BIOMECHANICS AND CONSEQUENCES OF TYPICAL INJURIES TO SELECTED GROUPS OF ROAD USERS

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RESULTS AFTER 10 YEARS OF ACCIDENT RESEARCH AT HANNOVER

by

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Introduction

For more than 10 years traffic accident research is carried out by the Traumatology Department of the Hannover Medical School. In 1971 the in depth accident studies were started in cooperation with the Volkswagen company. From 1973 they were continued together with the Institute for Automotive Engineering of the Technical University Berlin and supported by the Bundesanstalt für Straßenwesen, Cologne. Data collection of traffic accidents with personal injuries was performed by an interdisciplinary team of traumatology surgeons, automotive engineers and traffic psychologists. More than 2000 accidents were evaluated in various studies.

This report shows some of the important results of our work and demonstrates the advantage of in depth accident studies in comparison with other methods of accident research.

Material and methods

The data acquisition team of the Hannover Accident Research is alerted by the central dispatch center of the fire brigade. Two vehicles head for the site of the accident with siren and blue light.

The injured persons are accompanied on their way to the hospital by the medical specialist, who as a rule is a medical student, who thoroughly records the extent of the injuries, also by photographs. Both of the technicians remain at the scene of the accident and explore the data. Their vehicle is equipped with a photogrammetric camera. Based on the stereo photographs of the site of the accident a true to scale plan is drawn later on (photogrammetric method). On average about 1500 items are stored by computer (1).

The complete data collection consists of:

1. Data acquisition forms with technical and medical part
2. Protocols of interviews with persons involved in the accident and with witnesses
3. Photographic documentation of the scene of the accident, the vehicles involved and the injuries
4. True to scale scetch of accident situation
5. Additional documents such as autopsy reports, medical expert opinions, police reports and court records (Fig. 1).

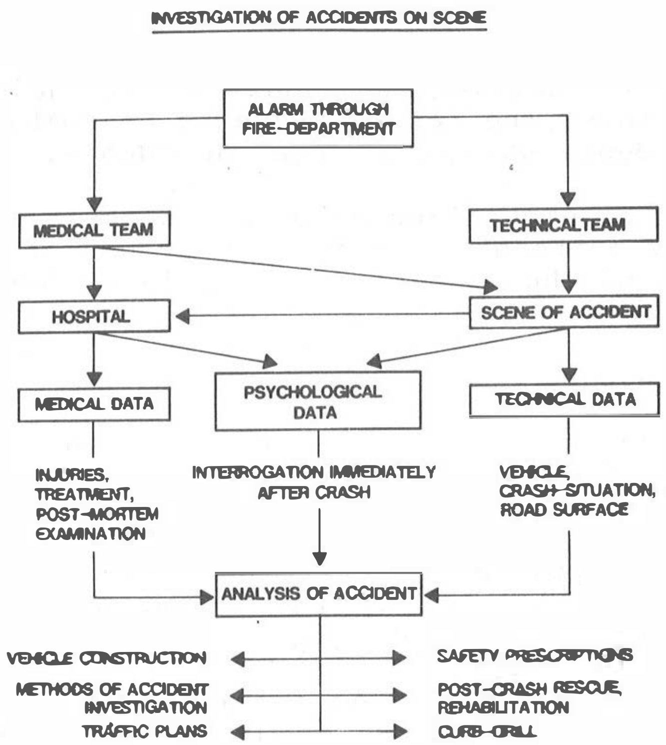


Fig. 1 Organization of the Hannover Accident Research

Acquisition of a concise reconstruction of the accident and a thorough analysis of the mechanisms of the injury is made possible by the close cooperation of the traumatology surgeons and engineers. The method of data acquisition at the scene of the accidents turns out to be rather expensive but seems to be superior to any other method hitherto used for accident analysis.

The federal accident statistics are indeed based on a rather high number of accidents but relatively few items are recorded at the scene of the accident by police officers. In most cases only those traces are documented which are important in deciding the question of guilt. The extent of injuries is neglected and especially in fatalities indications as to the cause of death are missed.

The insurance companies' large number statistics provide a survey of the types of collision and the injuries. The data is collected retrospectively, so detailed information regarding the accident situation, the extent and severity of injuries is not available. Therefore no statement is possible according to the kinematics and the cause of injuries.

In contrast to that the in depth study of single cases, as carried out in Hannover, delivers statements of high quality and objectivity for well defined problems. These results however, have to be converted and correlated to other statistics involving large number of cases.

Experimental investigations with anthropometric dummies are carried out by the automobile industry. To gain a practical information from this, the results have to be combined with basic data from the in depth studies of real accidents.

A point that must be emphasized about our work is the description of typical injury patterns of different groups of road users and the demonstration of the mode of injury origin. Some examples are presented here.

Accidents with passenger cars

Accidents involving passenger cars are dominant in the federal statistics (64%). One of the most insteresting aspects is to investigate the effectivity of protective measures for the car passengers. Whereas collisions of the cars with pedestrians and with two wheelers in most cases have no serious consequences for the passengers, the collision with a second car or a truck or an obstacle may cause serious injuries.

Firstly, in our investigation the frontal collision with 70% is far above the impacts to the side with 26% and impacts to the rear with 4%.

After the impact the vehicle is heavily decelerated but the passengers continue to move towards the original driving direction with the pre-crash speed. The unprotected passengers strikes against the frontal structures inside the vehicle with the exposed parts of the body. At first the knee strikes the dashboard, followed by contact of the chest and / or the head with the steering wheel (drivers) or the upper part of the dashboard (front seat passengers) (7). In most cases the head crashes against the windscreen or penetrates it (Fig. 4a). Depending on the run-out phase of the vehicle an additional impact to the frontal, lateral or rear structures is possible.

Accordingly with kinematics typical injuries may be observed.
So called serial fractures of the leg occur as a result of the primary impact of the knee with the dashboard (7). Patella fractures, ligamental knee instabilities and fractures of the tibial head are common. More proximal bending femur fractures and

hip luxation or hip luxation fractures are typical (Fig.2).

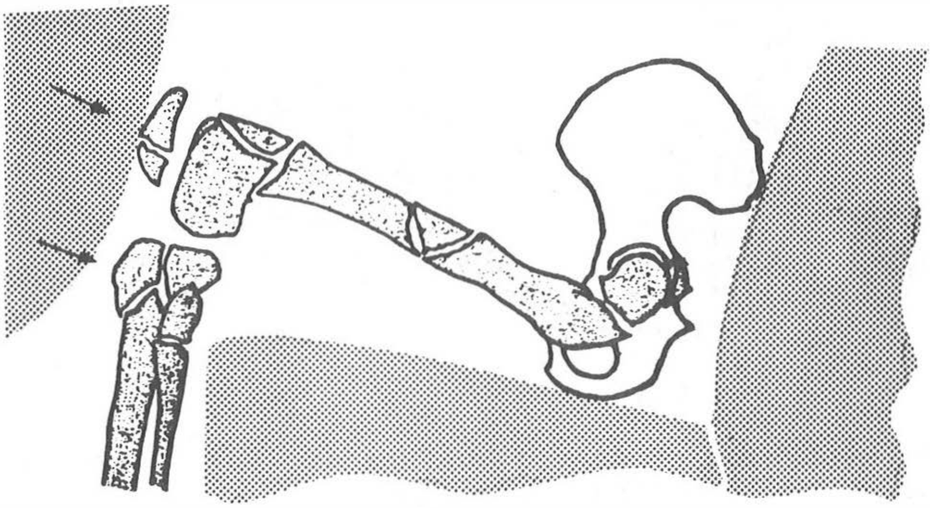


Fig. 2 ·Serial leg fractures due to the impact of the knee against the dashboard

The almost unrestrained impact of the thorax with the interior frontal structures causes serious injuries such as: serial rib fractures, pneumo- and haemato-thorax, lung contusions, injuries of the mediastinal organs.

The extent and severity of these thoracic injuries may be of decisive importance for the survival of the accident victim, as these damages tend to cause life-threatening complications during the intensive care period.

Injuries of the mediastinal organs occur with high kinetic energy, the biomechanics of aortic ruptures were investigated in a separate study (4). In most cases diagonal forces were observed, leading from right ventral caudal to left dorsal cranial. Mediastinal soft tissues are pressed towards the aortic arc due to the thoracic wall compression. The aortic arc is shifted to the cranial, deflected and twisted. This leads to rupture at the transition of the aortic arc to the fixed descending part exactly at the ventral concavity of the aorta, the site of maximum tension and shearing forces (Fig. 3).

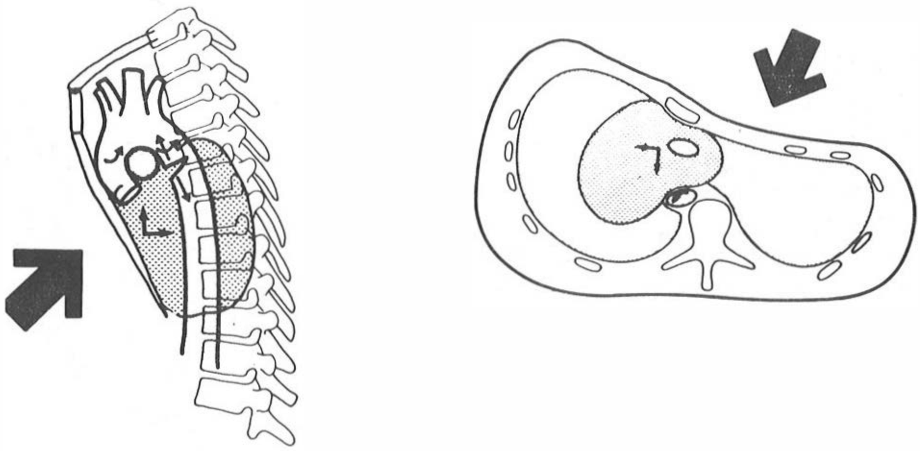


Fig. 3 Biomechanics of Aortic Rupture at Typical Location as a Result of Traffic Accidents

Thoracic Compressions due to the Impact from the right caudal Region

External thorax compression during the early diastole leads to extensive pressure in the supravalvular aorta and may cause a rupture of a normal aortic valve as well as ruptures of other heart valves or the myocardium.

The severity of the haed injury is generally most important for the prognosis of the patient. Severe cranio-cerebral trauma is acquired with the head impact to the A-pillar of the windscreen frame or when the head penetrates the windscreen. Special attention should be paid to less severe but as a result aesthetically deforming facial wounds caused by windscreens made of one pane safety glass, particularly by the sharp edges of the broken windscreen remaining within the frame (2). These injuries are generally not dangerous but cause a lot of surgical problems for the extraction of multiple foreign bodies is difficult. But also serious injuries are observed such as perforating eye wounds and division of the cervical vessels with fatal outcome.

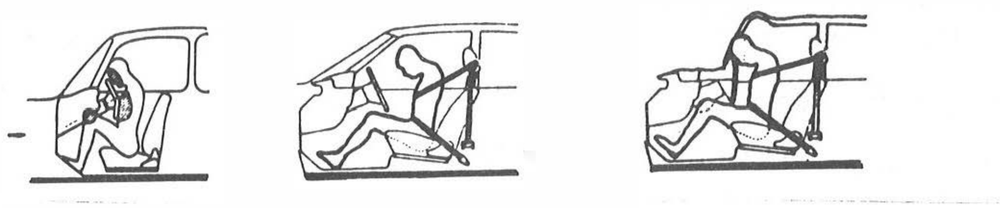
The protective effect of seat belts may be explained by the influence on the kinematic performance.

The impact of the passengers with the car interior structures should be avoided by diminishing the extent of movement (Fig. 4b). To achieve this the three point seat belt must be properly attached to parts of the body with high loading capacity, this is the pelvis, the thorax and the shoulder. For reliable prevention of the impact the belt must not be worn too loose and the position of the seat has to be as far back as possible. Under these circumstances optimal protection against frontal collisions can be reached. The highly dangerous contact of the head with the windscreen may be prevented and facial lacerations avoided. The forces transmitted by the seat belt cause a higher incidence of bruises and abrasions in the belt area, especially the thorax and the shoulder. Even the higher incidence of clavicula fractures can be regarded as positive for this is a relatively banal injury and it can be assumed that the belt has probably prevented much more severe damages (12).

The impact of the knee cannot completely be avoided by the use of seat belts. This is due to the short distance between the knee and the dashboard and to some degree the lengthening of the belt as well as the relatively free movement of the legs. The severity of leg injuries however is dramatically diminished which is also true for the impact of the thorax with the steering wheel and other frontal structures.

Injuries to the arms are not influenced by the wearing of seat belts for the upper extremities are thrown freely forward at the impact.

Fig. 4 Examples for Motion of Car Occupants



a without seatbelt

b with seatbelt

c influence of high intrusion or malfunction of seatbelt

It must be pointed out that a reduction of injuries can only be reached by meticulous wearing of the restraint system, in case of malfunction typical injuries may be caused by the seat belt. Frequently problems are due to loose belts. Therefore the design of the lower part of the dashboard as a kind of knee pad is favourable, also to protect the abdomen, which has to withstand high energy absorption when the belt function is not optimal. The so called submarining, that is the slipping of the body under the belt as a result of loose belts and weak seat constructions, can be especially harmful. Severe intraabdominal lesions were observed, frequently leading to fatal results. Ruptures of the spleen, liver and bowel are common and rupture of the abdominal aorta was observed in some cases too.

It is interesting that persons with relatively short thighs are more exposed to the submarining phenomena for they miss the energy absorbing knee contact.

The limitation of the protective quality of restraint systems is reached when the passenger compartment is deformed (Fig. 4c). This is frequently observed with side impacts, even when the energy absorption is relatively low. Severe head and thorax injuries are more frequent with this crash constellation, and compared with the frontal collision severe or lethal injury patterns are twice as frequent (10). A distinct exposure and an especially low effect of seat belts was established for the passengers on the impact side, for in nearly all cases an intrusion into the passenger compartment was observed. Being thrown out of the car was avoided by the belts and therefore a reduction of the injuries to a passenger on the opposite side of the impact was found.

In the case of an impact to the rear of a car, the so called whiplash injuries of the cervical spine are found. This mechanism causes at least distorsions of the cervical spine which are not considered dangerous, but tend to cause persisting complaints, therapeutical and compensation problems. Especially when no head-rests are used, ligamental injuries, fractures and luxation fractures of the cervical spine are caused by the back-slinging head and the overextension.

<u>Accidents with trucks</u>

182 persons were injured in traffic accidents involving trucks. 40 of them (22%) died, only three being injured as passengers of a truck. According to this we found most of the truck drivers uninjured whereas in collisions with cars the car passengers sustained serious injuries depending on the energy transformed and on the site of the impact. This may be explained by the constructive incompatibility of the collision partners, which does not only mean the completely different vehicle mass but also the missing energy absorption by the rigid truck frame and the different height of the bumpers (Fig. 5).This is also true for the passengers of light lorries, who are scarcely protected in collisions with heavy trucks because of constructive dificiency of the lorry passenger compartment. Injuries to the thorax and to the lower extremities were dominant in truck passengers.

Fig. 5 Example of car to Truck Accidents
Influence of different vehicle weights, different vehicle structures, different bumper locations

Accidents with pedestrians

Pedestrians are involved in only 8% of the traffic accidents in the F.R.G., but in contrast they contribute 12% of all injured traffic victims. In most accidents the pedestrian is hit by the front of a passenger car. The kinematics (Fig. 6) are influenced by the following factors:

- vehicle geometry
- impact speed
- collision constellation
- personal geometry

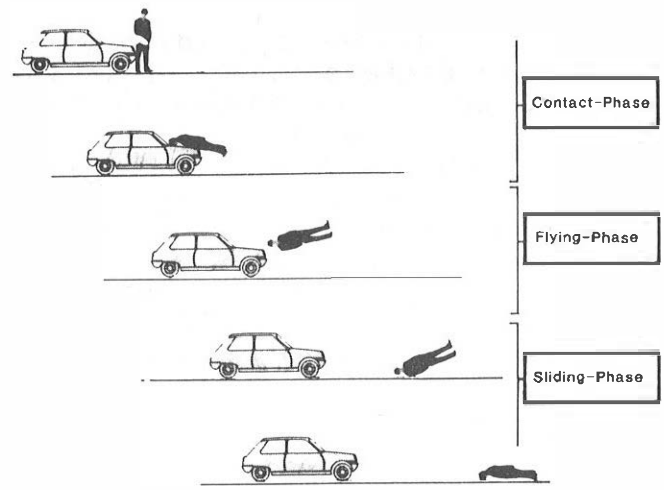


Fig. 6 Individual phases of Motions in Pedestrian Accidents

The injury pattern is also determined by the age of the pedestrian, the sites of the body impact with the vehicle and with the street during the final sliding phase. Children and young adults show different injury patterns compared with older pedestrians (more than 65 years) (3, 9). This may be explained by two reasons:

- The centre of gravity depending on the body height is different in both groups, which leads to different kinematics.

- The tissue rigidity especially of the skeleton is diminished in aging persons as well as the compensation capacity of the injured cerebrum and other organs.

Among both age groups the most serious damages were caused by the collision with a box-shape front profile. Injuries to the whole body, predominantly serious thoracic, cranio-cerebral and abominal trauma is acquired through the almost complete surface contact.

The wedge-shaped front profile of cars proved to be least damaging to colliding children and young adults. The point of the first impact is located inferior to the centre of gravity so that the young person is scooped up and the head strikes to the front bonnet. Therefore the focal points of injuries are essentially the leg and head region.

For adults' collision with the same front profile type a more pronounced turning motion is observed. Because of the low impact point and the higher centre of gravity a long lever arm leads to accelerated rotation of the body and high impact velocity of the head. The impact of the thorax with the front bonnet causes extensive rib fractures, predominantly with old people. In case of short front bonnets the head hits the windscreen frame even when the collision speed is low.

The kinematics of adult pedestrians colliding with pontoon-shape vehicles are only slightly different. At first the front bumper hits the lower leg, followed by an impact of the pelvic region with the anterior edge of the bonnet. The rotation of the whole body is followed by the contact of the chest and head with the front bonnet surface, the windscreen or its frame. In the next phase of motion the pedestrian comes free of the vehicle, either in free flight or slipping away from the front structures, depending on the amount of deceleration of the vehicle. The final impact with the street is sometimes combined with a distinct sliding phase, which mostly causes only minor injuries.

Accidents with bicycle riders

The impact kinematics of bicycle-riders involved in a collision are quite similar to those of pedestrians, because of the relatively low speed compared to passenger-cars (6).

The collision with a front of a car is predominant and the bicycle rider is scooped onto the front bonnet. The centre of gravity is located higher due to the seating position on the bicycle. So the head impact is more frequently found with the windscreen and its frame (Fig. 7). 15% of all injuries among bicycle riders were caused by these parts of the vehicle and the incidence of head injuries was the highest among all groups of road-users (85%).

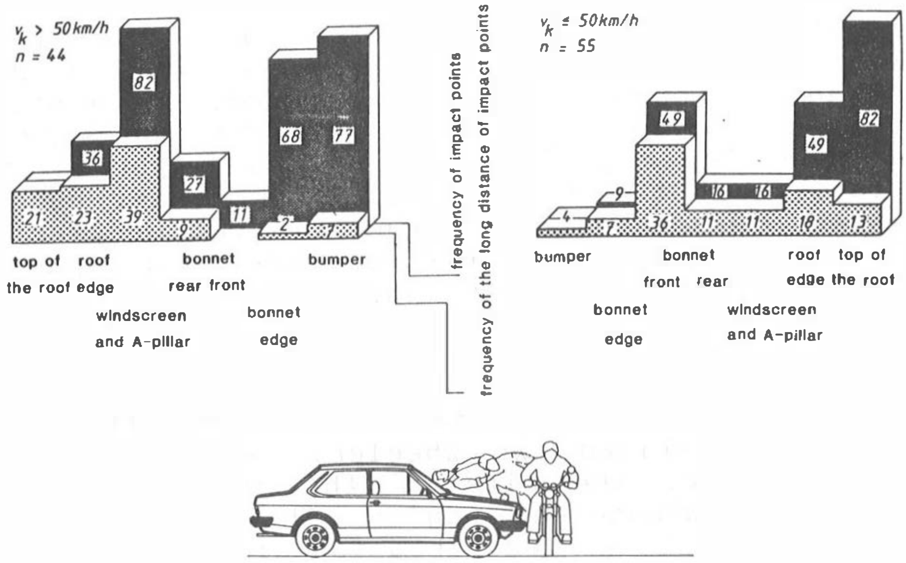


Fig. 7 Example of Car to Bicycle Collisions and Frequency of Impact Points with two impact Speed ranges (> 50 km/h and ≤ 50 km/h)

Accidents with motorized two-wheelers

Motorcycle riders are characterized by their own high collision speed, so that the kinematics are influenced by various parameters:

- site of the impact with the motorcycle and collision partner
- collision angle
- mass relation of both partners
- velocity of both partners

Injuries may be acquired during any of three accident phases:

- impact phase
- flight phase
- run-out phase

In order to explain typical injury patterns as a consequence of certain motion sequences the complex accident kinematics were categorized (11) into collision types, kinematic groups and run-out groups (Fig. 8).

It was noticed that injuries to the lower extremities ranged up to 80% among motorized two wheelers, with about the same percentage within all of the collision types. The maximal average injury severity of the legs was found with an impact against the front of a passenger car. The front bumper caused most of the severe leg damages. Especially with high energy transformation compound fractures, open fractures and severe soft tissue contusions were found.

When the motorcycle collided with the side of a passenger car, less severe leg injuries were established but a high amount of serious cranio-cerebral trauma was found. As mentioned above these injuries are in general decisive for the survival of the injured person. The high incidence of head injuries is explained by the kinematics of a side impact with a car. Because of the height of the passenger compartment the two wheeler in general cannot overfly the collision partner. The head impact to the A- or B-pillar causes most severe injuries.

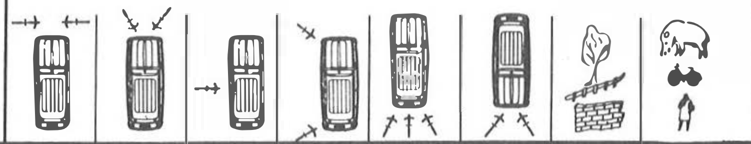
With other collision types a free flight of the two wheeler without any head impact is frequently observed. This may be explained by the relatively high speed and different collision angles of the motorized two wheeler. Nevertheless, if a head impact takes place, the site of the impact is located more centrally to the windscreen region. This corresponds with the high centre of gravity as described for bicycle riders.

The street contact, either as secondary or as single contact, does generally cause less severe injuries, except when there are obstacles within the sliding course. In this connection it has to be mentioned that 13.5% of the helmet-wearers lost their helmet during the accident phase, so that severe or even lethal head injuries may be acquired secondary to the less severe primary head impact.

In general the protective quality of the wearing of crash helmets could be confirmed (6). 67% of the helmet wearers in our survey did not acquire any head injury compared with only 32% of the non helmet wearers. A reduction of the severity of injuries could be proved for soft tissue damages as well as for severe lesions such as skull fractures (with helmet 9%, without 91%).

A complete protection against head injuries can not be expected, so that in cases with high energy transformation and high impact velocity lethal cranio-cerebral trauma can be observed dispite the wearing of crash helmets.

An important problem of injured two wheelers are the serious long term consequences, which were investigated in a clinical study (5). It was proved that the length of hospitalization, the number of operations and the period of absence from work is mainly dependent on the severity of leg injuries. Fractures of the lower leg, especially when combined with soft tissue damage turned out to be most unfavourable in this respect. They most frequently lead to complications and the permanent disability is 3 times as high as with injury patterns not involving the lower extremities.



		characteristic collision type							
type		1	2	3	4	5	6	7	8
definitions	impact point on collision partner (clockwise)	11 12 01		08 09 10	02 03 04	11 12 01	05 06 07	cycle 01-12	
	classification of collision-angles (Grad)	90 ± 20 270	180 ± 69	90 ± 20 270	180 ± 89 0	0 ± 89	0 ± 89	0-360	
all motorized two-wheelers		20,4	22,4	15,1	17,6	5,9	7,7	2,9	4,8

Kinematic groups for the trajectory in accidents with two-wheel riders (n=272)

flight without impact	thrown upon the collision partner	direct impact and seated	impact on the collision partner with change in direction	impact on the collision partner without change in direction	slipped off the collision partner	indirect collision
A	B	C	D	E	F	G
11,8	15,1	2,9	36,4	7,7	6,3	15,1

Kind of outrun after the flying-phase of a two-wheeler

-groups-

slipped away	roll over	small impact point	large impact point	run over	other (unknown)
-all motorized two-wheels-					
73,2	1,8	12,9	5,5	1,5	5,1

Fig. 8 Various kinematic Performances in Two-Wheel Accidents

Conclusions

The results presented in this study illustrate only a part of our work. They are of relevance not only for basic investigations but also for practical purposes. The development of new safety concepts must be based on exact knowledge about the kind, the extent and the location of injuries and about their origin. This can only be reached by in depth accident studies of single cases. Forensic medicine problems may be solved by proving the correlation between the accident forces and the injury pattern. The experienced traumatology surgeon is able to judge an injury in respect of therapeutical problems, complications and long term consequences. The severity of these problems does not always correlate to the Abbreviated Injury Scale (8), which is widely used to grade the severity of tissue damage. These aspects prove that accident research is only effective with interdisciplinary cooperation. Engineers and physicians are called upon to proceed with investigations in the complex field of traffic accidents so as to gain an optimal injury prevention for all road users.

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