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Whiplash-type neck distortion in restrained car drivers: frequency, causes and long-term results

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Abstract An analysis was made of 1176 whiplash-type neck distortions taken from a total of 3838 restrained car driver incident reports. The percentage of whiplash-type neck distortion among injured drivers increased from less than 10% in 1985 to over 30% in 1997. Most occurred in head-on crashes or crashes with multiple collisions; only 15% occurred in rear-end collisions. More than 1,000 questionnaires were sent to the injured to find out about the duration and type of complaints caused by their cervical spine injury. Although only 138 (12%) returned the questionnaire, which may not be a representative sample, a further analysis was carried out. Of the 138, 121 (88%) indicated that they had suffered or were still suffering from their symptoms. The percentages of the various complaints were as follows: pain (74%), tension (6%) and stiffness (5%) in the head (27%),

neck (55%) and shoulder (8%). The duration of the complaints was longest after multiple collisions and when the onset of complaints was longer than 24 h after trauma. Women and elderly persons predominated slightly in the group with longer duration of complaints. A correlation between the severity of the accompanying injuries and duration of complaints was found. Lack of adequate follow-up for patients with less severe injuries posed considerable difficulties for this retrospective study. In order to better evaluate this problem, prospective studies are necessary, with documentation including diagnosis, treatments, complaint duration and type.

Key words Car accident · Whiplash-type neck distortion · Duration of complaints · Injury mechanism · Prognostic factors

Introduction

Although improved passenger security by means of safety-belts and airbags has led to decreased frequency of injuries related to car accidents, the frequency of whiplash-type neck distortions has increased over recent years [11, 14, 25]. Contrary to what has previously been suggested, the origin of these injuries is not limited to rear-end collisions [6]. Cervical spine injuries are caused mainly by head-on collisions, even at low speed [15]. “Whiplash injuries” are defined as soft tissue injuries,

which are assessed according to the Abbreviated Injury Scale (AIS) of the spine as minor grade 1 injuries [1]. In the literature, the term “whiplash injury” is loosely defined as an injury characterised mainly by pain and also as a cervical spine distortion without osseous or ligamentous instability [7]. The costs of such “whiplash injuries” nevertheless amount to approximately 10 billion Euros for Europe every year [15, 18]. At the time of the beginning of the study, less than 1% of all cars involved in crashes were equipped with airbags. Therefore, it was questionable whether there would be a group of airbag protected injured of sufficient size to evaluate the protective effect

of the airbag. The total injury severity for each patient was estimated by the Injury Severity Score (ISS) [2]. Long-term results of these whiplash-type neck distortions were also evaluated via reports of chronic complaints. The entire evaluation was independent of insurance data, since injured persons were evaluated by medical personnel directly at the scene of the accident.

Materials and methods

The occurrence of whiplash-type neck distortions in restrained car drivers was examined in a statistical retrospective analysis of car accident files from 1 January 1985 to 30 April 1997.

The accident files had been prepared by scientific teams at the Accident Research Unit, headed by the technical author (D.O.). The teams were informed directly via police radio and arrived at the accident scenes quickly in their own operation vehicles. In the area of the rural district and the town of Hannover, Germany, approximately 6,000 vehicular collisions with consequent injuries to persons happen every year. Around 1,000 (17%) of these collisions have been documented annually since 1988. This was done according to a statistical sample design plan. In the years 1973–87, an average of 300 vehicular collisions per year were evaluated. In addition to technical indications and an evaluation of the damage to the car, the files also include medical details concerning injuries to persons and the degree of their seriousness. The first medical institution providing care for the injured persons documented the diagnosis and types of injury. To provide a sufficient registration of any injuries recognised at a later stage, the files were completed at the end of the treatment by including the data from the final medical report. Those reports were routinely sent to the Accident Research Unit. Photographs of the vehicular collision scene and the cars, taken from outside and inside, as well as the relevant radiographs were also collected by the staff of the Accident Research Unit. These files can be used for a technical and medical accident analysis at a later stage. Through this database we were able to reconstruct the origin, type and extent of injury.

A letter was sent to 97% ($n = 1,136$) of the patients with whiplash-type neck distortions. The selection was based on availability of addresses and was completely independent of insurance data. On the basis of the questionnaires, which were returned and answered by 138 persons, the onset, duration and type of any complaints and the frequency of claiming damages were investigated. With regard to those with complaints of long duration, efforts were made to discover special features in the way their injury had occurred and to compare these against the total group. The statistical analyses for mean value differences utilised a double-sided t -test for unpaired random samples with unequal variance. Group differences were analysed with a chi-square, linear-trend or Kruskal-Wallis test. In a decision tree analysis with CART (Classification and Regression Trees), the predicting factors for the different durations of complaints were isolated [4].

Results

Accident demographics

In the 10,770 traffic accidents evaluated between the years 1985 and 1997, a total of 3,838 car drivers wearing seat belts were injured ("total seat belt group"). In 1,176 of these accident victims (30.6%), a whiplash-type neck distortion of type AIS 1 ("whiplash group"), i.e. pure soft

Fig. 1 Numbers of total accidents, of injuries in the total seat belt group, and of injuries in the whiplash group, evaluated from 1 January 1985 to 30 April 1997, and proportion of injuries in the whiplash group, compared with the total seat belt group (percentage)

tissue injury without osseous and ligamentous instability, was diagnosed clinically and by means of radiographs (including extension/flexion views to exclude fractures and/or instability). The total AIS of head and neck was defined as a maximum of 1 in the whiplash group, i.e. head injuries were excluded from the whiplash group. During the time period of investigation, the percentage of injured drivers suffering whiplash-type neck distortion rose from less than 10% to over 30% (Fig. 1). Forty-eight percent ($n = 566$) of the whiplash group ($n = 1,176$) were women, compared to only 37% women ($n = 1,435$) in the total seat belt group ($n = 3,838$). Thus, 39.4% of the women in the total seat belt group sustained a whiplash-type neck distortion. The average age in the whiplash group at the time of the accident was 34 years (range 18–82 years). Forty-nine percent of this group were 30 years and younger; only 25% were older than 42 years (Fig. 2). Given the high number of cases, the difference in age between the whiplash group ($n = 1,176$, mean age 34.20 years) and no-whiplash group ($n = 2,662$, mean age 35.68 years) was significant (t -test: $P = 0.003$), even if the mean age differed only slightly.

In the evaluation of how the accidents occurred, the angle, extent of the passenger compartment deformation, de-

Fig.2 Age distribution (percentage) within the whiplash group ($n = 1,176$) and no-whiplash group ($n = 2,662$)

formation direction and effect of the crash on the passengers were analysed.

The actual impact of the vehicle is described by the impulse angle; this angle includes all the forces that are effective on the vehicle and its occupants. The impulse angles were classified into 12 different groups. The '180° or -180°' group ($\pm 15^\circ$) corresponds to an impact directed from front to rear. Only in 26% of cases within the whiplash group (230 of the 983 where impulse angles were analysed) did an impulse angle from rear to front ($0/360^\circ \pm 15^\circ$) occur. In over half (55%, $n = 516$), the impulse angle was opposite, in the $150^\circ/180^\circ/210^\circ$ groups ($\triangle -210^\circ/-180^\circ/-150^\circ$), i.e. the impact direction was from front toward rear. In 17.8% of the affected vehicles ($n = 167$), the impact occurred with impulse angles in groups $240^\circ/270^\circ/300^\circ$ ($\triangle -120^\circ/-90^\circ/-60^\circ$), which corresponds to an impact from the left, and impulse angles in groups $60^\circ/90^\circ/120^\circ$ ($\triangle -300^\circ/-270^\circ/-240^\circ$), which corresponds to an impact from the right side (Fig. 3).

The impact aspects were classified into head-on, side, and multiple collision, as well as roll-over and rear-end collision. Only in 15.2% of collisions within the whiplash group (152 of the 997 cases in which the collision type was analysed) was it a case of a pure rear-end collision; 35.6% ($n = 355$) were head-on crashes and 36.2% ($n = 361$) crashes with multiple collisions. Eleven percent of injuries ($n = 114$) within the whiplash group occurred

Fig.3 Distribution of the impulse angles across 938 drivers from the whiplash group ($n = 1,176$) and number of collisions at different impulse angles (*in bold*). Impulse angle $180^\circ/-180^\circ$ corresponds with an impact directed from front to rear

with side collisions, and only 1.5% ($n = 15$) suffered the injuries when the car rolled over. In the total seat belt group (collision type analysed in 3,546 cases), head-on crashes and crashes with multiple collisions, each accounting for 36% of the total, are, however, more frequent than rear-end collisions (6.7%). Side impacts account for 17.7% of collisions, and roll-overs for 1.5%. Following a rear-end collision, 60% within the total seat belt group suffered a whiplash-type neck distortion, whereas the figure for the other collision types was only 25% (chi-square test: $P < 0.001$).

A parameter for the severity of the accident is the change in speed as a consequence of the collision, Δv . This can be determined retrospectively from the extent of the deformation, the breaking and skidding distances measured at the scene of the accident and the ascertained collision and final position of the car. In 23.2% of collisions ($n = 231$) within the whiplash group (Δv analysed in 997 cases), Δv was 10 km/h or less, which corresponds to a very minor crash; 29.5% ($n = 295$) had a Δv of 11 to 20 km/h and 20% ($n = 63$) each in the ranges of 21 to 30 and 31 to 50 km/h ($n = 75$). Only 5.8% ($n = 20$) of the patients with whiplash-type neck distortion had suffered the injury in a high-energy accident with a Δv of more than 50 km/h. However, the mean Δv in the whiplash group was significantly higher in comparison to that in the no-whiplash group (t -test: $P = 0.005$).

Fig. 4 Change in speed as a consequence of the collision, Δv , and type of collision in 997 injuries in the whiplash group ($n = 1,176$)

The various types of collisions differed regarding the Δv . In the whiplash group, 42% of the 152 rear-end collisions ($n = 64$) were minor ($\Delta v < 10$ km/h), while in the case of head-on collisions, only 10% (36 of 355) were minor. Overall, the average Δv was highest in the head-on collisions. The accidents with roll-over ($n = 15$) had a low Δv (≤ 10 km/h) in 46% of the cases (Fig. 4).

The total severity of the patients' injuries was evaluated according to the Injury Severity Score (ISS) [2]. This score also permits a prognosis in addition to the evaluation of the injury severity. It is calculated as the sum of the squared AIS of the three major injuries, and was determined in 99% of patients ($n = 3,794$) in the total seat belt group. Thirty-five percent ($n = 410$) in the whiplash group (ISS determined in 1,170 cases) had a score of 1, which corresponds to an isolated whiplash-type neck distortion. Only 26% ($n = 316$) had an ISS of more than 2 [for example: ISS 3 $\rightarrow$ whiplash-type neck distortion (AIS 1) and additionally two single injuries (both AIS 1)]. In comparison to the no-whiplash group (ISS determined in 2,624 cases), the whiplash group (ISS determined in 1,170 cases) had a lower rate of isolated injuries (ISS 1) and multiple injuries (ISS ≥ 5) (Fig. 5). The average ISS of the whiplash group (mean ISS = 2.6) was significantly

Fig. 5 Comparison of percentages of Injury Severity Score (ISS 1 to 38) in 2,624 injuries in the no-whiplash group ($n = 2,662$) and 1,170 injuries in the whiplash group ($n = 1,176$). (In the whiplash group, an ISS of 4 and 8 is not possible, because every person in this group has at least one injury AIS 1: the whiplash-type neck distortion. An ISS of 7 is not possible at all)

lower than that of the no-whiplash group (mean ISS = 5.8) (t -test: $P = 0.001$). Even when contemplating the single ISS groups, the injured in the no-whiplash group were more frequently in the higher ISS groups (linear-trend test: $P < 0.001$).

Long-term consequences

At the end of 1997, 1,136 persons (97%) of the whiplash group ($n = 1,176$) were written to and asked about type, onset and duration of their complaints. Additionally, questions were asked about any treatments received. A total of 138 (12.1%) of those written to completed and returned the form (follow-up group). The following results are based upon the collected questionnaires. Thirty-seven percent ($n = 51$) had persistent complaints at the time they were questioned. The percentage of those with complaints fluctuated considerably over the last 10 years of the investigated period; however, it was not possible to recognise any clear trends (Fig. 6).

Altogether, 121 (87.7%) within the follow-up group had complaints. Up to three different complaints were identified. A total of 190 individual complaints were localised to the neck itself (55.3%); 26.8% were localised to the head and 7.5% to the shoulder areas. In 74% of the complaints it was a case of pain. Tension (6.3%) and restricted range of motion (5.3%) occurred considerably less. Fifty percent of the complaints had begun immediately after the accident, a further 26% within the first 6 h,

Fig. 6 Annual number of drivers of the whiplash group with complaints persisting till the end of 1997, in absolute numbers (*left*) and as percentages (*right*) of annually evaluated questionnaires (total number of evaluated questionnaires $n = 138$)

Duration of the complaints in days

Onset \ Duration	at once	≤6h	6-12h	12-24h	>24h
n	86	46	16	11	14
Mean duration	334	289	347	210	595
Median duration	42	21	42	21	180

Fig. 7 Onset and duration of the 190 single complaints (for example: complaints started at once ($n = 86$) had a mean duration of 334 days and a median duration of 42 days)

9% after 6–12 h, 6% after 12–24 h and 8% after more than 24 h. Complaints starting within the first 24 h revealed no significance in regard to the duration of symptoms (Kruskal-Wallis test: $P = 0.23$). However, complaints that had begun after more than 24 h lasted for twice as long as the rest (Fig. 7). This difference was highly significant (Kruskal-Wallis test: $P < 0.001$).

The average duration for all complaints was 336 days (median 42 days). Fifty percent of the complaints lasted more than 60 days. Two groups of nearly equal size, one with a duration of complaints of 60 days maximum (subgroup I, $n = 53$), and the other with a duration of over 60 days (subgroup II, $n = 55$) were evaluated. The remaining 13 of the 121 individuals with complaints within the follow-up group were left out of the following evaluations because values concerning the corresponding items were missing from their data set.

Age at the time of the accident

Forty-one percent ($n = 482$) in the whiplash group ($n = 1,176$) were less than 27 years old. Within subgroup II (duration of complaints > 60 days, $n = 55$), 27% ($n = 15$) were younger than 27 years, in contrast to 40% ($n = 21$) in subgroup I (duration of complaints ≤ 60 days, $n = 53$). Patients in subgroup II showed the highest average age

Fig. 8 Comparison of age distributions (percentages) across the total whiplash group ($n = 1,176$) and separately for follow-up subgroups I (complaints ≤ 60 days, $n = 53$) and II (complaints > 60 days, $n = 55$)

(38 years). Subgroup I (mean age 36.7 years) and the whiplash group (mean age 34 years) showed almost the same age distribution, except in the age group “> 67 years”, which had a rate of almost 10% within subgroup I (Fig. 8). There was hardly any difference in the distribution between the sexes, either. There were more men than women in subgroup I (m:f 53:47). More women had longer lasting complaints (i.e. subgroup II) (m:f 44:56). The differences in sex and age were not significant, however (chi-square test: $P = 0.339$).

Impulse angle

The impulse angles of the two groups with different durations of complaints differed only slightly. In both groups collisions directed from the front to the rear (180° – -180° and 210° – -150°) dominated. Impulse angles directed from the rear to the front occurred in 18/17% within subgroups I/II (Fig. 9).

Fig. 9 Distribution of impulse angles across subgroups I (*underlined numbers*) and II (*standard numbers*), and number of collisions at different impulse angles. (Impulse angle 180° – -180° corresponds with collision directed from front to rear)

Fig. 10 Comparison of Δv distributions (percentages) across the total whiplash group ($n = 997$) and subgroups I and II of follow-up group ($n = 138$)

The parameter Δv

This parameter correlates with the severity of the accident. Surprisingly, subgroup I had higher Δv values (Δv 31–50 and > 50 km/h). Forty-one percent of the patients in subgroup II had an accident at a Δv of only 11–20 km/h. In the accidents of the most minor severity ($\Delta v \leq 10$ km/h), patients with complaints were *underrepresented* in comparison to the whiplash group ($n = 1,176$) (Fig. 10). Despite a considerable difference in the Δv mean values between subgroups I (51 km/h) and II (22 km/h) no significant difference was revealed (t -test: $P = 0.211$).

Collision type

Head-on collision occurred in 47% within subgroup I and in 28% within subgroup II. Forty-three percent within subgroup II and 36% within subgroup I suffered from crashes with multiple collisions. The other collision types occurred with similar frequencies across the different groups (Fig. 11). After head-on collisions, only 36% had longer lasting complaints, whereas after crashes with multiple collisions, 71% had longer lasting complaints (chi-square test: $P = 0.05$). In the other collision types, 50% of the injured had longer lasting complaints.

Fig. 11 Comparison of type of collision distributions (percentages) across the total whiplash group ($n = 997$) and subgroups I and II

Fig. 12 Comparison of Injury Severity Score (ISS) distributions (percentages) across subgroups I and II. ISS scores of 4, 7 and 8 are not possible, because every person in these group has at least one injury AIS 1 (the whiplash-type neck distortion)

Injury Severity Score (ISS)

The classification according to the Injury Severity Score (ISS) revealed significant differences between the two subgroups (chi-square test: $P = 0.03$). The patients of sub-

group II were overrepresented in the groups with higher ISS (6 and > 7), whereas the injured of subgroup I dominated the ISS 1 group (Fig. 12).

Predicting factors

In a decision tree analysis, the predicting factors for duration of complaints were isolated [4]. This statistical procedure allows division of a cohort into groups under pre-specified criteria. In subgroups I and II, age, gender, ISS, Δv , impulse angle and type of collision were used as criteria for a decision tree. The ISS was the most predictive factor for the duration of complaints for the entire group ($P = 0.004$). Eleven of the 12 patients with an ISS of more than 5 had complaints for more than 60 days (subgroup II). For patients with an ISS of 5 or less, the Δv was the most important factor for separating subgroups I and II ($P = 0.029$). Surprisingly, 22 of the 31 patients with a Δv of more than 25 km/h were in subgroup I (duration of complaints ≥ 60 days). The remaining 65 patients were divided by type of collision. Of the 19 persons with multiple collision type, 16 had long lasting complaints (subgroup II). On the other hand, 60% of the patients who were involved in non-multiple collisions (head-on, side, rear-end, roll-over) were in subgroup I. Age, gender and impulse angle were not of predictive value in this statistical review (Fig. 13).

Claiming damages

Seventy-seven of the follow-up group (65%) stated that they had claimed damages on an insurance ("damage claiming group"). Of those, 20 (26%) actually recovered money. This group did not show any difference with those who did not recover any damages they had claimed for, as regards accident demographics or long term consequences. The damage claiming group did not differ from the rest of the follow-up group (those who did not claim damages on an insurance, "no-damage claiming group", $n = 61$) in accident demographics. There was also no difference in the frequency of complaints. The duration of complaints was shorter in the damage claiming group (mean 280 days vs 349 days in the no-damage claiming group).

Discussion

A considerable increase in the rate of traffic accidents with high numbers of casualties has occurred in the 1950s, 1960s and 1970s. However, a reduction in injuries has been registered in the most recent decades, despite constantly increasing accident numbers [22, 23]. This may be due to the obligatory wearing of seat belts. Safety has been considerably improved through reinforcement of

Fig. 13 Decision tree analysis with CART (Classification and Regression Trees) [4] of 108 patients with complaints in follow up group (n = 138)

vehicles and by means of the airbag [12, 24, 25]. Nevertheless, whiplash injuries have continued to increase over the last 10 years. This increase applies to the absolute numbers as well as to the percentages of whiplash-type neck distortion in injured drivers. This percentage rose from under 10% in 1985/86 to over 30% in 1995 and later. A major reason for this increase may be a higher level of individual expectation regarding this injury nowadays. Another reason is based on improved passenger restraint, which results in increased movement of the non-fixed head and neck in relation to a well-stabilised torso. This is particularly true in head-on collisions. Pure head-on collisions accounted for 36% of our patients with a whiplash-type neck distortion. This is a considerably higher rate of whiplash injury than is found in pure rear-end collisions (15%). With insurance regulations, the question of collision direction plays an important role. According to insurance definition in Germany, a whiplash-type neck distortion can only occur with an impact directly from the front or rear [19]. The high rate of side collisions with a whiplash-type neck distortion (11%) in our study clearly disproves this.

Minor accidents as a “trigger” for a whiplash-type neck distortion occur more and more. In our study, in 23% of the cases, the change in Δv amounted to 10 km/h or less. The proportion of very minor accidents as a causative factor was still lower in the case of the head-on collisions. This could be due to bio-mechanical reasons. In the anatomical-functional structure of the neck muscles, the extensors prevail. More stability is possible with flexion forces, as occur in head-on collisions. To what extent the posture of the car occupant plays a role is unknown. Prevailing extensor muscles may either prevent or cause a

whiplash-type neck distortion. The increase in the number of minor accidents leading to a diagnosis of whiplash-type neck distortion may be explained by an enhanced sensitivity of the affected persons. The ease of claiming damages definitely plays an important role.

Whiplash injuries are minor injuries according to the Abbreviated Injury Scale (AIS type 1) of the spine. Moreover, they usually occur in the form of an isolated injury. Only one-quarter of the patients achieved an Injury Severity Score (ISS) of more than 2. Despite this low severity of injury, a high percentage of chronic complaints occurred in the second part of our study. In that part, we tried to evaluate the initial complaints and long-term consequences retrospectively. Although we sent letters to more than 1,000 of the injured, we received only 138 (12%) completed questionnaires. While this may not be a representative sample, a further analysis of these 138 persons was conducted as a second part of the study. In comparison to the literature, a cohort of 138 whiplash-type neck distortions with long-term follow-up is a high number. We consider that the results of this part of the study are of sufficient value to be reported.

The initial complaints involved pain in three-quarters of the cases – only half of which, however, were localised to the neck itself. Over one-third affected the head and shoulder. A classification of the severity of pain was not included in the questionnaire. Half of the complaints lasted longer than 60 days. We found no difference in the duration of complaints where the complaint had begun within the first 24 h. However, those with complaints starting after 24 h reported a complaint duration twice as long as the others. This is contrary to the theory, applied up to now, that early commencement of complaints meant

a longer duration of complaints [13]. In the group with longer lasting complaints, women predominated slightly; in the other group men predominated. Nevertheless, the differences between the sexes in our study was not as significant as other authors have described [8, 16]. Also, the group with a higher average age revealed a longer duration of complaints. The duration of complaints did not correlate with the impulse angle. The Δv of the group with shorter lasting complaints was in fact higher. This can be partially explained by the higher proportion of head-on collisions in this group. The ISS permitted a prognosis regarding the duration of complaints. Almost half of the patients with short-term complaints had an isolated injury (ISS 1); in the other group, this was true for only one-third. Regarding our results, individual pain digestion seemed to be a critical factor, as discussed and mentioned extensively in the literature, although this was not investigated in our study [3, 5, 8–10, 17, 20].

Conclusion

In the analysis of insurance-independent data, it is the accident mechanism that is relevant from a prognostic point of view, not the accident severity. Initial symptoms and chronic complaints can, therefore, not be substantiated sufficiently by accident conditions alone. Aside from a slight correlation between accompanying injuries and the duration of the complaints, only the perception of the individual and their way of coping with complaints remain decisive factors. Lack of adequate follow-up for patients with less severe injuries posed considerable difficulties for this retrospective study. The evaluation and documentation of injured persons directly at the scene of the accident has advantages over later arising reports, which may be coloured by perspectives of compensation. Delayed initial complaints on the other hand, were only documented if the affected patient had been registered at all due to any suspicion of personal damage. In order to solve this problem, prospective studies are necessary that include the documentation of the diagnosis, treatment, duration and type of all complaints.

References

1. American Association for Automotive Medicine (1995) Abbreviated Injury Scale, Revision 90. American Association for Automotive Medicine, Morton Grove, Illinois
2. Baker ST, O'Neill B, Heddon W, Long EB (1974) The Injury Severity Score: a method for describing patients with multiple injuries and evaluating emergency care. *J Trauma* 14: 187–195
3. Barrett K, Buxton N, Redmond AD, Jones JM, Boughey A, Ward AB (1995) A comparison of symptoms experienced following minor head injury and acute neck strain (whiplash injury). *J Accid Emerg Med* 12: 173–176
4. Brieman L, Friedman J, Olshen R, Stone C (1984) Classification and regression. Wadsworth, Pacific Grove
5. Gargan MF, Bannister GC (1994) The rate of recovery following whiplash injury. *Eur Spine J* 3: 162–164
6. Gargan MF, Bannister GC, Main CS, Hollis ST (1997) The behavioural response to whiplash injury. *J Bone Joint Surg Br* 79: 523–526
7. Jenzer G, Walz F (1991) Die "Schwere" des "Schleudertraumas der Halswirbelsäule". *Z Unfallchir Versicherungsmed* 84: 7–19
8. Jonsson HJ, Cesarini K, Sahlstedt B, Rauschnig W (1994) Findings and outcome in whiplash-type neck distortions. *Spine* 19: 2733–2743
9. Karlsborg M, Smed A, Jespersen H, Stephensen S, Cortsen M, Jennum P, Herning M, Korfitsen E, Werdelin L (1997) A prospective study of 39 patients with whiplash injury. *Acta Neurol Scand* 95: 65–72
10. Kessels RP, Keyser A, Verhagen WI, van Luijckelaar EL (1998) The whiplash syndrome: a psychophysiological and neuropsychological study towards attention. *Acta Neurol Scand* 97: 188–193
11. Kuner EH, Schlickewei W, Oltmanns D (1995) Der Airbagschutz beim Verkehrsunfall. Änderung im Verletzungsmuster und Reduktion der Verletzungsschwere. *Unfallchirurgie* 21: 92–99
12. Mackay M (1994) Engineering in accidents: vehicle design and injuries. *Injury* 25: 615–621
13. McKinney MB (1994) Behandlung der HWS-Distorsion bei sog. "Schleudererletzungen". *Orthopäde* 23: 287
14. Otte, D (1995) Report of the airbag effectiveness in real life accidents. Proc. 39th Stapp Car Crash Conf. SAE no. 952701, San Diego, 1995
15. Otte D, Pohlemann T, Blauth M (1998) HWS Distorsionen im geringen Unfallsschwerebereich. *Verkehrsunfall Fahrzeugtech* 1: 15–21
16. Pennie B, Agambar L (1991) Patterns of injury and recovery in whiplash. *Injury* 22: 57–59
17. Radanov BP, Di Stefano G, Schnidrig A, Sturzenegger M, Augustiny KF (1993) Cognitive functioning after common whiplash. A controlled follow-up study. *Arch Neurol* 50: 87–91
18. Radanov BP, Dvorak J (1996) Spine update. Impaired cognitive functioning after whiplash injury of the cervical spine. *Spine* 21: 392–397
19. Schmidt G (1989) Biomechanik des Schleudertraumas der Halswirbelsäule. *Versicherungsmedizin* 41: 121–126
20. Smed A (1997) Cognitive function and distress after common whiplash injury. *Acta Neurol Scand* 95: 73–80
21. Squires B, Gargan MF, Bannister GC (1996) Soft-tissue injuries of the cervical spine. 15-year follow-up. *J Bone Joint Surg Br* 78: 955–957
22. Suren EG, Sturtz G, Tscherne H, Behrens S, Gotzen L (1977) Verletzungsverteilung und -ursachen bei gurtgeschützten PKW-Insassen. *Chir Forum Exp Klin Forsch* 114–118
23. Tscherne H, Appel H, Behrens S (1978) Patterns of injuries of restrained car passengers. *Langenbecks Arch Chir* 347: 331–344
24. Walz E (1997) Biomechanics and injury prevention in road traffic. *Ther Umsch* 54: 238–241
25. Zador PL, Ciccone MA (1993) Automobile driver fatalities in frontal impacts: air bags compared with manual belts. *Am J Public Health* 83: 661–666