RISK AND MECHANISMS OF INJURIES TO THE CERVICAL SPINE IN TRAFFIC ACCIDENTS

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ABSTRACT

This paper presents the results of a field study in the Hannover area (Federal Republic of Germany). 5,759 people injured in traffic accidents, were examined with regard to injuries of the cervical spine. 2.1% received injuries of the cervical spine; 1.04% morphologically non-definable injuries (AIS=1), and 0.97% bony or ligamentary injuries (AIS>1). The definition of the 'whiplash injury' is elucidated, and the risk for these particular injuries is described, according to the type of traffic participation of the injured.

1. OBJECTIVE

Injuries of the cervical spine to victims of traffic accidents range from diagnostically difficult to define 'whiplash trauma', almost without any symptoms (AIS 1) to the luxation fracture with tetraplegia (AIS 6). The conception of the slinging injury was first used by GAY and ABOTT (1) as a pure hyperextension injury. They later extended the meaning of this conception to the so-called 'whiplash injury'. Other authors have been occupied with the conception of the whiplash trauma. They use this name for all injuries resulting from a slinging movement of the head, with and without head impact, among others MÜLLER (2), GÖGLER (3), KUHLENDAHL (4), and JANZEN (5). They differentiate between hyperextension by direct impact to the front-half of the head and the isolated slinging trauma, without head impact. This division is used in our own analysis (6).

The existing difficulty in diagnosis, evaluation and assignment of the so-called 'whiplash injury' is evident from the various definitions. This means that the medical diagnosis, e.g. pain in the neck, is always assigned to a causal mechanism, in this case 'whiplash'. With diagnostically definable injuries, however, the medical diagnosis itself is used for the description of the injury, for instant the luxation fracture. This explains the wide scale of frequency reports about cervical spine injuries in the literature.

As can be seen from the literature, the majority of slinging trauma to car passengers occur in rear collisions (7,8). BRAUNSTEIN (9) reports that in the USA from 1952 to 1955 out of 1,000 car accidents, 6.8% of the injured passengers received cervical spine injuries. THORSON (10) analyzed 2,500 injured traffic participants in Upsalla (Sweden). 4% of them received cervical spine injuries. According to THORSON, 0,2% of those were clear whiplash injuries.
In the Federal Republic of Germany, approximately 17% of car passengers received injuries to the cervical spine, 0,3% of them damaged the bony parts, according to a study of the HUK Association (11). In 50% of the cases, the cervical spine injuries were caused by an impact to the rear of the car. The HUK Association investigates the possibility of a higher risk for severe, life threatening injuries in frontal collisions.

This study is intended to describe the type and frequency of injuries to the cervical spine for various traffic participants, to illustrate the characteristics of the so-called 'whiplash injury'. In this attempt, the technical-medical evaluation of the concept of 'whiplash trauma' is used for the morphologically ill-defined distortion of the cervical spine (AIS 1), caused by hyper-extension and/or hyperflexion or rotation. All bony and ligamentary injuries are pooled in a second group AIS > 1.

2. DATA FOR THE STUDY

2,111 traffic accidents were at our disposal for the study, involving 5,759 persons. Frequency, localization, accident mechanisms and accompanying injuries of traffic participants with cervical spine injuries are investigated in the study. Within the framework of the Local Accident Investigations in the town and country district of Hannover (FRG), all traffic accidents were documented, reconstructed an analyzed by an interdisciplinary research team (12). An extensive documentation of technical details, like skid marks, final position of the vehicle, deformation patterns of the vehicle exterior and the passengers compartment is made. All injuries are established with regard to type, severity (AIS) and location.

3. INJURY TO THE CERVICAL SPINE

3.1 Type of traffic participation

2.1% of all traffic participants suffered injuries of the cervical spine. 1.04% of these were so-called clear whiplash injuries (AIS = 1), and 0,97% were bony and ligamentary injuries of injury severity degree AIS > 1. Pedestrians and users of motorized two-wheelers clearly face the greater risk for spinal injuries (table 1). 3.4% of the pedestrians received cervical spine injuries, but only 0.2% of them suffered so-called whiplash injuries. 3.3% of the motorized two-wheel riders with cervical spine injuries received clearly more bony, respectively ligamentary injuries to the cervical spine. Car passengers received cervical spine injuries in 1.9% of the cases, but these were predominantly whiplash injuries (1.3%). Passengers of trucks, however, only received these injuries in 0.2% of the cases.

3.2 Distribution of age and sex

While 50% of all traffic participants in the study population were under the age of 30, only 30% of this age group received injuries to the cervical spine (table 2). This fact shows that older people past the age of 30 are clearly more susceptible to this kind of injury than younger ones. 56.9% of the study population are males.

3.3 Car passengers

Compared with drivers, and with passengers in the rear seats, front passengers have a higher incidence of these particular injuries (table 3). 3.4% of the front-seat passengers without belt and 4.4% of the belt-protected ones received cervical spine injuries. While an even greater percentage of injuries to the cervical spine was established with belt usage, this number is based on a higher percentage of the so-called whiplash injuries (3.6%). Bony and ligamentary injuries were established in only 0.8% of the cases with belt usage. No injuries at all to the cervical spine were found with three belt-wearing rear-seat passengers. Despite the fact that ejection of belt-wearing passengers is possible, no cervical spine injuries were established. These facts prove the protective quality of the seat-belt. 11.9% of the ejected, not belt-protected passengers received cervical spine injuries (table 3a).

Car passengers are exposed to a very great risk for cervical spine injuries in rear collisions as well as in rollover accidents (table 4). Only 3.9% of the car passengers were subjected to a rear collision, and 3.8% in rollovers of the vehicle.

18.2% of the persons with cervical spine injuries were involved in rear collisions, and 7.8% were in overturning cars (table 4a). The velocity change during a collision appears to have some influence, as far as cervical spine injuries are concerned. In rear collisions, these injuries already occur with very low changes of speed. In frontal and lateral collisions, they were established only in higher vehicle velocity changes (table 4b). In frontal as well as in lateral impacts, no cervical spine injuries were established with ΔV below 10 km/h. 6.7% of the passengers in vehicles hit at the rear, suffered cervical spine injuries in a speed change of up to 10 km/h.

Persons with cervical spine injuries are generally susceptible to a higher degree of trauma to the whole body, and to injuries of multiple body regions. Especially the head, thorax, pelvis as well as upper and lower extremities receive a higher degree of trauma (tables 5a and b). 24.8% of all belt-wearing car passengers received head injuries, 55.6% with diagnosed whiplash injuries, and 42.9% of those with bony or ligamentary injuries to the cervical spine also suffered head injuries (table 5b).

3.4 Riders of two-wheelers

The majority of two-wheel riders in this study received slight and medium injuries (74.4% OAIS - severity degrees 1 to 3). Those with cervical spine injuries were mainly seriously injured (57.7% OAIS 5 and 6; table 6).

Riders of motorized two-wheelers are in more danger than users of non-motorized two-wheelers of receiving cervical spine injuries. 85.7% of those with cervical spine injuries wore crash helmets. It is remarkable that two-wheel users with cervical spine injuries (users of motorized two-wheelers inclusive cyclists) suffered clearly more abdominal injuries (42.9%), compared with other injured two-wheel riders (15.4%). The established higher proportion of injuries to head, thorax, pelvis/abdomen and extremities shows a considerable impact to the whole body.

3.5 Pedestrians

The highest percentage (3.4%) of cervical spine injuries was established with pedestrians. A high degree of traumatizing to the thorax, abdomen and pelvis was additionally established here (table 7). 88.2% of those persons with cervical spine injuries also suffered injuries of the thorax, 64.7% to the abdomen/pelvis. Almost all pedestrians with an injured cervical vertebra received very severe, respectively fatal injuries (OAIS 6, n = 15), due to the high traumatizing degree of the whole body.

For patients with cervical spine injuries, the collision speed exceeded 40 km/h, in 88.2% of the cases (table 8). When comparing the collision speeds of all injured pedestrians, a higher risk for cervical spine injuries is evident with higher speeds.

4. DISCUSSION

For all traffic members cervical spine injuries (AIS > 0) were established in our study in 2% of the cases. Considering the methods used by the local accident investigation in the town and rural district of Hannover, with documentations in approximately 30 clinics, this percentage of injury probability for the cervical spine can be assumed for accidents in the whole German Federal Republic. They are predominantly so-called 'whiplash traumas', with AIS 1, received by 1.1% of injured traffic participants: 0.9% of them received bony, respectively ligamentary injuries of the cervical spine. These can be assigned to severity degree AIS > 1.

According to this study, pedestrians are especially at risk. Almost 3.4% of them received exclusively bony or ligamentary injuries of the cervical spine (AIS > 1). These injuries occurred mainly in higher collision speeds, exceeding 40 km/h, together with severe trauma of the whole body, especially the thorax. The analysis shows:- With a sudden head deceleration the spine is loaded by the mass of the body and its consequent gliding (the so-called 'sliding up'). This causes compression and bending of the cervical spine (table 9). The process leads especially to fractures of the lower cervical spine, C5 to C7, and to luxation fractures in the upper half, above C5, with neurological non-functioning (table 10). During the sliding phase of the body in direction of the windscreen, the rest of the vertebra column (dorsal- and lumbar vertebra) is exposed to high pressure and high risk for injury.

Beside pedestrians, users of motorized two-wheelers are very susceptible to cervical spine injuries. 3.3% of the motorized two-wheel riders received such injuries, 2.4% AIS > 1. As before, cervical spine injuries are nearly always found in connection with head impacts, respectively with impact of the body trunk. It seems that the sliding process (table 9) is responsible for the occurrance of this particular injury. A greater risk for cervical spine injuries, in connection with helmet usage could not be confirmed in this study, despite the fact that more cervical spine injuries were registered among helmet wearers, compared with two-wheel riders, without helmets.

In contrast to pedestrians and motorized two-wheel users, cyclists (with still a high proportion of 2.4%) suffered fewer cervical spine injuries, 1.7% AIS > 1. The higher position of the center of gravity, in connection with the low proper motion of the bicycle seems to have a lower risk for cervical spine injuries. For this reason, an axial or bending pressure is not established to such high degree. The predominantly younger ages of those traffic participants would explain the fewer injuries of the cervical spine in this age group, compared with pedestrians.

For car passengers a further disadvantage is illustrated by another injury mechanism (table 11). This is the tossing movement of the head, already described as 'whiplash injury'. 1.9% of the car passengers suffered cervical spine injuries, 1.3% AIS > 1. Car passengers in the co-driver's seat suffer more cervical spine injuries than their fellow passengers in the rear of the car. These injuries frequently occur in rear collisions. They already happen with low impacts of Δv, below 10 km/h. Contrary to the rear impact, a lesser injury risk is established for frontal and side collisions. This is also the case in accidents by rollover. For belt-protected car passengers, the injury risk for the cervical spine seems higher than for those without belt. Cervical spine injuries for belt users, however, consist mainly of clear distortions (AIS = 1), caused by the tossing movement of the head. For unprotected persons, more bony or ligamentary injuries of the cervical spine (AIS > 1) were registered. This cognition correlates with other studies: A substantial reduction of serious/critical neck injuries was found with belted occupants. On the other hand, the frequency of minor neck injuries with belted occupants is slightly higher (literature study in 13).

Mechanisms

When seen in connection with different accident conditions, cervical spine injuries basically show two kinds of mechanisms (tables 9 and 11), i.e.

the clear tossing movement of the head with antero retroflexion movements of the cervical vertebra (table 9), in connection with traction forces, due to a deceleration of the head. In some cases, fractures and luxation fractures of the cervical spine were established, without head impact, in rear-end impacts. With a belt-protected passenger of advanced age, a dens-fracture could be observed, after a frontal impact of the car.

Another mechanism which is responsible for cervical spine injuries is:

the 'sliding-up mechanism', a sliding of the body whilst the head remains in a fixed position, after an impact to the head (table 11).

A rotation of the head around an axis in the impact point leads to a hyperflexion, and to hyperextension trauma of the cervical spine. Thus it destroys the bony and the ligamentary structures by axial compression of the cervical spine.

As far as the distribution of injuries to the single segments of the cervical spine is concerned, there is an accumulation in the region of the upper and lower cervical spine, especially for fractures and for luxation fractures in the lower and upper region. These are often accompanied by competitive injuries of the remaining cervical spine and the skull base. This is especially the case with pedestrians and cyclists.

According to a model demonstration by FIALA (quoted in 14), the neck may be seen as an elastic rod, with joints in C1 and C6. As confirmed by our observations, hyperflexion then hyperextension movements which occur in increasing numbers in the region of these two segments, lead to injuries of the bony and the ligamentary structures. Damage to several adjoining segments were observed in approximately 25% of the injured persons. Injured segments separated by uninjured segments, were established only now and then, with fatally injured persons. In a study by ALKAR et al. (15), injuries of two non-adjacent cervical spine segments were found in three cases. The weaker link between occiput and C1 permits luxations and luxation fractures. Our study demonstrates the fact that persons over 30 years of age clearly face a higher risk for cervical spine injuries. Children under 10 very rarely receive severe cervical spine injuries.

Our study proves that the conception of the 'whiplash injury' can not be regarded as a clear definition, but exclusively describes the causal mechanisms. This, however, can not be established by the diagnosis of an examined patient. FAY and ABOTT (1) originally used this conception almost without exception for hyperextension injuries, mainly whiplash movements of the neck. For juridical use, the meaning of this conception was later broadened. In the case of any diffuse discomfort in the cervical spine region, in the absence of a morphological correlation, and in connection with an accident mechanism like a rear collision, a whiplash injury was diagnosed by the doctor. This diagnosis was accepted by insurance companies for any claims resulting from an accident. This misunderstanding lead to biased statistical statements in regard to cervical spine injuries, as they often included completely different injury types.

It is, therefore, suggested that future publications divide cervical spine injuries into two groups:

1. morphologically non-definable, so-called distortions (AIS 1);
2. bony or ligamentary injuries (AIS > 1).

The term 'whiplash' should be used exclusively to describe the causal mechanism. Only when comprehensively applied, can the accident analyses efficiently serve as a measure in accident prophylaxis.

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injured persons	kind of traffic members					
	occupants		two-wheel-riders		pedes-	all
	of cars	of trucks	motorized	bicycles	trians	persons
	100%	100%	100%	100%	100%	100%
total [n]	4085	453	422	300	499	5759
with cervical spine injuries	1,9%	0,2%	3,3%	2,4%	3,4%	2,01%
whiplash injuries AIS = 1	1,3%	-,-	0,9%	0,7%	0,2%	1,04%
bony/ligamentary injuries AIS > 1	0,6%	0,2%	2,4%	1,7%	3,2%	0,97%

TABLE 1: FREQUENCY OF INJURIES TO THE CERVICAL SPINE (AIS = 1 / AIS > 1) ACCORDING TO THE TYPE OF TRAFFIC PARTICIPATION

	total	persons with cervical spine injuries
	n=5237	n=116
male	68,2%	56,9%
female	31,8%	43,1%

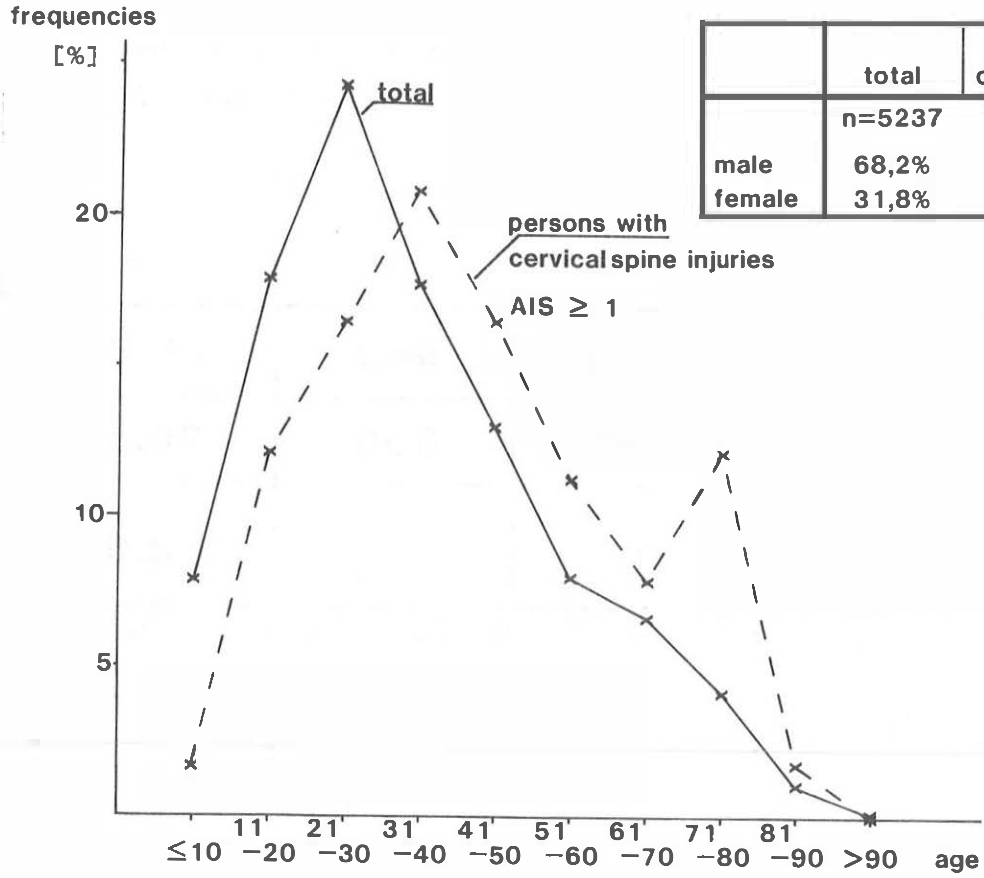

TABLE 2: DISTRIBUTION OF AGE AND SEX FOR PERSONS WITH CERVICAL SPINE INJURIES (AIS ≥ 1)

seating position	car-occupants without seat belts			
	with cervical spine injuries		total	
	AIS = 1	AIS > 1	n	%
driver	1,6%	0,5%	1339	55,5
co-driver	2,1%	1,3%	529	21,9
rear occupant	1,5%	0,4%	544	22,6
thrown out of vehicle	6,3%	5,6%	126	5,2

TABLE 3a

seating position	car-occupants with seat belts			
	with cervical spine injuries		total	
	AIS = 1	AIS > 1	n	%
driver	1,5%	0,4%	942	70,8
co-driver	3,6%	0,8%	358	26,8
rear occupant	-,-	-,-	34	2,6
thrown out of vehicle	-,-	-,-	8	0,6

TABLE 3b

TABLE 3: INJURY FREQUENCY OF THE CERVICAL SPINE FOR CAR OCCUPANTS, ACCORDING TO SEATING POSITION IN THE ACCIDENT CAR, WITH AND WITHOUT BELT USAGE

	distribution of vehicle impact regions				
	front	side	rear	roll over	others
all car occupants (n=4085)	66,3%	24,7%	3,9%	3,8%	1,3%
persons with cervical spine injuries (n=77)	49,4%	22,1%	18,2%	7,8%	2,5%

TABLE 4a

main impact		portion of car occupants with cervical spine injuries — speed absorption Δv [km/h]				
		1-10	11-30	31-50	>50	total
vehicle region	front	n=92	n=630	n=613	n=208	n=1593
		-,-	1,2%	2,4%	7,2%	2,4%
	side	n=72	n=300	n=284	n=93	n=749
		-,-	1,0%	2,8%	6,5%	2,3%
	rear	n=15	n=76	n=38	n=12	n=141
		6,7%	9,2%	10,5%	16,7%	9,9%

(persons each speed and impact region ≙ 100 %)

TABLE 4b

TABLE 4: INJURY FREQUENCY OF THE CERVICAL SPINE (AIS ≥ 1) FOR CAR PASSENGERS, DIVIDED BY REGIONS OF VEHICLE IMPACT (TABLE 4a) AS WELL AS THE LEVEL OF SPEED ABSORPTION DUE TO THE COLLISION (Δ V) AND REGION OF VEHICLE IMPACT (TABLE 4b)

frequencies of injured bodyregions of car-occupants
without seat belts

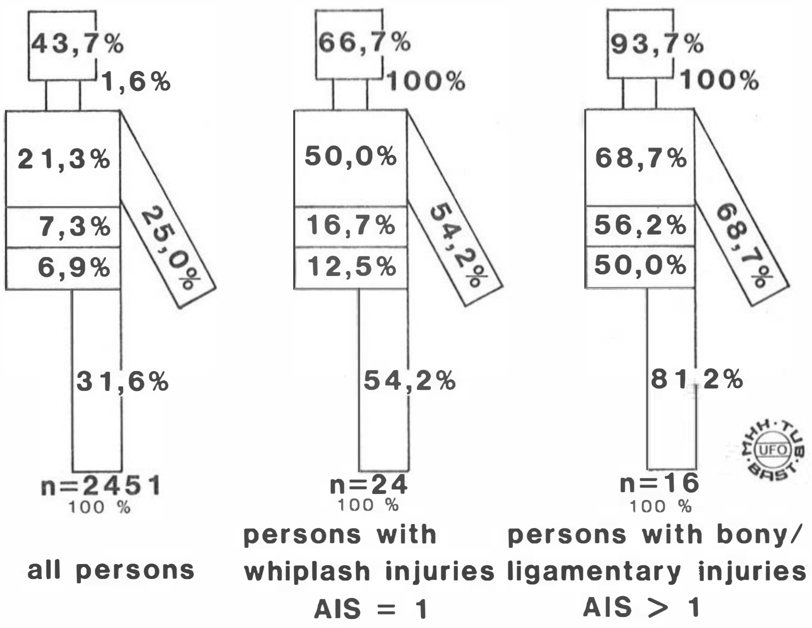

TABLE 5a

frequencies of injured bodyregions of car-occupants
with seat belts

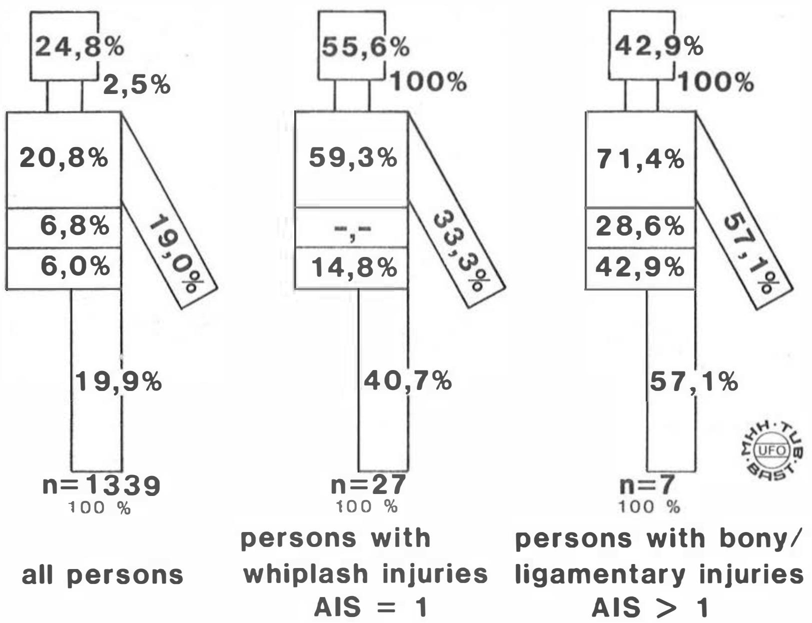

TABLE 5b

TABLE 5: ACCOMPANYING INJURIES ON BODY OF CAR PASSENGERS WITH CERVICAL SPINE INJURIES WITH (TABLE 5b) AND WITHOUT (TABLE 5a) SEAT BELTS

frequencies of injured bodyregions

of two-wheel-riders

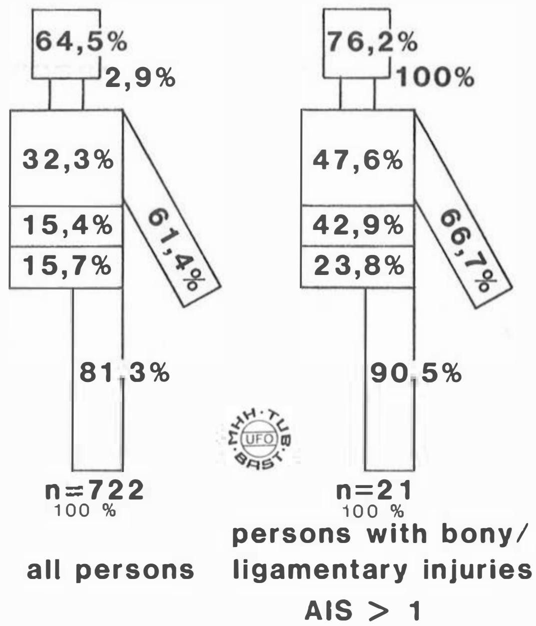

TABLE 6: ACCOMPANYING INJURIES ON BODY OF TWO-WHEEL-RIDERS WITH CERVICAL SPINE INJURIES (n=722 ≙ 100 % / n=21 ≙ 100 %)

frequencies of injured bodyregions

of pedestrians

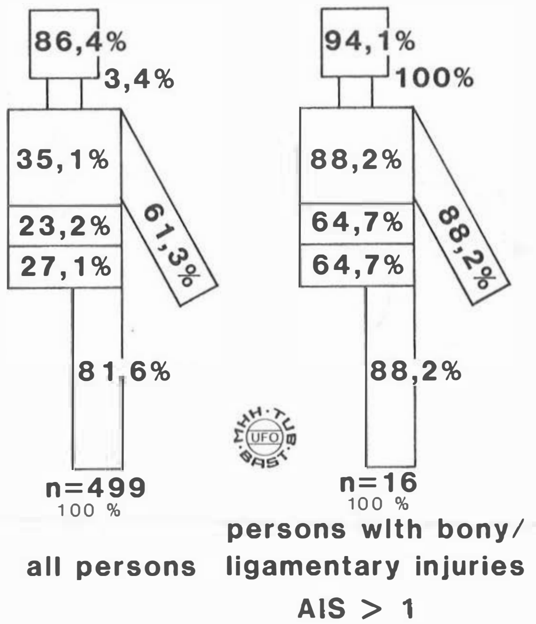

TABLE 7: ACCOMPANYING INJURIES ON BODY OF PEDESTRIANS WITH CERVICAL SPINE INJURIES (n=499 ≙ 100 % / n=17 ≙ 100 %)

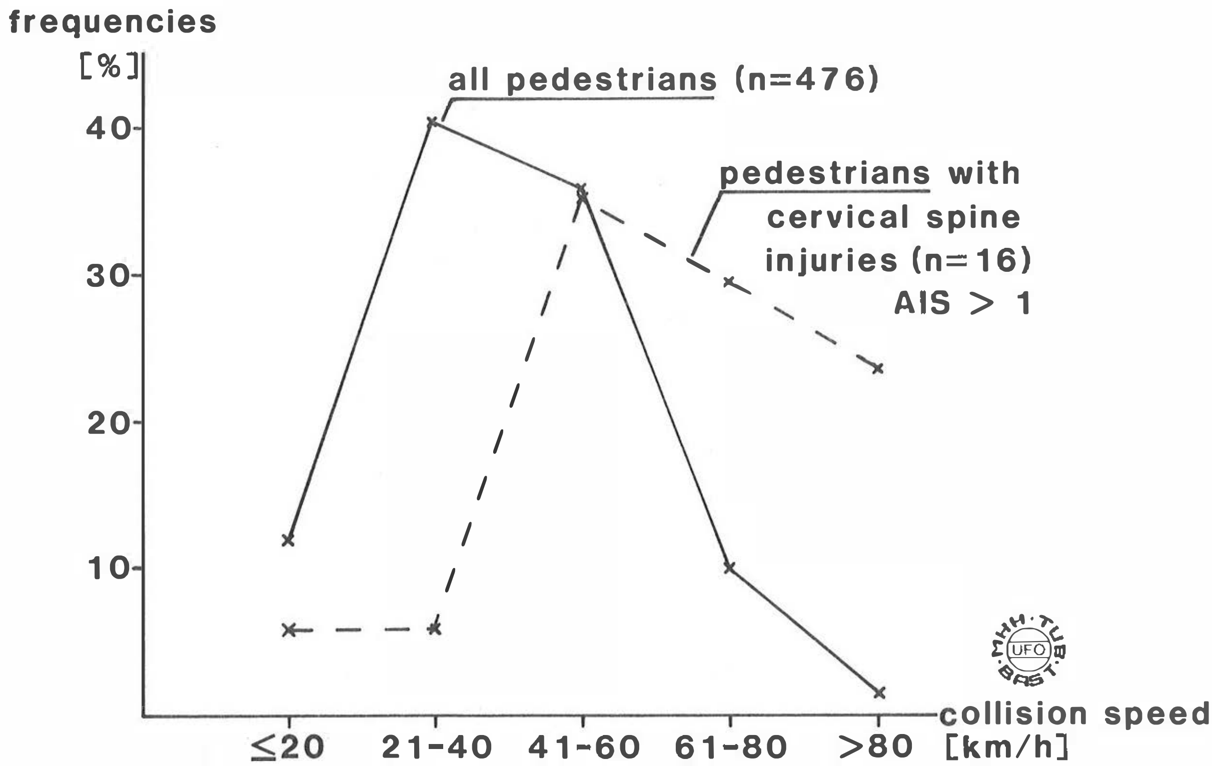

TABLE 8: ESTABLISHED KOLLISION SPEEDS FOR PEDESTRIANS WITH CERVICAL SPINE INJURIES AIS > 1, IN COMPARSION WITH COLLISION SPEEDS OF THE TOTAL OF INJURED PEDESTRIANS

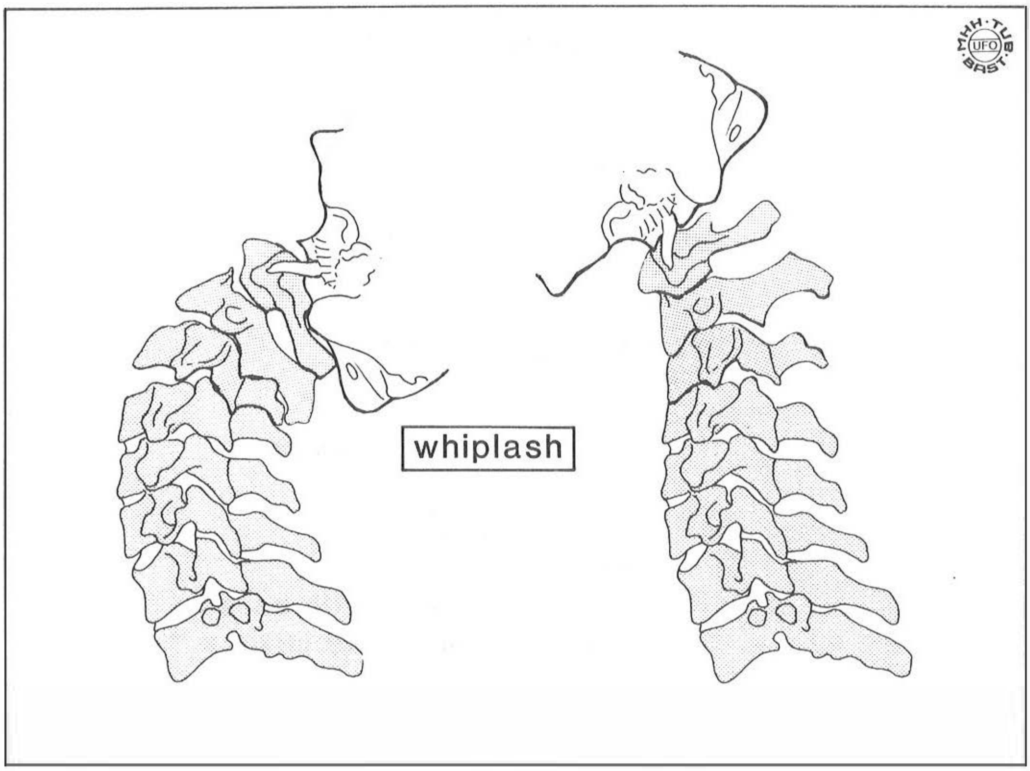

TABLE 9: KINEMATIC LEADING TO HIGH RISK FOR CERVICAL SPINE INJURIES

	cervical spine fractures						cervical spine luxation fractures					
	car occupants		two-wheel riders		pedestrians		car occupants		two-wheel riders		pedestrians	
	total n=10	nl[1] n=4	total n=4	nl[1] n=1	total n=8	nl[1] n=1	total n=16	nl[1] n=10	total n=13	nl[1] n=6	total n=12	nl[1] n=6
C1	1	1					4	3	2	2	3	2
C2	4	1	1	1	1				1	1	2	2
C3	1						2				1	1
C4			1				1	1			1	1
C5					1							
C6	3	2	1		2		2	2				
C7	1		1		4	1	3	2	2	2		
with dens / Th 1	1	1	1	1	1				1	1	1	
unstability without specific localisation							4	2	7	2	2	2
additional fracture of the base of the skull	3		1		3		1		3		2	
additional remaining vertebral	1		1		7		2		2		5	

[1] nl = with neurological lesion

car-occupants n = 22 two-wheel-riders n = 14 pedestrians n = 16

TABLE 10: TYPE AND LOCATION OF CERVICAL SPINE INJURIES (AIS > 1) ACCORDING TO TYPE OF TRAFFIC PARTICIPATION

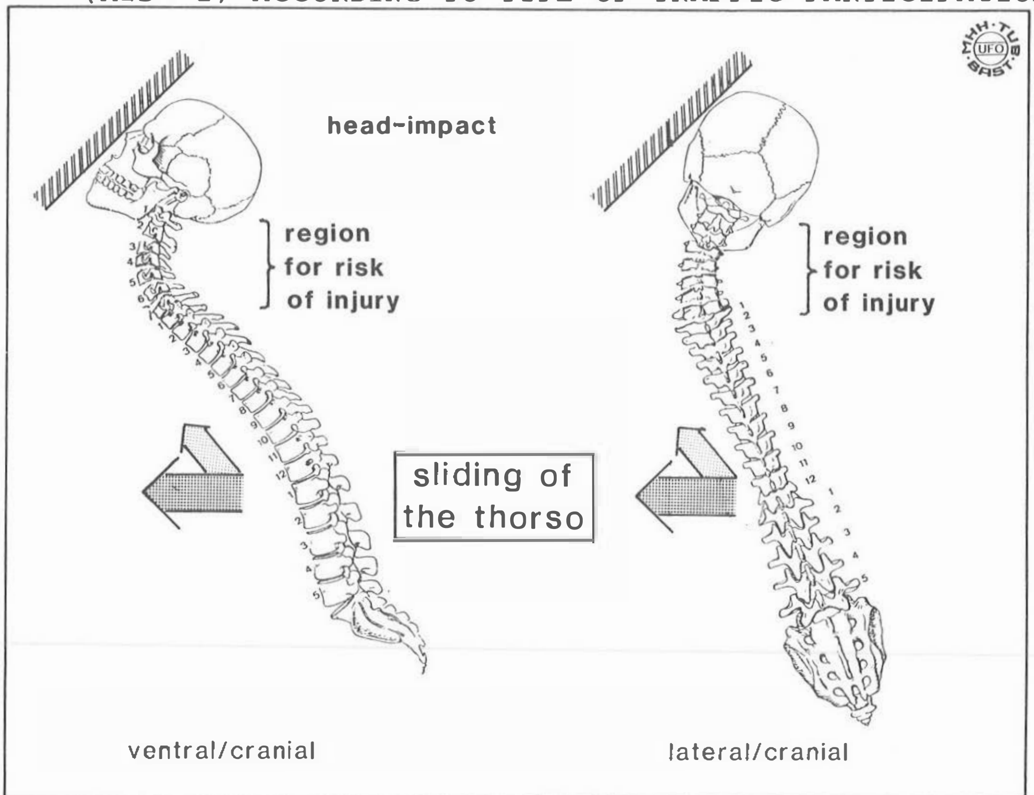

TABLE 11: KINEMATIC LEADING TO HIGH RISK FOR CERVICAL SPINE INJURIES