# SIGNIFICANCE OF SOFT TISSUE NECK INJURIES AIS 1 IN THE ACCIDENT SCENE AND DEFORMATION CHARACTERISTICS OF CARS WITH DELTA-V UP TO 10 KM/H

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## ABSTRACT

The task of this study is to analyse the injury pattern of soft tissue neck injuries AIS 1 so called distortions, the descriptions of pains and the deformation characteristics of the cars in low speed collision up to delta-v 10 km/h in frontal and rear end collisions. 50% of distortions occur under frontal collisions. The basis of this study are 1238 belted car occupants with neck distortions AIS 1 documented by the in-depth-investigation team of the Accident Research Unit at Medical University Hannover. The detailed deformation characteristics of 117 belted car occupants with delta-v up to 10 km/h are analysed compared to the injury pattern and long term consequences. Pain descriptions are analysed with questionnaires sent to these patients several years after event.

## 1. INTRODUCTION AND PERSPECTIVE

The cervical vertebra movement can lead to injuries, the so-called „whiplash trauma", described by Guy and Abbot (1), 1953 as whiplash injuries. This injury pattern was recorded frequently in the 60's and for this reason was subject of many publications. In the 60's most cars had no headrest. Subsequently, this resulted in serious bony and ligamentary injuries to the cervical vertebra in the course of accidents in which a moving car collides with a stationary car, due to a backward overstretching of the head and neck. This often leads to paraplegia (Schmidt and Kallieris -2). Gögler (3) presumed that the occurrance of cervical vertebra injuries based on a two-phase opposing moving of the head, from primary hyperextension to secondary hyperflexion. Background of most publications were mainly bony and ligamentary injuries. Biomechanical and accident-analytical research demonstrates the mechanisms of hyperextension and flexion (among others Ziffer - 4, Clemens and Burrow -5) as well as the influence of the ligament system which guarantees the functioning of the spine

(among others Stofft - 6). Saturnus (7) explains the extent of the soft-tissue neck injury as the so-called distortion as a result of the multiple contraction of the primarily abruptly overstretched muscle groups. For Szabo (8) is the cause to be seen in the shearing force produced by the movement of the neck. By implementation of improved seat comfort and headrest support it was possible to reduce the proportion of serious cervical vertebra injuries from more than 10% in 1965 (Müller -9) to approximately 3% in 1985 (Kamieth -10). Today they rate to 0.6% (Münker et al -10) which is very rare. However, like accident investigations show, an increase in soft-tissue cervical vertebra injuries, the so-called distortions, is apparent, especially in connection with belt and airbag use (Otte -12). All these injuries are strains with severity grade AIS 1 defined as distortions. A comparison of investigation of traffic accidents from 1985 to 1989 established that 10.6% of car passengers suffered AIS 1 neck injuries. In accidents from 1990 to 1994, however, these were 15.1% (Otte -13). Walz (14) regarded the term "whiplash trauma" as not to be correct and points out that this term exclusively describes the mechanism as diagnosis and would not be applicable. The same applies to whiplash as well as accelleration injuries which are here also occasionally mentioned. According to an interdisciplinary consens, for such injury consequences the diagnosis "distortion" should be used as far as they are not luxations or fractures (15).

While bony or ligmentary injuries AIS 2 and above are with 1.7% very rare, distortions of the neck AIS 1 are with 25.5% especially frequent for belt-protected passengers (fig. 1). The latter gain from the point of view of sick insurances and experts increasingly more importance. The Association of German Insurers (VdS -16) reports that costs for long term consequences of national economy in Germany have amounted to 700 million ECU. Reports from other countries also pointed out of high costs, the Netherlands for instance 300 million ECU (Wismans -17), and Sweden of 210 million ECU (Tingvall -18). This means that total costs for the whole of Europe each year will amount from 5 to 10 billion ECU for after effects of these soft tissue neck injuries AIS 1 suffered by patients.

Fig. 1 Percentual proportion of persons with cervical vertebra injuries, differentiated by AIS 1 and above, localisation neck, thoracic and lumbar spine and traffic participation (100% all persons for each traffic participation).

**portion of spine injuries**

n=12105 injured persons

| spine | pedes-trians (n=1584) | bicyclists (n=2508) | mot. two-wheeler (n=1171) | truck occu-pants (n=367) | car occupants unbelted (n=1622) | car occupants **belted (n=4853)** |
|---|---|---|---|---|---|---|
| **neck** | | | | | | |
| **distortion AIS 1** | **1,4%** | **3,5%** | **4,3%** | **18,8%** | **16,4%** | **25,5%** |
| AIS > 1 | 1,4% | 0,4% | 1,4% | 1,1% | 1,9% | **1,7%** |
| **thoracic** | | | | | | |
| AIS 1 | 0,1% | 0,1% | 0,1% | 0,3% | 0,2% | **0,7%** |
| AIS > 1 | 1,2% | 0,6% | 1,2% | 0,5% | 1,1% | **0,5%** |
| **lumbar** | | | | | | |
| AIS 1 | 0,1% | 0,1% | 0,3% | - | 0,2% | **0,7%** |
| AIS > 1 | 1,7% | 0,5% | 1,2% | 1,4% | 1,0% | **0,9%** |

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Neck distortions are diagnosed as a rule by the physician, on the basis of clinical symptoms, including not always confirmation by radiological findings. As a rule different distinct pain in the neck region and shoulder muscles, like mobile restrictions and local sensitivity to pressure in the region of the upper and lower cervical vertebra or the shoulder, further difficulties in swallowing or tinnitus. Cephalo-cervical and vegetative symptoms like jaw-joint complaints, dizziness, temporary loss of vision and hearing, perspiration and feeling of coldness, symptoms make it difficult for the physician to associate diagnostic findings for a sured proofed neck distortion.

In view of a critical scientific evaluation the question may arise if it is really an injury or only subjective findings in form of pain symptoms as a result of muscle contraction. Symptoms are often pointed out directly after the accident event but days or even weeks after the accident occurance.

The possibilities of making the complaints mentioned by the patient and the structural damage comprehensible are very limited. By several sides an attempt is made to subsummit the occuring symptoms and to find a severity degree for these injuries (Erdmann -19, Schroeter -20). When evaluating the influence of accident type and applied force (place of impact, frontal and rear collision) as well as the information about the extent and degree of damage to the vehicle, the question concerning the accident correlation is often met with scepticism.

In the real accident occurance patients are still found with such complaints within the so-called "low speed impacts".

The literature on the subject is very extensive and is often engaged in clinical observations, and on the description of long term consequences as well as pathological and mechanical explanations based on hospital studies and post-mortal structure tests of the cervical vertebra. For the infliction of structural

defects on the cervical vertebra there are different load criteria, the speed change delta-v for instance which varies between 6 to 20 km/h. There were further sled tests carried out with test persons simulated car impact collisions (Steffan - 21, Uno -22). In these test conditions the lower limits for the appearence of findings in the cervical vertebra region or complaints by persons involved in delta-v values of less than 9 to 15 km/h respectively are found too. Trials with test persons have the disadvantage that although they get close to the accident medical conditions, they do not sufficiently cover the medical conditions of the uninjured person into consideration (increased muscle tonus as a result of exspectation). The test trials however reveal an important parameter of influence on the formation of complaints symptomatic, i.e. the geometry of seat and headrest. Acceleration measurings on motor-scooters and the comparison with collision points to the fact that these persons do not complain about any pain though quite similar accelerations existed (Meyer et al -23). In view of the different deceleration characteristics comparisons of real accident situations with the impact situation for motor-scooters is as a rule not possible.

For this reason, the resulting neck distortions makes important demands on further fundamental cognitions, especially the correlation of pain symptoms expressed by patients, of the accident mechanisms as well as the accident severity. It must be the objective to reduce the frequency of this injury pattern, on the one hand by improving the vehicle safety, on the other hand for the sake of an experts.

## 2. BASIS AND METHOD OF THE STUDY

By experience and cognitions of the Accident Research Unit Hannover[1] (Otte -24) accidents from 1985 to 1995 were evaluated. From 4.853 belt-protected car passengers n = 1238 persons suffered neck distortions AIS 1 (25.5%). These persons were analysed in respect of injury type and accident conditions compared to the total group of all injured and belted occupants. The evaluation was made on the basis of the statistic spot-check plan, used in the accident investigation, with statistic consideration of the collected data and correlation with the official statistic.

For such particular accidents in which cars collided with a speed change of less than delta-v 10 km/h, due to the collision, a special analysis was made (n = 117).

For these cases the deformation patterns on the car were investigated and described in detail. The determination of the delta-v is established from the accident reconstruction at the site of accident, made by the team, i.e. measuring of accident traces, vehicle final positions and an impact-analytical and mathematical supported collision analysis. For cases in which hardly any damages to the vehicle could be observed and for which the final position of the vehicle were not known, an estimation for the speed level was made. All

[1] In order of Federal Highway Research Institute (BASt)

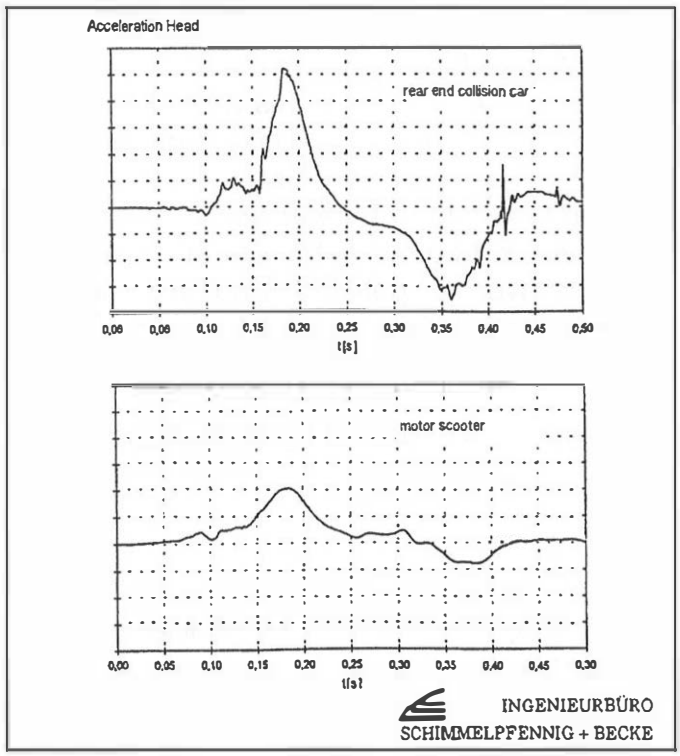
patients with neck distortion received a special questionnaire months after the accident event. It was the objective to statistically record over a period of almost 10 years after the accident the evaluation of traumatic long term consequences in long-time diagramme. Beyond this indications for the pain symptoms that resulted from the injuries were asked for. The present quota of replies was 30%, this correlates with comparable studies. In investigations of accidents with injured persons by a scientific team at the place of accident, including information by the police and rescue service, predominantly injured persons were included who had to be admitted to hospital, respectively those who already complained about pains at the site of the accident. This describes the investigated collective of patients who did not got any financial compensation for personal sufferings for inflicted pains and, therefore this differs from other studies of the same theme.

## 3. DEFINITION OF CERVICAL VERTEBRA DISTORTION AND KINEMATICS

In order to indicate whether a passenger could suffer a neck distortion in a traffic accident, knowledge about the passengers relative movement inside the car and load on the cervical vertebra as well as its kinematics is required. For this reason it is absolutely necessary to reconstruct the accident phases. The more precisely this can be done, the better the level of the accident severity and the kinematics of the cervical vertebra during the crash phase can be determined.

During the accident phase the passenger is following a relative movement, and in rear collisions a backward movement. This kinematic is influenced by the acceleration characteristic, i.e. in what period of time the load bearing due to the acceleration/deceleration takes place. An impact on easily deformable sheet-metal structures for instance leads to a relatively regular increase of the acceleration load, where as an impact on hard frame structures produces higher acceleration load during a short period of time. For an evaluation of a neck distortion it is by no means not required to observe the deformation pattern of both colliding cars, but those of the impacted one, the case vehicle. Vehicles with trailer-coupler have with similar impact impulse a different deceleration. The same deposition can be made for the often carried out comparison with motor-scooter collisions which have no plastic deformation characteristics (fig. 2).

Fig. 2 Characteristic of the time - acceleration curve of the head movement for tests in rear-end collisions with delta-v of approx. 9 km/h of cars, as well as of two-passenger motor-scooters (source Bühmann -25)




The level of the vehicle acceleration can be measured in the experimental collision analysis. On so-called dummies acceleration recorders are positioned on different parts of the body, but in the real traffic accident the acceleration peak can not even be measured on the vehicle. An accident data recorder would make this possible. One resort for quantification of the accident severity within the framework of accident investigations is the speed change of the vehicle within the collision delta-v or the energetic speed change EES respectively. This can in many cases be estimated by experts from the trace pattern at the site of accident, as well as from the deformation patterns on the car.

The kinematics of the body are influenced by the structure of the back seat and the structure of the headrest geometry. If the headrest is not situated in a proper position to the head (head top point = headrest upper edge) and the head extended above the headrest or between the headrest and the head is a gap, it could be a movement of the head and neck segment in a more dorsal position. This can cause a hypertension movement and/or a shearing load to the cervical vertebra with actions of ligaments and muscles.

In frontal collisions relative movements are also observed which may lead to a forward movement of the head and consequently to a bending or shearing of the cervical vertebra within the frame of the flexion. Beside this fact, the moving capacity of the cervical vertebra in ventral direction is larger in comparison with the dorsal direction. Therefore, in rear impacts the injury threshold will be reached sooner. The first amazing fact (fig. 3) is that about 50% of all neck

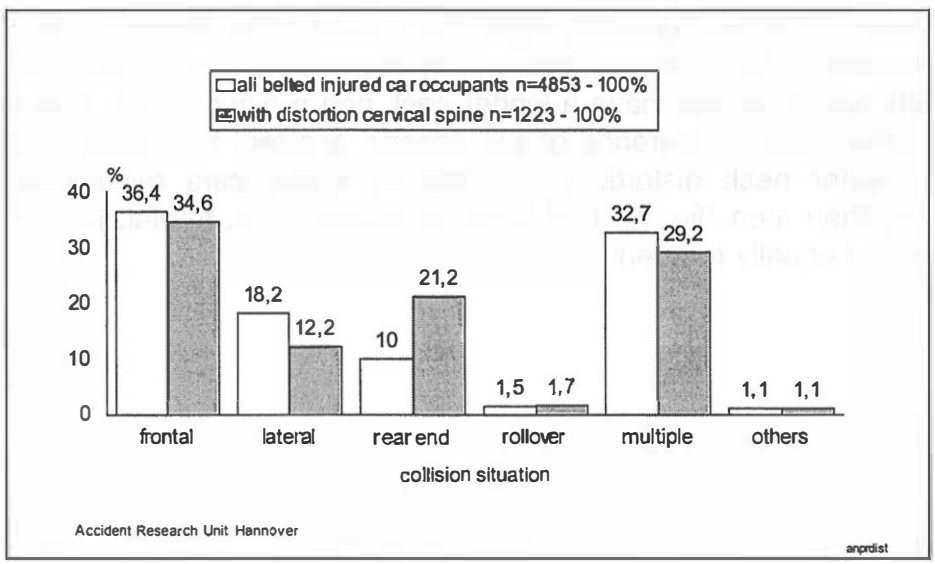
distortions were diagnosed with patients who were involved in frontal collisions. For the evaluation of injuries to the cervical vertebra it is, therefore, necessary to observe the actual impact direction. It must further be established to which extent rotation movements of the vehicle took place during an excentric impact, and in correlation with the simultaneous rotation was responsible for the forward movement of the head. Only after cognitions about the relative movement of the passenger and evaluation of the kinematics of the cervical vertebra, can the occurance probability of bony and/or ligamentary injuries and the distortion be evaluated.

The characteristic of the established injuries which may be of a different degree has to be included in the evaluation of the "soft tissue neck trauma". The term "whiplash trauma" is often used in medical reports of patient treatment. Injuries are on the one hand strains the so-called distortion, according to clinical findings, with pain symptoms to head, neck and shoulders, caused by pulling or relative moment of neck and shoulder muscles or the nerves respectively. As an injury severity, these are to be evaluated as AIS-1 of the Abbbreviated Injury Scale of the American Association of Automative Medicine (26). Bony and ligamentary injuries to the cervical vertebra are belong to the severe injury degree AIS 2 and higher. These too could be regarded as an injury mechanism by a bending movement, as it is called whiplash mechanism.

## 4. FREQUENCY OF NECK DISTORTION IN CAR ACCIDENTS

21.2% of the documented cases with neck distortions occur in rear, 34.6% in frontal collisions (fig. 3).

Fig. 3 Frequency of kind of collision of cars with and without neck distortions

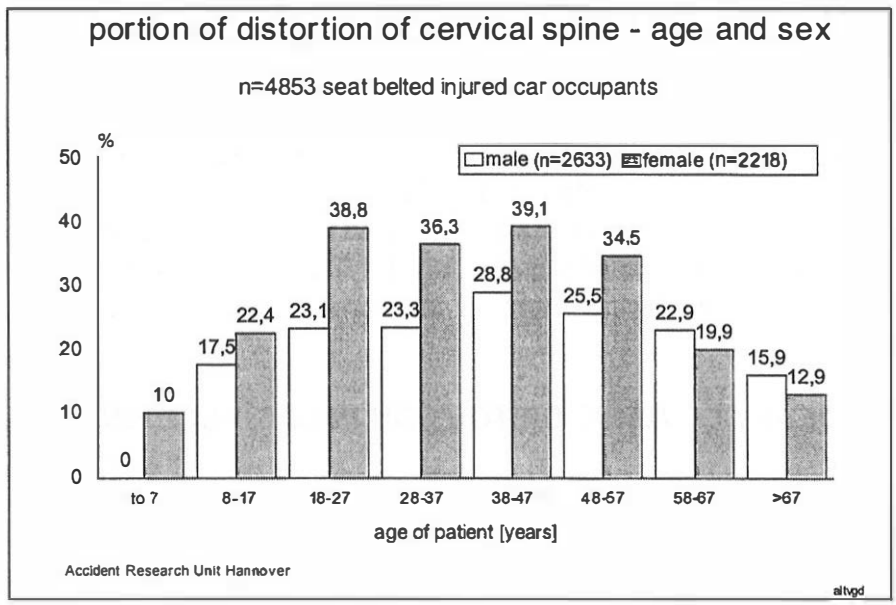



Cervical vertebra distortions were also established to a rate of 12.2% in lateral collisions and at 1.7% within the incident of rollovers. Multiple collisions are to a rate of 29.2% very frequent. A comparison of all belt protected and

injured passengers shows however that exclusively the rear end collision presents an exceptionally high risk for cervical vertebra distortions.

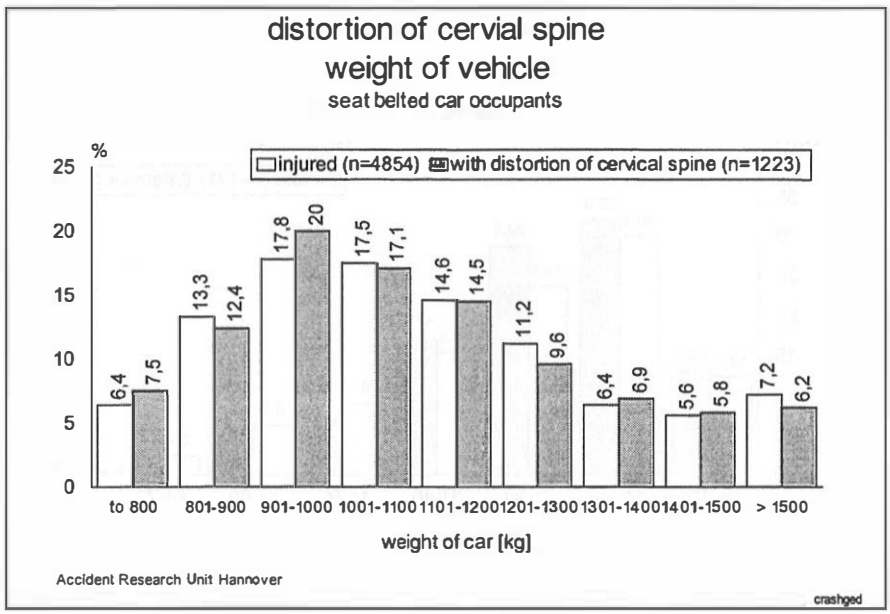
As far as the different seat positions in cars are concerned, no exceptionally higher frequency for neck distortions is established. About 75% of the persons with neck injuries are drivers, 58.4% were females and only 41.9% males, while 51.3% of all belt-protected injured car passengers were males and 44.9% females. Women suffer neck distortions more frequently than men. Especially in the age groups 18 to 57 years the portion of persons with distortions are significantly higher (fig. 4).

Fig. 4 Portion of injured belt-protected car passengers with neck distortion separated by sex and age



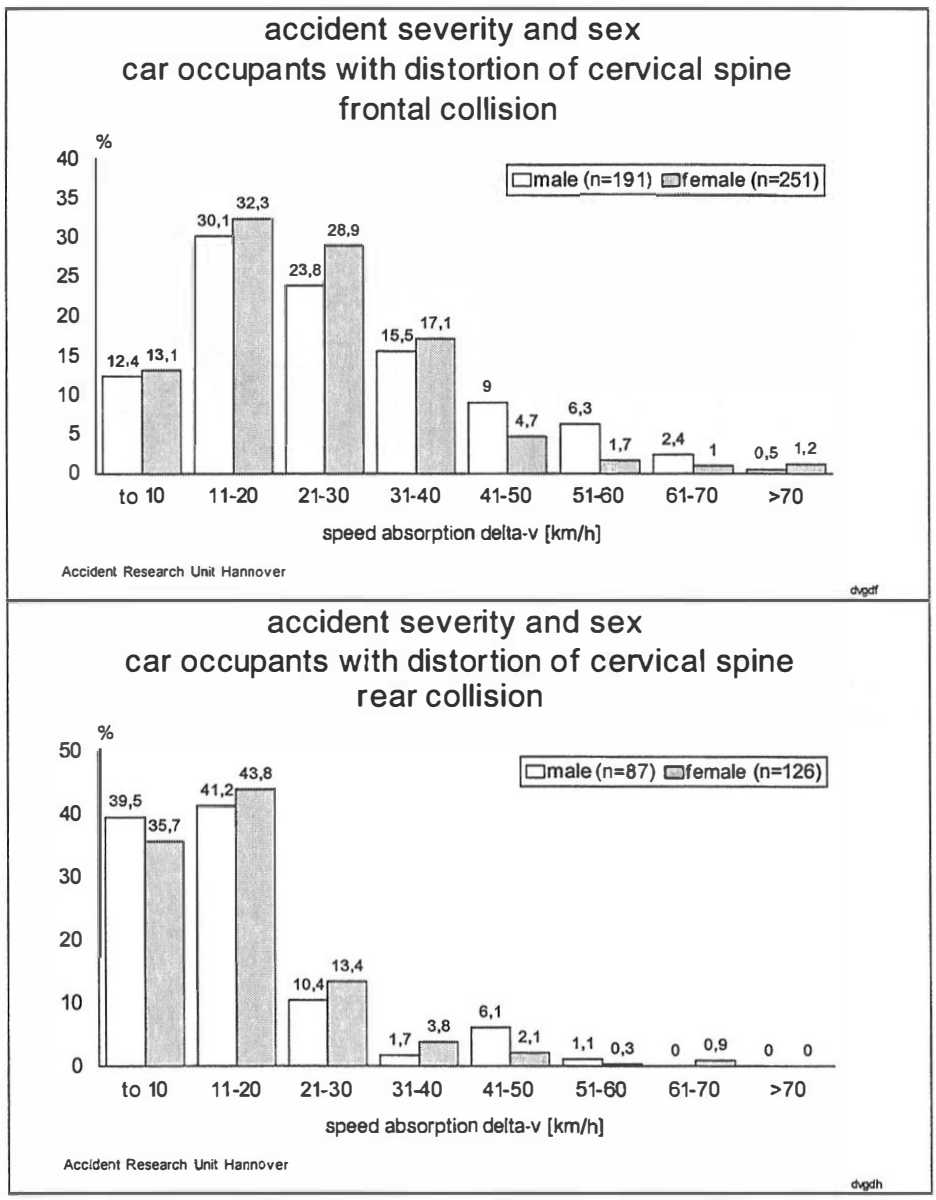

A reason for the exceptionally high injury risk for neck distortions to females could be seen in the anatomic dissimilarity of the sexes. In comparison of their own body height women have a longer neck and a bigger head. This analysis further shows some difference of sex-specific accident framework conditions. Women suffer neck distortions in small or lighter cars respectively more frequently than men (fig. 5). The kinds of collisions i.e. frontal, lateral or else are however equally frequent.

Fig. 5 Distribution of cars weight for people with neck distortions (100% ) compared to all injured car passengers (100%) .




As they usually drive lighter cars, the accident severity for women is normally lower because the mass of the car is included in the impact impulse. In these cases the speed change delta-v (fig. 6) is an accident severity parameter.

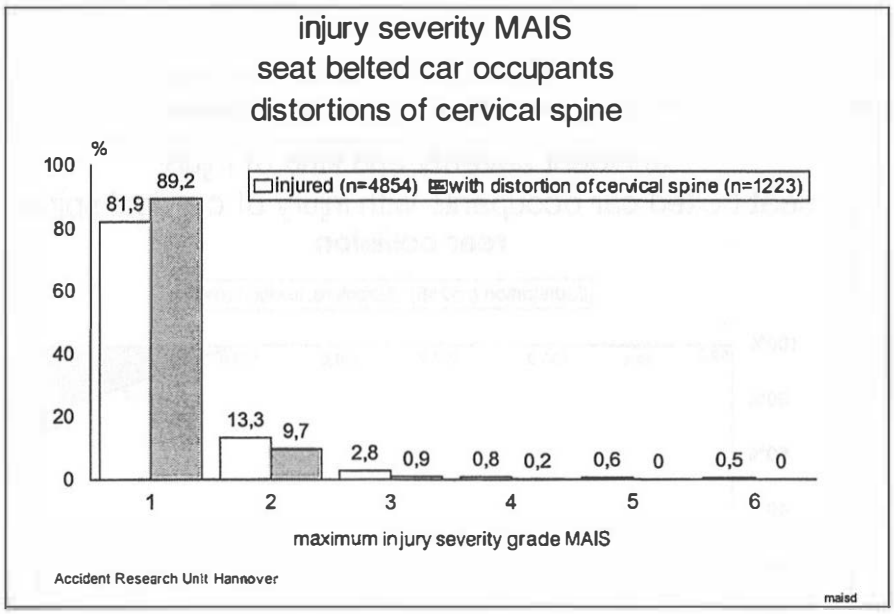
Fig. 6 Percentual distribution of delta-v comparing for male (100%) and female (100%) occupants




Neck distortions are more frequent in rear collisions than in frontal collisions at lower delta-v levels. In frontal collisions women represent a higher percentage of lower delta-v values in comparison with men. No difference is observed in rear collisions.

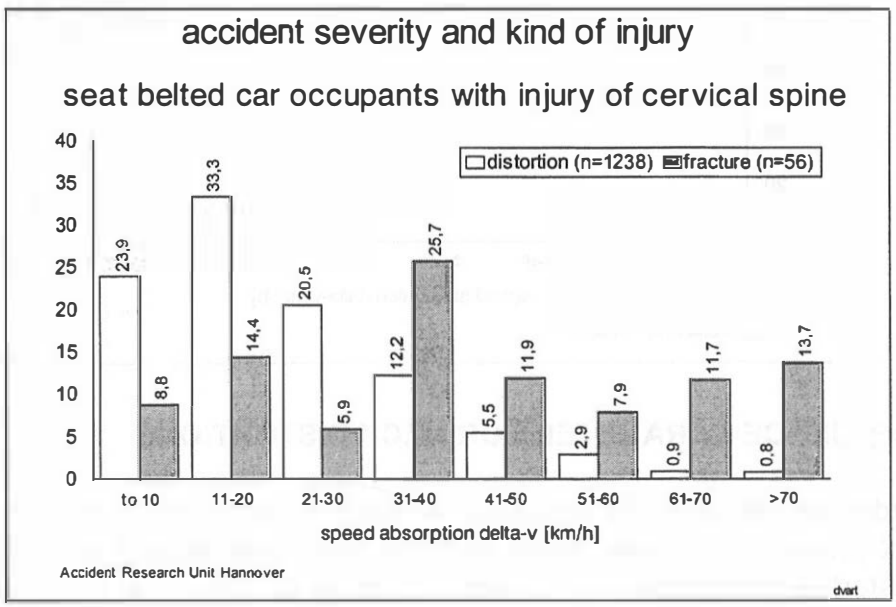
No great difference is shown in the distribution of the maximum total injury severity MAIS between car passengers with neck distortions and all other injured car passengers. 89.2% of the cervical vertebra injured suffered injuries of severity degree MAIS 1 compared with 81.9% of all injured belt-protected car passengers. It is noticeable that neck distortions are more frequently diagnosed when there are hardly any other severe injuries (fig. 7). No distortions were found at injury severity degrees of MAIS 5 and 6.

Fig. 7 Injury severity degree MAIS of persons with neck distortion (100%) compared with all injured belted occupants (100%)




Only an insignificantly higher proportion of vehicles with neck injured persons belonged to the weight category of 900 to 1,000 kilos (20% compared with 17.8%). The mass relation of the colliding vehicles can from a statistical point of view not be regarded as an influencial factor for neck distortions. For persons with neck distortions mainly lower delta-v values were observed, i.e. the accident severity is usually slight (fig. 8). Fractures/luxation fractures occur mostly at speed changes delta-v above 30 km /h.

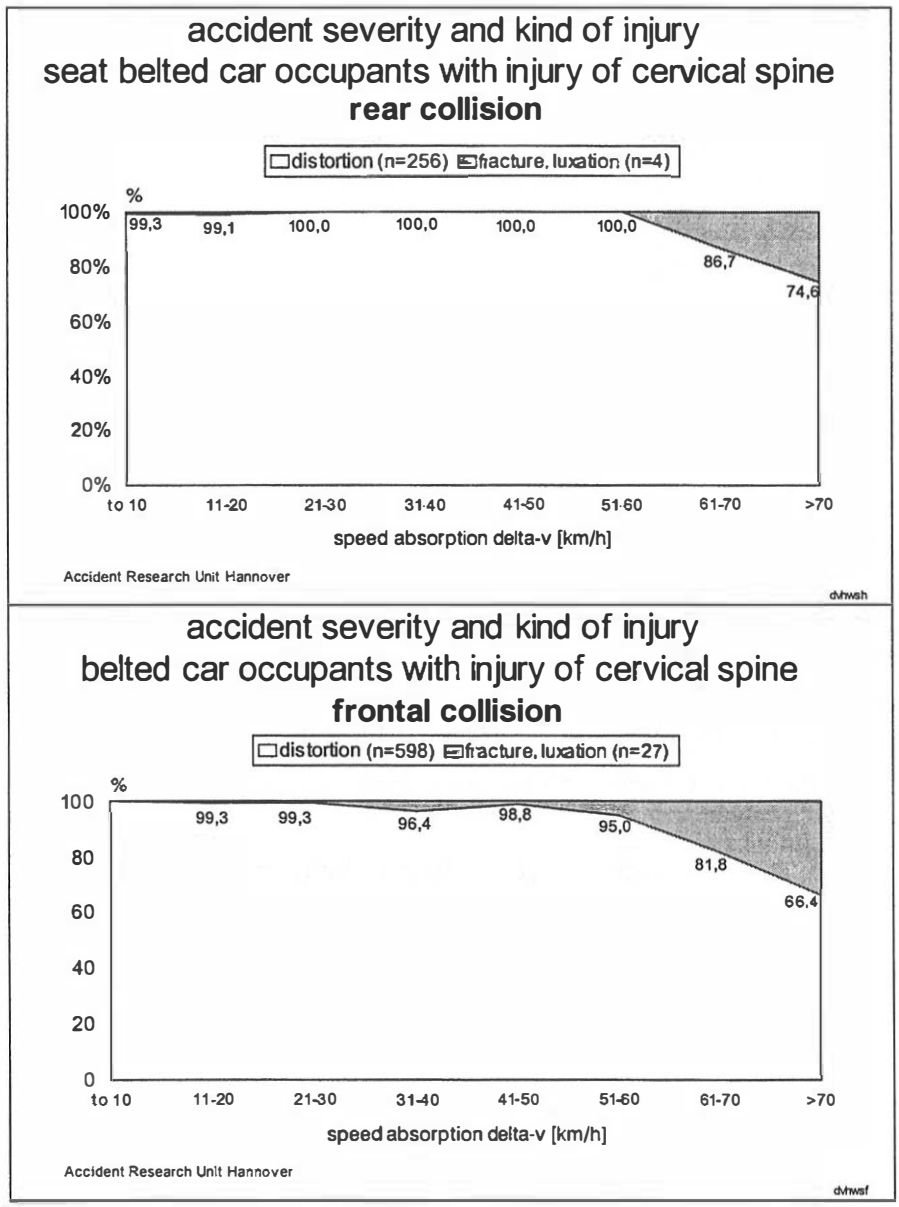
Fig. 8 Frequency of cervical vertebra injured persons at various delta-v values, differentiated by distortions and fractures/luxations




Looking to drivers with cervical spine injuries in relation to the accident severity delta-v a risk for fractures exists for higher delta-v in frontal as well as

rear collisions of more than 30 km/h, the lowest delta-v concerning fractures were found in frontal collision with 17 km/h and in rear collisions with 10 km/h (fig. 9).

Fig. 9 Proportion of different injury types distortion respectively fracture/luxation at different delta-v levels (100% all persons with cervical vertebra injuries)



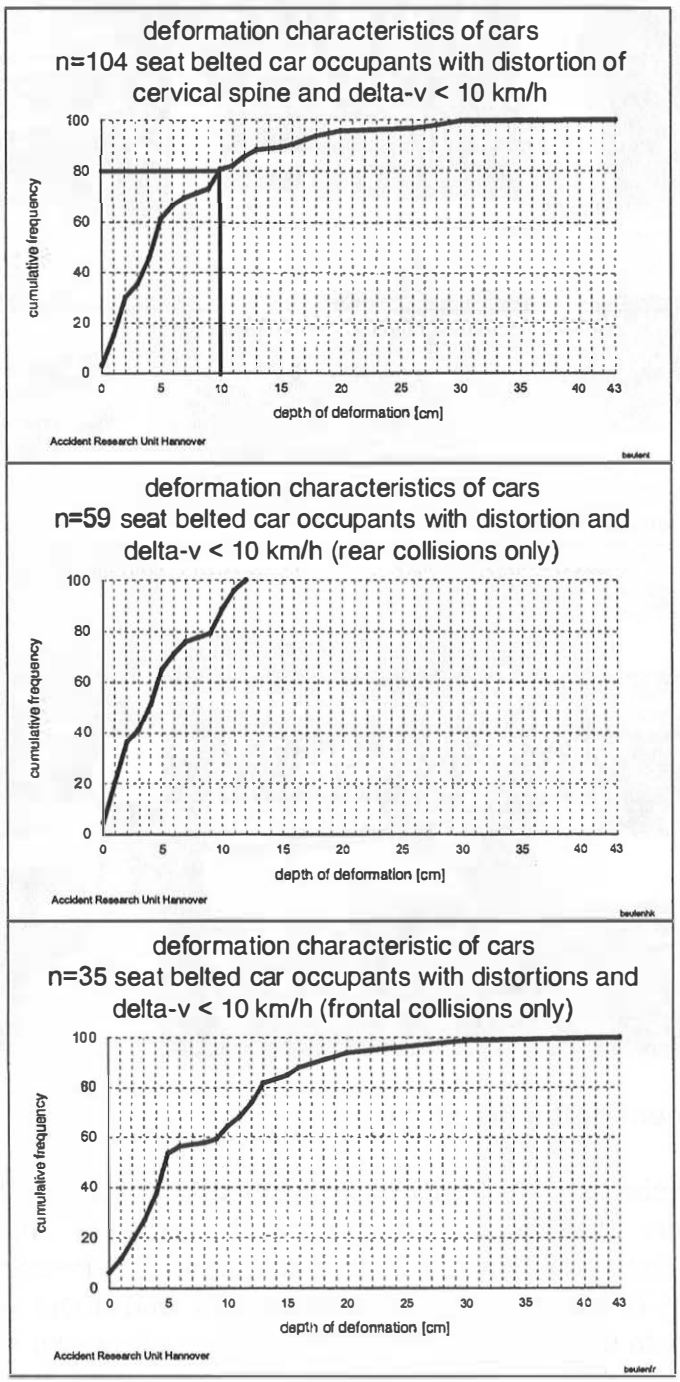

## 5. INFLUENCE PARAMETER FOR NECK DISTORTIONS

In order to estimate the influence of load in accidents during the actual accident phase, exclusively those persons were investigated who suffered a neck distortion in the region of a speed change of delta-v up to 10 km/h. For this purpose the picture of the deformation and injury pattern were correlatingly compared.

## 5.1 Deformation depth

80% of the cars with delta-v values <10 km/h had measurable deformation depths of up to 10 cm (fig. 10). In 90% of the frontal collisions with delta-v <10 km/h there were even deformation depths of up to 18 cm, in 90% of the rear collisions up to 10 cm.

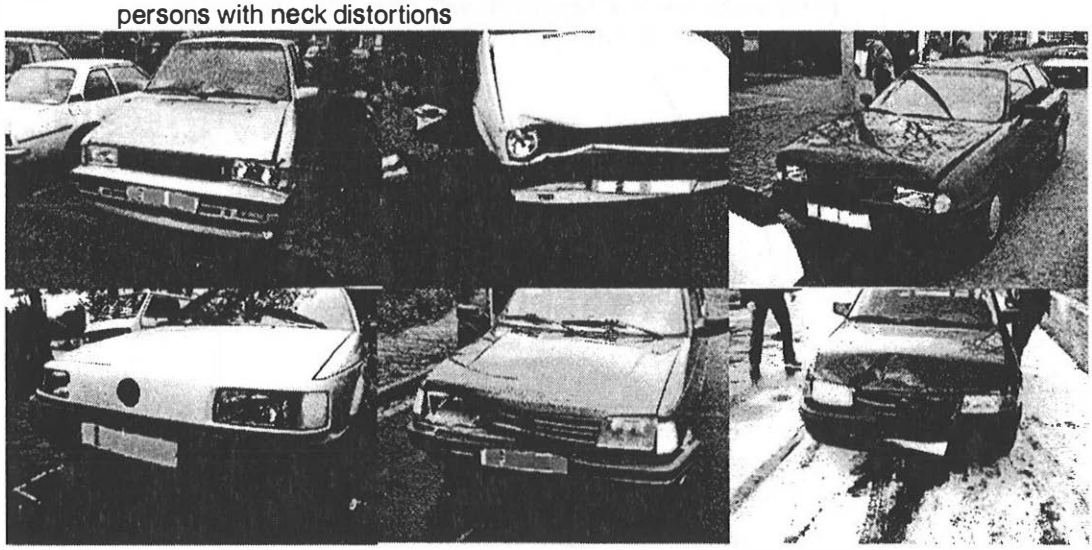
Fig. 10 Maximum deformation depths measured on cars with persons suffering neck distortions



It is remarkable that about 40% of all cars in rear collisions had only minimum deformation depths of up to 2 cm. The pictures in fig. 11 show such cars (after rear collisions) in which the drivers suffered a cervical vertebra distortion. The pictures in fig. 12 show those after frontal collisions.

Fig. 11 Selection of photographs of rear end after **rear collision**, delta-v <10 km/h - person with neck distortion

Fig. 12 Selection of photographs of car front after **frontal collision** delta-v <10 km/h - persons with neck distortions



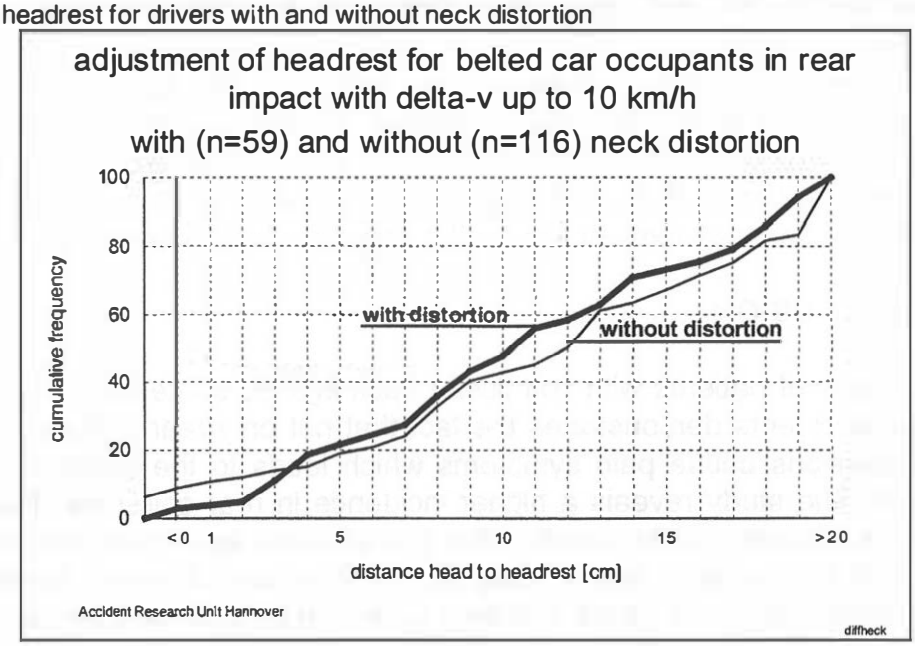
## 5.2 Adjustment of the headrest

In order to establish which influence the headrest has on the occurance of cervical vertebra distortions, the measured height of the headrest was compared with the seating height of the passenger. The investigation disclosed that the seating height of a person corresponds with about 53% of the body height, for men as well as for women. Women were however smaller than men through all age groups. While no influence of the age and the body height of a

person points to the possibility of causing a cervical vertebra distortion, an influence of the difference between seating height and height of the headrest could be presumed with considerable probability (fig. 13). This becomes evident on the presumption that a difference in measurement of up to 5 cm for a height of the headrest would still be regarded as correct. In view of these facts, it can be stated that in 80% of the neck distortions and at delta-v values up to 10 km/h the headrests were not correctly positioned.

The distribution of cumulated frequency of the differential measurement for occupants with and without neck distortions at the same delta-v-range looks like very similar. It is on a principle meaning, that with increasing distance of head to headrest a higher incidence for neck injuries exists. Therefore the conclusion of this result could be, that there is no high responsibility of an hyperextension motion for neck distortion injuries. Rather the thesis is evident, that rearward head motion occured horizontal within the first milliseconds after bumper contact and a shearing load is influenced the neck distortion occurance mainly.

Fig. 13 Cumulated frequency of the horizontal measurement - head top to upper edge of headrest for drivers with and without neck distortion




## 6. PAIN SYMPTOMATIC AND LONG TERM CONSEQUENCES

From the medical point of view, the diagnosis, the therapy and the long term consequences of neck distortions are difficult to define. As morphological comprehensible findings are missing, the medical judgement is mainly based on subjective symptoms mentioned by the patient. After a neck distortion and an interval more or less free of symptoms immediately after the accident, as a rule complaints in the sense of muscle contractions and mobile restrictions of the cervical vertebra muscles appear. It is noticeable that 60% of the documented persons with neck distortions complained about relevant pains

already at the site of the accident, immediately after the accident occurance. As a rule, these complaints last for a maximum period of 2 to 4 weeks. In some cases, they may last longer and lead to permanent obstructions. Especially the assessment of these long-term complaints is difficult in view of the fact that a causality with the accident occurance often can not be depicted with certainty, especially when structural damages are missing.

Within the framework of the investigations 45 patients with neck distortions (AIS 1) were contacted by questionnaires or telephone and asked about any complaints after the accident. These were 23 patients after frontal impacts and 22 after rear impacts. 38 of these 45 patients mentioned complaints. 5% of these complaints prevailed over a few days (max. 5 days), 7 patients had pain over a maximum of 3 weeks. 2 patients still had these complaints at the time of the assessment (6 years after the accident). 27 of the 45 patients, however, complained of pain exclusively on the day of the accident. Both patients with permanent complaints were involved in a rear collision, with 10 cm deformtion depth. On the other hand, patients remained free from complaints despite considerable deformation of their vehicle, in frontal (45 cm) as well as in rear impacts (up to 11 cm), after short-time pain symptoms directly after the accident .

Therefore a correlation between the extent of the complaints and the characteristics of frontal and rear collisions as well as the accident severity (deformation depth and extension) cannot be established. The differential measurement, i.e. head top and upper edge of headrest does not show any noticeable facts as an explanation for the prevailing pain symptoms.

## 7. CONCLUSION

This study of patients with soft tissue neck injuries so called neck distortion after car accidents demonstrates the fact that not only rear collisions but also frontal collisions cause pain symptoms which leads to the diagnosis of neck distortion. The study reveals a higher incidence in rear collisions. These pain symptoms appear mainly directly after the accident and could established at the site of the accident mainly. Only few of them are of longer duration. The observations also show cases with long term pain symptoms, after accidents in the so-called "low speed" region delta-v up to 10 km/h, in frontal as well as in rear collisions.

In view of the multifarious symptom complexity and the great number of possible influences only extensive studies with sufficiently great numbers of cases can provide more information about possible connections between the technical limits and biological reaction of the human being. This study will continue.

The significance of this study must beyond any doubt be seen in the basic total of the investigated patients who were examined by a research team at the site of the accident. For this reason they do not represent any insurance-relevant cases which were mostly subject of earlier studies. It is possible that for this reason patients with long-term pain symptoms are quite seldom in this

study. But the principle statement a large time duration after accident event and pain reaction is one indication for the severity of the trauma level could not be established. Most of the occupants with neck distortion had pain on the day of accident only. Another principle meaning for the mechanism of neck distortion in low speed impact could not confirmed, that with increasing distance of head to headrest a higher incidence for neck injuries exists. The distribution of cumulated frequency of the differential measurement for occupants with and without neck distortions at the same delta-v-range looks like very similar. The explanation for this could be the fact, that there is no high responsibility of an hyperextension motion for neck distortion injuries. Rather the thesis is evident, that rearward head motion occured horizontal within the first milliseconds after bumper contact and a shearing load is influenced the muscle strains resulting in pains defined as neck distortion. The advice to the study by Szabo (8) is suitable for the explanation of the mechanism, which should be seen mainly in the horizontal motion and not in hyperextension or hyperflexion for the occurance of neck distortion in low speed impacts.

## REFERENCE


(1) Gay, J.R.; Abott, K.H.
Common Whiplash Injuries of the Neck
J. Amer. Med. Ass. 152, 1698, (1953)

(2) Schmidt, G.; Kallieris, D.
Rekonstruktion des Unfallherganges bei Halsverletzungen
Zeitschrift Rechtsmedizin Bd. 72, 1-7, (1973)

(3) Gögler, E.
Schleuderverletzungen der Halswirbelsäule
Zeitschrift Wirbelsäule in Diagnostik und Therapie, Bd. 25, Hippokrates Verlag (1965)

(4) Ziffer, D.
Das Verhalten der Halswirbelsäule in Verbindung mit Schädelbasis und oberer Brustwirbelsäule
Zbl. Verkehrsmedizin Bd. 13, 193-217, (1967)

(5) Clemens, H.J.; Burow, K.
Experimentelle Untersuchungen zur Verletzungsmechanik der Halswirbelsäule beim Frontal- und Heckaufprall
Arch. Orthop. Unfall-Chir. 74, 116-145, (1972)

(6) Stofft, E.
Der Bandapparat der HWS
Phys. Med. Rehab. Bd. 11, 133-137, (1970)

(7) Saternus, K.S.
Mechanik des Schleudertraumas der HWS
Zeitschrift Rechtsmedizin 88, 1-11, (1982)

(8) Szabo, T.J.; Welcher, J.B.
Human Subject Kinematics and Electromyographic Activity During Low Speed Rear Impacts
SAE Paper 962432, 40th Stapp Car Crash Conference, (1996)

(9) Müller, E.
Schleuderverletzungen des Kopfhalteapparates
Zeitschr. Internist, 7. Jahrg. Heft 3, 89-94, (1966)

(10) Kamreth, H.
Das Schleudertrauma der HWS
Hippokrates Verlag Stuttgart (1990)

(11) Münker, H.; Rehart, S.; Langwieder, K.; Hett, W.
HWS-Beschleunigungsverletzungen
arzt + auto 71, 6-13, (1996)

(12) Otte, D.
Fahrzeugsicherheit 95 - Passive Sicherheit von Pkw bei Verkehrsunfällen
Bundesanstalt für Straßenwesen, Bergisch-Gladbach, (1997)

(13) Otte, D.
Review of the airbag effectiveness in real life accidents
Proc. 39th Stapp Car Crash Conf. SAE Nr. 952701, San Diego, USA, (1995)

(14) Walz, F.
Biomechanische Aspekte der HWS-Verletzungen
Zeitschrift Orthopädie 23, 262-267, (1994)

(15) Moorahend, U.
Die Beschleunigungverletzung der HWS mit interdisziplinärem Konsens
Fischer Verlag Stuttgart 197-208 (1993)

(16) VdS
Fahrzeugsicherheit 90
Verband der Schadenversicherer, München (1994)

(17) Wismans, J.
Incidentie a preventie van hel „whiplash" trauma
Report TNO Crash Safety Research Centre, Delft, The Netherlands (1994)

(18) Tingvall, C.
Personal Communication to Prof. Tingvall, (1996)

(19) Erdmann, H.
Schleuderverletzung der HWS
Wirbelsäule Forschung, Prox. 56, 14-18, (1973)

(20) Schroeter, F.
Ausheilungsergebnisse nach Beschleunigungsverletzung
Fischer Verlag, Die Beschleunigungsverletzung, 25-37, (1993)

(21) Steffan, H.
HWS-Untersuchungen mit Probanden
TU Graz, PCCrash Nachrichten, Heft 2/93, (1993)

(22) Ueno, K.; Kano, M.
Influences of the physical parameters on the risk of neck injuries in low speed impact rear end collision
IRCOBI 201-212, (1993)

(23) Meyer, S.; Hugemann, W.; Weber, M.
Belastung der HWS durch Auffahrunfälle
Zeitschr. Verkehrsunfall und Fahrzeugtechnik, (1994)

(24) Otte, D.
Die Verkehrsunfallforschung der Medizinischen Hochschule Hannover als Beispiel für die Bedeutung und Nutzen eines am Unfallort arbeitenden wissenschaftlichen Teams
Brandschutz, Deutsche Feuerwehr Zeitung, 6, 370-377, (1994)

(25) Bührmann, R.
Experimentelle Untersuchungen der kollisionsbedingten Geschwindigkeitsänderung zur Bestimmung der biomechanischen Belastung
Diplomarbeit FH Osnabrück und Ingenieurbüro Schimmelpfennig + Becke, Osnabrück, (1997)

(26) Amercian Association for Automotive Medicine
Abbreviated Injury Scale - Revision 90
Am. Ass. F. Autom. Med., Morton Grove, Illinois, USA (1990)