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Head Position and Impact Direction in Whiplash Injuries: Associations with MRI-Verified Lesions of Ligaments and Membranes in the Upper Cervical Spine

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ABSTRACT

In the present study, we compared magnetic resonance imaging (MRI) findings of soft tissue structures in the upper cervical spine between whiplash-associated disorder (WAD) patients and population-based control persons, and examined whether MRI-verified abnormalities in WAD patients were related to accident-related factors hypothesized to be of importance for severity of injury. A total of 92 whiplash patients and 30 control persons, randomly drawn, were included. Information on the accident-related factors (i.e., head position and impact direction) was obtained by a questionnaire that was answered within 1 week after the accident. The MRI examination was performed 2–9 (mean 6) years after the accident. Focus was on MRI abnormalities of the alar and the transverse ligaments, and the tectorial and posterior atlanto-occipital membranes, graded 0–3. For all neck structures, the whiplash patients had more high-grade lesions (grade 2 or 3) than the control persons (Chi-square test, $p < 0.055$). An abnormal alar ligament was most common (66.3% graded 2 or 3). Whiplash patients who had been sitting with their head/neck turned to one side at the moment of collision more often had high-grade lesions of the alar and transverse ligaments ($p < 0.001$, $p = 0.040$, respectively). Severe injuries to the transverse ligament and the posterior atlanto-occipital membrane were more common in front than in rear end collisions ($p < 0.001$, $p = 0.001$, respectively). In conclusion, the difference in MRI-verified lesions between WAD patients and control persons, and in particular the association with head position and impact direction at time of accident, indicate that these lesions are caused by the whiplash trauma.

Key words: alar ligament; head position; impact direction; magnetic resonance imaging; transverse ligament; whiplash injury

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INTRODUCTION

WHIPLASH-ASSOCIATED DISORDER (WAD) caused by a motor vehicle collision is a severe medical problem. There has been a striking lack of significant pathological findings by clinical or radiological examinations of WAD patients (Bogduk et al., 2001). So far, the diagnosis has primarily been based on the patient history weighted against well-known symptoms associated with whiplash trauma (Barnsley et al., 1994; Bogduk et al., 2000; Eck et al., 2001; Miettinen et al., 2002; Olivengren et al., 1999). Nevertheless, in the definition of whiplash-associated disorder grade 2 (WAD2; Spitzer et al., 1995), injuries to soft tissue structures such as the articular capsules, ligaments, tendons, and muscles, were regarded as a potential cause of symptoms. No details about specific structures were suggested, however.

Dvorak et al. (1987a,b, 1988) postulated that the alar ligaments could be injured after a neck trauma, in particular in connection with head rotation at time of accident. When evaluating the structure of the alar and the transverse ligaments, Saldinger et al. (1990) concluded that their findings supported the hypothesis that these ligaments could be irreversibly overstretched or even ruptured when the head is rotated and, in addition, bent by impact trauma. Such a movement is common in unexpected rear-end collisions (Saldinger et al., 1990). In our recent study (Kaale et al., 2005), we found a significant association between self-reported head and neck pain and functional disability in WAD2 patients and the severity of magnetic resonance imaging (MRI)–verified lesions of ligaments and membranes in the upper cervical spine (Krakenes et al., 2002, 2003a,b), in particular the alar and transverse ligaments. Thus, there seems to be some growing evidence that WADs can be linked to soft tissue lesions in the cranio-vertebral junction.

The definition of a whiplash trauma has been unclear. Most studies only include rear-end impacts (Hirsch et al., 1988; Norris et al., 1983; Yang et al., 2003; Stemper et al., 2003). The definition given by the Quebec Task Force in 1995 also includes side impact (Spitzer et al., 1995). Some authors include both front-end and rear-end impacts as a cause of WADs (Jakobsson, 2004; Kullgren et al., 2000). Direction of impact, as represented by front-end, rear-end, or side impact, may be of importance for the location or severity of the whiplash injury. However, few studies have explored this issue.

The aim of the present study was to compare MRI findings of soft tissue structures in the upper cervical spine between WAD patients and control persons, and to examine whether MRI-verified abnormalities were related to accident-related factors. Focus was on the alar and the transverse ligaments, and the tectorial and the atlanto-occipital membranes. The two ligaments have previously been postulated to be particularly exposed in a whiplash trauma, with severity of injury depending on head position (neutral/rotated) at the moment of collision. The two membranes also have important functions in controlling the intersegmental stability and mobility between the occiput and the upper cervical spine, and are expected to be vulnerable to external forces at work during an automobile collision. We have previously given a detailed description on how these neck structures, as well as abnormalities, can be visualized and classified by MRI (Krakenes et al., 2001, 2002, 2003a,b). A potential relationship with factors acting at the instant of collision would indicate that the observed changes are caused by the whiplash loading.

MATERIALS AND METHODS

Patients and Controls

All individuals diagnosed by a local physician as having had a recent whiplash injury in seven rural communities in Western Norway were registered prospectively from 1992 to 1998, 342 in all. The inclusion criteria corresponded to the type 2 of the Quebec Task Force (QTF) of Whiplash Associated Disorders, which included neck complaint and musculoskeletal signs (Spitzer et al., 1995). The inclusion criteria for type 2 before QTF in 1995 were the same, except for the neurological signs included by Hirsch and Norris (Hirsch et al., 1988; Norris et al., 1983).

The patients were graded both in the acute phase and 12–16 weeks later. Only the patients who fulfilled the QTF criteria for grade 2 after 12–16 weeks were included. Plain x-ray films of the neck were normal in all the patients in the acute stage. None of the patients had neurological deficits.

Within 1 week after the accident, the patients answered a questionnaire regarding details about the car accident. In this questionnaire, the patients were asked to indicate the direction of the impact (front or rear), and whether the head was rotated or not at the time of impact.

Of the initial 342 eligible persons, a total of 45 were excluded due to missing information on the accident-related factors, previous neck injuries, or sitting in the back seat. Of the remaining 297, one hundred were invited to participate in this study, 50 randomly drawn from each of the two groups defined by neck position. A total of 93 gave their informed consent, whereas seven rejected or did not answer. Due to claustrophobia during the MRI examination, one patient was later excluded, leaving 92 WAD patients eligible for analyses—45 with neutral and 47 with rotated head/neck position. There was no significant difference in gender or age at time of the MRI examination between the groups defined by neck position (Table 1). Those having been in a front-end collision were slightly older than those who had been in a rear-end collision, but there was no gender difference (Table 1).

A total of 100 control persons living in the same geographical area, randomly drawn from a list of 300 names generated by Norway Statistics, received a preliminary request about participation. Of the 75 persons that were willing to participate, five were excluded because of a history of neck injury. Of the remaining 70 persons, 50 were invited to participate. A total of 38 agreed to participate, whereas 12 gave a negative or no answer. Eight patients (seven males and one female) did not show up on the MRI examination day. The control persons (n = 30) were older than the WAD patients (mean age 45.3 vs. 39.1 years, $p = 0.005$), but had similar gender distribution (63.3% vs. 64.1% women in the control and WAD group, respectively, $p = 0.94$). Ethic approval for this project was given by the ethical committee of the University of Bergen.

MRI Classification

The MRI examinations were performed with a 1.5-Tesla system (Magnetom Vision; Siemens Medical System, Erlangen, Germany). A standard head coil was used, and proton density-weighted sequences with 2-mm-thick slices were obtained in three orthogonal planes with the head and neck in a neutral position (Krakenes et al., 2001).

Each ligament and membrane was classified in one out of four possible predefined categories, referred to as MRI grade 0–3. The following classification system was applied: grade 0 reflected a normal structure. The alar and transverse ligaments were classified as grade 1 when less than one third of the cross section area showed increased signal intensity, as grade 2 when more than one third, but less than two thirds, showed increased signal intensity, and as grade 3 when more than two thirds of the cross section area showed increased signal intensity. The posterior atlanto-occipital membrane was evaluated indirectly by changes in the adjacent dura mater. An irregularity or thinning of the dura was classified as grade 1, discontinuity as grade 2, and discontinuity with a dural flap as grade 3. Grade 1–3 classification of the tectorial membrane was diagnosed when less than one third, between one third and two thirds, and more than two thirds of the membrane was absent, and only the dura mater was remaining.

Image interpretation was done blinded to any clinical information. The consistency in grading varied considerably, both between observers and for the different structures evaluated. Generally, we found better kappa values comparing two observations (3 months apart) for the same observer (0.33–0.86)

TABLE 1. DEMOGRAPHIC CHARACTERISTICS IN WHIPLASH PATIENTS BY HEAD POSITION AND IMPACT DIRECTION

	Head position			*Impact direction*		
	Neutral, n *(%)*	*Rotated,* n *(%)*	p-*value*[a]	*Front,* n *(%)*	*Rear end,* n *(%)*	p-*value*[a]
Total	45 (48.9)	47 (51.5)		54 (58.7)	38 (38.0)	
Gender			0.95			0.30
Men	16 (35.6)	17 (36.2)		17 (31.5)	16 (42.1)	
Women	29 (64.4)	30 (63.8)		37 (68.5)	22 (57.6)	
Age at MRI, years			0.19			0.26
<35	15 (33.3)	11 (23.4)		13 (24.1)	13 (34.2)	
35–44	12 (26.7)	21 (44.7)		18 (33.3)	15 (39.5)	
≥45	18 (40.0)	15 (31.9)		23 (42.6)	10 (26.3)	
Mean (SD)	38.6 (11.9)	39.6 (9.2)	0.65[b]	40.8 (10.6)	36.8 (10.2)	0.071[b]
Range	14–60	14–55		14–60	14–53	
Years since collision			0.50			0.15
<3	4 (8.9)	8 (17.0)		5 (9.3)	7 (18.4)	
3–6	21 (46.7)	21 (44.7)		29 (53.7)	13 (34.2)	
6–9	20 (44.4)	18 (38.3)		20 (37.0)	18 (47.4)	
Mean (SD)	6.0 (1.9)	5.5 (2.2)	0.17[b]	5.6 (1.8)	5.9 (2.3)	0.49[b]
Range	2.5–9.0	1.9–9.0		1.9–9.0	2.1–9.0	

[a]Chi-square test for difference in distribution between groups.
[b]Two-sample *t*-test for difference in mean values between groups.

than for pair wise agreement between different observers (0.24–0.70). As expected, we also found better agreement within the two most experienced observers (0.51–0.86) than within the less experienced one (0.33–0.65). Results from inter- and intra observer study together showed good agreement for the posterior atlanto-occipital membrane (0.61–0.86), moderate to good for the alar ligaments (0.43–0.70) and for the tectorial membrane (0.47–0.70). Lowest agreement was obtained for the transverse ligament (0.24–0.73). More detailed information on the MRI protocol, visualizations, and reliability of the classification criteria is given elsewhere (Krakenes et al., 2001, 2002, 2003a,b; Kaale et al., 2005). The mean time from the collision to the MRI examination among the WAD patients was 6 years (range 2–9 years), and did not differ by study group (Table 1). This time-delay was partly due to the prospective registration of WAD patients, and partly due to time spent on developing the MR protocol.

Statistical Analysis

Chi-square and Fisher's exact tests were used to compare the MRI grading between WAD patients and control persons, as well as comparing subgroups defined by the accident-related factors. To evaluate whether the severity of lesions changed with time, we compared MRI findings between categories of time since the accident. Furthermore, the analyses of associations with the accident-related factors were also repeated within categories of time since the accident. In addition, the analyses were repeated using MRI classifications made by two other independent radiologists.

TABLE 2. MRI CLASSIFICATION OF LIGAMENTS AND MEMBRANES IN THE CONTROL GROUP AND IN THE WHIPLASH GROUP

	Control group, n *(%)*	*Whiplash group,* n *(%)*	p-*values*[a]
Alar ligaments			<0.001
(left and/or right)[b]			<0.001
Grade 0	19 (63.3)	16 (17.4)	
Grade 1	9 (30.0)	15 (16.3)	
Grade 2	2 (6.7)	30 (32.6)	
Grade 3	0 (0.0)	31 (33.7)	
Transverse			0.055
ligament			0.044
Grade 0	16 (53.3)	33 (35.9)	
Grade 1	8 (26.7)	22 (23.9)	
Grade 2	6 (20.0)	19 (20.7)	
Grade 3	0 (0.0)	18 (19.6)	
Tectorial			0.035[d]
membrane[c]			0.016[d]
Grade 0	25 (86.2)	54 (58.7)	
Grade 1	4 (13.8)	22 (23.9)	
Grade 2	0 (0.0)	11 (12.0)	
Grade 3	0 (0.0)	5 (5.4)	
Post. atlanto-			0.020[d]
occ. membrane[c]			0.014
Grade 0	25 (86.2)	51 (55.4)	
Grade 1	3 (10.3)	19 (20.7)	
Grade 2	1 (3.4)	11 (12.0)	
Grade 3	0 (0.0)	11 (12.0)	

[a]Chi-square test for differences in MRI classification between groups.
[b]Highest grade assigned if different between left and right side.
[c]One missing value in the control group (not examined).
[d]Fisher's exact test for difference between groups.
MRI, magnetic resonance imaging.

RESULTS

For all the neck structures considered, the chronic whiplash patients had significantly more MRI high-grade changes than the controls, although the difference for the transverse ligament was on border of statistical significance (Table 2). Changes in the alar ligaments were most common, as 66% of the patients had changes graded 2 or 3 in this structure. The lowest prevalence of high-grade MRI changes was seen for the tectorial membrane (17.4%).

None of the control persons had the most pronounced MRI changes (grade 3) in any of the five investigated structures. Moderate MRI changes (grade 2) were observed for a few structures (nine out of a total of $5 \times 30 = 150$ evaluated structures) in the control persons.

Head/Neck Position (Rotated or Neutral)

The patients who had the head rotated at the instant of collision had more often high-grade MRI changes of the alar ligaments than those with the head in a neutral position (Table 3, $p < 0.001$). A total of 61.7% of the patients with rotated neck position had alar ligament grade 3 lesions, as opposed to only 4.4% in the patient group with neutral neck position. The association between head position and high-grade lesions (grade 2–3) of the alar ligaments was more pronounced in rear-end (93.8% vs. 31.8%, $p < 0.0001$, Fisher's exact test) than in front col-

TABLE 3. MRI CLASSIFICATION OF LIGAMENTS AND MEMBRANES IN WHIPLASH PATIENTS BY HEAD POSITION AND IMPACT DIRECTION AT THE MOMENT OF COLLISION

	Head position			*Impact direction*		
	Neutral, n *(%)*	*Rotated,* n *(%)*	p-*value*[a]	*Front,* n *(%)*	*Rear end,* n *(%)*	p-*value*[a]
Alar ligaments			<0.001			0.52
(left and/or right)[b]			<0.001			0.15
Grade 0	13 (28.9)	3 (6.4)		8 (14.8)	8 (21.1)	
Grade 1	11 (24.4)	4 (8.5)		7 (13.0)	8 (21.1)	
Grade 2	19 (42.2)	11 (23.4)		20 (37.0)	10 (26.3)	
Grade 3	2 (4.4)	29 (61.7)		19 (35.2)	12 (31.6)	
Transverse			0.040			<0.001
ligament			0.64			<0.001
Grade 0	16 (35.6)	17 (36.2)		13 (24.1)	20 (52.6)	
Grade 1	12 (26.7)	10 (21.3)		8 (14.8)	14 (36.8)	
Grade 2	13 (28.9)	6 (12.8)		16 (29.6)	3 (7.9)	
Grade 3	4 (8.9)	14 (29.8)		17 (31.5)	1 (2.6)	
Tectorial			0.031[c]			0.29[c]
membrane			0.92			0.15
Grade 0	24 (53.3)	30 (63.8)		30 (55.6)	24 (63.2)	
Grade 1	13 (28.9)	9 (19.1)		12 (22.2)	10 (26.3)	
Grade 2	8 (17.8)	3 (6.4)		7 (13.0)	4 (10.5)	
Grade 3	0 (0.0)	5 (10.6)		5 (9.3)	0 (0.0)	
Post. atlanto-			0.82			0.001[c]
occ. membrane[c]			0.71			<0.001
Grade 0	26 (57.8)	25 (53.2)		23 (42.6)	28 (73.7)	
Grade 1	9 (20.0)	10 (21.3)		11 (20.4)	8 (21.1)	
Grade 2	6 (13.3)	5 (10.6)		9 (16.7)	2 (5.3)	
Grade 3	4 (8.9)	7 (14.9)		11 (20.4)	0 (0.0)	

[a]Chi-square test for differences in MRI-classification between groups (result for combined categories, grade 0–1 vs. 2–3, is shown in second line).

[b]Highest grade assigned if different between left and right side.

[c]Fisher's exact test for difference between groups.

MRI, magnetic resonance imaging.

lision (80.6% vs. 60.9%, $p = 0.13$, Fisher's exact test). In rear end collisions, in the subgroup reporting having the neck/head turned to one side ($n = 16$), the right alar ligament seemed more vulnerable when the head/neck had been turned to the left than to the right side (100% vs. 40% graded 2–3, $p = 0.018$, Fisher's exact test), whereas no such association was seen for the left alar ligament (90.9% vs. 80.0% graded 2–3 when turning left or right, respectively, $p = 1.00$, Fisher's exact test). Numbers were low, however (only five reporting turning right, 11 turning left). No association with direction of rotation were seen in front collisions ($n = 31$; 18 turning right, 13 turning left).

High-grade lesions to the transverse ligament were also more common among patients with the head turned at the instant of collision (Table 3, 29.8% and 8.9% grade 3 lesions among those with rotated and neutral head position, respectively). Similar results appeared for the tectorial membrane, although with rather few high-grade changes (Table 3). No significant association was found between head position and lesions to the posterior atlanto-occipital membrane.

Impact Direction (Front- or Rear-end)

Severe MRI changes in the transverse ligament and the posterior atlanto-occipital membrane were considerably more common in front-end than in rear-end collisions (Table 3, $p < 0.001$ and $p = 0.001$, respectively). A total of 31.5% of the patients with a front-end collision had grade 3 changes of the transverse ligament, compared with 2.6% for patients with a rear-end collision. The corresponding numbers for the posterior atlanto-occipital membrane were 20.4% and 0.0%, respectively. These associations were consistently observed in the two subgroups defined by head position.

There was no significant difference between front- and rear-end impact for the alar ligaments or the tectorial membrane. However, among patients with the head/neck in neutral position, there was a higher proportion of high-grade changes (grade 2–3) of the alar ligament in front-end than in rear-end collisions (61% vs. 32%, $p = 0.051$).

Consistency in Results

No significant association was found between MRI lesions (grade 0–3) and time since the injury (<3, 3–6, or ≥6 years) for any of the ligaments or membranes. The results according to head position and impact direction were consistently observed in subgroups of time since injury (cut point on median value, i.e., 6 years).

The analyses were repeated using MRI classification made by two other radiologists. The difference in MRI grading according to head position (neutral vs. rotated) was consistently observed for the alar and the transverse ligaments, but not for the two membranes, possible due to a general lower number of high-grade lesions in these structures. The more severe lesions of the posterior atlanto-occipital membrane and the transverse ligament after a front compared to a rear-end collision, was also consistently observed.

DISCUSSION

In the present study, a considerably higher proportion of the whiplash group had MR evidence of abnormalities in ligaments and membranes in the upper cervical spine, as compared with the control group. Pronounced MR changes were found especially in the alar ligaments, with 66% of the whiplash patients having changes graded 2 or 3. Rotation of the head/neck during the impact enhanced the frequency of high-grade MR changes in the alar ligaments, the transverse ligament, and the tectorial membrane. Direction of the impact (front- or rear-end) also had significant effects on the type and prevalence of the observed MR changes. The difference in MR findings between whiplash patients and the control persons, as well as the consistent association with factors decisive for direction of internal and external forces at the instant of collision, indicates that the soft tissue lesions, as observed on MR, indeed are consequences of the whiplash trauma.

Information regarding impact direction and head/neck position was obtained through a questionnaire that the patients fulfilled shortly after the accident. The study participants had the opportunity to choose a "do not remember" response category, but only 45 of the total of 342 WAD patients (13.2%) used this category. Nevertheless, if incorrect information on head-position were given, we would expect it to be independent of the severity of the injury, as assessed by MRI. A potential error in the data would then, if anything, underestimate the difference between the groups defined by head position. A potential recall bias, however, may lead to an overestimation. Nevertheless, we believe that our results cannot be completely explained by misclassification or recall bias.

We used MR to search for ligament and membrane lesions in the upper cervical spine. Normal ligaments show low signal intensity, appearing dark on proton density-weighted sequences (Erickson, 1997; Noto et al., 1989; Schneck et al., 1992). Increased signal intensity within the substance of a ligament is used as a sign of disruption, either partial or total (Beltran et al., 1986; Lee et al., 1988; Gallimore et al., 1986). Our evaluation was based on the assumption that the degree of ligament injury correlates to the extent of the hyper-intense signal in cross-section area.

In the present study, we focused on neck structures in the upper cervical spine that are expected to be particularly vulnerable in a whiplash trauma. Saldinger et al. (1990) found that both the transverse and the alar ligaments consisted of collagen fibres, with very few elastic fibres in the peripheral layer. The collagen and the fibre orientation determine the mechanical properties of these ligaments, leaving them without much elasticity. The mechanical properties of these ligaments are also decisive for their ability to withstand physiological load (Dvorak et al., 1988). Crisco et al. (1991) and Dvorak et al. (1987a,b) emphasized the biomechanical role for the alar and the transverse ligaments in the stability of the cranio-vertebral junction. The alar ligament restrains rotation of the upper cervical spine, whereas the transverse ligament restricts flexion as well as anterior displacement of the atlas. Panjabi et al. (1991a,b) examined the biomechanical role of the alar ligaments with the purpose of determining its role in rotation, flexion, extension, and lateral bending in the upper cervical spine. They found that cutting the alar ligaments caused increased motion in the upper two levels of the cervical spine for motions in all three planes. The present finding of an association with rotation of the head/neck, as well as heterogeneity according to type of collision (front- or rear-end), indicate that impact direction at the moment of collision indeed is of importance for location and severity of injuries. Detailed analyses revealed a more pronounced association with head rotation in rear-end than in front collisions, in particular for the alar ligaments. This finding supports the hypothesis that the alar ligaments are particularly vulnerable when the head is rotated and, in addition, bent by impact trauma (Dvorak et al., 1987a,b, 1988), especially in unexpected rear-end collision (Saldinger et al., 1990). In our recent study (Kaale et al., 2005), an abnormal alar ligament was also the strongest predictor for severity of subjective symptoms, as assessed by self-reported pain and functional disability, in WAD patients. A somewhat weaker association was found for the transverse ligament, and also the posterior atlanto-occipital membrane, in a joint analysis of associations with multiple lesions. Thus, whereas our previous results indicate that soft tissue lesions in the cranio-vertebral junction are associated with subjective symptoms among the WAD patients, the present findings link these lesions to the whiplash episode.

Traditionally, whiplash injuries have been associated with a rear-end collision. In the present study, we also considered front-end collisions. We found that lesions both of the transverse ligament and the posterior atlanto-occipital membrane were more common in front- than in rear-end collisions. It is reasonable to believe that the hyper-flexion (Adams, 1992) of the head and neck that occurs during front-end impact, with overstretching of these structures, is the main cause of the observed changes.

Other factors than those considered in the present study, like speed, type of headrest, other aspects regarding sitting position, and fitness level of each person, may also be of importance for severity of lesions. However, unless such factors also are strongly related to the accident-related factors considered in the present study, they cannot act as confounders. We are not aware of any factor that could possibly be related to head position. Thus, we believe that our results regarding the association between head/neck rotation and severity of injury are real. Higher relative vehicle speed may be more common in front than in rear end collisions, and may also lead to more severe injuries. If speed has acted as a confounder, we would expect an association with impact direction for all soft tissue structures considered. However, we found an association only with injuries to the transverse ligament and the posterior atlanto-occipital membrane. The somewhat higher proportion of high-grade MR abnormalities in the alar ligament in front collision in the subgroup of patients with neutral neck position may be related to high speed, however.

Our control group was slightly older than the WAD patients at the time of MRI examination were. If increasing age leads to changes in the structure considered, such age-related changes may underestimate a difference between the patient and the control group. In general, however, there were very few high-grade MR changes in the controls. As there was no age difference between the patient subgroups, the MR differences between these groups cannot be explained by an age factor.

In conclusion, the marked difference in MR abnormalities between WAD patients and control persons, and in particular the consistent association with accident-related factors among the WAD patients, indicate that the MR verified lesions are caused by the previous whiplash trauma. We found no association between the severity of MR abnormalities and the time since collision. This observation indicates that the MR changes indeed represent chronic lesions, although we did not have access to repeated measurements in the patients. We also found that front-end impact affected some of the structures, and we therefore suggest that front-end collisions should be included in the definition of potential causes of a whiplash trauma, not only rear-end or side impact.

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AU3
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