AN IN-DEPTH STUDY OF NECK INJURIES IN REAR END COLLISIONS

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ABSTRACT

An in-depth study of neck injuries in rear end collisions was made in order to investigate the severity of the injuries and the injury mechanisms in correlation with occupant and vehicle parameters.

The study included 33 occupants and their vehicles involved in 26 rear end collisions. Extensive interviews and technical examinations were made as soon as possible after the accident. Medical examinations were made at this time and a year later.

No severe injuries according to the AIS classification were noted. However, various degrees of neck injury-related discomfort were noted in all but four cases. Prolonged discomfort, lasting more than 3 months, was noted for about 40 per cent of all the occupants who had neck symptoms after the accident.

The duration of the neck symptoms was related to the estimated horizontal distance between the head and the head restraint at the time of the accident and, to some extent, to the deformation of the occupant's car in cases where any side beam was deformed.

Neck injuries sustained in traffic accidents are seldom fatal, but can lead to permanent impairment. The majority are acceleration injuries or cervical spine distortions caused by rear end collisions. These so-called "whiplash" injuries cause many diagnostic and therapeutic problems, and may be associated with a variety of symptoms which do not clearly correlate with the accident. The uncertain connection between the symptoms and the accident, the lack of physicians familiar with these injuries, and the uncertainty as to the most effective medical treatment will often prolong the time between the accident, medical care, and the final legal settlement, causing the injured considerable suffering and involving society in tremendous expense [1].

"Whiplash" injuries have been investigated theoretically, in experiments, and after real accidents for more than thirty years. Most modern cars are equipped with head restraints designed to prevent this type of injury. Nevertheless, neck injuries are still common in rear end collisions, which indicates that the protective equipment is not functioning satisfactorily. There is also some controversy about the injury mechanisms, although it is generally considered that hyperextension is involved [2]. Furthermore, during the later part of the impact, the body probably recoils owing to the elastic properties of the seat backrest and the chest, and this may put an extra strain on the cervical spine. According to a computer simulation devised by McKenzie and Williams [3], a soft seat backrest caused greater acceleration of the head and reaction forces in the cervical spine during the final part of the collision than a hard one. Theoretically, a pure elastic load-deformation characteristic seems unfavourable, and some investigators have postulated that a controlled plastic yield of the seat backrest during the impact would have a beneficial effect [4,5].

AIM

The aim of this study was to investigate neck injuries sustained in rear end collisions and correlate the severity of the injuries with the various accident, occupant, and vehicle parameters. We also wanted to form a basis for experimental studies on neck injuries in order to improve the protective properties built into the vehicles.

MATERIAL AND METHODS

A study was made of accidents that had occurred in the Gothenburg region in Sweden during 1987-88 and were reported by the Volvo Traffic Accident Group [6] or by the Traffic Injury Register [7]. A case was included in the study if any severe pre-accident neck and shoulder disorder could be excluded. One accident involving two occupants was thus ineligible for the investigation. A total of 26 rear end collisions (clockwise 5-7, without any secondary impact) involving 33 front seat occupants in Volvo cars met the criterion and entered the study.

An extensive interview and a medical examination were carried out as soon as possible after the accident. A reconstruction was made of the impact sequence and the injury mechanism was postulated on the basis of the interview data and a detailed investigation of the accident site and the vehicles.

In each case, the force of the impact was estimated by measuring the permanent maximum deformation of the rear end of the accident car. The deformation was "translated" into an "Energy Equivalent Speed" (EES), specified from barrier crash tests.

The character of the crash pulse was classified according to which parts of the accident car had been deformed. The rear side member was said to have been "activated" if it was hit or permanently deformed in the impact direction causing a "stiff" pulse, and "non-activated", causing a "soft" pulse, if it had not been involved at all.

The horizontal and vertical distances between the head and the head restraint just before impact were estimated with the occupant sitting in the accident car or in a similar car after the accident. The residual deformation of the seat backrest was defined as the increment of the inclination angle of the seat backrest between its normal position, as estimated by the occupant, and the position reached after the accident.

Signs and symptoms associated with neck injuries, the range of movement of the cervical spine, and discomfort related to specific movements of the neck, which might have occurred during impact, were thoroughly documented. The long-term consequences of the neck injuries were elicited from questionnaires given three and twelve months after the accidents. A second medical examination was made if there were still neck symptoms after one year.

The neck injuries were classified according to a slight modification of the criteria defined by Waris et al [8] (Table I).

Table I Neck injury criteria

1. Unspecified neck symptoms (UNS)
2. Tension neck syndrome (TNS)
   More than one of the following:
   - Pain or ache in the neck or shoulder
   - Fatigue or weakness in the neck or shoulder
   - Stiffness in the neck or shoulder
   - Headache

   Combined with both of the following:
   - Spasm or tightness in the neck or shoulder muscles
   - Tenderness of the neck or shoulder muscles
3. Cervical syndrome (CS)
   More than two of the following:
   - Pain or ache in the neck or shoulder
   - Stiffness in the neck or shoulder
   - Pain in the arm, not segmentally distributed
   - Paresthesia in the arm
   - Numbness in the arm

   Combined with both of the following:
   - Restricted movement of the neck or shoulder
   - Pain in the neck or shoulder during movement of the neck
4. Cervical rhizopatia (CR)
   More than one of the following:
   - Pain or ache in the neck or shoulder
   - Stiffness in the neck or shoulder
   - Numbness in the arm

   Combined with both of the following:
   - Pain in the arm, segmentally distributed (rhizopatia)
   - Intensified pain radiating to the arm during movement of the neck or neurological disturbances in the arm or shoulder

The relationship between the injury outcome and the various accident parameters was investigated statistically using logistic regression analysis [9].

RESULTS AND COMMENTS

An overall view of the accident and occupant data is presented in the appendix. The accident car was hit by another car in 23 accidents, a van in one, a bus in one, and a truck in one accident. The car was stationary in 20 accidents involving 23 occupants.

In all, 27 of the occupants were men (24 drivers and three front seat passengers) and six women (two drivers and four front seat passengers). All the occupants were wearing their seat belts and their seats were provided with fixed head restraints.

Four of the occupants did not experience any neck discomfort at all after the accident. The other 29 sustained various types of neck injury with neck-shoulder-arm discomfort of varying degree and duration (Tables II and III).

Table II Duration of neck symptoms

Duration	Number	%(of 33)
Initially	29	88
> 1 week	19	58
> 1 month	14	42
> 3 months	13	39
> 12 months	12	36

Table III Initial diagnosis and one year later

Initial		One year later: None	UNS	TNS	CS	CR
UNS	8	6	2			
TNS	15	10		4		1
CS	5			2	3	
CR	1	1				
Total	29	17	2	6	3	1

At the initial examination, six occupants complained of headache, one of vertigo, one of sensitivity to light, and one of memory disturbances. All of these symptoms had disappeared after one year.

Five occupants also sustained minor injuries to other parts of the body, mainly the back and lower extremities.

The duration of the neck symptoms increased if the estimated distance between the head and the head restraint exceeded 10 cm (Table IV). This relationship was statistically significant ($p<0.01$).

Table IV Duration of neck symptoms in relation to the estimated horizontal distance between the head and the head restraint

Distance (cm)	Duration of neck symptoms: Less than a year	At least a year	Total
<10	17	4	21
>=10	3	7	10
Unclear	1	1	2
Total	21	12	33

The Energy Equivalent Speed was less than 10 km/h in five accidents involving six occupants. Sixteen accidents, involving 20 occupants, occurred at 10<=EES<20 km/h. In five accidents, involving seven occupants, the EES was 20 km/h or more.

The frequency of the rear side member activation within the EES categories is shown in Table V.

Table V Duration of neck symptoms in relation to the Energy Equivalent Speed (EES) and the character of the impact pulse (rear side member activated or not).

EES (km/h)	Activated rear side member	Duration of neck symptoms: Less than a year	At least a year	Total
<10	no	1	0	1
<10	yes	3	2	5
Subtotal		4	2	6
10 - <20	no	0	1	1
10 - <20	yes	12	7	19
Subtotal		12	8	20
>=20	no	1	2	3
>=20	yes	4	0	4
Subtotal		5	2	7
Total		21	12	33

There was no correlation between the duration of the neck symptoms and the Energy Equivalent Speed (EES) per se or between the character ("stiff" or "soft") of the impact pulse per se. There was no correlation either between the EES and the type of injury according to the classification in Table I, or between the duration of the symptoms and the age of the occupant.

However, where any of the rear side members had been activated, tests with the logistic regression model indicate that although it was not statistically significant, there was some correlation between the duration of the neck symptoms and the degree to which the impacted car was deformed, as expressed by the square of the maximum permanent deformation.

The seat backrest was deflected compared with the original position for 16 occupants. For five of these, the neck symptoms persisted for more than a year. The seat backrest was not deflected for 17 occupants. For seven of these, the neck symptoms persisted for more than a year (Table VI). There was thus no statistically significant relationship between the seat deflection and the duration of the neck symptoms. However, there were four occupants who were not injured at all. The rear side members of the impacted vehicles were activated in all these four cases ("stiff" pulse). The Energy Equivalent Speed was 9, 16, 16 and 19 km/h, respectively, and except for the 9 km/h-case the seat backrest was deflected.

Table VI Duration of neck symptoms in relation to seat deflection.

Seat deflection	Duration of neck symptoms		Total
	Less than a year	At least a year	
No	10	7	17
yes	11	5	16
Total	21	12	33

DISCUSSION

All the injuries in this study were of minor severity according to the AIS classification (AIS=1). Most of the occupants (70%) sustained neck injuries with symptoms localized to the neck only (UNS or TNS). These injuries seem to have a good prognosis compared with neck injuries with symptoms radiating to the arms or stiffness and restriction of movements of the neck or shoulder. This concurs with the results of a previous study of neck injuries after traffic accidents in Gothenburg in 1983 [10] and the results presented by Norris och Watt from Sheffield during 1977-80 [11].

The duration of the neck symptoms was chosen as the main measure of the neck injury severity. Pain radiating from the neck to the shoulder and arm and limited motion of the cervical spine or shoulder did not correlate with any of the accident parameters.

Prolonged neck discomfort (more than one year) correlated with an increase in the horizontal distance between the head and the head restraint (P<0.01). There was a short distance of less than 10 cm between the head and the head restraint for 17 of 26 occupants injured in accidents with a "stiff" impact pulse. Only two (12%) of the 17 had neck symptoms lasting more than a year. In the remaining 9 cases, the distance between the head and the head restraint was long, ie 10 cm or more. Six (67%) of the 9 had neck symptoms lasting more than a year.

There was no correlation between the EES per se or the character ("stiff" or "soft") of the impact pulse per se, on the one hand, and the duration of the neck symptoms on the other. However, although it was not statistically significant, there was some correlation between prolonged neck discomfort and the square of the maximum deformation of the car, where any of the rear side members were activated.

The neck injury mechanism could not be clarified in detail in this study. However, the relationship between an increase in the horizontal distance between the head and the head restraint and prolonged neck symptoms indicates that reducing the "backward" movement of the head in relation to the chest might be of primary importance. This movement is probably a combination of a shear displacement and hyperextension of the cervical spine. For practical reasons, the estimated horizontal distance between the head and the head restraint was divided into two categories: less than 10 cm and 10 cm or more. However, it is reasonable to believe that the shorter the distance the less the likelihood that the various tissues involved would be strained. A solution which garantees a minimum distance between the head and the head restraint for all occupants would be ideal.

Hyperflexion of the cervical spine is by definition a part of the "whiplash" motion. An isolated hyperflexion will cause neck symptoms that are difficult to distinguish from those of a combined hyperextension and hyperflexion movement [12]. It would seem reasonable, therefore, to try to reduce both the hyperextension and hyperflexion.

Hyperflexion of the cervical spine might still occur even if the head restraint is in the optimal position to prevent hyperextension. In fact, hyperflexion is likely to occur if the head restraint and seat backrest are very resilient. It is probable that the diagonal part of the seat belt also increases hyperflexion as it restrains the body after it has been accelerated by the seat backrest during the first part of the impact. As a matter of fact, the use of seat belts has been shown to correlate with an increased risk of neck injuries in different types of car accident in Gothenburg [13]. However, the overall protective effect of the seat belt in traffic accidents in general is quite clear.

Theoretically, the risk of sustaining a hyperflexion injury in a rear end collision might be reduced if the seat backrest and head restraint were less resilient, ie more plastic. Such plastic deformation might be achieved with a torque-sensitive coupling introduced in the connection between the seat and the seat backrest. In fact, such plastic deformation ocurred in those cases where there was a permanent deflection of the seat backrest. There may be other solutions to this problem as well.

In this study, no correlation was found between the severity of the neck injury and the permanent deflection of the seat backrest. However, the number of cases is too small to permit any conclusions as to the possible protective effect of such seat backrest deflection.

Theoretically, a controlled deflection of the seat backrest, within certain limits, is also an attractive way to reduce hyperextension of the cervical spine if the distance between the head and the head restraint is too great. However, the relationship between the viscoelastic properties of the chest and the seat backrest and head restraint, on the one hand, and the kinematics of the body during and after impact, on the other, is complex. The elasticity of the seat backrest and chest might still cause the body to recoil even if there is a deflection of the seat backrest. McKenzie and Williams [3] have remarked that the elasticity of the seat backrest will increase the strain on the cervical spine during hyperflexion. Many of the occupants in this study also described violent hyperflexion of the cervical spine at the accident.

The results of this study also indicate that the shape of the impact pulse has a greater influence on the severity of the neck injury than the amount of transferred energy. It is reasonable to believe that during the first part of the acceleration a "stiff" impact pulse will cause greater movement of the cervical spine before the head hits the restraint than a "soft" impact pulse. One way to examine this hypothesis would be to study the influence of the distance between the head and the head restraint on the neck injuries noted in accidents with and without activation of the rear side members. There are not enough cases in this study, however, for such an analysis. This hypothesis ought to be explored in further accident studies and tests.

CONCLUSIONS

A distance of more than 10 cm between the head and the head restraint correlates with an increased risk of neck injuries in rear end collisions.

The duration of the neck symptoms caused by rear end collisions seems to correlate with the degree to which the impacted car was deformed, as expressed by the square of the maximum permanent deformation, provided that one of the rear side members had been activated.

In theory, the risk of "whiplash" injuries would decrease if the relative motion of the head and trunk were diminished. The hypothesis is that this could be achieved by allowing for a controlled plastic deformation of the seat backrest and rear side members during the initial stage of the impact. A less resilient seat backrest would also reduce the recoil of the body during the latter stage of the impact thereby diminishing the risk of hyperflexion injuries to the cervical spine. Such an alteration in design, however, would require care and judgement so as not to expose the rear seat occupants to risk of injury.

Further studies on the injury mechanisms and on the influence of the above-mentioned accident parameters would appear to be of great importance. The hypothesis that a controlled seat backrest deflection might be instrumental in reducing neck injuries is also worthy of attention.

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Appendix

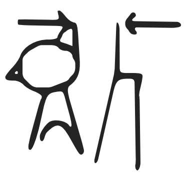
VEHICLE DATA					OCCUPANT DATA					
Case No	Impacting vehicle	EES (m/s)	Impact pulse	Seat back-rest deflection (degrees)	Position	Age	Sex	Height (cm)	Weight (kg)	Awareness
1	bus	16	stiff	>15	driver	46	man	182	88	unclear
2	bus	16	stiff	11-15	fr pass	42	man	184	86	no
3	car	16	soft	0	driver	51	man	181	82	yes
4	car	13	stiff	0	driver	23	man	183	73	no
5	car	16	stiff	0	driver	51	man	179	71	no
6	car	12	stiff	11-15	driver	49	man	185	87	no
7	car	12	stiff	1-10	fr pass	38	man	186	88	no
8	car	19	stiff	11-15	driver	47	man	181	90	no
9	car	19	stiff	0	driver	22	man	186	75	no
10	car	17	stiff	0	driver	51	man	173	100	no
11	car	13	stiff	1-10	driver	34	man	172	77	yes
12	car	5	stiff	0	driver	36	man	182	69	no
13	car	10	stiff	1-10	driver	62	man	179	85	no
14	car	19	stiff	11-15	driver	61	man	173	73	yes
15	car	19	stiff	0	fr pass	59	woman	167	61	no
16	van	24	soft	11-15	driver	42	woman	176	65	yes
17	car	22	stiff	1-10	driver	34	woman	163	50	no
18	car	27	stiff	>15	driver	60	man	176	76	no
19	car	27	stiff	>15	fr pass	59	woman	164	57	no
20	truck	9	soft	0	driver	50	man	171	78	no
21	car	24	stiff	0	driver	77	man	168	72	no
22	car	20	soft	0	driver	19	man	184	74	no
23	car	20	soft	0	fr pass	20	man	187	90	no
24	car	11	stiff	0	driver	46	man	182	70	no
25	car	9	stiff	0	driver	36	man	176	77	no
26	car	18	stiff	1-10	driver	36	man	194	87	yes
27	car	9	stiff	0	driver	54	man	156	63	yes
28	car	9	stiff	0	fr pass	86	woman	153	57	no
29	car	9	stiff	0	driver	41	man	188	70	no
30	car	15	stiff	0	driver	49	man	172	70	yes
31	car	18	stiff	11-15	driver	28	man	175	70	no
32	car	16	stiff	1-10	driver	64	man	177	83	no
33	car	16	stiff	1-10	fr pass	61	woman	164	70	no

Appendix (continued)

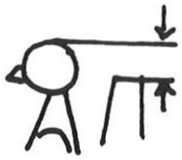
OCCUPANT DATA						INJURY DATA			
Case No	Body position	Body torsion	Head torsion	Head-head restraint horizontal distance (cm)	Head-head restraint vertical distance (cm)	Diagnosis acute	Diagnosis one year	Duration of symptoms d=days m=months	Injury mechanism (Legend below)
1	upright	right	right	8	14	DNS	DNS	0d	3
2	forward	neutral	unclear	23	12	TNS	TNS	>12m	1
3	backward	neutral	neutral	7	15	CS	CS	>12m	1
4	backward	neutral	neutral	8	14	DNS	DNS	0-7d	1
5	backward	neutral	neutral	5	8	DNS	DNS	0-7d	1
6	backward	neutral	neutral	6	12	DNS	DNS	0-7d	1
7	upright	neutral	left	6	10	TNS	DNS	0-7d	2
8	backward	neutral	left	10	10	DNS	DNS	0d	2
9	backward	neutral	neutral	18	17	CS	TNS	>12m	1
10	backward	neutral	neutral	16	6	TNS	DNS	>12m	1
11	upright	neutral	neutral	9	5	TNS	DNS	7-30d	1
12	upright	neutral	neutral	17	7	TNS	CR	>12m	1
13	upright	neutral	neutral	12	13	CS	CS	>12m	1
14	backward	right	right	10	6	CR	DNS	4-11m	3
15	backward	neutral	neutral	0	4	TNS	DNS	7-30d	1
16	backward	neutral	neutral	9	10	TNS	TNS	>12m	1
17	backward	neutral	left	4	4	DNS	DNS	7-30d	1
18	upright	neutral	neutral	6	13	DNS	DNS	7-30d	1
19	upright	neutral	neutral	10	3	TNS	DNS	1-3m	1
20	backward	neutral	right	6	6	DNS	DNS	0-7d	1
21	upright	neutral	neutral	8	5	DNS	DNS	0-7d	1
22	backward	neutral	neutral	9	13	DNS	DNS	0-7d	1
23	backward	neutral	neutral	10	15	TNS	DNS	>12m	1
24	upright	neutral	right	10	12	TNS	TNS	>12m	3
25	forward	neutral	neutral	7	10	TNS	DNS	7-30d	1
26	upright	right	right	7	20	TNS	DNS	0-7d	3
27	upright	neutral	right	5	1	DNS	DNS	0d	1
28	upright	neutral	neutral	5	3	TNS	TNS	>12m	1
29	upright	neutral	neutral	6	9	DNS	DNS	0-7d	1
30	upright	neutral	right	3	11	TNS	DNS	0-7d	3
31	unclear	left	left	8	11	CS	CS	>12m	2
32	upright	neutral	neutral	?	?	CS	CS	>12m	1
33	upright	neutral	neutral	?	?	DNS	DNS	0d	1

Head-head restraint

Horizontal distance



Vertical distance



Injury mechanism

1 Hyperextension
2 Hyperextension + lateral bending to the left
3 Hyperextension + lateral bending to the right