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Whiplash injury: cases with a long period of sick leave need biomechanical assessment

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Abstract A total of 668 cases of cervical spine disorders (CSD) sustained in automotive collisions were analysed. All cases had a minimum sick leave duration of 4 weeks. To evaluate these cases a scheme was developed that takes into account technical, medical, and biomechanical aspects. For each case, the delta- v value of the underlying collision was estimated, the medical files were analysed, and a QTF (Québec Task Force) grade was assigned. In addition, the medical history of the patient was reviewed. It was found that the QTF grade for patients *with* pre-existing damage of the neck or pre-existing signs differed significantly from those patients *without* such a history. The overall assessment, which stated the extent to which the symptoms claimed could be explained by the impact, was also

found to be significantly influenced by a history of neck injury. The results of the study showed that in about 50% of the cases where the technical analysis alone would not suggest that the symptoms shown could be explained by the impact, those symptoms could be explained when patient history and the collision circumstances were taken into consideration. It also found that medical evaluation based on a QTF grade alone cannot assess the explicability of claimed CSD without taking into account the collision circumstances. Therefore, the assessment of critical individual relevant biomechanical factors is necessary.

Keywords Cervical spine · Neck injury · Whiplash-associated disorders · Motor vehicle accident · Biomechanics

Introduction

Cervical spine disorders (CSD) sustained in motor vehicle accidents are still a major concern, and numbers are even increasing [10, 11, 25]. These neck injuries, often also referred to as “whiplash” injuries or whiplash-associated disorders (WAD), are most often ranked as a minor injury on the abbreviated injury scale (AIS) [1]. To be more specific about the extent of the neck injury, a classification system was developed by the Québec Task Force on Whiplash Associated Disorders [21]. This scaling system comprises five grades, ranging from QTF 0 (“no com-

plaint about the neck/no physical signs”) to QTF 4 (“neck complaint and fracture or dislocation”).

Although most sufferers will make a complete recovery within a short period of time, some will develop prolonged medical problems. In fact, WADs are among the most common causes of medical disability in car occupants [2]. This can result in long periods of sick leave and granting of disability pensions. In addition, these cases often result in legal procedures requiring an assessment by an expert witness to assess the likelihood that the injury claimed is causally linked to an accident [28, 29]. Hence, the socioeconomic significance of these injuries is tremendous. Consequently, a greater understanding of the vehi-

cle, collision and occupant parameters that are prevalent in WAD is needed in order to develop preventative measures.

Even though the socioeconomic impact of these injuries is regarded as significant, few investigations are presented that analyse the long-term consequences.

Different definitions with respect to the duration of long-term consequences are used in the literature. Krafft et al. [12], for instance, regard symptoms that last longer than 1 month as long-term consequences. Whereas in their study on the prognostic value of the QTF classification, Hartling et al. [10] set a minimum of 6 months of symptoms, while Sturzenegger et al. [22] and Richter et al. [20] chose a 1-year threshold to study the long-term outcome.

To identify risk factors in both the technical arena as well as in the medical arena was the aim of many other studies. To date, it is well accepted that WAD can be obtained from various impact conditions [27]. Rear-end collisions are widely regarded as the most common cause of CSD [2, 9, 11]. Other studies report a higher frequency of neck injury in frontal collisions [19]. As the collision severity is often assessed by the collision-induced velocity change (Δv) value, several publications correlated Δv levels with the risk of sustaining neck injury. Langwieder and Hell [13] report that low Δv crashes of up to 15 km/h predominate. Castro et al. [3] indicate that about 65% of the insurance claims take place in accidents with velocity changes of up to 15 km/h.

Other work has analysed the significance of the crash pulse shape in rear-end collisions [12]. With regard to long-term consequences, a correlation was found between the pulse characteristics and symptoms that last longer than 1 month, distinguishing between different degrees of QTF 0–3.

Concerning the patient's age as a risk factor for WAD, the literature is not conclusive. While Temming and Zobel [25] found a higher risk for the group aged between 20 and 50 years, Dolinis [6] did not see a significant difference between age groups below and above 40 years. With regard to gender, a higher risk of sustaining neck injuries is reported for females in both frontal and rear-end collisions [4, 6, 16, 19, 25]. Versteegen et al. [26], in contrast, observed no gender difference when studying the long-term outcome over a 25-year time span.

Suissa et al. [23] investigated the relation between initial symptoms of CSD and the prognosis. They concluded that patients with musculoskeletal and neurological signs and symptoms will have a longer recovery period. Others pointed out that the individual medical history of neck pain is the most important risk factor for CSD [6].

The purpose of the current, retrospective study was to analyse the consequences of WADs that were sustained in automotive accidents and that resulted in a sick leave lasting more than 4 weeks. Special emphasis was put on the biomechanical assessment of such cases.

Materials and methods

Starting in May 2000, a biomechanical assessment procedure to analyse CSD sustained in automotive accidents was introduced. Accompanying that assessment procedure, a database was established. The cases to be entered into the database were all received from a major Swiss accident insurer (SUVA), and all cases in the study therefore represent CSD claims seeking compensation payment. The cases are collected by the local agencies of the insurer throughout Switzerland, which are responsible for gathering the relevant technical and medical information. The study set as an entry criterion the requirement that the patient had to have been on sick leave for longer than 4 weeks. In general, duration of sick leave has to be confirmed by a physician in order for the patient to receive any payment from the insurer. Hence, the cases assessed have a common medical basis. Furthermore, it should be noted that, with very few exceptions, only private sector employees are eligible to be insured with that particular accident insurer. Government employees, the self-employed, retired people, housewives, students, and children are therefore not included in this sample. Additionally, in all cases CSD was the predominant complaint, otherwise the insurance agency would not have registered the case under this scheme.

During a 20-month period, data from 668 patients claiming CSD were collected. All cases were assessed technically, medically, and biomechanically by our group.

Within the technical part, a rough technical assessment carried out by a mechanical engineer experienced in accident reconstruction describes the vehicle loading conditions. This section mainly relies on pictures of the vehicles involved in the collision under investigation (including vehicles other than the one of the patient). Estimates or bills of the repair costs of the vehicles involved are also taken into consideration. In some cases full accident reconstruction was available. From this technical assessment, the kinematics of the accident – the motion of the vehicles, the collision circumstances and the consequent car loading – are estimated. The collision-induced velocity change (Δv) of the vehicle under consideration was taken as the measure of collision severity. The Δv corresponds approximately to the integral of the translational vehicle deceleration over the collision time for collisions that are characterised by one, in essence, unidirectional impact. To determine the Δv , the deformation of the vehicle is analysed by reflecting the energy that was needed to cause such deformation, taking into consideration vehicle-specific factors such as, for instance, the stiffness of the deformed structures, mass, impact height, and degree of overlap [5, 15, 18]. However, as usually no detailed accident reconstruction, i.e. no calculation of the Δv range and the acceleration, is performed, a rather rough scale is used to classify the collision severity. A coding system was developed to register the Δv range obtained from that rough technical analysis. The Δv range was not *calculated* by a comprehensive computer analysis, it was *estimated* in terms of its relation to a Δv range of 10–15 km/h for rear-end and side impacts and 20–30 km/h for frontal impacts. The choice of such intervals is based on the assumption that for a so-called “standard case”, a range of 10–15 km/h and 20–30 km/h, respectively, is in the range of harmlessness concerning CSD. These intervals summarise various volunteer tests, laboratory experiments, and evaluations of real-world accidents [3, 8, 13, 17]. With respect to those Δv intervals, a coding system as illustrated in Fig. 1 was established, ranging from 1 (“well below the range of harmlessness”) to 4 (“well above the range of harmlessness”).

Next in the assessment procedure, the medical files of the patient are analysed and summarised by a physician. A standardised form was developed to register information on the initial findings as well as on the results of follow-up examinations, if carried out. The assessment relied solely on the facts stated in the medical files; the patient was not directly contacted. The coding introduced

Fig. 1 Delta- v intervals in relation to the “range of harmlessness” ($\leftrightarrow$) for a “standard case”, defined as 10–15 km/h in rear-end and side collisions, and 20–30 km/h in frontal collisions

by the Québec Task Force [21] was used to classify the extent of neck injury. Grade QTF 0 was not considered in the analysis, because of the entry criterion of the cohort.

Finally, a biomechanical assessment was performed by a specially trained engineer or physician, taking into account the technical aspects and the medical history of the patient as well as the individual physique of the patient to estimate the motion of the spine during the collision. As for the technical coding system, a “standard case” was defined as the basis for the biomechanical coding system. This “standard case” can be described by a scenario that assumes the patient:

- Was in a conventional car seat
- Was aged below 50 (F)/55 (M) years
- Had no substantial pre-existing damage of the neck (resulting from either pathological processes, degenerative changes or earlier traumatic impacts)
- Was wearing a safety belt
- Was not sitting in a posture that might introduce additional loading to the neck (out of position problem)

If the occupant does not meet all of the “standard” requirements, the limit has to be reconsidered critically, and in some cases adjusted. If, for example, two patients face a similar collision, but one is aged 30 and one is aged 70 with a degenerated cervical spine, it would not be reasonable to assess the two cases in the same way. It is assumed that a loading to the 70-year-old spine is more likely to explain the WAD symptoms. Analogously, for side impacts, the sitting position of the occupant (near or far side) and a possible resulting head contact have to be considered. The need for adjustment also applies if the seat does not meet the criterion of being conventional, i.e., if for instance the photographs of the vehicle show that the head restraint was badly positioned (e.g. Chapline et al. [4]), but also in a positive sense if, for instance, the seat incorporates a special whiplash protection device like WHIPS [14] or SAHR [30].

Thus, based on diverse background information, the specific motion of the (cervical) spine during the impact is assessed. Hence, the biomechanical injury assessment results in a judgement about to what extent the injury claimed can be explained by the accident. Again, this final assessment was rated by a coding system analogous to the delta- v coding, with 1 meaning “cannot be explained”, 2 “can hardly be explained”, 3 “can probably be explained”, and 4 “can certainly be explained”.

In this study the database was evaluated by means of descriptive statistics and multi-way cross-calculation tables, using χ^2 statistics to check for significant differences in frequencies. Calculations were performed using the software SYSTAT version 10 [24].

Results

Injury epidemiology

Of the 668 injury cases recorded, 48.4% ($n=323$) involved women and 51.6% ($n=345$) men. The average age was 37.6 ± 10.9 years (mean $\pm$ SD) and 39.5 ± 10.8 years, respectively. Women measured 167 ± 6.4 cm in height and 64.9 ± 12.7 kg in weight. For men, the average height and weight were found to be 175.0 ± 7.4 cm and 79.1 ± 11.9 kg, respectively.

Most of those injured were drivers (80.4%; $n=526$), while 15.3% ($n=102$) were front-seat passengers, 3.3% ($n=22$) were back-seat passengers, and 1.0% were either sitting in other places or could not state their seating position.

Eighty-five percent of the cases were reported from agencies situated in the German speaking part of Switzerland, while the French and the Italian speaking parts accounted for 5% and 10% of the cases respectively.

Impact classification

Details of the vehicle of the injured party (make, model, year) as well as details about the collision partner(s) were registered in the database. From the information available (police reports, pictures of the accident scene and the vehicles involved, bills of repair costs), the impact type was determined and classified as frontal (head-on) collision, rear-end collision, side collision, or roll-over. The impact direction was evaluated by assessing the impact angle.

Most occupants in our sample were injured in pure rear-end collisions (see Table 1), followed by those injured in frontal collisions. Of 668 cases, 130 (i.e. 19.5%) sustained multiple collisions, which in 88 cases consisted of a rear-end impact followed by a frontal collision. For other cases with multiple impacts, the primary collision was often followed by impacting an obstacle rather than another car. Figure 2 illustrates the delta- v ranges estimated in the technical section of the assessment procedure.

Table 1 Impact classification

Collision type	Frequency of occurrence	
	<i>N</i>	%
Rear-end	447	67.0
Frontal	140	21.0
Left side	32	4.8
Right side	15	2.2
Roll-over	4	0.6
Others/unknown	30	4.4

Fig. 2 Distribution of estimated delta-v ranges. The values are given as percentages, where 100% represents 668 cases, 447 cases, and 140 cases for all collisions, rear-end collisions, and frontal collisions, respectively

Medical findings

Evaluating the medical information, 115 different parameters were recorded including, for example, initial symptoms claimed and their onset time. As an overall criterion for neck injury, the QTF code was assigned for each case (Fig. 3). In addition to the symptoms shown after the accident, the medical history of the patient was analysed. The medical files as well as questionnaires completed by the insurance agency were checked for information on pre-existing neck problems like, for instance, pathological

Fig. 3 Québec Task Force (QTF) grade distribution. The values are given as percentages, where 100% represents 668 cases, 447 cases, and 140 cases for all collisions, rear-end collisions, and frontal collisions, respectively

processes, degenerative changes or previous traumatic impacts. Where follow-up reports (overall status reports) summarising the patient's progress during medical treatment were available, those were also recorded in the database. Generally, such follow-up examinations are not mandatory; they are scheduled if regarded necessary. Of the total number of 668 cases, 342 had a follow-up report at 6.8 weeks (average) after the accident. For 264 cases a further follow-up examination was reported on average 17.7 months after the accident. It is interesting to note that neither the QTF code nor the delta-v code were significantly different when comparing the groups that had follow-up examinations (Table 2). However, the psychological aspects became more important the longer the treatment lasted. While a deterioration of psychological state was found for 7.6% of patients who had a first follow-up examination, this increased to 13.6% of those who also had a further follow-up examination.

Biomechanical assessment

Based on the technical code and the medical findings, in particular the QTF grade, the final biomechanical assessment was performed. Additionally, any pre-existing damage of the spine, special collision circumstances (e.g. head impact, not wearing the seat belt, strong rotation motion, sitting out of position), and the age of the injured were taken into account to assign the biomechanical code as described above. Hence, the extent of explicability of the neck injury was assessed by comparison with the "standard case", for which limits had been defined. Results of the biomechanical assessment are shown in Fig. 4.

In order to analyse the strength and the influence of the parameters recorded, multi-direction cross-calculation table analysis was performed. Additionally, χ^2 statistics were used to check for significant differences. The results of these statistical tests are shown in Table 2. The relevance of the final biomechanical assessment was checked by comparing the biomechanical codes of all cases with the biomechanical codes of cases with a low delta-v rating (Fig. 4).

Discussion

A database recording 668 CSD cases sustained in automotive crashes that caused the injured to take more than 4 weeks' sick leave was established. To analyse the data, a biomechanical assessment scheme was developed using different coding systems for technical, medical, and biomechanical aspects.

These 668 cases represent roughly 6% of the total number of all cases of CSD claimed by the 1.9 million insured of SUVA, i.e. including cases not meeting the entry criterion for this study. Thus, about 6% of all cases reported tend to result in a long period of sick leave.

Table 2 Results of statistical evaluation testing for significant differences for various parameters (*QTF* Québec Task Force grade)

Variable A	Variable B	Statistical tools used	P-value ($\alpha=0.05$)
QTF first follow-up	QTF second follow-up	Cross-calculation tables	0.650
Delta-v first follow-up	Delta-v second follow-up	Cross-calculation tables	0.158
QTF rear-end	QTF frontal	χ^2	0.344
QTF rear-end	QTF side right	χ^2	0.534
QTF rear-end	QTF side left	χ^2	0.731
QTF rear-end	QTF roll-over	Fisher exact	0.000
QTF male	QTF female	Cross-calculation tables	0.766
QTF with pre-existing damage	QTF without pre-existing damage	Cross-calculation tables	0.000
QTF with pre-existing signs	QTF without pre-existing signs	Cross-calculation tables	0.004
QTF out-of-position	QTF not out-of-position	Cross-calculation tables	0.834
QTF younger than 50 years	QTF older than 50 years	Cross-calculation tables	0.465
QTF wearing seat belt	QTF not wearing seat belt	Cross-calculation tables	0.394

Fig. 4 Distribution of the biomechanical rating for all cases (100%=668) and for cases with a delta-v code of 1.5 or less (100%=190)

A major limitation of this study was the lack of a control group that did not exhibit any CSD at all, or for which the injuries resulted in a sick leave lasting less than 4 weeks. Such data were not available, so that only comparisons within the sample were possible. It should also be noted that CSD had to be the predominant injury for the patient to be included in this study. Therefore, the sample consists mainly of isolated CSD.

The results show that the sample consists of about the same number of female and male patients. This finding is in agreement with the results reported by Versteegen et al. [26], who analysed the long-term outcome of WAD. The average age was similar for men and women. This result is not surprising, in the sense that the injured had generally to be employed at the time of the accident. Consequently, the age range lies within the minimum age for driving and the legal maximum for working, i.e. between 18 and 65 years. Analysing the age data graphically (Fig. 5) showed that the grade QTF 4 was found to have a much smaller spread and higher median value, but this finding

was not significant. Height and weight did not show a significant difference for the QTF distribution either, although the median values are slightly higher for higher QTF grades (Fig. 5). The finding that the QTF grade did not differ significantly according to gender (Table 2) suggests women are at no higher risk.

The much higher number of cases from the German speaking part of Switzerland can partly be explained by the larger size and population of this part of the country. However, relating the CSD cases to the total number of accidents reported to the insurer, and assuming that the frequency of occurrence of CSD from car accidents is about the same everywhere in the country, it emerged that the French speaking part is strongly underrepresented. This cannot be explained with the data at hand.

As for the technical section, the evaluation of the delta-v ranges showed that the majority of all cases were found within the range of code 2, i.e. approximately 8–12.5 km/h for rear-end and 18–25 km/h for frontal impacts. Although the rear-end cases were predominant in the sample, the frontal cases did not show significantly higher delta-v codes and QTF values (Table 2). Hence, unlike the findings reported by Temming and Zobel [25] that most studies showing a high proportion of frontal impacts as reason for neck complaints have a bias towards more severe collisions, no bias towards more severe injuries for frontal collisions was observed here. Other collision types did not result in significantly different QTF grades when compared to the outcome for rear-end impacts, except for the small number of roll-over events, which led to higher QTF grades. As to be expected, drivers and front seat passengers accounted for most (94%) of all claims. Multiple collisions were not further analysed in this study; only the primary impact was regarded.

In order to assess the medical state of the injured, the symptoms were recorded and the QTF grade was assigned accordingly. The influence of various parameters on the QTF grade was tested (Table 2). Grouping the injured in categories “above/below 50 years of age” and “(not) sit-

Fig.5 Boxplots showing the distribution of age (years), height (cm), weight (kg) over QTF

ting out of position” did not result in significantly different QTF scores. However, testing the groups *with* versus *without* pre-existing damage and *with* versus *without* pre-existing signs showed a statistically significant influence of the QTF value. This finding corroborates the results of the study by Dolinis [6], which indicated that a history of neck injury along with female sex were the only two statistically significant predictors of CSD occurrence.

To further analyse the influence of the medical history, the biomechanical rating was compared to the delta- v rating. Generally, the technical and biomechanical evaluations mostly correlated well, i.e. in 77% of the cases the difference between the technical and the biomechanical rating was 1 or less. As illustrated in Fig.4, most cases (73%) were rated 2.5 or more on the biomechanical scale, i.e. for those cases it was possible to explain the medical findings by the specific accidental and individual biomechanically relevant factors. However, looking at the distribution of cases with a technical rating of 1.5 or lower (Fig.4), it stands out that only 18 out of 190 cases received a similar biomechanical rating (1.5 or lower). For

93 out of 190 cases the biomechanical rating was 2.5 or higher. In other words, in 49% of the cases where the technical rating would suggest that the symptoms shown could not be explained biomechanically by the impact, the symptoms could be explained by taking into account the patient’s medical history and the collision circumstances. Hence, the technical evaluation *alone* would not have found an explanation for the CSD, but the specific biomechanical assessment did. Therefore, discussing limits for delta- v values, which are based on the car alone, cannot be satisfactory. They can only be valid for a specific case like, for example, the “standard case” defined in this study. The QTF, by its nature as a medically based criterion, correlates well with the biomechanical code, but to the best of our knowledge, the way that pre-existing damage affects the QTF and the recovery time has not yet been investigated. Thus we suggest that the medical history for each patient be explicitly considered.

Of course we are aware of the fact that the results obtained here are based on a medically biased sample which exhibits longer than usual recovery time, but cases that

might turn out to become critical later and therefore needing detailed assessment are included in the sample.

In summary, this study clearly indicates that on the one hand the technical analysis must be supplemented by an assessment of critical individual relevant biomechanical factors. On the other hand, the medical evaluation using QTF grades alone cannot assess the explicability of CSD claimed without considering the collision circumstances.

The biomechanical assessment scheme as used here seems suitable, although it only states that the biomechanical influences on the patient of a given collision are able (or unable) to *explain* the symptoms found. A quantitative degree of probability cannot be given by a biomechanical evaluation. The second restriction imposed on the biomechanical assessment consists of the time horizon that causality deliberations are bound to. Within the period of time between accident and assessment, chronification of the symptoms and signs could occur; an effect which, to our knowledge, has never been stringently linked to the actual biomechanical loads of the collisions. In other words, there are many non-biomechanical influences that determine whether or not chronification occurs.

First results for the follow-up examinations seem to indicate that psychological aspects gain more importance

the longer the treatment lasts – an outcome that was also reported by Eck et al. [7], who stressed the relevance of stressful life events and psychosocial problems. More detailed analysis of those follow-up examinations should be carried out in future.

Conclusions

In a retrospective study, 668 cases of patients claiming CSD were evaluated. A technical code based on delta- v estimations, the QTF, and a biomechanical code were assigned for each case. It was found that QTF values for patients with pre-existing damage of the neck and those with pre-existing signs or symptoms differ significantly from those without such a history. Analysing the biomechanical assessment scheme used, it emerged that a technical analysis should always be supplemented by considering biomechanical relevant factors. In this study 49% of the cases with a delta- v range lower than a commonly accepted threshold would have been judged differently had the patient's medical history not been taken into account.

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