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MR ANALYSIS OF THE TRANSVERSE LIGAMENT IN THE LATE STAGE OF WHIPLASH INJURY

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Abstract

Purpose: To analyse and classify structural changes in the transverse ligament in the late stage of whiplash injury by use of high-resolution MRI, and to evaluate the reliability of our classification.

Material and Methods: Ninety-two whiplash-injured (2–9 years previously, mean 6 years) and 30 non-injured individuals underwent proton-weighted MR imaging of the craniovertebral junction in three orthogonal planes. Structural changes in the transverse ligaments were graded twice (grades 1–3) based on increased signal, independently by 3 radiologists with a 4-month interval. Inter- and intraobserver statistics were calculated by ordinary and weighted kappa (K).

Results: Image quality was excellent in 109 cases and slightly reduced in 13. Twenty-two out of 30 ligaments in the control group were classified as normal (73%) compared with only 32 out of 92 in the injured group (36%). Two or all 3 observers agreed in their grading in 101 out of 122 ligaments (83%). Intraobserver agreement (weighted K) was fair to good (0.33–0.73). Pair-wise interobserver agreement was fair (0.24–0.39). Reasons for divergent grading were insufficient knowledge of normal variations, low signal intensity in the peridental soft tissue obscuring the ligament and interpretation flaw.

Conclusion: Whiplash trauma can damage the transverse ligament. By use of high-resolution proton-weighted MR images such lesions can be detected and classified. The reliability of this classification still needs improvement.

Key words: Cervical spine; craniovertebral junction; whiplash injury; transverse ligament; magnetic resonance imaging.

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The transverse ligament of the atlas is a tight band, which acts as a sling holding the dens against the anterior arch of the atlas. It represents the primary restraint to anterior dislocation of C1 on C2. The biomechanic properties of the transverse ligament have been thoroughly investigated *in vitro*. It is the strongest ligament in the craniovertebral junction with a failure load that ranges from 220–1590 N (9, 18, 24).

The craniovertebral ligaments are vulnerable to high-speed trauma. Atlanto-occipital dislocation with major ligament disruption is well known, especially in children (4, 14). Traumatic disruption of the transverse ligament shown as anterior atlas translation of more than 3 mm has sporadically been reported (12, 16, 22). Such injury is easily overlooked on post-mortem examination, and might be under-diagnosed in clinical settings as well (21).

Atlantoaxial instability has previously been based on criteria drawn from computerized tomography or plain radiographic studies, which indirectly indicates rupture of the transverse ligament. Using MR imaging, Dickman et al. visualized the transverse ligament itself in injured and non-injured subjects. They concluded that MR imaging accurately depicted the anatomical integrity of this ligament (8). Furthermore, they were able to diagnose disruptions involving the ligament substance as well as avulsions at the atlantal tubercle (7). To the best of our knowledge, the transverse ligament has not been previously studied in whiplash trauma.

The aims of our study were: (a) to analyse and classify structural changes in the transverse ligament in the late stage of whiplash injury and (b) to evaluate the reliability of the ligament classification by intra- and interobserver calculations.

Material and Methods

All individuals diagnosed having had a recent whiplash injury by their primary care doctor in seven communities in Western Norway were prospectively registered. Neck X-ray in the acute phase was normal in all. Only patients classified as injury grade 2 after 12–16 weeks were included, 342 altogether. Grade 2, defined according to the Québec task force of whiplash-associated disorders is: Neck complaint with local tenderness and reduced range of neck motion without any neurological signs (25). From this sample, 100 patients were randomly drawn and invited to participate. Ninety-three accepted and gave their informed consent. One had to be excluded due to claustrophobia. Hence the study comprised 92 injured subjects, 33 males and 59 females with a mean age of 40 years (range 14–61 years) at the MR examination. The mean duration between injury and MR examination was 6 years (range 2–9 years).

A control group of 100 individuals were generated by Norway Statistics. Seventy-five were willing to participate, but 5 had to be excluded because of previous neck trauma. Fifty were randomly drawn from this sample of 70. Only 30 of them turned up for MR examination, 11 males and 19 females with a mean age of 46 years (range 28–66 years).

Images were obtained at 1.5-T scanner using fast spin echo proton-density-weighted MR sequences with 2-mm-thick, interleaved sections. Transverse sections from the foramen magnum to the base of the dens were initially obtained. An axial section of the transverse ligament was used as a locator to create the coronal and sagittal images. Our imaging protocol has been comprehensively described in a previous paper (20).

To differentiate between transverse ligaments with no, mild, moderate or severe lesions (grades 0–3) the following criteria for ligament changes were used: grade 0: ligament with low signal intensity, appearing dark (Figs 1 and 2); grade 1: slightly increased signal intensity, well-defined or slightly diffuse margins (Fig. 3); grade 2: moderately increased signal intensity with or without diffuse margins (Fig. 4); and grade 3: markedly increased signal intensity, identical to that of muscle tissue or higher, and ill-defined margins (Figs 5, 6). The increased signal could either be uni- or bilateral. A hyperintense signal should always be present in at least two imaging planes to avoid a volume-averaging artefact being misinterpreted as a lesion. Two observers had 10 years of MR experience (J.K. and G.M), 3 years for the third (H.N.). To obtain a joint understanding of the classification criteria, a pilot study of 10 cases was performed. Interpreta-

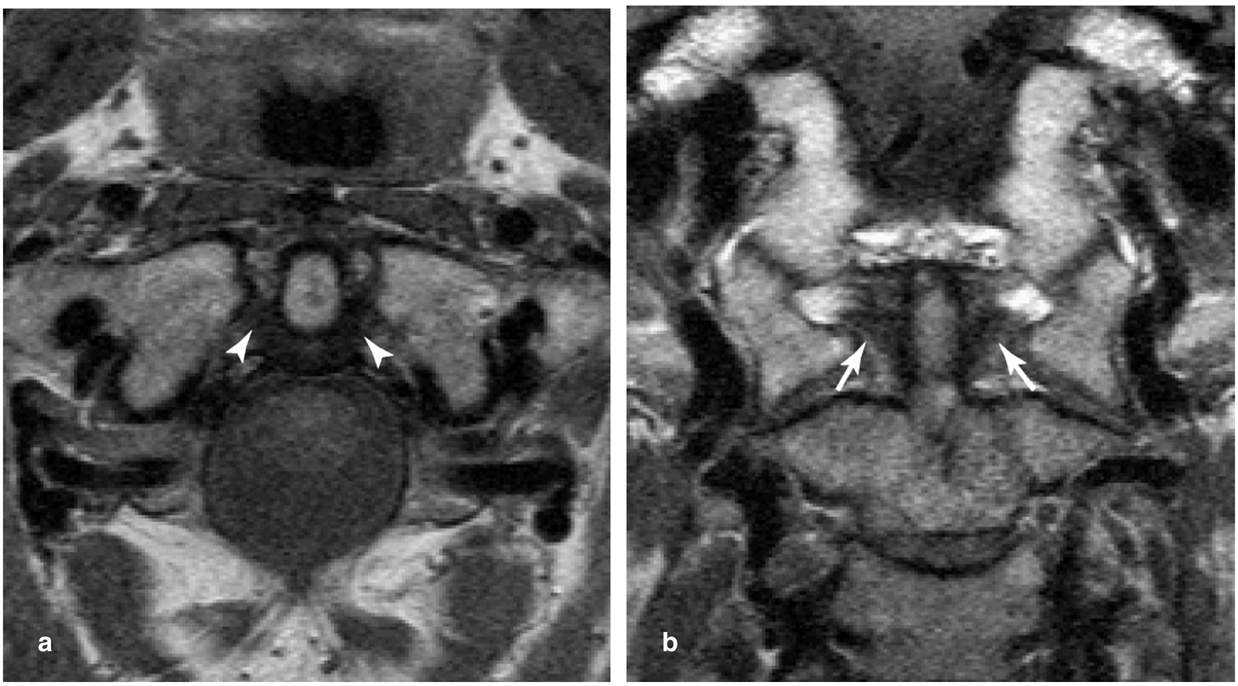

Fig. 1. a, b) Axial and coronal proton-weighted (2,200/15) fast spin-echo MR images of a slightly thickened transverse ligament. a) The signal intensity is slightly increased throughout the ligament (arrowheads). b) Well-defined ligament with low signal intensity (arrows).

Fig. 2. a, b) Axial and coronal proton-weighted (2,200/15) fast spin-echo MR images of a ligament with blurred anterior margins. a) The peridental soft tissue (asterisk) is hypointense and obscures the ligament, which also shows low signal intensity (arrowheads). b) Well-defined ligament with the same low signal intensity (arrows) should be assigned as normal.

tion results were compared, and differences in use of the criteria were discussed (results are not shown).

The MR images of the 92 injured and the 30 non-injured individuals were mixed in random order. They were evaluated twice with a 4-month interval by the same 3 neuroradiologists who were blinded

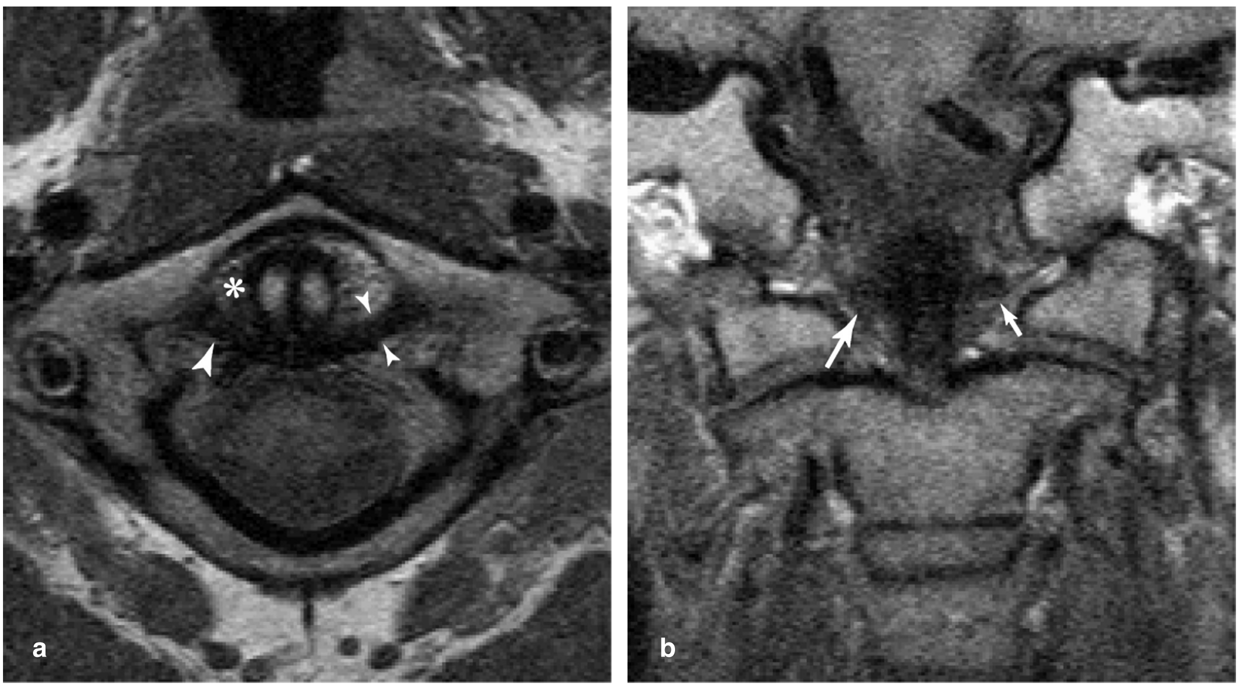

Fig. 3. a, b) Axial and coronal proton-weighted (2,200/15) fast spin-echo MR images of a grade 1 lesion on the right side. a) Right half of the ligament shows slightly increased signal intensity (arrowhead), whereas the left part is well defined (small arrowheads). Note the decreased signal intensity adjacent to the ligament (asterisk) obscuring its margin. b) Slightly increased signal intensity on the right side (arrow), whereas the left part is well defined with low signal intensity (small arrow).

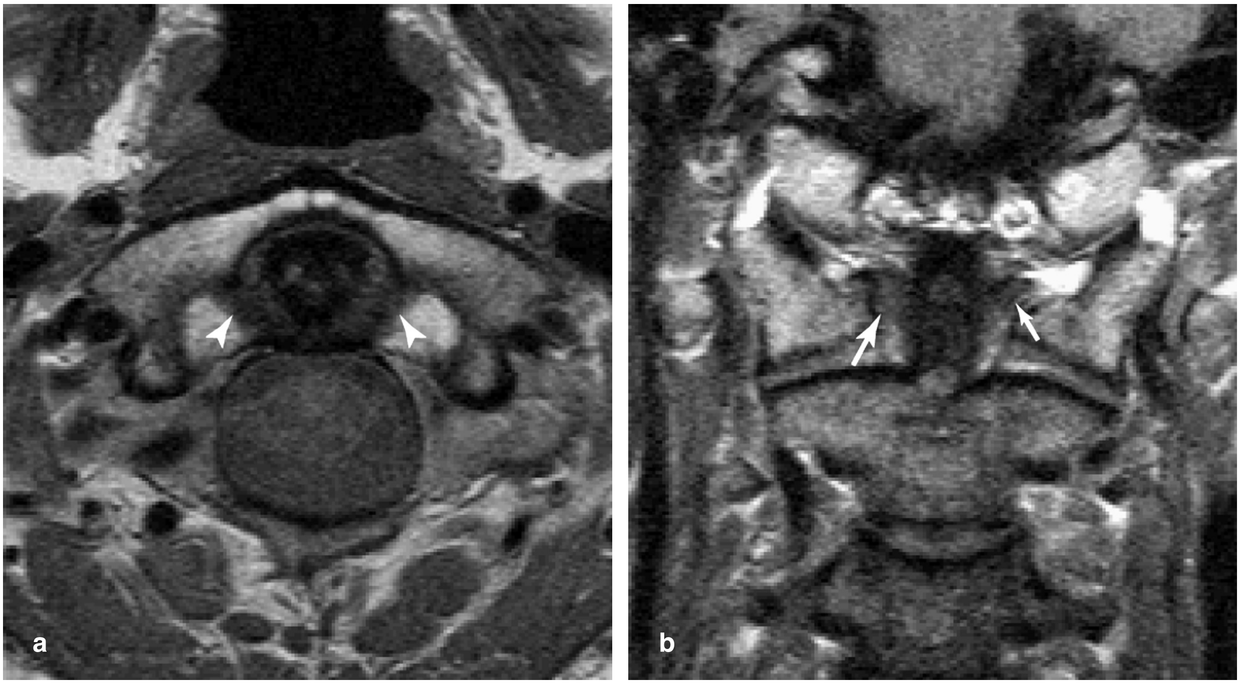

Fig. 4. a, b) Axial and coronal proton-weighted (2,200/15) fast spin-echo MR images of a transverse ligament with a swollen appearance, classified as grade 2. a) The ligament is thickened with moderately increased signal intensity and blurred margins (arrowheads). b) Moderately increased signal intensity throughout the cross-section area, slightly more prominent on the right (arrow) than on the left side (small arrow).

to clinical information. Ligaments rated two steps or more differently in the first vs. the second evaluation were re-evaluated, and each observer was asked to identify possible reasons for disagreement. The same was done for cases where all 3 observers disagreed in the second evaluation.

Kappa (K) coefficients were used to evaluate intraobserver agreement (comparing first and second interpretation) and pair-wise interobserver agreement (13, 19). Ordinary K was calculated on the basis of all four possible MR gradings (0–3), and pairs of grades combined (0–1 vs. 2–3). Weighted K was calculated as well; full agreement: 1; a one-step difference: 0.67; a two-step difference: 0.33; and a three-step difference; 0.00. $K < 0.20$ is generally regarded as indicating poor, 0.21–0.40 fair, 0.41–0.60 moderate and >0.60 good agreement (2). Consistent differences between the first and second gradings, and pair-wise differences between 2 observers were examined using the McNemar test for symmetry (1, 3). A ligament was assigned to a specific grade when 2 or all 3 observers agreed at the second evaluation.

Results

The transverse ligament could be evaluated in all 122 cases. Image quality was reduced in 13 due to motion-artefacts. The ligament was seen in two or sometimes three axial images and usually in two coronal ones. Figures 1–6 show an axial section through the mid-portion and a coronal section close to the insertion site. Sagittal images added little extra information.

Pair-wise interobserver agreement at the second grading, and intraobserver agreement for the first vs. second grading for all four transverse ligament grades are given in Table 1. Interobserver K showed poor to fair agreement (0.17–0.27), weighted K fair agreement (0.24–0.39) and dichotomized groups (grades 0–1 vs. 2–3) moderate agreement (0.43–0.47). One observer reported significantly more grade 2 and 3 lesions ($p < 0.05$). Intraobserver calculations showed fair to good ordinary K (0.21–0.62), whereas weighted K was fair for one observer and good for two (0.33–0.73). Dichotomizing the groups did not improve the agreement (0.34–0.78). One observer assigned significantly higher grades at the first than second evaluation ($p < 0.05$). Twenty-two ligaments (6%) were rated two or three steps differently at the first vs. the second evaluation. The main reasons for divergent rating are given in Table 2. Too little emphasis on coronal images and low signal intensity in the peridental space were the two identifiable reasons.

At the second grading, 2 or all 3 observers agreed on the grade in 101 ligaments, 83% of the total. Based on this agreement there were 54 grade 0 ligaments, 22 in the non-injured group. Three ligaments showed increased thickness and slightly

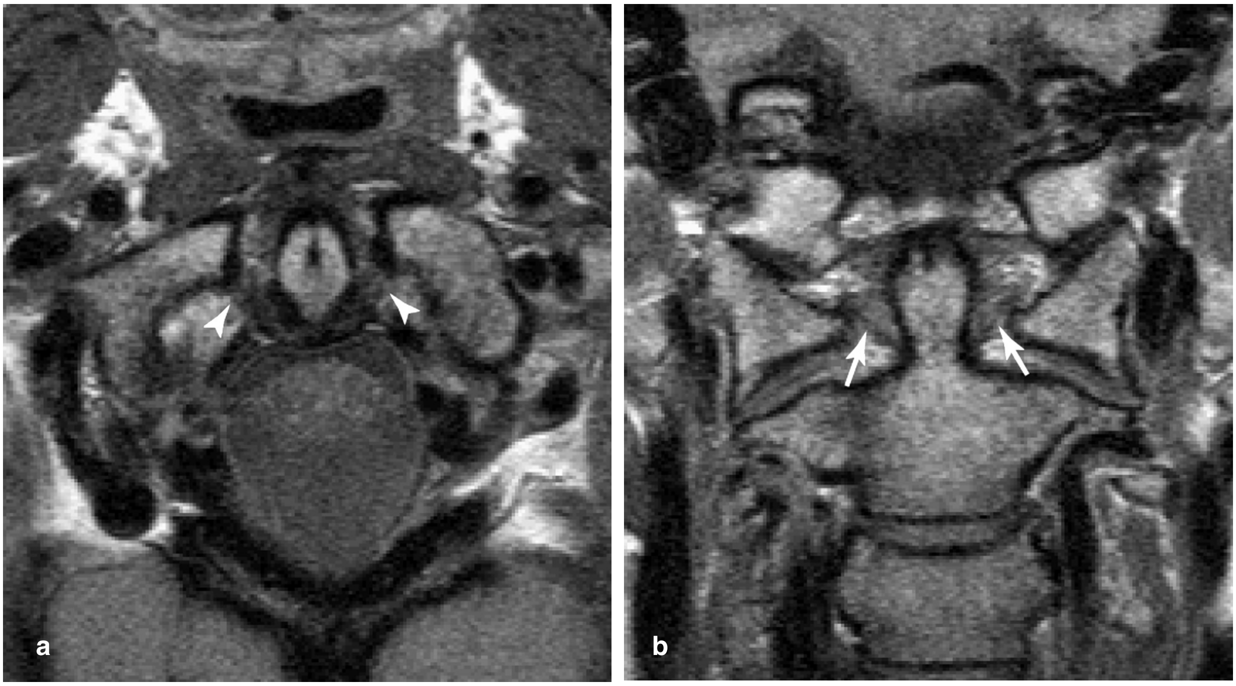

Fig. 5. a, b) Axial and coronal proton-weighted (2,200/15) fast spin-echo MR images of a transverse ligament classified as grade 3. a) The ligament shows a markedly increased signal near the atlantal insertion bilaterally (arrowheads). b) Markedly increased signal throughout the cross-section area bilaterally (arrows).

increased signal intensity on axial images, but still a low signal in the coronal plane (Fig. 1). Usually the ligament could be separated from the adjacent soft tissue. However, in 8 cases the soft tissue in the anterior atlantal space showed low signal intensity, obscuring the transverse ligament partly or totally in the axial plane, but not in the coronal plane (Fig. 2).

Slightly increased signal intensity was found in 23 cases, unilaterally in 10 (Fig. 3) and bilaterally in 13 ligaments (grade 1). Only three of these were in the non-injured group. One case showed the same low signal intensity in the peridental space (as in Fig. 2).

Nineteen ligaments, three in the non-injured group, were assigned to grade 2. These ligaments showed moderately increased signal intensity, three uni- and 16 bilaterally. Fifteen ligaments had a swollen appearance (Fig. 4). The anterior margin was partly or totally blurred in 17 ligaments (Fig. 4).

The ligaments classified as grade 3, five altogether and none in the non-injured group, showed markedly increased signal intensity uni- or bilaterally in both imaging planes and all of them appeared swollen. They almost coalesced with the peridental soft tissue despite the high or intermedi-

Table 1

Pair-wise interobserver agreement (second grading), intraobserver agreement (first vs. second grading), kappa coefficients (K) for agreement and p-*values given by the McNemar test for symmetry in classifying 122 transverse ligaments (grades 0–3) by 3 observers (J.K., G.M., H.N.)*

Observers	% in grades				Disagreement (%)	K (95% confidence intervals)		*p*
Interobserver	0	1	2	3		Ordinary	Weighted	
J.K. vs. G.M.	27.9	4.9	11.5	2.5	53.2	0.23 (0.11–0.35)	0.35 (0.23–0.47)	<0.05*
J.K. vs. H.N.	27.9	4.9	7.4	1.6	58.2	0.17 (0.07–0.27)	0.24 (0.13–0.34)	<0.01*
H.N. vs. GM	36.1	10.7	4.9	1.6	46.7	0.27 (0.14–0.40)	0.39 (0.26–0.51)	0.19
Intraobserver								
J.K.	32.8	5.7	13.9	9.8	37.8	0.47 (0.36–0.59)	0.67 (0.58–0.75)	0.30
G.M.	40.2	13.9	13.1	7.4	25.4	0.62 (0.51–0.74)	0.73 (0.64–0.82)	0.15
H.N.	26.2	9.8	8.2	0.8	55.0	0.21 0.09–0.33)	0.33 (0.22–0.44)	<0.01†

*J.K. rated significantly more grade 2 and 3 lesions than G.M. and H.N. †H.N. rated significantly higher in first vs. second grading.

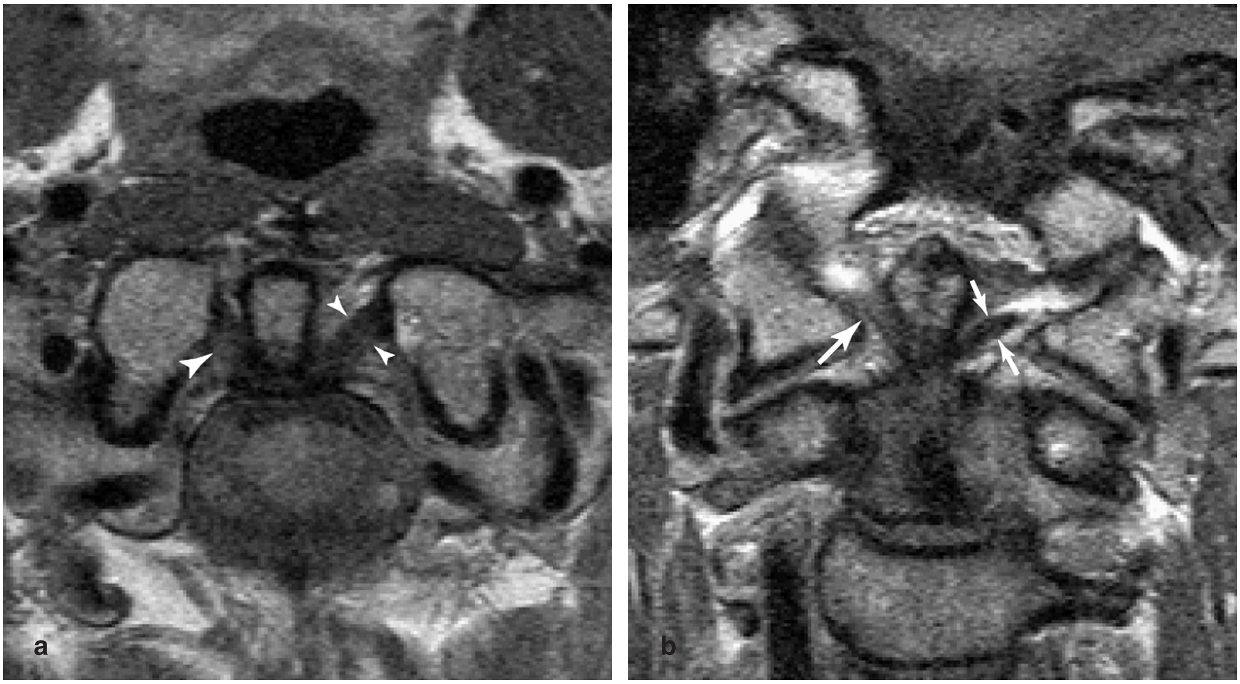

Fig. 6. a, b) Axial and coronal proton-weighted (2,200/15) fast spin-echo MR images of a unilateral grade 3 lesion. a) In the axial plane, the ligament shows increased signal intensity near the right atlantal insertion (arrowhead), normal signal intensity on the left side (small arrowheads). b) The ligament is ill-defined due to high signal intensity on the right side (arrow), whereas the left part is well defined and appears dark (small arrows).

ate signal intensity (Fig. 5). Four ligaments showed a uniform signal increase, whereas one had a unilateral lesion (Fig. 6). Discontinuity as a sign of complete disruption was never observed.

For 21 ligaments (17%), all three observers rated them differently. Two were in the non-injured group. In 13 of them, no particular reason for the inconsistency could be identified other than interpretation flaw (Table 2).

Discussion

We have examined the transverse ligament in whiplash-injured individuals several years after the accident by use of high-resolution proton-weighted MR-sequences. Twenty-three per cent of them had a moderately or markedly increased signal throughout the entire cross-section of the ligament uni- or bilaterally whereas only minor changes were observed in the control group. The transverse ligament has not previously been focused as a potential injury-site in whiplash trauma. Recent studies of the whiplash trauma mechanism have proven that anterior translation as well as hyperflexion takes place in the upper cervical spine (15, 17). Such a mechanism can strain the transverse ligament.

Normal ligaments appear as a uniform dark band on standard spin-echo pulse sequences (10). Increased signal intensity within a ligament or an irregular contour is regarded as signs of ligament

Table 2

Main reasons for pair-wise interobserver 2- or 3-step disagreement in the second grading of 122 ligaments and for similar intraobserver disagreement between first and second gradings (122 ligaments graded twice) for all three observers

	Number of ligaments	
Reasons for disagreement	Interobserver	Intraobserver
Insufficient understanding of anatomy		4
Low signal in peridental space obscuring ligament	3	10
Too little emphasize on coronal images	3	3
Reduced image quality	2	
Thin ligament due to lesion or normal variation		1
Interpretation flaw	13	2
Total	21	22

injury (6, 11). For chronic ankle ligament sprain, there is good correlation between preoperative MR evaluation and intraoperative assessment (5). Thickened ligaments with increased signal intensity and irregular margins were the most frequent MR-findings. Our grading system was primarily based on the signal intensity level within the ligament. Increased thickness and diffuse margins were seen as well in the majority of ligaments with higher grading. Thick ligaments without signal increase should be regarded as normal variant (20).

The intraobserver agreement was good for the 2 most experienced observers, whereas the pair-wise interobserver agreement was only fair. Studies of grading severity generally show greater observer variation than studies of diagnosing presence or absence only (23). K-values show that the criteria are applicable. However, the number of interpretation flaws indicates that the pilot study was too limited. Better training of the radiologists and improved MR-technology, especially high-tesla systems giving increased signal-to-noise, should improve image quality and increase grading reliability of transverse ligament lesions.

This study shows the importance of evaluating the transverse ligament in more than one imaging plane. The ligament is flattened in its median portion where it arches around the dens. On its course from the dens to the atlantal tubercles, the ligament twists into an oblique-horizontal orientation (20). In the axial imaging plane, this oblique orientation causes volume averaging, which could simulate a lesion. To differentiate between a true hyperintense signal and this volume averaging, coronal images were crucial. Too little emphasis on coronal images was an important reason for inconsistent grading. Right and left anterior oblique/sagittal series should also be considered to obtain a perpendicular cross-section view through the transverse ligament between the dens and the lateral insertions.

A difficulty in evaluating the transverse ligaments was the hypointense signal in the peridental soft tissue blurring the ligament. This signal could be due to reparative fibrosis. However, it was observed also in ligaments with normal or only slightly increased signal. Three ligaments in the non-injured group were classified as grade 2 because they coalesced with this tissue. Reassessment of these three cases showed low signal intensity in the coronal plane. Degeneration and calcification could be another cause of such changes (26), consistent with their occurrence also in the control group. We believe that ligament injury can induce similar low signal intensity. Such changes were seen adjacent to a unilateral lesion in a few cases as in Fig. 3, as well as in a majority of grade 2 lesions.

Because of great variation in the tensile strength of normal transverse ligaments (1–3), grade 1 lesions may have little clinical significance. To evaluate how our method distinguished between normal and slightly abnormal ligaments and those with more severe changes, our data were dichotomized. Moderate and good kappa values were then obtained both for intra- and interobserver agreement. A differentiation between injured and non-injured ligaments might be sufficient in clinical practice.

In conclusion, by use of high-resolution proton-weighted MR sequences we found structural changes in the transverse ligament concomitant with ligament sprain several years after whiplash trauma. The grading of such lesions is difficult, and our study has revealed several pitfalls. Further development of MR technology and more experience in image reading should improve the grading consistency. The reported protocol has the potential to become an important tool to differentiate between normal and sprained transverse ligaments.

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REFERENCES

1. Altman DG. Comparing groups – categorical data. *In*: Practical Statistics for Medical Research, 1st edn, p. 276. Edited by DG Altman. Chapman & Hall/CRC 1997.
2. Altman DG. Some common problems in medical research. *In*: Practical Statistics for Medical Research, 1st edn, p. 396. Edited by DG Altman. Chapman & Hall/CRC 1997.
3. Brennan P, Silman A. Statistical methods for assessing observer variability in clinical measures. Br. Med. J. 1992; 304: 1491–4.
4. Bulas DI, Fitz CR, Johnson DL. Traumatic atlanto-occipital dislocation in children. Radiology 1993; 188: 155–8.
5. Cardone BW, Erickson SJ, Den Hartog BD, Carrera GF. MRI of injury to the lateral collateral ligamentous complex of the ankle. J. Comput. Assist. Tomogr. 1993; 17: 102–7.
6. Chandnani VP, Harper MT, Ficke JR, et al. Chronic ankle instability: evaluation with MR arthrography, MR imaging, and stress radiography. Radiology 1994; 192: 189–94.
7. Dickman CA, Greene KA, Sonntag VK. Injuries involving the transverse atlantal ligament: classification and treatment guidelines based upon experience with 39 injuries. Neurosurgery 1996; 38: 44–50.
8. Dickman CA, Mamourian A, Sonntag VK, Drayer BP. Magnetic resonance imaging of the transverse atlantal ligament for the evaluation of atlantoaxial instability. J. Neurosurg. 1991; 75: 221–7.
9. Dvorak J, Schneider E, Saldinger P, Rahm B. Biomechanics of the craniocervical region: the alar and transverse ligaments. J. Orthop. Res. 1988; 6: 452–61.

10. Erickson SJ. High-resolution imaging of the musculoskeletal system. Radiology 1997; 205: 593–618.
11. Farooki S, Seeger LL. Magnetic resonance imaging in the evaluation of ligament injuries. Skeletal. Radiol. 1999; 28: 61–74.
12. Fielding JW, van Cochran GB, Lawsing JF, Hohl M. Tears of the transverse ligament of the atlas: a clinical and biomechanical study. J. Bone Joint Surg. 1974; 56: 1683–91.
13. Fleiss JL. The measurement of interrater agreement. *In*: Statistical Methods for Rates and Proportions, 2nd edn, p. 212. Edited by JL Fleiss. John Wiley & Sons 1981.
14. Grabb CG, Frye TA, Hedlund GL, Vaid YN, Grabb P, Royal SA. MRI diagnosis of suspected atlanto-occipital dissociation in childhood. Pediatr. Radiol. 1999; 29: 275–81.
15. Grauer JN, Panjabi MM, Cholewicki J, Nibu K, Dvorak J. Whiplash produces an S-shaped curvature of the neck with hyperextension at lower levels. Spine 1998; 22: 2489–94.
16. Greene KA, Dickman CA, Marciano FF, Drabier J, Drayer BP, Sonntag VK. Transverse atlantal ligament disruption associated with odontoid fractures. Spine 1994; 19: 2307–14.
17. Grifka J, Hedtmann A, Pape HG, Witte H, Bar HF. Biomechanics of injury of the cervical spine. Orthopäde [German] 1998; 27: 802–12.
18. Heller JG, Amrani J, Hutton WC. Transverse ligament failure; a biomechanical study. J. Spinal Disord. 1993; 6: 162–5.
19. Krakenes J, Kaale BR, Moen G, Nordli H, Gilhus NE, Rorvik J. MRI assessment of the alar ligaments in the late stage of whiplash injury – a study on structural abnormalities and observer agreement. Neuroradiology 2002; 44: 617. Erratum: Neuroradiology 2002; 44: 874–6.
20. Krakenes J, Kaale BR, Rorvik J, Gilhus NE. MRI assessment of normal ligamentous structures in the craniovertebral junction. Neuroradiology 2001; 43: 1089–97.
21. Krantz P. Isolated disruption of the transverse ligament of the atlas: an injury easily overlooked at post-mortem examination. Injury 1980; 2: 168–70.
22. Lipson SJ. Fractures of the atlas associated with fractures of the odontoid process and transverse ligament ruptures. J. Bone Joint Surg. 1977; 59: 940–3.
23. Robinson PJ. Radiology's Achilles' heel: error and variation in the interpretation of the Röntgen image. Br. J. Radiol. 1997; 70: 1085–98.
24. Spence KF, Decker S, Sell KW. Bursting atlantal fracture associated with rupture of the transverse ligament. J. Bone Joint Surg. 1970; 52: 543–9.
25. Spitzer WO, Skovron ML, Salmi LR et al. Scientific monograph of the Quebec Task Force on Whiplash-Associated Disorders: Redefining 'whiplash' and its management. Spine 1995; 20 (8 Suppl.): 1S–73S.
26. Zapletal J, Hekster RE, Straver JS, Wilmink JT, Hermans J. Association of transverse ligament calcification with anterior atlanto-odontoid osteoarthritis: CT findings. Neuroradiol. 1995; 37: 667–9.