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Biomechanical assessment of soft tissue cervical spine disorders and expert opinion in low speed collisions

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Abstract

The multidisciplinary research of injury mechanisms and injury prevention requires the asessment of the technical and biomechanical circumstances of a collision; moreover, the causality assessment in the individual cases is facilitated by taking these aspects into account. In fact, only specially trained engineers and biomechanical experts are in a position to evaluate these relevant basic facts. In many crucial court cases, important technical factors such as collision angle, structural stiffness, extent of intrusion and the vehicle's velocity change are often ignored. The purely medical causality assessment is often based only on a coincidence of time of the 'accident' and the onset of the disorders. Unfortunately, statements about the 'accident speed' or the nebulous 'accident energy' are often made by clinicians with neither a proper collision documentation nor the necessary biomechanical and technical background. In order to overcome shortcomings of injury causality assessment as well as the terminology associated with soft tissue cervical spine injuries, a subdivision of the term 'accident severity' into four classes is proposed. Consequently, an 'accident severity assessment' can only be performed by a collaboration of four corresponding classes of experts, i.e. the engineer (dynamic loading of the vehicle), the biomechanical expert (biomechanical loading of the occupant), the physician (clinically diagnosable injuries), and eventually the psychiatrist (subjective sequelae individually experienced by the victim). © 2000 Elsevier Science Ltd. All rights reserved.

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1. Injury mechanisms

The injury mechanisms which may cause soft tissue neck disorders of occupants of the struck car in rear end collisions are multiple and not all of them are fully understood biomechanically (Huelke and Nusholtz, 1986; Backaitis, 1993; Walz and Muser, 1995; Yoganandan et al., 1998). However, some of the possible mechanisms have been identified: In the very first phase, only the upper thorax is pushed forward in the shoulder area by the seat back which is being accelerated. This first results in a purely translational forward movement of the thoracic column relative to the head, which, because of its inertia, remains in its original position. This effect has been observed in experiments with special dummy necks (TRID-neck, BioRID: Svensson and Lövsund, 1992; Davidsson et al., 1998) as well as in volunteer and cadaver tests (McConnell et al., 1993; Geigl et al. 1994; Castro et al., 1997; Eichberger et al., 1998; Ono et al., 1998; Svensson, 1998; Yoganandan et al., 1998; Wheeler et al., 1998). This relative translation between head and thorax (no head rotation, Penning, 1994) is forcing the upper cervical spine into an anteflexion and the lower cervical spine into an extension (= retroflexion), forming an S-shape from C7 to C0 (Fig. 1). At the upper cervical level, the surfaces of the joints are more or less shaped horizontally and shear movement between vertebrae is greater. Headaches, which are often erroneously thought to be caused by cerebral concussion or a mild traumatic brain injury can be initiated by lesions in this area of the cervical spine.

The anteflexion and stretching of the rear part of the upper cervical spine introduced by the rearward head translation may be the reason for muscular pain, ten-

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derness of the dorsal neck area, and occipital headache; the latter is possibly because of the stretching of the N. occipitalis major. Therefore, a forward rebound in the second phase of the collision, stretching the dorsal muscles, is not necessary for the explanation of these dorsal affections.

A head restraint is considered to be positioned correctly if at least its top aligns vertically with the top of the head. Head restraints are frequently positioned too low, which can lead to more serious injuries than without any head restraint (Hell et al., 1998). The majority of vehicle seats seen today show deficiencies in that they do not allow for a proper adjustment of the head restraint, especially for tall people. In such cases a hyperextension can be the reason for injury. However, true hyperextension is much less frequent than in earlier years, because some minimal restraint is provided even by a non-optimal head restraint. Automatic position monitoring and adjustment for the head–neck restraint in both the horizontal and vertical axis could alleviate these shortcomings. Such a system, consisting of electronic sensing devices, control circuitry, and electrical adjustment mechanisms, has been described (Muser et al., 1994) and implemented in a prototype seat that also allows for plastic yielding of the seat back (Dippel et al., 1997).

During the first phase of the impact, acceleration forces from the seat back acting on the thoracic spine lead to a straightening of the spine and eventually also to a 'ramping' upwards movement. Especially with a hard seat back, this leads to a compressive force on the vertebrae, which, in turn, promotes shearing movement of the vertebrae between each other Yang et al., 1997). This 'sliding' movement leads to an impingement of the

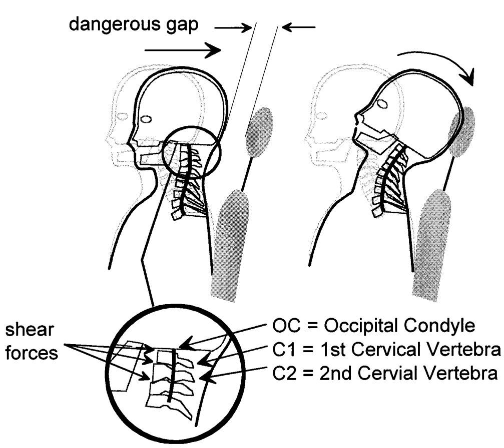

Fig. 1. Head and cervical spine movements in a rear end collision. Phase 1 — left: rearward translation of the head resulting in a S-shaped cervical spine with shear forces, especially at the level OC–C2 (see enlargement underneath) with the possibility of injury in spite of head restraint because of gap head–head restraint. Phase 2 — right: subsequent cervical spine extension, mitigated by the head restraint.

zygapophyseal joints (facets of the intervertebral joints) (Ono et al., 1998). The knowledge of this injury mechanism probably has implications for the therapy of neck trauma-related headache and neck pain: the neurosurgical denaturation of the nerves innervating the painful joint has been proven to be effective (Bogduk and Lord, 1998).

Another injury mechanism could be the pressure gradient that develops in the venous and cerebrospinal fluid during the S-shape phase of the cervical spine, thereby possibly injuring nerve root ganglions (Aldman, 1986; Boström et al., 1998; Svensson, 1998).

In addition, if a head contact (against parts of the vehicle interior other than the head restraint) occurs, a completely different loading pattern of the cervical spine is observed. This mechanism can, all else being equal, indirectly induce higher loads to the spine than a pure acceleration mechanism without head impact. However, this effect has to be evaluated in detail for each individual accident, taking into account the estimated impact speed of the head and the characteristics of the impact zone. Many alleged 'whiplash' mechanisms are in fact (head) contact mechanisms and therefore have to be judged differently, from a biomechanical point of view (Walz, 1994; Walz and Muser, 1995).

2. Biomechanical expert opinion

2.1. *Definitions*

The professional quality of causality assessment today, as experienced by the authors, is very often not satisfactory. Insurance agents, doctors and judges try to get an idea about the 'violence' of the accident — whatever this might mean — by looking at the photographs and reading the statements of the drivers involved about the 'accident speed'. This procedure is not capable of revealing the quantitative facts of the collision circumstances; expressions like 'walking speed', 'without braking', 'with high velocity' etc. seem to describe the collision rather accurately, but the expert can not draw any reliable and quantitative conclusions out of such pseudo-quantitative expressions. While the 'impact speed' is mostly overestimated, on the other hand, a 'parking lot accident', 'no damage to the bumper' etc. is often erroneously assumed to be a 'minor accident', and thus thought to have only a minor injury potential. Doctors should not interpret the car damage with regard to the injury potential because 'the photograph' alone is often misleading persons which are not specifically trained accident reconstructionists.

In contrast to these postulates, medical reports often contain a confusion and mixture of medical and mechanical terms. Apart from the actual medical findings such as distortion, soft tissue neck injury, neck sprain, e.g. also the alleged mechanisms such as contact or non-contact mechanism, flexion, extension, translation, compression, or, even worse, the misleading and incorrect term ‘whiplash’ are stated often by physicians. Because the exact injury mechanism is often not known even after a careful biomechanical investigation, a term that mixes the physical criterion ‘mechanism’ with the morphological criterion ‘injury’ should not be used anymore. In addition, the term ‘whiplash’ is loaded with negative emotional aspects which, in some cases, might even psychosomatically influence the patient towards remaining ill for a longer period of time.

Therefore if a causality assessment of a specific collision is required, the technical reconstruction leading to the crash severity for the car has to be taken into account as well as the resulting biomechanical loading of the occupant. In critical cases, it is impossible to link ‘the accident’ with the medical findings without first performing these two steps. We feel that in the majority of the crucial cases with medically documented pain but no or only few objective medical signs, the key question is not whether the patient is a simulant or malingerer but whether his medical status is related to the collision under consideration or whether it has other reasons.

The biomechanical judgement is based first on the review of the technical analysis concerning the car, second of the injuries reported by the physician and third, on the fundamental criteria of injury biomechanics (see 2.2 — biomechanical aspects). The more accurate facts are available the more exact the biomechanical assessment can be. We are convinced that in the individual case the actual injury mechanisms and the question of causality can only be dealt with after a comprehensive interdisciplinary evaluation. Many crucial court cases could be avoided if professional technical and biomechanical assessments of the collision circumstances were performed before the case has gone into the ‘court battle’.

2.2. *‘Seriousness of the collision’, ‘crash severity’, ‘speed’*

In case reports as well as in scientific publications these terms are often used without proper definitions of their meaning. The engineer is mainly referring to the estimated vehicle loads, while the physician is concerned with the injury severity. Thus, the same terms have different meanings and if used in a different way, are bound to induce misunderstandings (Berg et al., 1998). In medical documents, statements of ‘speed’ are usually based on the non-verifiable information from witnesses, concerned parties, auxiliary medical personnel, police reports, or even on inadmissible ‘estimates’ of the doctor based on the degree of injury (Fig. 2).

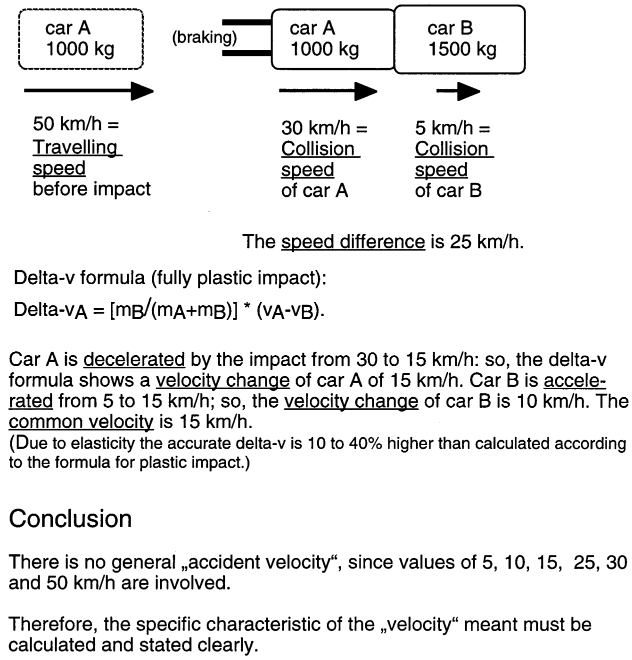

Fig. 2. Prerequisites: car A (1000 kg) travels at 50 km/h, brakes down to 30 km/h and hits the heavier slowly rolling car B (5 km/h, 1500 kg) at the rear end.

In order to overcome the shortcomings of a misleading general description of the ‘accident severity’, we propose to break down the whole complex into four different types of loading and individual condition: (a) vehicle dynamics — the dynamic loading of the vehicle during the collision must be assessed by the technical expert. A comprehensive and objective documentation of the vehicle-related aspects is absolutely necessary, such as photographs of the vehicles involved and a listing of the damaged car parts. The influence of the different masses of the two cars involved and their structural stiffness are important as well. The relevant parameters are Δv (velocity change of the car in question during the collision phase, i.e. about 0.1–0.2 s), the car acceleration and, in some cases, the rotation of the car; (b) medical findings — a comprehensive description of the injury or the disorders is needed. The statement ‘whiplash injury’ is just an assumption and therefore insufficient and meaningless. Type and severity of the injuries and the individual sequelae for the patient concerning the degree of physical impairment and disability can only be assessed by the physician based on a careful medical examination. The more details of the disorders and morphological findings are known, the better the subsequent biomechanical judgement will be. In critical cases, a neuropsychologist or/and a psychiatrist must judge the degree of psychic disability subjectively experienced by the patient. If a physician has to answer questions about the causality of ‘the accident’, he must be briefed about the actual technical and biomechanical collision circumstances in order to prevent a causality assessment based on incorrect technical and biomechanical assumptions; (c) biomechanical aspects — parameters such as seat belt use, head restraint and seat properties, out-of-position problems, additional head impact (other than to the head restraint), mechanical properties of impacted areas, rotation of the car etc. have to be investigated in order to reveal the biomechanical loading of the occupant based on the actual 'coupling' of the different body parts with the corresponding vehicle parts. Moreover, individual parameters influencing injury biomechanics such as age, body size, and pre-existing damage to the spine have to be taken into account. Such a biomechanical assessment can be performed only by someone with a comprehensive knowledge of collision mechanics as well as injury biomechanics; physicians treating patients usually are not trained in this complex interdisciplinary field. The biomechanical expert, on the other hand, is not capable to assess the duration of the impairment in an individual case because, especially when psychic disorders occur after soft tissue neck injuries, this is influenced by numerous factors not related to biomechanics.

3. Summary and conclusion

In the majority of the crucial cases with medically documented pain and no or only few objective medical signs, the key question is not whether the patient is a simulant but whether his medical status is related to the collision under consideration or if it has other reasons. Therefore, the technical assessment of the collision severity with respect to the car is as important as the analysis of the biomechanical loading of the occupant. Without this background, in many cases it is impossible from a scientific standpoint to correlate 'the (undefined) accident' with the medical findings, or, in other words, no explanation for the complaints are found from a biomechanical point of view. The biomechanical judgement is based on the review first of the technical documents concerning the car, second on the injuries reported by the physician and third, on the fundamental criteria of injury biomechanics. These are age, body size, pre-existing damage to the spine, out-of-position problems, additional head impact, seat belt use, parameters of the head restraint and the seat, rotation of the car etc. The accuracy of this information directly influences the accuracy of the biomechanical assessment. In the individual case, the actual injury mechanisms and the question of causality can only be dealt with after a comprehensive interdisciplinary evaluation. Many crucial court cases could be avoided if professional technical and biomechanical assessments of the collision circumstances were performed before the case has gone into the 'court battle'.

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