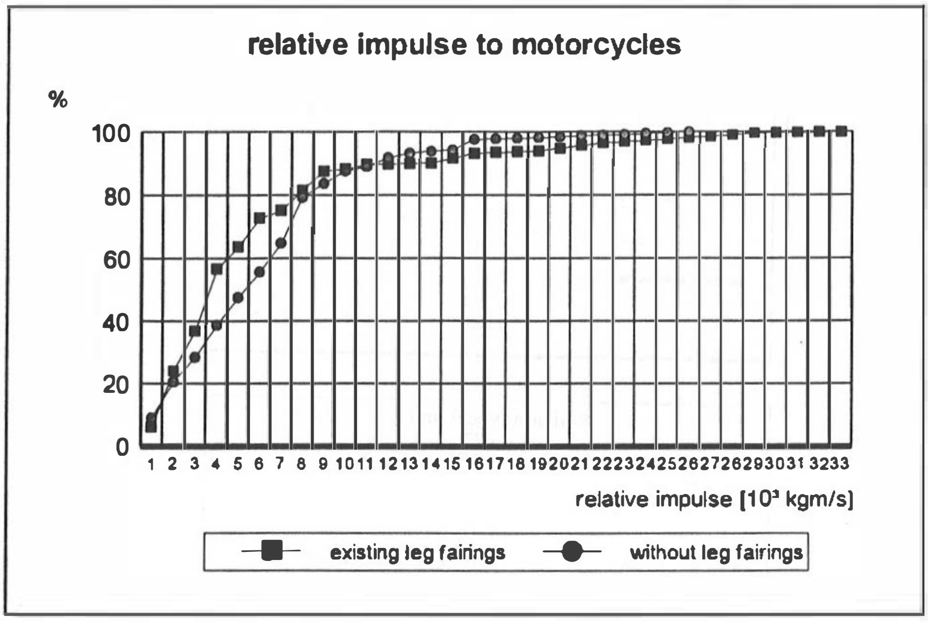
Fig. 2 Definition of relative impulse



$$I_{rel} = \sqrt[2]{I_{car}^2 + I_{cycle}^2 - 2 * I_{car} * I_{cycle} * \cos\alpha}$$

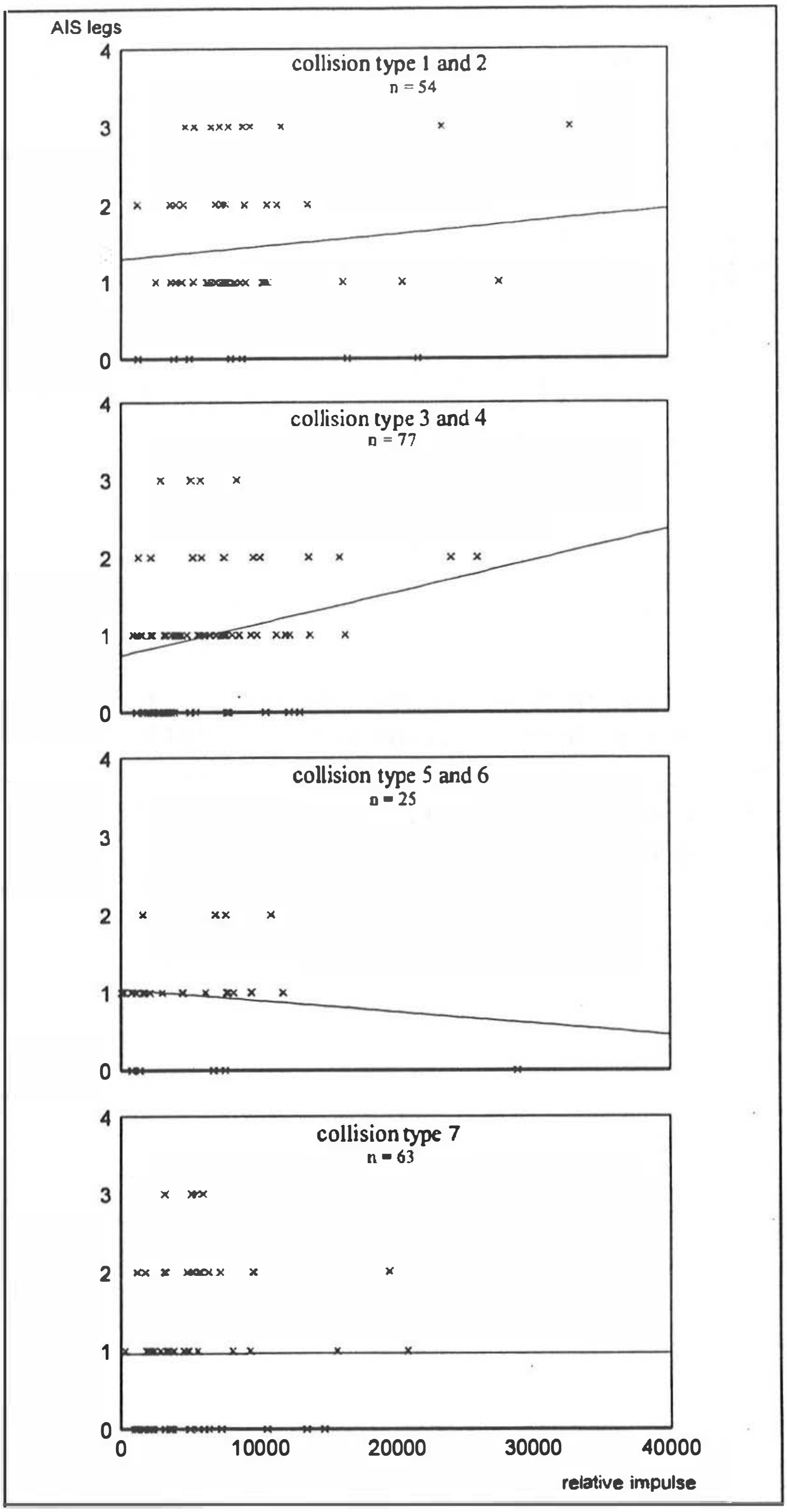
The collectives, with and without fairings, show a basically approximate course of the accumulated frequences (fig. 3). 80% of all motorcyclists collided in relative impulses of up to 8,000 kgm/s. With a motorcycle weight of 300 kilos, this correspondends with an impact speed of 96 km/h.

Fig. 3 Cumulative frequencies of relative impulse to motorcycles with and without leg fairings



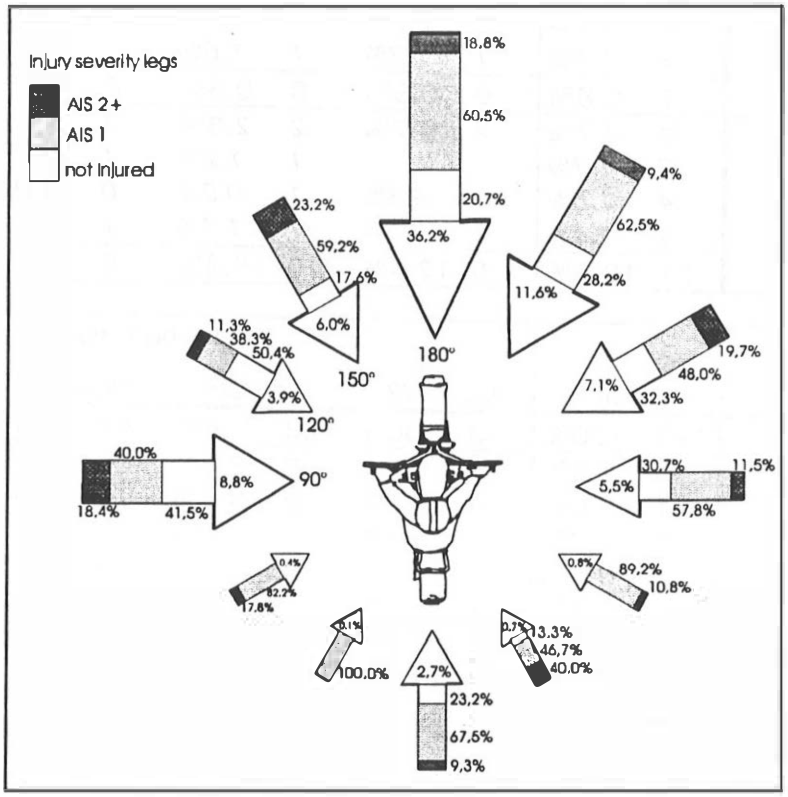
Energy seems to be less relevant for the occurance of leg injuries. In collision types 1 and 2, however, an increase of the severity degree AIS is definable with higher relative impulses (fig. 4). Injuries of severity degree AIS 3 can here only be established above 5000 kgm/s, while for other collision types with very low relative impulses higher severity degrees could already be registered. The constellation between motorcycle and car seems to have a much greater influence on the relative movement possibilities of the two-wheel driver, while the leg region is injured only by direct contact or compression forces respectively.

Fig. 4 Injury severity AIS of legs with and without leg fairings and relative impulse [kgm/s] for different collision types (curve inside: linear regression analysis)



The motorcycle is hitting most frequently from frontal directions ± 15° to the longitudinal axis (36.2%). Transverse frontal directions are also very frequent (fig. 5). It is not visible though that a respective impact direction is especially injury intensive, it seems to be most of the frontal oblique situations.

Fig. 5 Impact directions to motorcycles and injury severity for leg injuries in accidents with cars (30 degree classes ± 15)



5. Injury mechanisms

The lower leg is with 4.7% only one main region for fractures, but the feet are with 10.5% especially frequently injured, the thigh also, with 2.8% and the knee with 0.6% show a remarkable proportion of injuries to the involved motorcyclist. The exact localisation and the involved bony parts are illustrated in frequency and differentiated by collision types in tab. 4. On the foot region, the ankle joint, the mid foot region and the toes are especially involved. In collisions of motorcycles with the side of the car, the foot especially the toes are exposed to injury. The ankle joint region is more frequently injured in collisions with the car front.

Tab. 4 Portion of fractures of motorcyclists with and without leg fairings in collision with cars or obstacles

localisation of fractures	total		collision type type 1/2		type 3/4		type 5/6		type 7	
total	199	100%	43	100%	63	100%	47	100%	39	100%
upper leg	6	2.8%	1	3.5%	2	3.9%	-	-	2	4.1%
proximal	-	-	-	-	-	-	-	-	-	-
medial	*3*	*1.7%*	*1*	*2.2%*	*1*	*2.3%*	-	-	*1*	*2.4%*
distal	*2*	*1.1%*	*1*	*1.2%*	*1*	*1.6%*	-	-	*1*	*1.7%*
knee	1	0.6%	0	0.9%	0	0.5%	0	1.0%	-	-
lower leg	9	4.7%	2	5.7%	2	2.6%	3	6.2%	2	6.1%
proximal	*3*	*1.7%*	-	-	*1*	*1.2%*	*1*	*2.7%*	*1*	*3.8%*
medial	*4*	*1.8%*	*2*	*4.3%*	*1*	*0.9%*	*0*	*1.0%*	*1*	*1.5%*
distal	*4*	*1.8%*	*1*	*2.5%*	*1*	*1.4%*	*1*	*3.0%*	*0*	*0.7%*
foot	21	10.5%	5	12.5%	10	15.2%	2	5.1%	4	9.2%

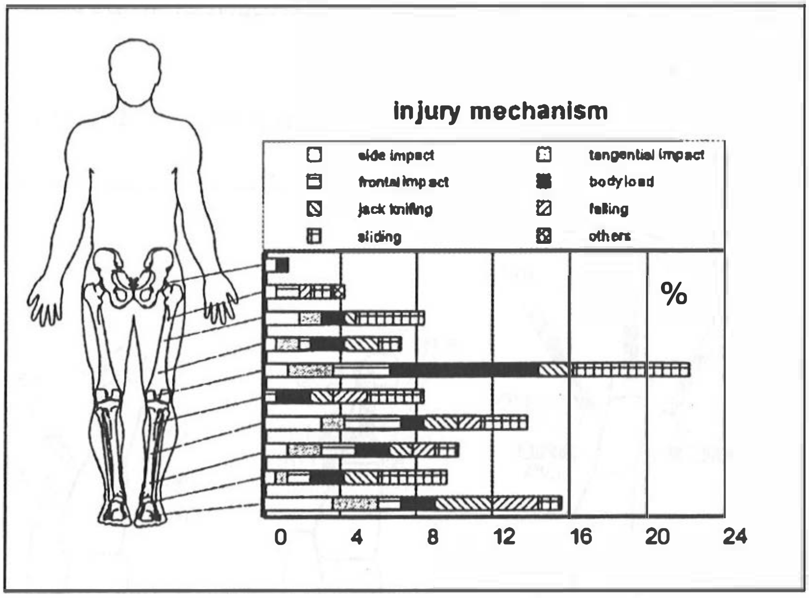
localisation of fractures	total		collision type type 1/2		type 3/4		type 5/6		type 7	
total	199	100%	43	100%	63	100%	47	100%	39	100%
upper leg	6	2.8%	1	3.5%	2	3.9%	-	-	2	4.1%
knee	1	0.6%	0	0.9%	0	0.5%	0	1.0%	-	-
lower leg	9	4.7%	2	5.7%	2	2.6%	3	6.2%	2	6.1%
fibula	1	0.7%	-	-	0	0.7%	0	0.8%	1	1.5%
tibia	4	2.1%	1	1.5%	-	-	2	4.4%	1	3.7%
fibula and tibia	3	1.6%	1	1.9%	1	1.9%	1	1.8%	0	0.9%
foot	21	10.5%	5	12.5%	10	15.2%	2	5.1%	4	9.2%
anklebone	4	1.9%	2	3.7%	1	0.9%	1	1.2%	1	2.9%
ankle joint	4	2.2%	1	1.5%	1	1.7%	0	1.0%	2	5.6%
calcaneus	2	0.9%	-	-	2	2.8%	-	-	-	-
tarsus	3	1.3%	2	3.9%	-	-	-	-	1	2.4%
metatarsale	6	3.1%	2	3.5%	3	4.5%	1	2.8%	0	1.2%
toes	4	1.9%	-	-	3	5.3%	-	-	0	1.2%

The injury mechanisms were evaluated from single-case analyses. The following 7 mechanisms were established, based on the impact to the leg as far as the leg movement is concerned. These are:

- lateral impact
- tangential impact
- frontal impact
- body sliding
- wrapping round
- falling
- running-out

The frequency of mechanisms with assignment to the respective injured body regions is shown in Fig. 6.

Fig. 6 Frequency, localisation and mechanism of leg injuries (100% all injury mechanisms)

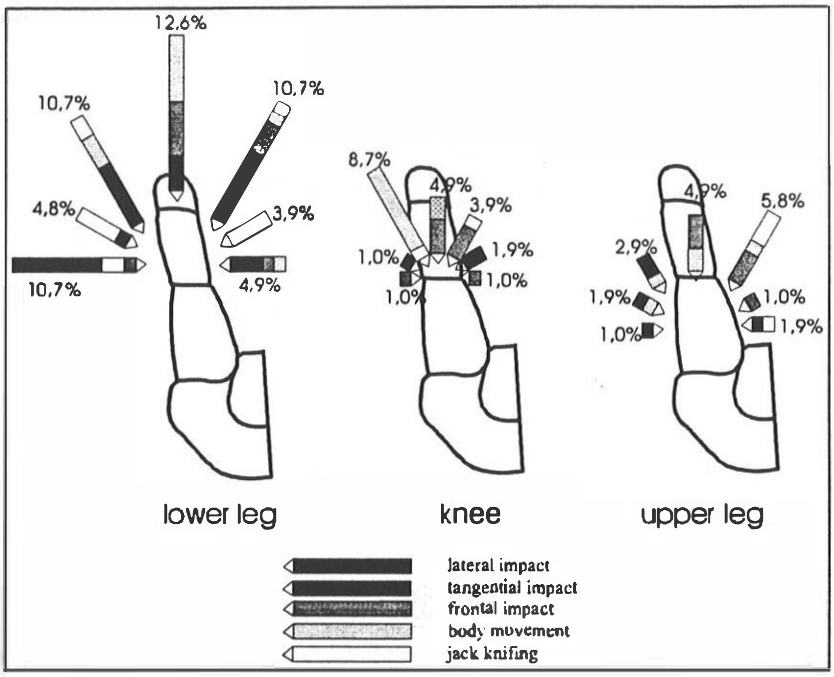


Body sliding can be regarded as an important injury mechanism (19%), in which the motorcyclist, after a frontal impact of the motorcycle is moved further forward and upward by mass inertia. In this process he is injured by the impact with his own motorcycle or a partner by the primary movement of his body. In a transverse angle or an excentric collision respectively, often a wrapping round of the motorcycle occurs (14%). In this process, the motorcycle, after a nearly frontal impact with the collision partner, rotates around its longitudinal axis or the primarly impacting front-wheel respectively. Consequently the motorcyclist's leg is trapped between motorcycle and collision partner. At a very oblique impact angle (collision types 1 and 4), the lateral impact of the leg dominates, in which the car front hits the motorcyclist directly against the tibia. This is injured by trapping or direct impact respectively (12%). A collision of the motorcycle in almost parallel direction of the longitudenal axis of the vehicle will lead to a so-called 'offset impact' of the motorcyclist, with the knees or the tibia to the front corner of the car (11%). This, as a rule is of special consequence, in view of the fact that the impact force is not reduced by the motorcycle, but exclusively transmitted to the motorcyclist. In consequence, an enormous load is taken into the knee, the thigh and the hip region. Due to the sitting position of the cyclist, the knee in its most frontal position of the lower extremeties is especially exposed by the sliding of the body relative to the cycle or the impact in an offset collision.

In accident situations, fall mechanisms may occur by which injuries are caused during the actual falling phase, by trapping of the motorcyclist between body and the road surface. Motorcycle and rider will only in second place impact the other vehicle. The most rare injury mechanism is the sliding of the motorcyclist and car along the body, which will only cause a tangent. This may occur with frontally approaching or vehicles driving in the same direction, with short-time impact effect.

These mechanisms can be analyses for different impact directions. The respective impulse direction can also be assigned to the frontal impact and the body sliding (fig. 7). Only on the right leg tangential impact mechanisms are apparent.

Fig. 7 Mechanism and impulse directions of impacts to different regions of the leg (100% all injury mechanisms)



It becomes apparent that the knee is much less frequently injured from the side than from the front. Injuries to the inner side of the legs were mainly caused by an impact on the own cycle. The thigh also shows mainly injuries by axial load, in a frontal impact of the motorcycle or by indirect impact of the rider with his motorcycle. Injuries by body sliding were established in increasing number on the right thigh, to the knee, however, more on the left side. This leads to the conclusion that the motorcyclist is often thrown tilted off his motorcycle. It is visible that in flight of the motorcyclist from his two-wheeler, the tibia is in most cases moved forward and is consequently injured. The rest of the body is lifted and the knees gain height, while the upper leg region is exposed to the force.

6. Recommendations for the shaping of leg protectors

Basing on a quantitative evaluation of the described accident situations, the following effectiveness for leg protectors on the cycle could be estimated:

engine bars: 20% of the injuries can be avoided or reduced
lateral impact protection: 44% effectivity
frontal impact protection: 68% effectivity

Only for 31% of the motorcyclists none of the described protectors would have achieved a considerable reduction of leg injuries. This fact clearly justifies the demand for constructural leg protectors on the motorcycle. In the study it was clearly established that by a protector or protection for the tibia respectively, an injury reduction for the leg region could be achieved, in frequency and severity. This is shown by the evaluation of present day fairing protectors fixed on motorcycles, even though only designed for aero-dynamic purposes, in comparison with accidents of motorcycles without any leg protection. For the head and thorax situation, however, an increase of injuries is established for motorcycles with leg fairings.

The fact that incuring leg injuries are predominantly soft-tissue lesions and the frequency of fractures in motorcycle accidents appears to be relatively low, could soon create the impression that leg protectors are unnecessary. This would, however, be a wrong conclusion, in view of the fact that traumatising of the legs is, as a rule, connected with considerable long-time effects. An investigation of persons with leg injuries established an average national economy expenditure of DM 33.202,-, basing on the new injury cost scale (ICS) by Zeidler et al (15), which includes single injuries established by the German Professional Trade Associations. Especially the collision type 1/2 is with DM 32.677,- and the isolated accident (collision type 7) with even DM 53.745,- remarkably expensive (tab. 5).

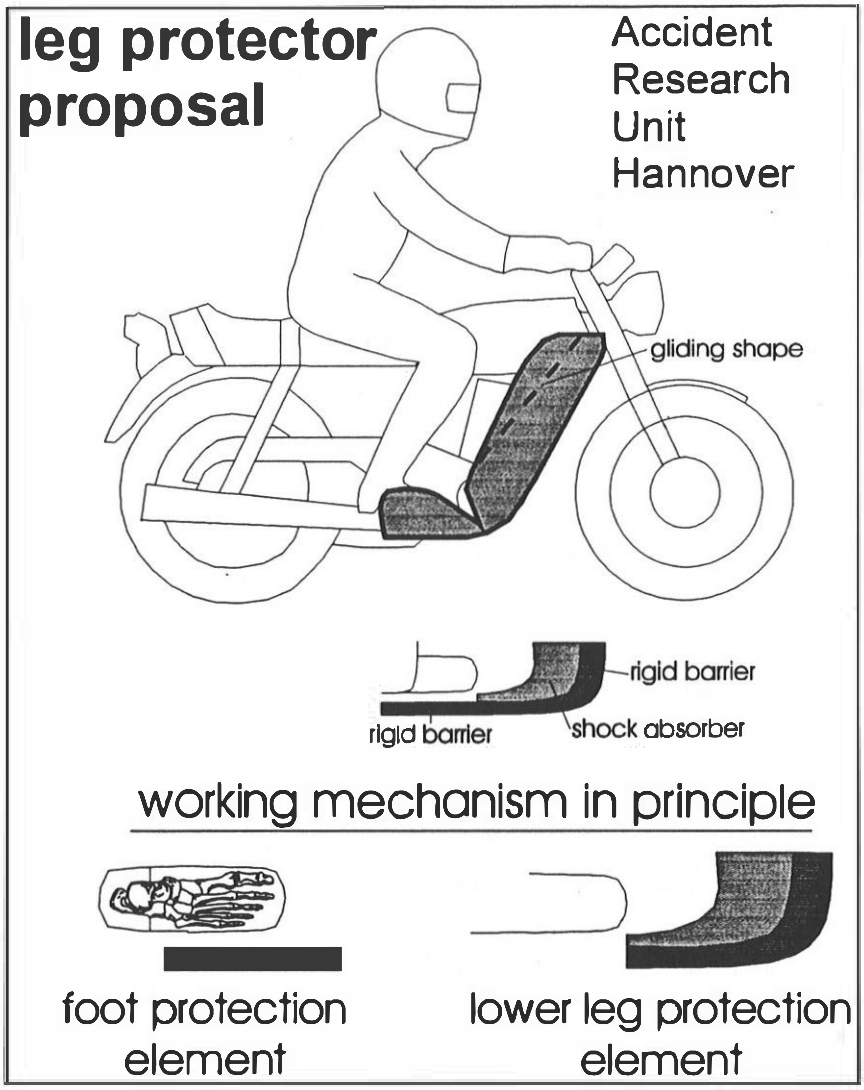
Tab. 5 Economy costs (ICS) of leg injuries of motorcyclists

	n	ICS isol. legs DM	ICS all body regions DM	ICS without leg injuries DM	reduction %
total	348	10665	33202	26186	21,1%
collision type					
type 1/2	63	16093	32677	22333	31,7%
type 3/4	121	8941	27584	23161	16,0%
type 5/6	75	9675	22372	14638	34,6%
type 7	81	11068	53745	45368	15,6%

With ICS the expenditures for each injury is registered by a computer. Therefore, a virtual base be evaluated for the patient collective of the Accident Research Unit, with the assumption that leg injures did not occur, but similar injuries in similar collision conditions. For leg injuries expenditures amounted to DM 10.665.--. The most expensive appears to be collision type 1/2 for which a reduction of 21.1% can be estimated, the highest reduction for collision type 1/2 (31.7%) and type 5/6 (34.6). Of these, foot fractures represent a very high proportion. In comparison with other injuries, foot fractures are connected with high injury consequences. According to investigations be the German professional trade associations (16) ankle and foot injuries require the longest stationary treatment (18%), have the highest rate of complications (19%) and require the most rehabilitation procedures(21%). A fracture of the calcaneus bone leads in most cases to a permanent defect, connected with a reduction of gainful employment capability (MdE= of 26.6%). In view of the fact that pension claims start already at 20%, foot fractures must from a traumatic point of view be regarded as a significant type of injury and thus justifies the demand for leg protectors for motorcyclists.

Certain constructional suggestions can be made for leg protectors (fig. 8). The foot has to be covered from the side and front. An absolute form firmness must be constructed for the elimination of compression effects. The tibia must be protected in the front by an energy absorbing element and the tibia must be gliding upwards during the relative movement of the collision phase. A lateral fairings of the tibia is not necessary if the transmitted impact occurs against the rigid part of the foot. As an additional demand to the direction of car manufactors as a rule, the bumper of the car must be positioned in this equal heights.

Fig. 8 Proposal for leg protection on cycles on the base of accident analyses



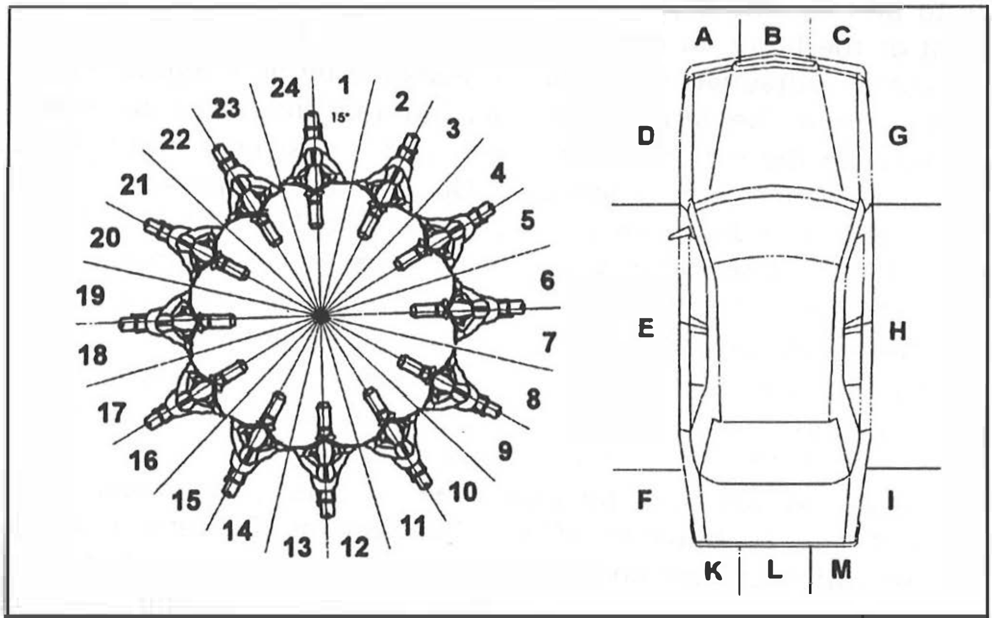
In accordance to the examined mechanisms the leg in the vertical view has not to be covered in the same extent. The lower leg must be covered for lateral and frontal protection, the knee and thigh only for frontal protection.
As the body of the motorcyclist is lifted off the motorcycle in a relatively upward movement, the tibia element should continue its vertical slope more oblique than the tibia body axis. The leg protector illustrated in fig. 8 seems to come up to the demands in the study. A removal of the motorcyclist from his motorcycle has to be made possible, and bending forces between foot and tibia must be eliminated by rigid frames, as the latter could lead to an injury increase for the ankle joint.

7. Recommendations for the testing of leg protectors

Basing on a detailed analysis of different types of collision constellations between car and cycle, the most important collision types for the risk of leg injuries were considered. For that the estimated collision angle with an range of 15 degrees and the point of impact to the car were taken into account. Out of a total number of 288 different possibilities the 10 most important collision types were evaluated in frequency for all motorcycle accidents and related to this for all motorcycle accidents with leg injuries of severity greater than AIS 1 (fig. 9).

For leg injuries the oblique impacts to the car front (A4) and to the car side (E14) are the dominant impacts, they have to be chosen for test procedures.

Fig. 9 288 possibilites of different collision types and the 10 most important types in frequencies



all cycles		severity leg AIS > 1	
collision type	%	collision type	%
L 12	16.3 %	E 14	7.6 %
K 12	12.6 %	A 4	6.9 %
D 14	10.4 %	K 12	5.2 %
G 1	8.6 %	A 3	4.6 %
E 14	7.5 %	B 3	4.4 %
C 20	6.6 %	B 21	4.0 %
D 13	5.8 %	A 2	3.5 %
C 6	5.8 %	C 20	3.5 %
B 2	5.6 %	G 1	3.2 %
A 3	5.2 %	B 2	2.7 %

8. Discussion

The study demonstrates the effectiveness of leg protectors. In view of the cognitions gained, it can be assumed that a protector in the leg region would result in a changed kinematic between motorcycle and rider. The study verifies the assumption that this may cause an increased risk for a head impact, connected with a higher injury risk for the thorax. The study, however, clearly shows that an injury reduction for the leg region is possible and expected. This is also verified by studies of Chinn and Sakamoto. With this study it could not following the results by Hurt (17) and Withaker (18) presented in accident investigations, that accessory engine guards did not affect leg injury occurence.

As the conclusion of this study it seems to be more a problem of design and collision constellation for the occurance of higher injury level with fairings.

The work of Schmeling et al (19), based on 63 full scale motorcycle/car impact tests, are shown the different effects of different designed add-on engine guards. The various side protection devices reported by Uto (20) gave some reduction in lower leg fractures.

From the study of the cognitions gained, the question remains whether an optimal designed protector must necessarily have this negative influence. It appears to be of prime importance to positively influence this stronger rotation movement of the body, or the downward directed flight motion respectively by further suitable protective elements, for instance by an integrated airbag on the handle bar. From the study, the question remains if all possible technical constructions for the leg protector design were considered, in order to keep the rotation movement at a minimum. Up-to-date analyses refer to already developed protectors by Bothwell, Bartol and Tadokoro, as well as the English prototypes UKDS. Connected with these are of course, constructive premises which would lead to forms of a special kinematic. An important aspect of this study is, however, the necessity of a stronger weighting of the foot region, which has not explicitly been considered in former studies concerning the developing of protectors. From an accident-analytic point of view, and in consideration of enormous long-time consequences, a protective element seems to be necessary, which could possible serve as a basis for a tibia leg protection, in order to create an optimum effect function for the further kinematic. The demands of different covering for different leg regions foot, tibia and knee opens the accordence to the comfort and motorcycle handling. The above study provided suggestions for this objective.

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