Evaluation guideline for whiplash associated disorders to occupants of struck vehicles in rear-end car-to-car minor crashes or striking vehicles in reverse car-to-car minor crashes

Version 1.1

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RCAR

Note: This document represents a compilation of research findings from various institutes, including the European Spine Society, biomechanical research centers, RCAR centers, and others. Its purpose is not to definitively ascertain injury risks for occupants in specific minor car-to-car collisions, but rather to facilitate an enhanced comprehension of evaluating injury risks for occupants involved in such car-to-car minor crashes.

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1. Glossary

- **ΔV** : The change of the velocity of a car between pre-collision and post-collision

  - ΔV can be calculated according to the technical reference of ISO/TR 12353-3.

Pre-collision V_{pre} = 10 km/h

Collision

Post-collision V_{post} = 15 km/h

$$\Delta V = V_{post} - V_{pre} = 15 \text{ km/h} - 10 \text{ km/h} = 5 \text{ km/h}$$

Fig. 1 Example of ΔV

- **Rear-end collision** : A type of collision that occurs when a trailing car collides with the rear end of a leading car

Fig. 2 Rear-end collision

- **Reverse collision** : A type of collision that occurs when a car moving in reverse impacts the front end of another car

Fig. 3 Reverse collision

- **Minor crash** : A collision between vehicles resulting in minor cosmetic or superficial damages, such as scratches or small dents, without significant structural compromise. Essential functional components, including the engine, transmission, and primary safety features, remain undamaged.

- **Passenger** or **Occupant** : The person who sits on any seat of a struck car.

- **Mean Acceleration** : The average acceleration experienced by a car body during an impact with another car or object
  - Mean acceleration can be calculated according to the technical reference of ISO/TR 12353-3.

- **WAD** (Whiplash-Associated Disorder) : The collection of symptoms affecting the neck triggered by an accident with an acceleration-deceleration mechanism

Table 1. WAD symptom of each grade

Grade	Clinical Presentation
WAD 0	No complaint , no physical sign(s)
WAD 1	Neck complaint of pain, stiffness, or tenderness only, no physical sign(s)
WAD 2	Neck complaint and Musculoskeletal sign(s)
WAD 3	Neck complaint and Neurological sign(s)
WAD 4	Neck complaint and Fracture or dislocation

- **No injury** (defined only in this document) : WAD 0
- **Initial symptom** (defined only in this document) : WAD 1
- **Injury** (defined only in this document) : WAD 2+

2. Motivation

The prevalence of neck pain claims has emerged as a prominent area of research due to the distinctive nature of these claims, characterized primarily by initial symptoms such as pain, stiffness, or tenderness in the neck, yet devoid of discernible physical indications such as musculoskeletal, neurological, or structural manifestations like fractures or dislocations. These symptomatic presentations are commonly reported subsequent to minor rear-end collisions characterized by marginal ΔV within the impacted vehicle.

The primary impediment lies in the inherent challenge of diagnosing these symptoms, which remains unattainable even through contemporary medical imaging modalities like MRI[1] or CT[2] scans. Consequently, medical practitioners predominantly rely on the subjective narratives provided by passengers to facilitate medical interventions, despite the absence of an objective foundation substantiating passengers' claims pertaining to the symptoms. A secondary challenge emerges in establishing a causal link between the symptoms described by passengers and the accident, a connection that eludes confirmation both from insurance entities and claimants.

In situations where insurers are obligated to indemnify such claims, the system is exposed to potential misuse, thus engendering elevated insurance premiums for other consumers, as will be demonstrated through illustrative instances. Despite notable advancements in seat design and enhanced occupant protection measures, neck pain claims continue to retain significance within certain nations. Exemplifying this significance, the Association of British Insurers (ABI) highlights the UK scenario, wherein claims encompassing initial symptoms impose an annual cost exceeding 2 billion pounds upon the insurance sector, contributing an additional burden of 90 pounds to the average annual motor insurance premium.

Analogous to the UK, compensatory actions undertaken by insurance providers in response to minor rear-end collisions have substantively augmented insurers' statistical expenditure concerning bodily injuries within several other nations. Consequently, concerted endeavors are being directed toward enhancing occupant safety protocols. Through the present document, RCAR aims to synthesize pivotal discoveries, many of which have predominantly circulated within local markets, alongside established evaluative methodologies, with the intent of rendering them accessible to interested stakeholders.

1 Magnetic Resonance Imaging
2 Computer Tomograph

3. Introduction – history of research

In the 1980s, insurers reported a notable surge in purported whiplash claims within specific European nations. The advancement of passive safety measures, attributed to enhanced vehicular structures and intricate restraint systems, led to a heightened discernibility of less severe bodily injuries. Among these, grievances centered around neck pain gained particular prominence. RCAR, an assemblage of research centers affiliated with insurance concerns, which initially directed its focus toward automotive repair investigations, established a specialized task force dedicated to the study of disorders linked to the neck during the latter part of the 1990s.

This task force, known as the International Insurers Whiplash Prevention Group (IIWPG), was convened with the primary objective of delving into this subject matter through collaborative engagements with medical practitioners and academic institutions. Grounded in both external and internally conducted research, the IIWPG furnished a foundational framework conducive to the technical comprehension of occupant load dynamics in incidents characterized by the forward acceleration of the impacted vehicle—namely, rear-end collisions.

Fig. 4 Full overlap rear-end collision

It was determined that the configuration of the seat, particularly the arrangement of the head restraint, exerts a pivotal influence on the pertinent occupant loadings. As such, the group's first product was a standardized procedure for the static evaluation of head restraint geometry, which was based on work by RCAR members Insurance Corporation of British Columbia and Insurance Institute for Highway Safety and which was adopted as an RCAR standard in 2000. The procedure assessed the degree to which restraints could be adjusted to be tall enough and close enough to support the heads of a range of occupant sizes in rear crashes. The IIWPG subsequently engaged in a collaborative effort with the Swedish Chalmers University and the dummy supplier Denton COE to assess and refine a specialized rear impact dummy, designated as the BioRID II. This dummy achieved serial production status by 2004. Simultaneously, the IIWPG introduced a dynamic testing protocol and rating criteria, which were initially adopted as assessment measures by insurers starting from 2004. This testing protocol empowered seat designers to quantitatively assess the protective potential of their designs and systematically enhance occupant safety.

At present, both static and dynamic evaluation methods have been adopted by most of the New Car Assessment Programs (NCAP) around the world. It is important to understand that the test criteria could not be based on values for human limits as it is common for high speed tests, e.g. the NCAP front crash tests, because such criteria did not exist for this low impact severity and still does not exist.

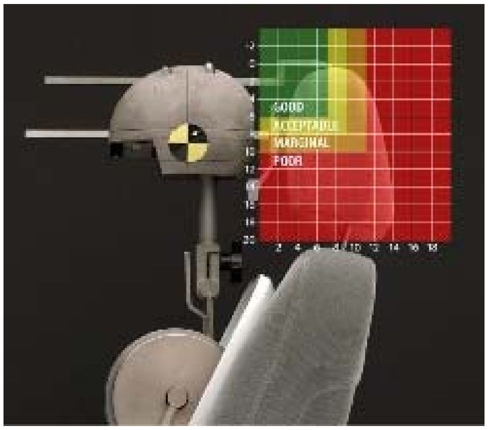

Fig. 5 Static evaluation by HRMD

Fig. 6 Dynamic evaluation

The IIWPG proposal relied primarily on statistical evidence showcasing the superior real-life performance of both the Volvo Whips seat and the Saab SARS seat. The underlying concept involved utilizing a seat that demonstrated superior real-world performance as a benchmark, allowing for a comparison of pertinent parameters related to neck loadings. Over time, as seats improved, these rating parameters were progressively adopted, compelling seat designers to minimize neck loadings to the greatest extent possible. The comprehensive assessment of a seat involves both a static rating and subsequent dynamic testing.

Presently, there exist seats in the market that limit the rearward head displacement of normally seated occupants with properly adjusted restraints in the event of a rear impact. Through the further endeavors of the IIWPG, in conjunction with those of automobile manufacturers, continuous enhancements have been made to vehicle and seat structures, yielding a substantially heightened level of protection. Contemporary vehicles are equipped with improved head restraints that closely approach the occupant's head or seats that pivot rearward, analogous to a baseball glove, in order to mitigate the impact on the occupant during rear-end collisions and avert whiplash injuries.

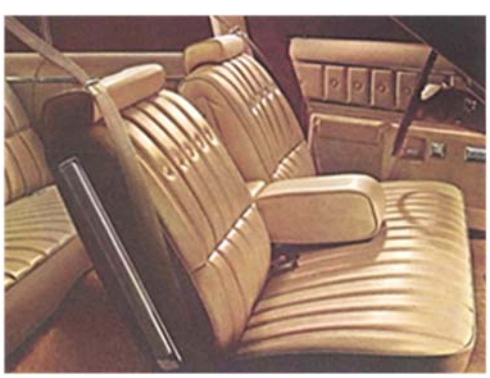

Fig. 7 Seat/head restraint of old car

Fig. 8 Seat/head restraint of modern car

4. Current situation

The compensation of neck pain claims resulting from accidents is a common practice in numerous countries. However, the emergence of this issue is not synchronized across all nations. The manifestation of neck pain claims as a widespread phenomenon in the market can distinctly occur at varying times in different countries, regardless of the technical condition of the vehicle fleet.

In South Korea, the severity of injuries resulting from traffic accidents is categorized into 14 grades in accordance with legal stipulations. The most severe classification, Grade 1, encompasses injuries such as brain damage with profound neurological symptoms and spinal damage resulting in paralysis. On the other end of the spectrum, Grade 14, the mildest classification, includes minor injuries like joint sprains of fingers or toes and bruises on arms or legs.

Regarding the treatment duration statistics for patients categorized under Grade 14 injury severity, it is observed that the 5th percentile corresponds to a single day, while the 95th percentile extends to 14 days, indicating a substantial disparity.

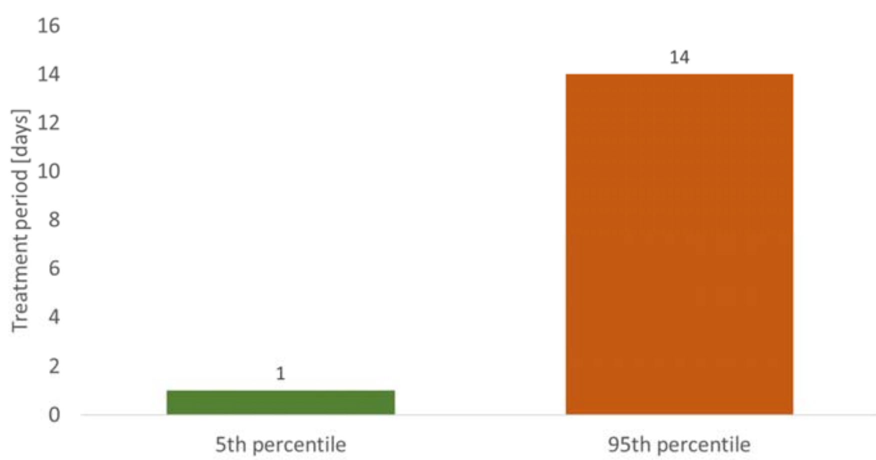

Fig. 9 Comparison of treatment duration
(5th and 95th percentile within grade 14 of minor injury group)

When comparing the medical expenses associated with symptoms such as cervical pain or lumbar pain, notable distinctions arise between motor insurance and national health insurance systems. Any bodily injuries resulting from traffic accidents are covered by motor insurance.

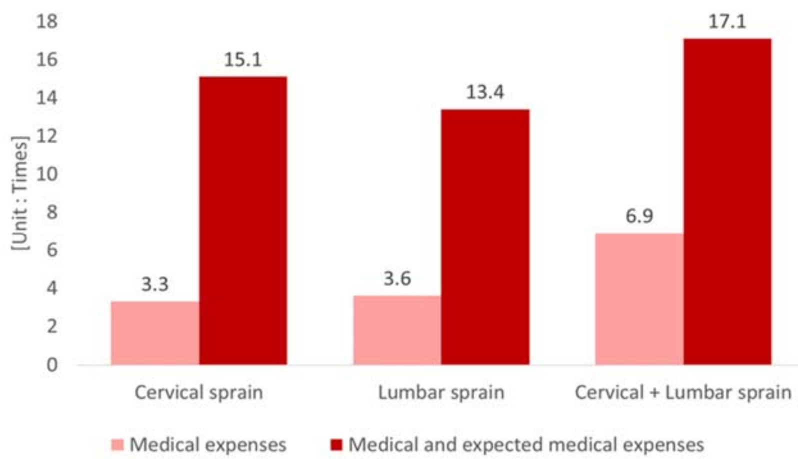

Fig. 10 Average compensation ratio (motor insurance divided by national health insurance)

The disparity in medical expenses between motor insurance and national health insurance may be attributed to the distinct characteristics inherent to each of these systems.

For motor insurance:

- The driver assigned a higher fault ratio for the cause of the accident is liable for the entirety of medical expenses incurred by all occupants of the opposing vehicle, including the driver with the lower fault ratio. This implies that the occupants of the opposing vehicle can avail medical treatments even in cases where a fault ratio is assigned, even if it is not zero percent.
- In the resolution process involving occupants of the struck vehicle and the opposing motor insurance company, the occupants are remunerated for projected supplementary medical interventions up until the point of recovery. This reimbursement, designated as "anticipated treatment expenses," and the compensation for "anticipated treatment expenses" escalates with the augmentation of actual medical expenditure.

For national health insurance:

- The system provides partial coverage for medical expenses, leaving the patient accountable for the residual cost.
- Should the aggregate sum of medical expenses rise, the patient's contribution towards these expenses would also witness an increase.

The financial ramifications of such compensation models can be considerable, as demonstrated by certain countries with an extensive history of neck pain claims. Among these countries, the United Kingdom is notable. According to research conducted by the European Insurance and Reinsurance Federation (now Insurance Europe) in 2004, neck pain claims constituted a substantial 76% of all bodily claims. Although the Legal Aid, Sentencing and Punishment of Offenders Act (LASPO) of 2012 evidently diminishing the expenses associated with civil litigation pertaining to whiplash claims, persistent challenges within the market endured.

According to data provided by the Association of British Insurers (ABI) for the year 2016/17, the number of claims stemming from road traffic accidents was approximately 50% higher than figures from 2006/07, notwithstanding a decrease in reported accidents and advancements in vehicle safety. Moreover, claims linked to whiplash injuries still accounted for roughly 85% of all road traffic accident claims. Consequently, the government endeavored to establish a more streamlined, effective, and economically feasible compensation framework.

On the 31st of May, 2021, the Whiplash Reform Programme was implemented for low-value road traffic accident (RTA) related personal injury claims, encompassing the following measures:

- a fixed tariff of compensation for whiplash injuries that last up to 2 years, which will provide clarity and certainty to claimants about the amount of personal injury damages they will receive for whiplash injuries.
- prohibition of the settlement of whiplash claims without appropriate medical evidence.
- elevation of the Small Claims Track (SCT) limit for RTA related Personal Injury claims from £1,000 to £5,000 via amendments to the Civil Procedure Rules.
- introduction of the Official Injury Claim service, facilitating all claimants, irrespective of legal representation, in initiating and resolving their own claims.

The statistics from a year since its implementation reveal certain figures in the claims.

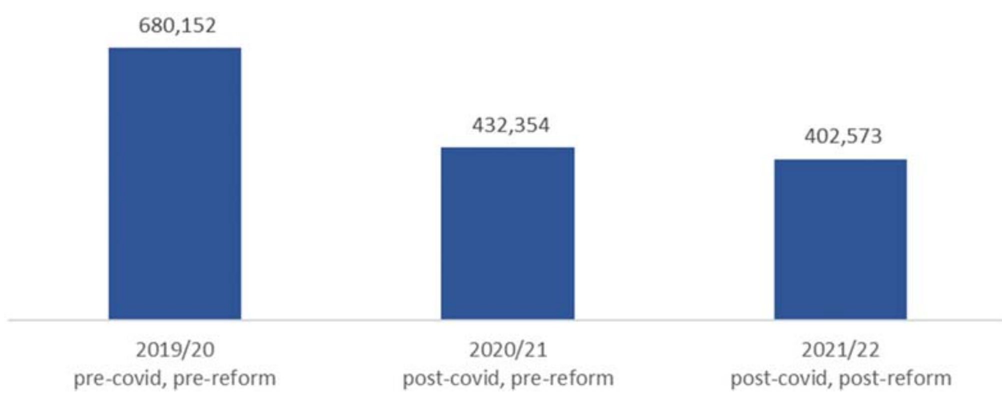

Fig. 11 Annual claims changes since implement of Whiplash Reform Programme

The Ministry of Justice in the UK has determined that the reduction in whiplash claims can, in part, be attributed to decreased travel during the COVID-19 pandemic. And also, when comparing whiplash claims to all personal injury claims, there has been a proportional decrease of whiplash claims. This leads to a consensus that the recent reforms appear to be effective.

Another illustrative case is Switzerland. Data from the Federal Statistical Office indicates a substantial increase in the number of individuals seeking disability insurance benefits since 1990. Notably, this increase is particularly pronounced when examining different linguistic regions. For instance, the costs associated with the diagnosis of "cervical spine distortion" witnessed a rapid surge of up to 600 percent in the German-speaking regions of Switzerland, while doubling in the rest of the country.

Based on a comparative study conducted in 2004, Switzerland's frequency of claims aligns with the European average. However, Switzerland has the highest claims expenditure, with an average cost of approximately Euro 35,000 per whiplash claim. This is in contrast to the European average of Euro 9,000.

However, the high average value is likely influenced by the Swiss insurance system and the substantial healthcare costs in Switzerland. It is crucial to rigorously assess the potential adverse effects of fraudulently obtained disability pensions on these figures. For many years in Switzerland, it has been postulated that the insurance fraud rate is approximately 10%, a figure estimated by a study from the Swiss Insurance Association (SVV). Consequently, every tenth case of loss may display indications of fraudulent activity.

Prior to 2010, to claim compensation, it was only necessary to provide evidence of a traffic accident, including collisions with a ΔV of less than 10 km/h, and the presence of whiplash was generally presumed. However, following a 2010 Federal Court ruling, the situation for establishing whiplash after vehicle collisions have changed.

Since 2010, individuals injured in traffic accidents, those with whiplash injuries, are required to provide evidence of the existence of such injuries(or even its impairment). Below are some of the salient points of this ruling:

- Individuals alleging whiplash injuries are now required to furnish medical documentation as evidence for their claims.
- In the medical documentation, it is imperative to demonstrate that the individual has sustained a physical injury, specifically to regions such as the cervical vertebrae or the spinal column.
- If evidence remains elusive despite employing the most advanced diagnostic technologies, the conditions surrounding the impairment must be substantiated.
- The medical documentation should conclusively demonstrate that the injury resulted from the vehicular accident.

The 2010 ruling made it more challenging for individuals to feign whiplash injuries. As a result, this not only reduced insurance fraud but also safeguarded the interests of those genuinely injured.

The marked decline in whiplash cases in Switzerland is prominently reflected in the annual accident statistics provided by insurance companies. From 2006 to 2018, the proportion of total expenses attributed to personal injuries from road traffic accidents diminished by nearly 10%. This reduction occurred despite concurrent rises in the population, number of vehicles, and overall traffic volume. Additionally, it is imperative to consider the general cost inflation within the healthcare system. On average, healthcare expenditures in Switzerland have escalated by approximately 2.8% annually in recent years.

Since 2010, Swiss courts have generally posited that whiplash injuries are recoverable and do not inherently persist for a lifetime. However, exceptions are acknowledged in cases of severe whiplash.

Spain serves as an illustrative example of a shift towards a more objective assessment procedure. A comparative study on minor cervical spine injuries was conducted in 2004 by the Comité Europeén des Assurances (CEA) in collaboration with the Association for the Study and Compensation of Bodily Injury (AREDOC) in France and the European Confederation of

Experts in Assessing and Compensating Bodily Injury (CEREDOC). The findings revealed that, approximately two decades ago, Spain aligned with the European average in terms of claims frequency.

Although no official figures have been published, experts believe that the average cost of a whiplash claim in Spain currently remains significantly below the European average of €9,000.

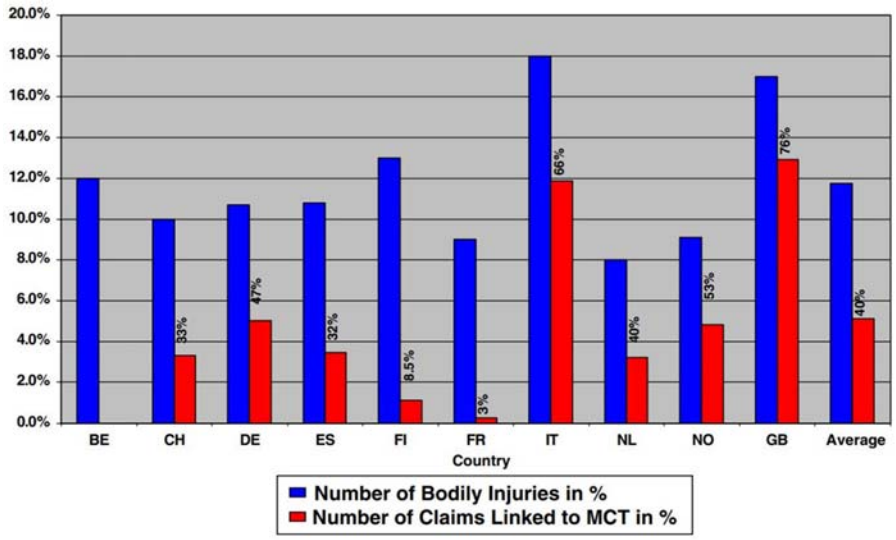

Fig. 12 CEA comparison of European countries regards neck pain claims

However, the frequency of whiplash claims has been increasing over the years, notwithstanding the tangible advancements in seats and head restraint technology that have permeated the market. This trend is possibly influenced by the Spanish claims management system, which has rendered minor cervical trauma claims almost an automated process, necessitating no substantiation beyond the claimant's expression of pain.

This trend appeared to shift following the enactment of Law 35/2015 on January 1, 2016, specifically due to its Article 135, which marks a pivotal turning point in this context. Presently, pursuing a whiplash injury claim in Spain demands a reasonable effort on the part of the claimant.

Article 135 of Law 35/2015 stipulates that minor cervical injuries diagnosed based on the injured party's testimony of pain, and which cannot be verified through supplementary medical tests, are compensated as temporary injuries. This is contingent upon the nature of the harmful event being likely to cause the damage, adhering to the ensuing comprehensive causation criteria.

Article 135 proceeds to enumerate the four causality criteria that must collectively be satisfied for an injured party who solely reports pain after an accident to receive compensation under the Law. These criteria encompass:

- Chronological: Symptomatology must manifest within a medically explicable timeframe. Notably significant is the manifestation of symptoms within 72 hours of the accident, during which the injured individual should seek medical attention.

- Exclusion: The presence of another causative factor unrelated to the accident that completely justifies the pathology.
- Topographic: The existence of a relationship between the affected area of the body and the injury, unless a pathogenic rationale is evident.
- Intensity: A consideration of the alignment between the sustained injury and the mechanism of its occurrence, incorporating variables like the accident's intensity, which influences the likelihood of its manifestation.

Sequelae arising from minor cervical spine trauma receive compensation solely upon the confirmation of their presence through a conclusive medical report subsequent to the period of temporary injury. This represents a distinctive facet of the new law, implying that if one or more sequelae are believed to be present following a whiplash incident, compensation will be granted solely upon the provision of a medically substantiated report.

The final causation criterion, intensity, pertains to the ΔV and/or mean acceleration of the vehicles involved in the accident, highlighting the significance of collision analysis within the Spanish system. At present, nearly every accident involving a whiplash claim necessitates an analysis of collision intensity.

5. Scope

This guideline is exclusively applicable to occupants involved in single car-to-car rear-end or reverse collisions occurring at low speeds. It is important to note that intricate crash scenarios, such as multiple collisions, lie beyond the purview of this document.

From a biomechanical vantage point, the cervical spine of the occupant in the struck vehicle during rear-end collisions or in the striking vehicle during reverse collisions is subjected to a load due to the impact from the rear. This engenders differential movement between the torso and the head. Broadly, alterations in the occupant's motion are invariably transmitted sequentially: from the lower seatback in the pelvic region, then through the upper seatback encompassing the torso or shoulder region, and ultimately through the head restraints to reach the head itself.

③ Head supported by the head restraint

② Acceleration of the torso by the seatback

① Transmission of force from the structure to the seat bracket

Fig. 13 Application of force to the occupant in the struck vehicle during rear-end collisions or in the striking vehicle during reverse collisions

Upon impact transmission to the shoulder, the inertia of the head initiates relative movements among the cervical spine vertebrae, the deep muscles of the neck, and the upper neck muscles. The extent to which muscles contribute to maintaining the sitting posture's homeostasis is inversely proportional to the speed of load transmission. In essence, slower load transmission allows the occupant to reflexively and responsively stabilize the head. Conversely, as the load transmission gradient steepens, the muscles' influence on head movement becomes progressively constrained.

The nature of this relative movement initially takes on a translational pattern (refer to Fig. 12, phase 1). During this phase, the head lags behind the torso, leading to deformation of the cervical spine into an S-shape configuration. Subsequently, the head undergoes rearward rotation (cervical spine extension, Fig. 12, phase 2) and is subsequently drawn forward by neck muscles before experiencing an accelerated forward motion (flexion, phase 3). This sequence of events closely resembles the motion of a whip. This analogy has led to the term "whiplash injury" being used to describe cervical spine injury in the occupant of the struck vehicle during rear-end collisions or in the striking vehicle during reverse collisions.

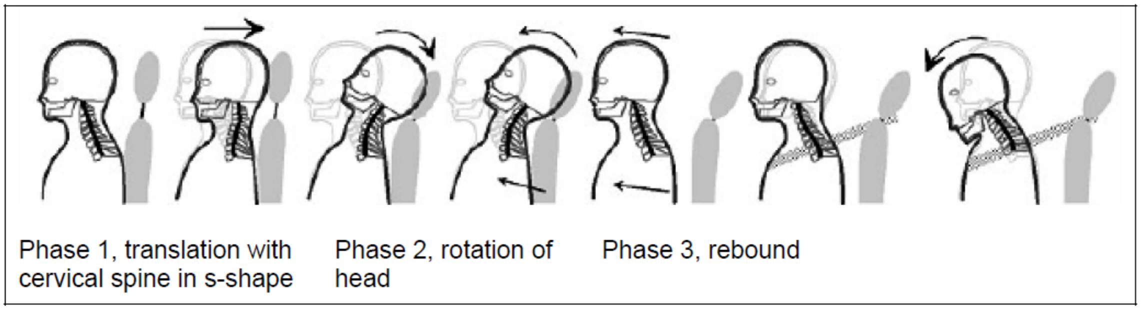

Fig. 14 Schematic illustration of distortion of the neck when thoracic spine accelerates without head support (according to Horion, LMU Reference? Number and linked source in “References”)

Fig. 15 Actual movement of head in a rear impact situation without head rest supporting the head (AZT Automotive GmbH)

Phase 2, however, may not occur for normally seated occupants with properly adjusted restraints in contemporary automobiles because new designs effectively restrict head movement in relation to the torso, even by the onset of phase 2 at the latest. But, instances may arise where users are not normally seated (e.g. leaning forward) or have misadjusted the head restraint, leading to a potential reduction in the seat's protective capacity.

Considerable efforts have been dedicated to investigating neck pain, prompting the question: Why? During an actual collision, the loading experienced by the occupant is contingent upon a multitude of parameters. Notably, the mass ratio of the vehicles involved significantly influences the distribution of energy during impact. Moreover, the energy absorption capacity of the vehicle's crash management system directly impacts the quantum of energy that can be transmitted to the occupant. Additionally, the inherent elasticity of the individual seat and the energy-absorbing attributes of the upholstery play a pivotal role in shaping occupant loading dynamics. Ultimately, the design of the seat emerges as a determinative factor governing neck loading. Additionally, the health status of the occupant significantly affects their vulnerability during such events. This enumeration is not exhaustive, underscoring that research in this domain extends beyond purely medical concerns.

Consequently, researchers often adopt a streamlined test framework, as this approach permits targeted exploration of specific facets within the intricate system. As a result, the current research findings are expressly applicable solely to passenger cars conforming to UNECE type M1 standards. The research focus also centers on minor collisions, characterized by relatively low ΔV values and typically devoid of structural vehicular damage.

6. Summaries of research and publications

Numerous institutions, including the European Spine Society, Biodynamic Research, Association for the Advancement of Automotive Medicine, as well as various universities and independent researchers, have generated substantial research findings. This paper endeavors to compile pertinent studies within the following categories: "accidentology research," "experimental research," and "evaluation methods for whiplash-associated disorders."

From a contemporary standpoint, it is unsurprising that the majority of outcomes demonstrate either no or very minimal injury risk in cases of minor rear-end collisions. While assessing extant studies, it is imperative to recognize that older studies pertain to seating technologies of their respective eras, often characterized by limited protective capabilities.

One of the primary objectives of these studies was to identify parameters of rear-impact accidents that correlate with injury risk. Overall, both ΔV and the mean acceleration (a_{mean}) of the impacted vehicle have been widely recognized as scales suitable for evaluating claims. While vehicle acceleration was deemed appropriate in some studies, the actual load on the occupant largely depends on the seat and only indirectly on the vehicle's structure. Moreover, a fundamental piece of information necessary for evaluating a specific case is the accident analyst's data on accident severity. The only parameter that can be inferred from accident analysis is ΔV. It is rare for an accident analyst to determine the car's acceleration, and when possible, only the average acceleration is available. Therefore, the determining parameter ΔV has been primarily considered for assessing the probability of whiplash injuries. However, some research has already explored the use of a_{mean}, which is expected to provide more precise information with the advent of in-vehicle data sources.

Accidentology research encompasses the following:

- "Report on whiplash injuries in frontal and rear-end crashes (© Folksam, Sweden, 2012)" presents an analysis of 175 instances of actual on-road rear-end collisions. The study reveals that cases of WAD2+ (Whiplash Associated Disorder Grade 2 and higher) exhibit a rapid escalation in the risk curve within the range of ΔV between 10 km/h and 15 km/h.

Table 2. Incidence of each WAD grade among 242 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+	
	No.	%	No.	%	No.	%
0-5	30	97	1	3	0	0
5-10	61	60	30	30	10	10
10-15	31	48	26	40	8	12
15-20	12	50	7	29	5	21
20-25	2	18	5	45	4	37
25-30	2	29	1	14	4	57
30-35	0	0	0	0	3	100
35-40	0	0	0	0	0	0

- "Analysis of Whiplash Associated Disorder Claims Using Real-World Data Retrieved from Event Data Recorders: A Case-Control Study" (© IRCOBI[3], AXA Winterthur et al., Switzerland, 2016)" is grounded in an analysis of 168 instances of actual on-road rear-end collision accidents. This study establishes that the statistical threshold for initial symptoms of WAD stands at 10 km/h of ΔV. However, the study says that beyond the sole consideration of ΔV, individual cases necessitate evaluation in light of additional parameters. These parameters encompass a medical history inclusive of prior complaints regarding neurological symptoms. This arises due to the study's basis in purely statistical observations.

Table 3. Incidence of each WAD grade among 172 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Unknown	
	No.	%	No.	%	No.	0%	No.	%
0-40	108	63	18	11	23	13	23	13

Experimental research with human subjects includes,

- "Human Subject Kinematics and Electromyographic Activity During Low-Speed Rear Impacts (© Society of Automotive Engineers, Inc., Biomechanical Research & Testing, LLC, USA, 1996)" indicates that among a group of 10 subjects subjected to vehicle-to-vehicle rear-end tests at a ΔV range of 7.5-10 km/h, none experienced injuries or reported pain during the subsequent two-week period after the collision.

Table 4. Incidence of each WAD grade among 10 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
7.5-10.0	10	100	0	0	0	0	-

- The scientific paper titled "Human Head and Neck Kinematics After Low Velocity Rear-End Impacts - Understanding 'Whiplash' (© Society of Automotive Engineers, Inc., Biodynamic Research Corp., USA, 1995)" says that a ΔV of 8 km/h appears to serve as a practical threshold for evaluating injury risk. This conclusion is drawn from a series of tests involving seven human subjects. Among these subjects, four were subjected to three separate test runs each, one subject underwent four test exposures, and two subjects were exposed to the test only once.

Table 5. Incidence of each WAD grade among 18 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
5.8-10.9	2	11	16	89	0	0	≤ 4 days

- The study titled "The Relationship between Clinical and Kinematic Responses from Human Subject Testing in Rear-End Automobile Collisions" (© Elsevier Science Ltd., AAAM[4], USA, 1999) presents the outcomes of a statistical analysis conducted on vehicle collision experiments involving 42 human subjects. Each subject participated

3 International Research Council on Biomechanics of Injury

4 Association for the Advancement of Automotive Medicine

in approximately two tests, resulting in a total of 81 tests administered. Among these, 42 tests were carried out at a ΔV of 4 km/h, and 39 tests were performed at a ΔV of 8 km/h. However, incomplete kinematic data was observed in six cases, leaving a final count of 75 valid tests for analysis.
The research paper indicates that among the 75 valid tests, 23 subjects exhibited symptoms. This group comprised 9 subjects exposed to a ΔV of 4 km/h and 14 subjects exposed to a ΔV of 8 km/h. Notably, all symptoms reported by the 23 subjects had resolved within a span of 5 days.

Table 6. Incidence of each WAD grade among 75 valid exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
4	Unknown	Unknown	9	Unknown	0	0	≤ 5 days
8	Unknown	Unknown	14	Unknown	0	0	
Total	52	69	23	31	0	0	

- "Human Occupant Kinematic Response to Low Speed Rear-End Impacts (© Biodynamics Engineering, Inc., USA, 1994)" presents the outcomes of six vehicle-to-vehicle rear-end collision tests involving five human subjects. Among these subjects, three exhibited cervical and/or lumbar spinal degeneration as evidenced by pre-test MRI scans. Only a solitary subject reported experiencing transient and minor neck stiffness.

Table 7. Incidence of each WAD grade among 7 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
8	6	86	1	14	0	0	≤ 1 day

- "The Movement of the Head and Cervical Spine During Rear-End Impacts (© Institute for Mechanics, University of Graz et al., Austria, 1994)" presents the outcomes of 37 sled tests conducted on 25 human subjects. None of the subjects exhibited initial symptoms or reported them.

Table 8. Incidence of each WAD grade among 37 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
6-12	37	100	0	0	0	0	-

- "Analysis of Kinematic Responses of Human Test Subjects to Low-Velocity Rear-End Impacts (© Biodynamic Research Corp., USA, 1993)" presents the outcomes of ten vehicle-to-vehicle tests involving four human subjects. Among them, three subjects exhibited initial symptoms that resolved within 3-4 days following their onset.

Table 9. Incidence of each WAD grade among 10 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
3.0-7.8	7	70	3	30	0	0	≤ 4 days

- "'Comparative Analysis of Low Speed Live Occupant Crash Test Results to Current Literature (© TSI Solutions Inc., USA, 2004)' presents the outcomes of a literature investigation concerning crash tests conducted at ΔVs lower than 12 km/h, involving a total of 767 human subjects. Among these 767 exposures, 27 instances reported initial symptoms that subsided within a span of 1 day (25 subjects) or 2 weeks (2 subjects) following their onset."

Table 10. Incidence of each WAD grade among 767 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
≤ 12	740	96.4	25	3.3	2	0.3	≤ 1 day(WAD1) 2 weeks(WAD2+)

- The statement "Do 'whiplash injuries' occur in low-speed rear impacts? (© Springer-Verlag, European Spine Society, 1997)" asserts that the biomechanical threshold for injury occurrence in rear-end collisions involving two vehicles is situated within a range of ΔV spanning from 10 to 15 km/h. This assessment is grounded in comprehensive investigations utilizing bumper-car-riding examinations as well as authentic vehicular collision trials conducted with a cohort of 19 human participants. Among the participants, encompassing both female and male subjects, three males and one female from the actual car-crash experiments documented the emergence of symptoms or minor soft tissue injuries, instances which abated within a temporal span of three days or less.
  Concurrently, a separate male subject within the same experimental context exhibited a decline in the rotational capacity of the cervical spine, that is, a 10° decrease towards the left, which persisted for a duration of 10 weeks.

Table 11. Incidence of each WAD grade among 19 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
8.7-14.2	14	74	4	21	1	5	≤ 3 days(WAD1) 10 weeks(WAD2+)

- "Rear Impact Tests with Bumper Cars" (conducted by AZT Automotive GmbH, Germany, 2009, financed by GDV) present the outcomes of bumper car collision tests involving 16 human participants. The study indicates that the rear-end collision dynamics of bumper cars are akin to those of conventional passenger cars, yet occupants subjected to bumper car collisions experience higher neck loading. Notably, owing to the substantial protective attributes conferred by head restraints and seats in modern passenger cars, the amplitude of motion is diminished, and loading to the neck are reduced in passenger car collisions as opposed to bumper car collisions of similar nature.
  None of the test subjects reported any discomfort, and there were no clinically significant observations following tests conducted at ΔV below 10 km/h.

Table 12. Incidence of each WAD grade among 32 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
6.9-8.8	32	100	0	0	0	0	-

Apart from AZT's study, ΔV = 10 km/h of the 'scientific evidence of no or no risk' is widely acknowledged within the German society. In the event of a legal dispute between the claimant and the insurer, the judge takes into account several factors, including witness testimonies, ΔV determined through accident analysis, biomechanical assessments, and medical expert opinions.

Based on established scientific understanding, the judge adopts the ΔV = 10 km/h as the 'threshold of no or low risk' when no superior information is available and in the absence of individual factors such as pre-existing conditions.

- The paper titled "A Study of Head and Neck Impact Using Human Volunteer Low-Speed Impact Tests" (© Korean Journal of Legal Medicine, National Forensic Service et al., South Korea, 2013) presents the outcomes of sled tests conducted at ΔVs (change in velocity) of approximately 8 km/h or lower, aimed at simulating minor rear-end collisions. The study engaged a cohort of 50 human subjects as participants, and among these individuals, six reported experiencing symptoms subsequent to the tests. Notably, these symptoms resolved within a period of two days or less.

Table 13. Incidence of each WAD grade among 50 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
4.7-8.1	44	88	6	12	0	0	≤ 2 days

- "Occupant's Injury Risk in Rear-end Minor Collision" (© KIDI/KART, South Korea, 2021) presents the outcomes of vehicle-to-vehicle rear-end collision experiments involving 24 human subjects. Sixteen tests were executed with subjects positioned in both the driver's seat and the rear seat, with ΔVs maintained at levels below 10 km/h. Among the subjects, eight reported experiencing initial symptoms subsequent to the tests. Notably, these symptoms disappeared within a span of 7-10 days following their onset.

Table 14. Incidence of each WAD grade among 24 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
1.5-9.4	16	67	8	33	0	0	7-10 days

Assessment of injury risk to the occupant of the struck vehicle in rear-end collisions or the striking vehicle in reverse collisions necessitates the consideration of individual factors, including seat/head restraint characteristics, occupant posture, seating position, and gender. These factors have been demonstrated to contribute to the variability of injury risk magnitude. Mitigation of whiplash risk can be achieved through the implementation of a well-rated seat/head restraint system within the vehicle[5], accompanied by the adoption of proper occupant posture during the accident event. Additionally, a front seating configuration, as opposed to rear seating, and a male driver, as opposed to a female driver, are associated with diminished risk levels.

However, research studies present notably divergent outcomes, particularly in cases of low-

5 The New Car Assessment Program (NCAP) in some countries conducts tests as part of vehicle safety evaluations. One aspect of these tests assesses the protective performance of the seat/head restraint against whiplash injuries.

ΔV accidents.

- Seat/Head Restraint and Occupant Posture

  The effectiveness of the seat/head restraint system in mitigating whiplash risk hinges on the alignment of an occupant's head within the coverage area of the restraint. When an occupant's head is not properly positioned, the head restraint's efficacy is compromised. Therefore, an assessment of the occupant's posture at the time of the accident is imperative to ascertain whether the head restraint provided adequate protection.

  The Bumper Car Study, conducted by AZT Automotive GmbH in 2009 with financial support from GDV, affirmed that the kinematics of rear-end collisions between two bumper cars closely resemble those between two conventional vehicles. Bumper-car-riding experiments revealed a lack of injury among human subjects exposed to ΔV up to 10 km/h. Nearly 900,000 bumper car rides during the 2007 and 2008 Oktoberfest events, yielded a mere one clinically significant case for each year. Notably, both instances were linked to pre-existing impairments.

  In summary, low-ΔV rear-end collisions involving two vehicles exhibit a similarity to the kinematics observed in collisions between two bumper cars. Remarkably, the collision between two bumper cars does not engender any discernible whiplash risk, even when accounting for the inferior seat geometry lacking a head restraint, as opposed to vehicles equipped with such restraints.

  Hence, a reasonable inference can be drawn that, in the context of the struck vehicle in rear-end crashes with ΔV of 10 km/h or less, or the striking vehicle in reverse crashes with ΔV of 10 km/h or less, the factors encompassing seat/head restraint and occupant posture wield negligible influence on the risk of whiplash injury, provided the vehicle features an adjustable head restraint capable of accommodating the occupant's head position.

- Seating Position

  Most passenger car seats are equipped with head restraints. If the seat is fitted with an adjustable head restraint that can be adapted to the occupant's head position, it could offer superior protection compared to a bumper car lacking such a head restraint.

  As a result, the seating position need not be a significant consideration for assessing injury risks to the occupant of the struck vehicle in rear-end collisions or the striking vehicle in reverse collisions at low ΔV when the seat is equipped with an adjustable head restraint. This finding is corroborated by the vehicle test results conducted by KIDI/KART, involving eight pairs of subjects occupying both the driver and back seats. Among the subjects in the driver seat, four out of eight exhibited initial symptoms without subsequent injury after the tests—mirroring the outcomes of the four out of eight subjects seated in the back seat.

- Gender

  In the referenced studies, data comparing males and females indicates that females generally exhibit a higher probability of presenting initial symptoms than males following low-ΔV rear-end collisions. However, it's crucial to understand that, under the conditions of low-ΔV, the higher possibility observed in females is primarily associated with the onset of initial symptoms and not with sustained injuries. These symptoms typically resolve within a few days without the need for medical intervention.

- The paper titled "Analysis of whiplash associated disorder claims using real-world data retrieved from event data recorders: a case-control study" also reports a higher risk among females for experiencing initial WAD symptoms. This observation is based on an analysis of 168 cases involving real-world rear-end collision accidents.
- In the study "Human Occupant Kinematic Response to Low Speed Rear-End Impacts," the majority of both male and female participants exhibited WAD0 symptoms, except for a single female participant who presented with WAD1 symptoms.

Table 15. Comparison between male and female of each WAD grade among 7 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+	
	No. (M/F)	% (M/F)	No. (M/F)	% (M/F)	No. (M/F)	% (M/F)
8	3/3	100/75	0/1	0/25	0/0	0/0

- The paper titled " Do “whiplash injuries” occur in low-speed rear impacts?" demonstrates that males exhibited a slightly higher incidence of initial symptoms associated with WAD compared to females.

Table 16. Comparison between male and female of each WAD grade among 19 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+	
	No. (M/F)	% (M/F)	No. (M/F)	% (M/F)	No. (M/F)	% (M/F)
8.7-14.2	10/4	72/80	3/1	21/20	1/0	7/0

- The study on 'Occupant Injury Risk in Minor Rear-End Collisions' reveals that females exhibit a higher incidence of initial symptoms compared to males.

Table 17. Comparison between male and female of each WAD grade among 24 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+	
	No. (M/F)	% (M/F)	No. (M/F)	% (M/F)	No. (M/F)	% (M/F)
1.5-9.4	13/3	81/38	3/5	19/62	0/0	0/0

- "Rear Impact Tests with Bumper Cars" reveals that neither males nor females exhibited initial symptoms.

Table 18. Comparison between male and female of each WAD grade among 20 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+	
	No. (M/F)	% (M/F)	No. (M/F)	% (M/F)	No. (M/F)	% (M/F)
7.5-10.0	10/10	100/100	0/0	0/0	0/0	0/0

- According to “IIHS head restraint ratings and insurance injury claim rates “, the IIHS examined 603,755 real-world crash data claims to determine whether vehicles with higher IIHS-rated seats/head restraints exhibited a reduced injury risk in rear-end collisions. Additionally, the study explored how the efficacy of these highly-rated seats correlated with the driver's gender.
  The findings revealed that the raw injury rate stood at 10% for men and 13% for women. The risk ratio, derived from statistical modeling, estimated a 1.18 times higher risk for women compared to men.

7. RCAR's recommendation

A significant number of neck pain claims following rear impacts are associated with accidents characterized by relatively low changes in speed. This type of complaint lacks verifiability through medical diagnosis. In many instances, no discernible symptoms can be identified. Additionally, when symptoms such as movement restrictions or abnormalities in the cervical spine are present, they cannot definitively be attributed solely to the accident. These symptoms may also result from natural aging processes or manifest in individuals who have not experienced an accident. To establish a comprehensive method for assessing the causality of complaints following an accident, it is imperative to incorporate supplementary information, such as engineering and biomechanical analyses, alongside medical symptoms within the evaluation process.

The necessity for such an evaluation procedure arises from the fact that in many countries, neck-related complaints subsequent to accidents are eligible for compensation from the responsible party. Without objective diagnostic methods, such a legal system becomes vulnerable to fraud, as it is relatively easy to allege neck pain without concrete evidence. This, in essence, would subvert the established principle that a claimed damage should be substantiated and validated by the claimant. While some countries observe escalating costs related to neck pain claims, others remain unaffected despite comparable traffic scenarios. Consequently, research has focused on identifying parameters that contribute to assessing the plausibility of such claims. A fundamental piece of information for this evaluation is the intensity of the alleged event, specifically, whether the impact severity aligns with the claimed neck injury. Several other factors, detailed in the cited sources, must also be taken into account.

At present, there exists a consensus that ΔV (change in velocity) plays a pivotal role in this context. This stems from the fact that ΔV directly quantifies the energy transmitted to the struck vehicle. Moreover, only ΔV can be evaluated by accident analysts using contemporary methods. These analysts predominantly base their assessments on damage patterns and reference data for comparison. Thus, an initial indication of the plausibility of neck complaints can be garnered from an analysis of the vehicle's damage. Nevertheless, damage patterns are subject to various influences; for instance, the effective interaction between bumper systems of two vehicles can facilitate the transfer of energy with minimal observable damage, as opposed to instances involving overriding cross members that produce deep intrusions at lower energy transfers. Factors like lateral offset between colliding cars and their mass ratio also exert significant influences. Consequently, evaluation should encompass both the struck and striking vehicles.

Extensive research over the past decades has centered around the concept of a "harmlessness limit" (Harmlosigkeitsgrenze), which would establish a threshold for impact severity below which further investigation into cervical spine distortion is deemed unnecessary. However, this notion conflicts with legal systems that do not endorse systematic exclusion of claims and mandate individualized evaluations. This legal framework accurately acknowledges the potential individual vulnerability of humans due to factors such as prior cervical spine injuries or the aging process.

Nonetheless, a widely accepted common understanding prevails that neck distortion is improbable for typical occupants subjected to a certain ΔV. While this threshold is not precisely defined, researchers have found changes in speed up to 15 km/h to be non-harmful. However, studies also indicate that complaints of neck pain can arise at speeds below ΔV = 10 km/h [1]. Thus, each case must be evaluated comprehensively. In Germany, a baseline of ΔV = 10 km/h has gained recognition as a widely endorsed scientific consensus and is frequently accepted by judges in claim assessments, especially when there is no evidence indicating higher vulnerability on the part of the claimant.

To assess the most robust evidence concerning the causal relationship of an accident with claimed neck pain, careful consideration of the following aspects is essential:

- Employing an engineering analysis in conjunction with medical diagnosis can provide a comprehensive evaluation of injury likelihood among occupants involved in minor collisions. An integral engineering parameter in this assessment is the ΔV experienced by the struck vehicle.
- According to the research, the range of ΔV associated with minimal to negligible injury risk to the occupant of the struck vehicle during rear-end collisions or the striking vehicle during reverse collisions is approximately 8 to 12 km/h.
- To ascertain the injury vulnerability of an occupant in the aftermath of a minor collision, a holistic evaluation necessitates the incorporation of the subsequent factors, in addition to the ΔV of the struck vehicle:
  - Physical constitution and age of the passengers in the impacted vehicle.
  - Prior illnesses or injuries to the cervical spine resulting from accidents.

Given these considerations, the RCAR suggests implementing a multi-step approach for the assessment of neck pain claims. The majority of claims can be resolved at Step 1, which necessitates no expert intervention. Steps 2 through 4 may be implemented for cases presented in court that require expert insights from accident analysts, independent medical practitioners, and biomechanists.

1. Evaluation of Vehicle Damage, Accident Circumstances, and Seat Performance:

   Certain characteristics serve as indicators of the energy transferred during the incident, such as minor damage characteristics including:

   - Surface-level scratches on clear coat or color coat of paint.
   - Minor scratches or deformations on plastic components.
   - Slight intrusions.

   The protective potential of the seat can be confirmed, for example, from new car assessment programs (NCAP). A loss adjuster is required to document damages on both involved vehicles. This documentation provides initial insight into the probability of a whiplash-associated disorder in relation to the existing scientific knowledge on relevant accident severity. Minor crashes usually exhibit cosmetic damage rather than structural impairment. In cases where no rear cross member is installed, even slight damage to the rear panel (not necessitating replacement) must be categorized as non-structural. This step necessitates experience and may not always be exact..

   Evaluating based on repair costs is less advisable owing to the influence of multiple factors. These factors include the car segment, which affects parts cost, and the presence of driver assistance systems. Notably, expenses related to these systems' sensors might not directly correlate with energy transfer. The seat acts as a conduit for energy transfer between the vehicle and its occupant. Modern seats, when correctly adjusted, generally reduce the neck load on the occupant of the struck vehicle during rear-end collisions or the striking vehicle during reverse collisions to near-zero levels. Consequently, they serve as valuable benchmarks for evaluating the likelihood of neck pain.

2. Evaluation of Accident Severity and Parameters:

   For cases necessitating a more detailed investigation, a qualified accident analyst is essential to calculate ΔV, determine the impact direction, and gather any other pertinent information related to the accident.

3. Evaluation of Claimant's Health Status:

   The primary treating physician is committed to providing the best possible treatment to their patient. Consequently, they might have limited scope to critically assess the patient's self-reported symptoms. Therefore, it is imperative to involve an independent physician for this stage of evaluation. This physician should possess expertise in the field of cervical spine medicine.

4. Evaluation of Biomechanical Loadings:

   The findings of the accident analyst regarding accident severity and impact direction, in conjunction with the statement concerning the occupant's relevant health condition, must be assessed by the biomechanist to ensure the most unbiased outcome.

Appendix. Cases of damage patterns

In rear-end or reverse minor collisions, even under identical ΔV conditions, the damage patterns observed in both the struck and striking vehicles can vary significantly. These damage patterns are influenced by various factors, including the type of car and occurrences of under-riding or over-riding, among others.

For specific examples of damage patterns, please refer to the websites listed below.

- CTS(crashtest-service.com)
- IIHS TechData(techdata.iihs.org)
- AGU(crashdb.agu.ch)

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