OCCURRENCE OF CERVICAL SPINE INJURIES IN CAR CRASHES

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A material of 600 rear-end impacts has been analysed in-depth in co-operation between engineers, physicians and university hospitals. The characteristics of the injury pattern are discussed with respect to car-related crash parameters. Cervical spine distortion injuries (CSD) are the dominating injury. The CSD injuries are differentiated by use of the internationally accepted Quebec Task Force Classification (QTF). Risk factors for neck injuries including possible long-term consequences are investigated. Results from more than 40 sled tests with volunteers are reported; different injury risk factors, for example males/females are discussed with respect to biomechanical factors. The study outlines requirements for improved seat/head-restraint systems and proposes test standards for the simulation of rear-end crashes.

Keywords: Cervical Spine distortion in Real Crashes, Improvement of Safety Standards

1. INTRODUCTION

The comparison of major accident samples from the German Motor insurers shows that the incidence of cervical spine injuries in Motor Vehicle Accidents have almost doubled in the last 20 years.
The assumed socio-economic losses for rear-end collisions in Germany (calculated after German Injury Cost Scale [1]) would amount up to 2 Billion Marks, that means about 1100 million EURO only for rear-end collision cases for the year 1990 in the old Federal Republic of Germany. In about 54% of all car-to-car accidents with personal injury the accident pattern was a rear end collision [2;3]. An estimation based on the insurance statistics in Germany came to about 200.000 reported cervical spine injuries after rear-end collisions for the year 1990 only in former Western-Germany.

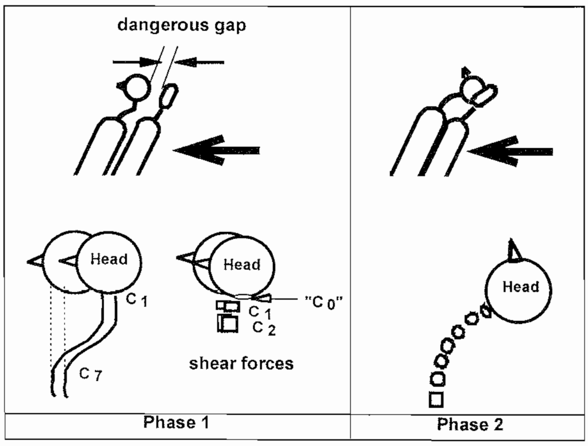

Figure 1: Injury mechanism after rear end collision. Source: Walz [4] (Phase 1: head translation; phase 2: neck extension)

In March 1995 Spitzer et al. published the results of the "Quebec Task Force on Whiplash Associated Disorders" (QTF). The scale is based on the division between subjective and objective criteria, as shown in table 1.

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TABLE 1: QTF Injury Degrees, The Quebec Classification of Whiplash Associated Disorders

In general, the awareness of the public concerning head-restraint adjustment is very poor. Volunteer tests [6;7] have clearly shown the importance of a short horizontal distance and correct height adjustment, which can significantly reduce the shearing movement, head extension angle and therefore the injury risk Unfortunately, in many cars it is simply not possible to reach a sufficient vertical and horizontal head-restraint position, especially for taller persons.

2. MATERIAL AND METHODS ACCIDENT INVESTIGATION

All 15.000 GDV "Vehicle Safety-90" (VS 90) cases (18% of all car-car collisions with injuries of the year 1990 in West-Germany) were screened to find out defined cases with: rear-end collision, single impact, claimed cervical spine injury (CSD), good medical documentation and photos of both cars involved, so that finally, a total number of 517 cases of rear-end collisions with 833

persons involved, 673 (80,8%) of them claiming injury, could be investigated.
It is important to remark that all reported injuries were taken into the sample. The proportion of aggravated cases in which the reported symptoms are not or only partly accident related could not be identified and may reach 50% [5;6].

3. RESULTS

3.1 Accident parameters

With over 85% the straight collision with an impact angle under 5% is representing the most frequent **collision type**. Nearly every second rear impact happens at an (full) overlap of 81% to 100%. Angled collisions showed no significant difference of the injury severity compared to non-angled collisions.

Generally low **velocity change** accidents (delta v up to 15 km/h) dominate the sample with 53,5%. Medium severe (delta v 16-25 km/h) accidents could be observed in 35%, whereas higher values (delta v over 25 km/h) occurred at only 11%.
Further data analysis shows no correlation between delta v and QTF injury degree in this data sample. Surprisingly at higher velocities the amount of high rated QTF degrees disappear and the amount of uninjured occupants is growing.

3.2 Vehicle parameters

The severity of cervical spine injury is highly related to the involved vehicles and to the geometry of the seatback and head-restraint construction. The stiffness of the energy absorbing zones and the car weight varies among car models, influencing the acceleration of the car.

Considering the different **head-restraint positions** the distribution of the different QTF injuries among the groups "low", "medium" or "high head-restraint" position compared to "no head-restraint" shows that: the lower the head-restraint position -the higher is the percentage of higher QTF degrees. In the "no head-restraint" group (which includes mostly passengers on the back seat), the situation is comparable to the "high head-restraint" group only with a higher number of QTF 3 injured persons. Under this point of view it is obviously better to have no head-restraint than having one with too low adjustment, however, a good (i.e. high) head-restraint position can help to avoid a higher severity of cervical spine injury, when compared with low head-restraint adjustment. Unfortunately it has to be noticed that the case number of the "high" group is very small.

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The **age** distribution of occupants with CSD was similar to the total group of occupants with minor injuries in general. A relatively large proportion of 27% reports injuries with CSD within the age group 18 to 24 years, while this group represents only 16 % of the participation in normal traffic. But the accident rate in this age class is higher (31,5% of minor injured car occupants are aged 18 to 24). On the other hand, the rate of CSD and minor injuries in the age groups over 30 years is lower than their risk exposure (distribution in traffic). The majority of injuries in the < 30 age group are QTF I to II injuries. The highest relative risk for suffering from a QTF III injury is, as expected, in the age group of 60 and older, which is nearly as doubled compared to risk exposure (participation in traffic). But it has to be taken into account that non-accident related effects like spine related neurological and degenerative signs influence particularly this older group.

Although the distribution of male and female claimants in the data material is nearly equal in absolute numbers, women suffer in a 1.4 times higher rate from CSD because of their smaller percentage of participation in traffic. **Gender** seems to be the most important parameter also in other studies [8].

22% of the occupants with known QTF degree were QTF1, 71% QTF2, 6% QTF3. The **symptom** predominantly claimed was neck pain (QTF1), followed by reduced neck movement and stiffness of the neck muscles (QTF2). The most frequent symptom leading to QTF3 was paraesthesia. **Full recovery** after isolated CSD was gained in 26-46 days in average depending on the CSD severity. The relatively high rate of 18.8% having not reached full recovery after 49 days (**long term cases**) seems probably to be a "selection effect" of the insurance data material.

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4.1 Objective

Which subject related parameters influence the kinematic response? Do accident investigation differences in gender correlate with sled tests?

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43 tests with 19 human volunteers with a German standard car seat had been performed at two delta v's 6.5 and 9.5 km/h. The sled pulses were between 3 and 4 g peak acceleration and expected to be under the injury limit.
The age of the subjects ranged between 17 and 51 years (mean 29.9 years), the height between 1.64 and 1.94m, and weight from 56 to 92 kg. 16 male and 3 female subjects have been tested, where the anthropometric characteristic of the tested females showed a lower neck circumference, lower head mass and body weight compared to the tested male volunteers. But also the males showed a wide variation in seating height, head mass and neck circumference.
Main interest was laid on the combination: 25° angle and high head-restraint position. In this group data from 17 slow and 16 fast tests was used for statistical analysis, especially the correlation between anthropometric data, muscle reflexes, horizontal distance between head and head-restraint and peak accelerations, time of peak acceleration, head-restraint force had been examined towards linear regression.

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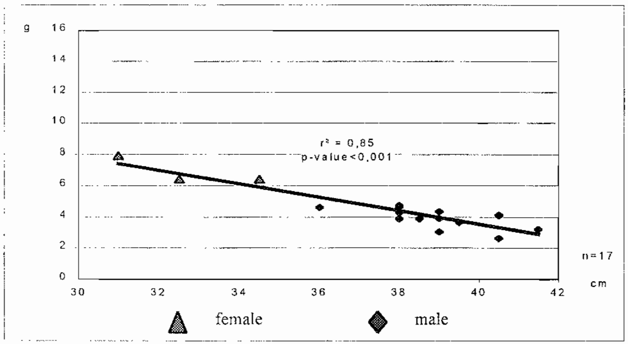

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Another correlation was found with the peak angular acceleration (flexion phase) versus the head/head-restraint distance. Here the tested females showed low values due to a relatively short gap. With increasing head/head-restraint-distance the peak angular acceleration for the flexion phase increases with a correlation of r^2 0.75 and r^2 0.85 (low and higher test velocity).
For the prior extension phase the distribution of peak values was widely different and no significant statistical correlation could be found.
In recent test series [6] long horizontal distance also turned out to be a risk factor for minor neck pain but more experiments and analyses should be carried out.

5. PROPOSED NEW TEST STANDARDS

From the real accident analysis and the sled test series it could be concluded that car seat and head-restraints have to be improved. This could be not only evaluated with static measurements, but also with dynamic tests where the seatback and head-restraint performance should be measured.
It appears to be beneficial to cover at first the most common impact configuration, which lies at:
<u>Δv 15 km/h with a crash pulse of approximately 6-7g</u>
to cover increased dynamics.
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Eventually for covering also higher delta v's another impact with a higher velocity:
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could be performed additionally for the test of the stability of the seat back.
The prevention of the total collapse of the seat back could be beneficial in the rare collision scenario with a high delta v rear impact.

If this test would be also integrated into FMVSS 301 (48 km/h 1.800 kg barrier impact for fuel tank integrity) against the car rear-end for a 1.100 kg car an average delta v of 30 km/h would be reached. This accident scenario is relatively rare and it represents the most catastrophic case in which the load limits of seat back could be reached. A design for such high energies would probably decrease the CSD protection in lower velocities.
The European test standard ECE R 34 covers an impact velocity of 35-38 km/h with a mass of the barrier of 1.100 kg resulting in a delta v of 20-25 km/h for a 1.100 kg car. Nevertheless this standard is rarely performed, because of the higher US specifications.

This underlines the strong need for improved rear-end impact standard specifications, where at least one delta v 15 km/h test should be performed firstly, which could be later followed by a test at higher velocity for optimization of the seat stability.

Following measurement parameters could be used:

NIC Neck Injury Criterion [10;11]
Neck forces and moments
Head x acceleration
Angular acceleration and velocity

It appears to be clear, that current biomechanical limits have to be refined, but even testing with a conventional dummy appears to be better than no testing. Improvements are coming out with refined necks and special rear-impact dummies in the near future.

6. DISCUSSION AND OUTLOOK

The database gives an overview about the full spectrum of insurance material being representative for Germany and is evenly distributed for car to car crashes, but a possible insurance bias could not be excluded. A high proportion of aggravated cases has to be considered. It was not the aim of this study to justify CSD within a certain biomechanical corridor, therefore all (including the possibly aggravated) injuries have been analysed for possible trends for a better medical objectifying of the injury.

This data material shows no correlation between QTF degree and delta v. Mostly low velocity (delta v up to 15 km/h) accidents dominate the sample with over 50%. The QTF injury severity appears to decrease at higher delta v (26-50 km/h) ranges. Possibly, the collapse or severe backward movement of the seat back at Δv higher than 25 km/h reducing head and torso relative movement is responsible for this "paradox". It could be concluded that the main problem area of CSD injuries is related to delta v 9-15 km/h where further research (volunteer tests, dummy development, seat testing) is rather important. The most beneficial range for an improved seat and head-restraint construction lies approximately between Δv 12-25 km/h.

Higher head-restraint adjustment seems to have strong positive effect in reducing QTF injury severity, whereas low head-restraint adjustment worsens the injury outcome even in comparison to no head-restraints. The effect might be explained by the height of the bending angle of the spine. Although many medical and diagnostic problems are not currently solved it seems to be clear that an improved seat-head-restraint construction could prevent or at least reduce the CSD injury risk, for example if head-restraints do not allow a low positioning (automatic positioning or integrated head-restraint [12;13]). Also rear seats should be fitted with adequate CSD protection.
The sled tests show the influence of a higher distance between head and head-restraint resulting in higher peak angular accelerations of the head. It appears to be a must for a well designed head-restraint to offer a short distance during the rear impact for as many sizes of occupants as possible [9].

The population at risk is distributed in all age classes, but females showed a 1.4 times higher injury occurrence, whereas other in-depth accident analysis indicate even a 2 times higher risk [8].
Older people showed an increased risk for high-rated (QTF III neurological deficits) CSD injuries.
The sled test results indicates that the higher risk population has a more fragile neck with a small circumference (female and male), but shows the highest head x peak acceleration values, which is statistically significant. The fact that women generally have smaller values for neck circumference suggest that this may be the actual risk factor, although more research in this area should be performed. Head acceleration should be further analysed as a general qualitative indicator for CSD injury.

Seat design, testing and dummy development should therefore not only focus on the 50percentile male, but also on the 5percentile female/male as well as the 95percentile male.

There is a strong need for an uniform test standard. Delta v of 15 km/h at approximately 6-7g peak acceleration covers many of the real accidents and could give a true chance for improving current seat design in preventing CSD injury. In our opinion too stiff seat frames for high velocity tests (delta v 30 km/h) are covering only very rare accident events and -in turn- could reduce the injury protection at lower delta v regions.

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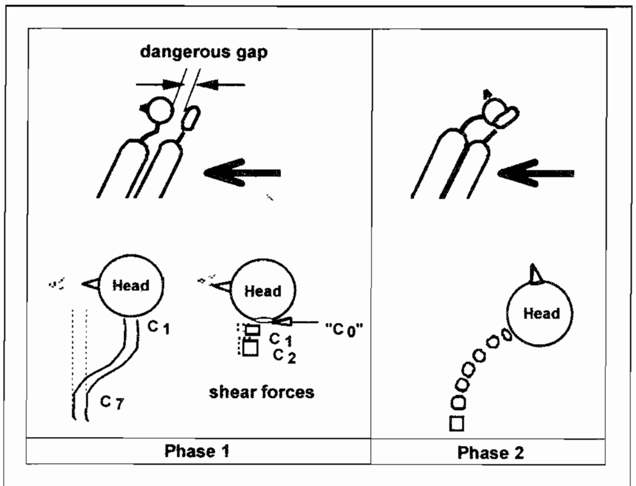

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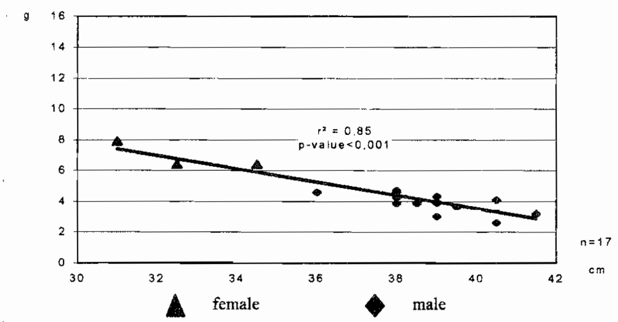

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6. DISCUSSION AND OUTLOOK

The database gives an overview about the full spectrum of insurance material being representative for Germany and is evenly distributed for car to car crashes, but a possible insurance bias could not be excluded. A high proportion of aggravated cases has to be considered. It was not the aim of this study to justify CSD within a certain biomechanical corridor, therefore all (including the possibly aggravated) injuries have been analysed for possible trends for a better medical objectifying of the injury.

This data material shows no correlation between QTF degree and delta v. Mostly low velocity (delta v up to 15 km/h) accidents dominate the sample with over 50%. The QTF injury severity appears to decrease at higher delta v (26-50 km/h) ranges. Possibly, the collapse or severe backward movement of the seat back at Δv higher than 25 km/h reducing head and torso relative movement is responsible for this "paradox". It could be concluded that the main problem area of CSD injuries is related to delta v 9-15 km/h where further research (volunteer tests, dummy development, seat testing) is rather important. The most beneficial range for an improved seat and head-restraint construction lies approximately between Δv 12-25 km/h.

Higher head-restraint adjustment seems to have strong positive effect in reducing QTF injury severity, whereas low head-restraint adjustment worsens the injury outcome even in comparison to no head-restraints. The effect might be explained by the height of the bending angle of the spine. Although many medical and diagnostic problems are not currently solved it seems to be clear that an improved seat-head-restraint construction could prevent or at least reduce the CSD injury risk, for example if head-restraints do not allow a low positioning (automatic positioning or integrated head-restraint [12;13]). Also rear seats should be fitted with adequate CSD protection.
The sled tests show the influence of a higher distance between head and head-restraint resulting in higher peak angular accelerations of the head. It appears to be a must for a well designed head-restraint to offer a short distance during the rear impact for as many sizes of occupants as possible [9].

The population at risk is distributed in all age classes, but females showed a 1.4 times higher injury occurrence, whereas other in-depth accident analysis indicate even a 2 times higher risk [8].
Older people showed an increased risk for high-rated (QTF III neurological deficits) CSD injuries.
The sled test results indicates that the higher risk population has a more fragile neck with a small circumference (female and male), but shows the highest head x peak acceleration values, which is statistically significant. The fact that women generally have smaller values for neck circumference suggest that this may be the actual risk factor, although more research in this area should be performed. Head acceleration should be further analysed as a general qualitative indicator for CSD injury.

Seat design, testing and dummy development should therefore not only focus on the 50percentile male, but also on the 5percentile female/male as well as the 95percentile male.

There is a strong need for an uniform test standard. Delta v of 15 km/h at approximately 6-7g peak acceleration covers many of the real accidents and could give a true chance for improving current seat design in preventing CSD injury. In our opinion too stiff seat frames for high velocity tests (delta v 30 km/h) are covering only very rare accident events and -in turn- could reduce the injury protection at lower delta v regions.

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