Magnetic resonance imaging of ligaments and membranes in the craniocervical junction in whiplash-associated injury and in healthy control subjects

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Background: The pathogenesis and imaging findings in whiplash-associated injury (WAD) are poorly understood and remain debatable.

Purpose: To assess the ligaments and membranes in the craniocervical junction with magnetic resonance imaging (MRI) in patients with WAD and to compare them with healthy control subjects.

Material and Methods: Twenty-eight patients with WAD were selected at random from a total number of 180 examined with MRI using 2-mm proton density (PD)-weighted images in three orthogonal planes at 1.5T. The patients were compared with 27 healthy control subjects without neck trauma.

Results: High signal intensity of the alar and transverse ligaments was quite common and was reported at an average of about 50% both among patients and control subjects. The incidence of abnormalities of the tectorial and posterior atlantooccipital membranes was low in both groups. No statistically significant difference between control subjects and patients with WAD was revealed for any of the structures assessed. Additional fat-suppressed images seemed to reduce the number of reported anomalies.

Conclusion: Due to lack of significant differences between patients with WAD and healthy control subjects, it is not recommended that MRI with the current technique and classification system be used in the routine workup of patients with WAD.

Key words: Ligaments; MR imaging; spine; trauma

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Whiplash-associated disorder (WAD) has become an increasingly important medical condition in recent decades (1–3). The incidence of reported WAD, and the amount of medicolegal issues associated with it, varies considerably between different countries (1, 3, 4). The pathogenesis of whiplash complaints is poorly understood. Most authors agree that it is multifactorial. Prognosis seems to be negatively influenced by female gender, low level of education, and pre-accident neck pain. Type of occupation and other personal, societal, and environmental factors are also possible predictors (2, 3, 5, 6); the severity of injury may influence the outcome as well (6). However, in an English study of subjects exposed to high-energy trauma, whiplash injury was not seen more frequently than neck pain in the general population (7). Treatment strategies in WAD range from conservative methods (8) to extensive surgical interventions with instrumental fixation from the occipital bone to the mid-cervical portion (9).

In recent years, attention has been drawn toward imaging of the ligaments and membranes in the craniocervical junction. By magnetic resonance imaging (MRI), these structures can be well visualized (10–15, 16). The purpose of the present study was therefore to assess MRI signal alterations of the ligaments and loss of integrity of the membranes in the craniocervical junction in patients with WAD, and to compare them with uninjured control subjects.

Material and Methods

Twenty-eight patients, 17 females and 11 males, aged 19–59 years, median 38 years, were selected from a total number of 180 patients with WAD consecutively...
examined with MRI from 1 to 7 years after a whiplash injury. All patients were given a number from one to 186. From this list, a random sampling was performed. The patients were compared with 27 uninjured control subjects, 13 females and 14 males, aged 21–66 years, median 36 years. None of the control subjects had a history of severe neck pain or injury to the head or neck. All MRI examinations were carried out using continuous 2-mm interleaved sagittal, coronal, and axial fast spin-echo proton density-weighted (PD) images at 1.5 Tesla with a Siemens Sonata MR unit (Erlangen, Germany), as described by Kråkenes et al. (11–14). In addition, sagittal images were repeated using PD fat suppression with the following parameters: repetition/echo time (TR/TE) 2370/11 ms, number of excitations (NEX) 5, field of view (FoV) 230 mm, bandwidth 121 Hz/pixel, acquisition time 7:34 min, matrix 224×512 giving a pixel size of 0.6x0.4 mm, in order to differentiate between fat in the ligaments and high-signal alterations caused by edema or fibrosis. All examinations were assessed by three independent neuroradiologists blinded to the classification by their colleagues on a 4-point scale ranging from 0 (normal) to 3 (maximal pathologic change) (11–14).

The classification was defined as follows. For alar ligaments, based on maximal cross-section involvement in sagittal images (11): grade 0, low signal throughout entire cross-section (Fig. 1); grade 1, high signal in 1/3 or less of cross-section; grade 2, high signal in 1/3–2/3 of cross-section; grade 3, high signal in 2/3 or more of cross-section (Fig. 2). For the transverse ligament (13): grade 0, ligament with low signal intensity, appearing dark; grade 1, slightly increased signal, well defined or slightly diffuse margins; grade 2, moderately increased signal intensity with or without diffuse margins (Fig. 3); grade 3, markedly increased signal intensity, identical to that of muscle tissue or higher, and ill-defined margins. For the tectorial membrane (12): grade 0, a membrane/dura mater complex thicker than the dura mater alone in all sagittal sections (Fig. 4); grade 1, only dura mater left in <1/3 of transverse width; grade 2, only dura mater left in 1/3 to 2/3 of transverse width; grade 3, only dura mater left in >2/3 of transverse width. For the posterior atlantooccipital membrane (12): grade 0, smooth and well-defined membrane/dura mater complex; grade 1, thinning, minor discontinuity, or a dural hump in <1/3 of transverse width (v. 5); grade 2, as grade 1, affecting 1/3–2/3 of transverse width; grade 3, discontinuity with or without a dural flap in >2/3 of transverse width.

The alar ligaments and the tectorial and posterior atlantooccipital membranes were assessed both with and without fat suppression. In the transverse ligaments, however, the assessment according to the current classification (13) is to a greater extent based on coronal and axial images. Therefore, this ligament was classified based on images without fat suppression only.

For the alar and transverse ligaments, interobserver variability was tested with the kappa value. In the tectorial and posterior atlantooccipital membranes, however, the frequency of abnormal findings was too low for a valid kappa-value calculation. Differences between patients and control subjects were calculated with the chi-square test (17). In cases where one of the expected values was below 5, the Fisher exact test was used (17). As the final result, the assessment by one of the authors (Ø.G.) was chosen (Table 1).

Results

Interobserver agreement was poor among all observers both for the alar ligaments (kappa: 0.05–0.40) and for the transverse ligament (kappa: 0.19–0.20). The classification of the ligaments and membranes of the craniocervical junction in WAD patients and control subjects appears in Table 1.

The transverse width was estimated by numbering all images in which the membranes could be appreciated.
In the alar ligaments, signal alterations were found in 27 of 56 ligaments in the WAD group and in 29 of 54 ligaments in control subjects. The proportion of high signal, including grades 2 and 3, was as high in control subjects as in patients. Imaging with fat suppression reduced the number of ligaments graded 2 and 3, leaving the grade 1 category essentially unchanged. Thus, with fat suppression, the proportion of normal ligaments increased both among patients and control subjects (Fig. 6).

High signal or blurred margins were seen in about half of the transverse ligaments in both groups (Fig. 3).

The vast majority of both patients and control subjects had normal tectorial membranes (Fig. 4).

On imaging without fat suppression, as many as 12 of the atlantooccipital membranes were deemed to be grade 1, both among WAD and control subjects. In both groups, however, a majority of membranes with a discontinuity on imaging without fat suppression were well defined on fat-suppressed images. Some other membranes were graded 1 due to the presence of a dural hump (Figs. 4 and 5).

**Discussion**

The current MRI technique (14) allows good visual resolution of the ligaments and membranes of the craniocervical junction. All structures were easily recognized in all patients and control subjects.

**Alar ligaments**

Both KRÅKENES et al. (11) and MYRAN et al. (15) found satisfactory interobserver agreement in their assessment of the alar ligaments. This differs from our results, which indicate that observer variation may influence the interpretation of the examinations. Using an open

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**Fig. 2.** Alar ligaments (arrows) with high signal intensity, grade 3 in a healthy control subject: sagittal PD (A) and coronal PD (B).

**Fig. 3.** Transverse ligament (arrows) with grade 2 signal in axial PD of a control subject.

**Fig. 4.** Normal tectorial membrane (arrows) and a posterior atlantooccipital membrane with a small dural hump (arrowheads): sagittal PD of a healthy control subject.
This assumption is supported by other studies of the alar ligaments in uninjured subjects demonstrating asymmetry (19) and high signal (18), respectively. Furthermore, biomechanical studies have not provided evidence of alar ligament involvement in whiplash injuries (20).

Transverse ligament
In a previous study (13), the transverse ligament was deemed normal in 22 of 30 (73%) control subjects compared to only 32 of 92 (36%) in a whiplash group. In our study, however, the proportion of low-signal transverse ligaments was essentially equal and about 50% in both groups.

Tectorial and posterior atlantooccipital membranes
Significantly more lesions of these structures have been observed in patients than in control subjects in another investigation, as well as a higher overall incidence of abnormalities (12). Our results, however, indicate that lesions of the tectorial and posterior atlantooccipital membranes are rare in both groups. We consider a dural hump of the posterior atlantooccipital membrane, previously assumed to be a traumatic lesion (12), to be a normal variant, which is quite frequently seen on routine examinations of the head and neck in nontraumatized subjects (Figs. 4 and 5).

Fat-saturated images
Fat-saturated PD imaging is widely used in musculoskeletal MRI. Fat saturation facilitates the differentiation between fat, which is suppressed by this technique, and fibrosis or edema, which retain high signal (21).

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<th>Table 1. Classification of ligaments and membranes of the craniocervical junction in whiplash-associated injury (WAD) and uninjured control subjects</th>
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*The right and left aspects of the transverse ligament were assessed separately.
High signal of the alar ligaments may, in some cases, be due to fat in the ligaments (Fig. 6). Fat may be a normal component of a ligament, and is frequently seen in other locations, e.g., the anterior cruciate ligament of the knee and the deltoid ligament of the ankle (21). Infiltration by fat may also be caused by inactivity.

Further, fat saturation allows for improved delineation of tendons, ligaments, and membranes. In the present study, this was particularly true for the posterior atlantooccipital membrane, which appeared normal using fat saturation in the vast majority of examinations deemed to be grade 1 injury without fat saturation (Table 1). The reduced number of high-signal alar ligaments on fat-suppressed images, and the improved delineation of the posterior atlantooccipital membrane, reducing the proportion of abnormalities reported for both structures, indicate that fat-suppressed sequences ought to be considered in future studies of the craniocervical junction.

High MR signal using PD sequences may also be caused by the magic-angle phenomenon, which occurs when examining structures orientated at an angle of 55° to the axis of the magnetic field (21). This may be of relevance for the alar ligaments in some patients. Additional T2-weighted images, which are less prone to this artifact, can solve the problem in equivocal cases. The routine use of longer TE sequences ought to be considered in further studies in WAD. Imaging at 3T and administration of intravenous contrast material also have the potential to improve image quality.

At present, a lack of association between exposure to whiplash injury and MR findings has been demonstrated in several studies (10, 15, 16, 18), of which a recent prospective study of the alar ligaments (15) strongly supports our results.

In conclusion, we cannot recommend that MRI with the current technique and classification system be used in the routine workup of patients with WAD.

References

8. Cassidy JD, Carroll LJ, Côte P, Frank J. Does multidisciplinary rehabilitation benefit whiplash recovery? Results