Delineation of Alar Ligament Morphology: Comparison of Magnetic Resonance Imaging at 1.5 and 3 Tesla

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abstract

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Rupture of the alar and transverse ligaments due to whiplash injury can lead to upper cervical spine instability and subsequent neurological deterioration. The purpose of this study was to evaluate the normal anatomical variability of the alar ligaments in asymptomatic individuals with 3-T magnetic resonance imaging (MRI) and to compare the findings with standard 1.5-T examinations.

Thirty-six participants underwent 3-T and 1.5-T MRIs. Magnetic resonance imaging findings were analyzed by classifying the alar ligaments with regard to the features detectability, signal intensity compared with muscle tissue, homogeneity, shape, spatial orientation, and symmetry. Delineation of the alar ligaments was significantly better on 3-T images, which were subjectively preferred for evaluation. The alar ligaments showed great variability. In the majority of participants, the alar ligaments were hypointense to muscle tissue, inhomogeneous, and different in shape and orientation. A statistically significantly higher number of ligaments appeared symmetric on 3-T imaging, indicating that 1.5-T imaging may underestimate the proportion of patients with normal, symmetric ligaments.

This study demonstrates that high-field 3-T MRI provides better visualization of the alar ligaments compared with 1.5-T MRI. The higher signal-to-noise ratio allows detection of small signal changes. A great interindividual variety of the MRI morphology of the alar ligaments was found in participants with no history of neck trauma. Further studies with more participants are necessary to evaluate alar ligament pathologies in patients with a history of whiplash injury.

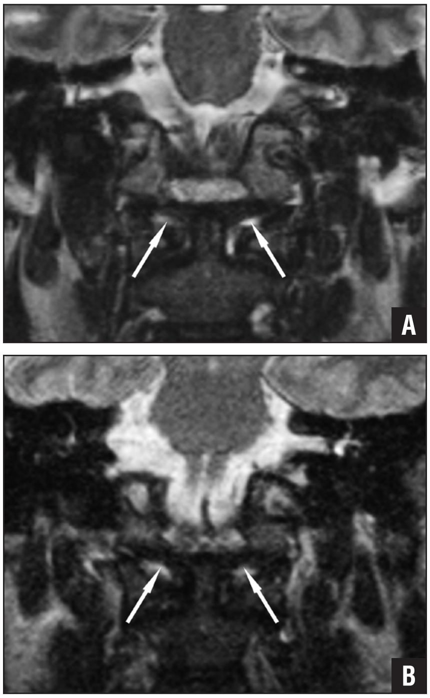

Figure: Three-T (A) and 1.5-T (B) magnetic resonance images showing the alar ligaments (arrows), which were classified as homogeneous, hypointense, and horizontal orientated with a convergent shape.

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Whiplash injury, one of the most common injuries following minor motor vehicle accidents, has been estimated to occur in approximately one-fifth of car occupants who present to the hospital after a crash.[1] Although most patients recover from a relatively benign injury, approximately one-quarter experience prolonged morbidity, with little prospect of complete resolution of pain and other symptoms.[2,3] The burden of these injuries to the community in health and welfare services costs, loss of earnings, and insurance claims is substantial.[4-6] Whiplash injury resembles an acceleration–deceleration mechanism with energy transfer to the neck with a variety of clinical manifestations.[7] Twenty-four percent to 70% of patients with whiplash-associated disorders are reported to have long-term symptoms. Up to 16% remain severely impaired many years after the accident, which interferes with their activities or daily living.[3,5,7-9]

The alar ligaments are considered an important ligamentous craniocervical structure for the integrity and stability of the craniocervical junction. Due to the lack of a disk and the horizontal nature of the facet joints, the stability of the atlantoaxial joint depends mainly on ligaments and muscles.[10] The most important function of the alar ligaments is the limitation of axial rotation, and they are most vulnerable when the head is rotated and flexed.[11] Rupture of the alar and transverse ligaments may occur without associated vertebral fracture and can lead to upper cervical spine instability and subsequent neurological deterioration.[12]

Although computed tomography has demonstrated its ability to visualize anatomy and pathology of the alar ligaments, the tissue contrast is poor.[13,14] Therefore, magnetic resonance imaging (MRI) is considered the modality of choice because of its high tissue contrast and multiplanar imaging capability.

With the increasing integration of 3-T MRI into clinical practice, the question arises if the application of this technology leads to better visualization of the alar ligaments. In theory, a linear relationship exists between signal-to-noise ratio and magnetic field strength. The purpose of this study was to evaluate the normal anatomical variability of the alar ligaments in asymptomatic individuals with 3-T MRI and to compare the findings with the authors' standard protocol examination. The authors aimed to demonstrate that this technique increases the reliability and accuracy of alar ligament lesion classification.

Materials and Methods

Institutional ethics committee approval and written consent of the participants were obtained. Thirty-six participants who were asymptomatic regarding neck pain and in systemic condition sufficiently stable to withstand multiple MRI studies were prospectively included in the study. The participants (10 women and 9 men; mean age, 32.2 years [age range, 19-89 years]) underwent coronal T2-weighted MRI on a 3-T scanner (MAGNETOM Trio; Siemens Healthcare, Erlangen, Germany) (repetition time, 3000 ms; echo time, 354 ms; slice thickness, 0.8 mm) and a 1.5-T scanner (MAGNETOM Vision; Siemens Healthcare) (repetition time, 6360, echo time, 107, slice thick-

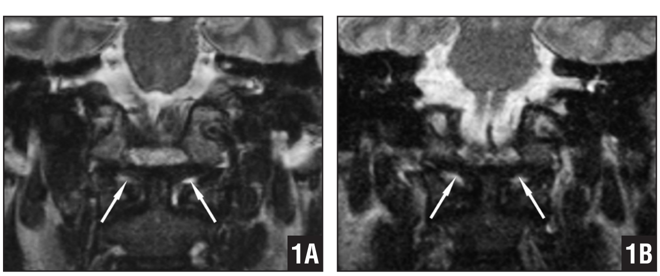

Figure 1: Three-T (A) and 1.5-T (B) magnetic resonance images showing the alar ligaments (arrows), which were classified as homogeneous, hypointense, and horizontal orientated with a convergent shape.

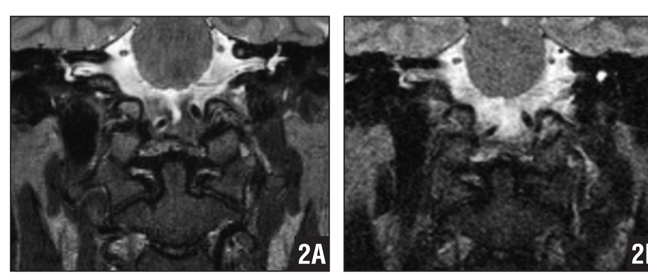

Figure 2: Three-T (A) and 1.5-T (B) magnetic resonance images showing the overall higher signal-to-noise ratio on 3-T imaging.

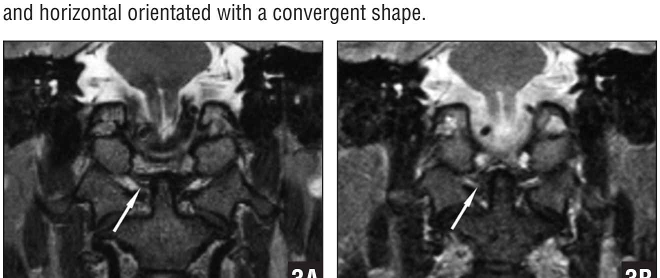

Figure 3: Three-T magnetic resonance image showing well-defined alar (arrow) and transverse ligaments (A). One point five-T magnetic resonance images showing that the inhomogeneity of the right alar ligament (arrow) visible on the 3-T image is not clearly visualized.

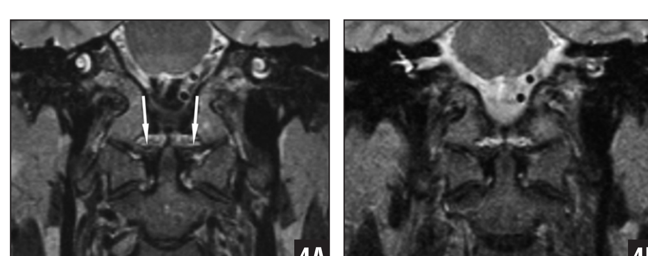

Figure 4: Three-T (A) and 1.5-T (B) magnetic resonance images showing the well-defined borders of the alar ligaments (arrows) on the 3-T image compared with the 1.5-T image.

Table 1

Attributes of Alar Ligaments on 1.5-T and 3-T MRI[a]

	Neuroradiologist A				Neuroradiologist B			
	1.5 T		3 T		1.5 T		3 T	
Attribute	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**
Features detectability								
Well-defined	16		32		16		33	
Irregular	20		4		20		3	
Poorly or not visualized	0		0		0		0	
Signal intensity								
Hypointense	29	30	31	31	31	32	31	29
Hyperintense	0	0	0	0	0	0	0	0
Isointense	7	6	5	5	5	4	5	7
Homogeneity								
Homogeneous	11	12	12	12	14	15	13	9
Inhomogeneous	25	24	24	24	22	21	23	27
Shape								
Convergent	24	20	21	20	22	20	22	21
Parallel	12	16	15	16	14	16	14	14
Divergent	0	0	0	0	0	0	0	1
Orientation								
Cranial	16	14	15	16	15	14	15	15
Caudal	20	22	21	20	21	22	21	21
Horizontal	0	0	0	0	0	0	0	0
Symmetry								
Symmetric	13		25		14		22	
Asymmetric	23		11		22		14	
Method preferred	1		35		0		36	

Abbreviation: MRI, magnetic resonance imaging.
[a]*Data presented as number.*

ness, 2 mm). Magnetic resonance imaging findings were analyzed independently by 2 neuroradiologists (R.D., P.S.) by classifying the alar ligaments (Figures 1-4) with regard to the features detectability (ie, well-defined, irregular, or poorly or not visualized), signal intensity in comparison with muscle tissue (ie, hypointense, isointense, or hyperintense), homogeneity (ie, homogeneous or inhomogeneous), shape (ie, convergent, parallel, or divergent), spatial orientation (ie, cranial, horizontal, or caudal) and symmetry (ie, symmetric or asymmetric). For each participant, the neuroradiologist gave an opinion on which method would be preferred for routine diagnosis.

Statistical analysis was performed with IBM SPSS version 19 software (IBM, Somers, New York).

Results

The alar ligaments could be detected in all participants on 1.5- and 3-T MRI (Table 1). Delineation (well-defined or irregular) was significantly better on 3-T MRI (Tables 2, 3). In all but 1 case, both neuroradiologists subjectively preferred the 3-T MRI for evaluation.

The alar ligaments showed great variability. Signal intensity of the alar ligaments on T2-weighted images was predominantly hypointense compared with muscle tissue (range, 81%-89%), followed by isointense (range, 14%-19%). In the majority of participants, the alar ligaments were inhomogeneous (range, 58%-75%), different in shape (range: convergent, 56%-67%; parallel, 33%-44%; divergent, 0%-3%), and dif-

Table 2

1.5 T vs 3 T Delineation

	1.5 T (n=72)		3 T (n=72)	
Delineation	**No.**	**%**	**No.**	**%**
Well-defined	32	44.4	65	90.3
Irregular	40	55.6	7	9.7

	3 T		
1.5 T	**Well-defined**	**Irregular**	**Total**
Well-defined	31	1	32
Irregular	34	6	40
Total	65	7	72

Table 3

Interobserver Variability

Attribute	Kappa Coefficient
Detectability	
1.5 T	0.775
3 T	0.842
Signal intensity	
1.5 T	
Right	0.801
Left	0.769
3 T	
Right	0.535
Left	0.801
Homogeneity	
1.5 T	
Right	0.696
Left	0.824
3 T	
Right	0.750
Left	0.533
Shape	
1.5 T	
Right	0.760
Left	0.775
3 T	
Right	0.827
Left	0.779
Orientation	
1.5 T	
Right	0.943
Left	1.00
3 T	
Right	1.000
Left	0.943
Symmetry	
1.5 T	0.822
3 T	0.696

ferent in orientation (range: cranial, 39%-44%; caudal, 0%; horizontal, 56%-61%). On 3-T MRI, the alar ligaments of more participants appeared symmetric (range, 61%-69%) than on 1.5-T MRI (range, 36%-39%). This indicates that 1.5-T imaging underestimates the proportion of patients with normal, symmetric alar ligaments.

No statistical difference existed between the 2 methods regarding signal intensity, homogeneity, shape, and spatial orientation. Detailed evaluation of the attribute delineation as the most important parameter for further evaluation was performed. Both neuroradiologists' results showed better detectability of the alar ligaments on 3-T MRI (Table 2). Only 9.7% of the alar ligaments were difficult to detect on 3-T MRI compared with 55.6% on 1.5-T MRI. This leads to a lower statistical probability of an irregular image on 3-T MRI (odds ratio, 0.086; $P<.001$). Furthermore, 3-T MRI showed symmetric alar ligaments in a significantly higher number of participants than did 1.5-T MRI ($P<.001$). Interobserver agreement was evaluated by calculation of the kappa coefficient per attribute. The interobserver correlation coefficient kappa was substantial (>0.6) or almost perfect (>0.8) in nearly all attributes (Table 3). No significant difference existed between the kappa values of both methods ($P=.683$).

Discussion

This study demonstrates that reliable assessment of alar ligaments by means of MRI can be achieved and that high-field 3-T MRI provides better visualization of the alar ligaments compared with 1.5-T MRI. To the authors' knowledge, this is the first study comparing 3- and 1.5-T MRI of the alar ligaments.

Debate is ongoing about the diagnostic value of MRI signal changes of the alar ligaments in healthy individuals and in patients after whiplash injury. Bitterling et al[15] concluded that signal alteration of the alar ligaments cannot be differentiated from common normal variants, and Myran et al[16] questioned the diagnostic value and clinical relevance of magnetic resonance detectable areas of high intensity in the alar ligaments. However, Vetti et al[17] recently reported that high signal changes of the alar and transverse ligaments are common in whiplash-associated disorders and unlikely to represent age-dependent degeneration. A decade ago, Pfirrmann et al[6] reported that structural alterations of the alar ligaments are frequent findings in asymptomatic individuals that limit their clinical relevance in the identification of the cause of neck pain in symptomatic patients. All of these authors operated with 1.0- or 1.5-T MRI.[6,15-17] With advances in imaging technology and the emergence of 3-T MRI, revalidation of the findings of these authors may be worthwhile, especially with regard to the high health care costs associated with whiplash-associated injuries. In the United States, whiplash injuries represent 30% to 40% of car insurance claims and cause related costs of approximately $7 billion per year.[18]

Due to their subtle structures and variable orientation, MRI of the alar ligaments is challenging. T2 contrast is helpful to differentiate the ligamentous structures of the spine from surrounding fatty tissue and muscles, as well as from cerebrospinal fluid.[19] The higher signal-to-noise ratio of 3-T MRI compared with 1.5-T MRI allows for the detection of small signal changes of a ligament, which at 1.5 T will likely not overcome the noise threshold.

In the current study, a great interindividual variety of MRI morphology of the alar ligaments was found. The current findings agree with those of orther studies.[6,16,20,21] A remarkable variation was found of all characteristic imaging patterns of MRI morphology of the alar ligaments, including shape, spatial orientation, symmetry, and signal intensity, because all participants had no known history of neck trauma. Because the attributes of homogeneity and signal intensity of the alar ligaments are thought to represent some correlate of ligament distortion or trauma, the normal variation of these characteristics in healthy individuals leads to the conclusion that the pathologic effect of these MRI signal alterations is of minor importance, especially in patients with late whiplash syndrome. Schrader et al[22] reported that chronic symptoms in patients with whiplash injury were not usually caused by the car accident but by the expectation of disability and family history, and that attribution of preexisting symptoms to the trauma may be more important determinants.

Conclusion

High-field 3-T MRI is a valuable diagnostic tool for imaging of the alar ligaments because of its excellent delineation of these ligaments compared with standard 1.5-T MRI. Further studies with more participants are necessary to evaluate alar ligament pathologies in patients with a history of whiplash injury. These studies should be performed using 3-T MRI.

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