REVIEW ARTICLE

Magnetic Resonance Imaging Anatomy of Alar Ligament: A Review of Literature

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ABSTRACT

Alar ligament is one of the most important craniocervical junction (CCJ) ligaments; acting as stabilizer of CCJ and limiting axial rotation. It may be involved in various pathological processes including trauma. Magnetic resonance imaging (MRI) is increasingly being used in cervical spine trauma as a supplement to conventional radiography and computed tomography (CT) to detect a wide range of severe cervical spine injuries. MR depiction of alar ligament requires special sequences despite no known established MR sequence is available. However, the role of MRI in minor or moderate trauma, including whiplash injuries, has long been debated, particularly when neurological dysfunction is absent, because no anatomical disruption other than degenerative disc disease have been reported. In this review, we provide detailed account on the current knowledge of MR visualization of normal alar ligament; outlining the variations in its signal intensity, dimension, shape and orientation.
Malaysian Journal of Medicine and Health Sciences (2023) 19(5):389-398. doi:10.47836/mjmhs19.5.44

Keywords: Alar ligament normal anatomy, Alar ligament variability, Alar ligament on 3.0T MRI, Alar ligament signal intensity

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INTRODUCTION

Alar ligament is one component of multiple ligaments residing around the craniovertebral junction (CVJ); in fact, it is one of the most important and detrimental if injured. It is a paired ligament that originates from the distal lateral ends of the odontoid of C2 and has two attachment sites: the medial aspect of the occipital condyles and the axis bilaterally (1). The CVJ ligamentous complex is intended to stabilise the atlanto-occipital and atlanto-axial joints; and the ligaments are further classified as intrinsic and extrinsic ligaments.

Together with the apical ligament, they form the odontoid ligament, which is one of the intrinsic ligaments; along with the tectorial membrane and cruciate ligament (2). They serve as CVJ stabilisers by limiting axial rotation. Aside from that, the alar ligament supports flexion and limits extension of the neck, as well as preventing odontoid dislocation in the longitudinal direction. Biomechanical cadaveric studies (3) have shown that this small ligament also serves as primary restraints to axial rotation and lateral flexion; when rotated to the right, the left becomes taut, and the other way around. Having said this, it allows for adequate mobility and stability as provided by the transverse ligament, while safeguarding the neurovascular structures that pass through the skull at the CVJ.

Tribute to the advent of MRI which provides enhanced tissue depiction from intense spatial resolution, attempts to visualize the alar ligament had long started since the early 2000's. This is particularly true with regards to stronger magnetic field MR scanner, whereby it is now possible to evaluate small CCJ ligamentous complex including alar ligament to its intricate features. As a result, MRI evaluation is frequently carried out, particularly in cases of traumatic injuries because it has been shown to be a valuable adjunct to computed tomography and conventional radiography in the detection of a variety of serious cervical spine injuries, including cord injury and disc herniation (4-11). MRI is also recommended for patients with neurological deficit, suspected ligamentous injury, and those who cannot be clinically assessed for more than 48 hours due to changed level of consciousness, as well as for patients with unstable cervical spine (2). However, in minor or moderate trauma including whiplash injuries, the role of MRI has been long debated especially in the absence of neurological deficit, since there have been no observed structural alterations other than age-related degenerative disc problems.

GROSS ANATOMY OF ALAR LIGAMENT

The intricate transitional zone between the skull and the spine is represented by the craniovertebral (CVJ) junction. The occiput (posterior base of the skull), foramen magnum, clivus, atlas, axis, ligaments of the atlantooccipital, and atlantoaxial articulations are some of the various components that make up this complicated equilibrium (12). Because of its osseous components, which are articulated with synovial joints, intrinsic ligaments, membranes and muscles, it should be regarded as anatomically and radiographically dissimilar from both the cranium and the cervical spine. It is well known for housing the spinal cord and several cranial nerves, but it also contains important blood vessels that supply the cervical cord parenchyma and the brain. As a result, injury to this area is therefore likely to have significant morbidity and mortality. The CVJ is subject to a demanding role because it must simultaneously allow extensive mobility while also containing, protecting, and supporting structures that are essential for function and, ultimately, evolutionary survival (4).

The atlanto-axial and atlanto-occipital joints are intended to be stabilised by the CVJ ligamentous complex, which is why the ligaments are divided into intrinsic and extrinsic ligaments. Being one of the intrinsic ligaments, alar ligament is paired in configuration with the ligament forming an angle greater than 108°. The paired alar ligament extends superolaterally from the dens and derives its name from the Latin word 'ala', which means wing-like. This ligament originates from the distal lateral ends of odontoid of C2 with two sites of attachments, which are the occipital condyles' medial aspect (also termed occipitoalar) as well as the axis (also termed atlantoalar) bilaterally. The dens and the medial side of the occipital condyles are connected by the alar ligaments which form thick strands of fibre (3). The tectorial membrane and alar ligament must be partially or totally ruptured for vertical distraction to occur at the atlantooccipital junction (5).

In previous studies of alar ligament in other mammalian counterpart (7), it was concurred the alar ligament develops from the lateral sides of dens, while there are differences on where it connects to the skull. In a few species, it also attaches at the lateral aspects of foramen magnum or the lateral masses of the atlas. While in others, it attaches solely to the occipital condyles. This is none other than corresponding to normal anatomical variation (13). The atlantal section of this ligament is primarily absent, which may suggest that it is an anatomical variation and not a vital component supporting the stability of the CVJ.

Previous cadaveric study presented to us by Iwanaga, Sardi, Voin, Chapman, Oskouian and Tubbs (3) showed that the alar ligament width is reduced towards its mid portion. This agrees with Krakenes, Kaale, Rorvik, and Gilhus (14) whereby the mid portion of the ligament is the thinnest part whereas the medial attachment is the thickest. Such configuration might suggest that the middle part of the ligament is the most fragile part hence the most likely to be torn. However, as many alar ligament lesions have been linked to condylar fractures, atlanto-axial dislocations, and atlanto-occipital dissociation, rupture is typically found close to the ligament's distal end.

EMBRYOLOGY OF ALAR LIGAMENT

The CVJ arises from mesoderm tissue, emerging in the 3rd week of gestation. Cells from the embryonic plate condense during gastrulation to create the parachordal mesoderm on either side of the notochord. Somites are segmental clusters formed when this mesoderm ultimately divides. This set of somites (the number of which is species-specific; in human consists of 42 pairs) will inevitably generate a variety of structures, including the vertebral column, the axial skeletal musculature, and the smooth muscle of the dermis. When grown, somites separate into dorsolateral dermomyotomes and ventromedial sclerotomes. Sclerotomes eventually give rise to membranes, ligaments, neural arches, and vertebral bodies.

The four occipital somites and the initial three cervical somites grow into the CVJ. The rostral basiocciput will develop from the first three occipital somites. The proatlas, a sclerotome that serves as the precursor to the CVJ is created when the fourth occipital somite joins the cranial portion of the first cervical somite. The first three occipital somites' sclerotome segments merge with the cranial portion of this sclerotome to create the basiocciput. The body of the axis is formed by a portion of the second cervical sclerotome, while the basal portion of the odontoid peg (dens) is formed by a portion of the first cervical sclerotome (C2 vertebra). The axial component of the first cervical sclerotome gives rise to both the alar ligament and the transverse ligamentous portion of the cruciform (cruciate) ligament (4). Eventually, human spine development will cease at third decades of life (12).

EVOLUTION IN MR ASSESSMENT OF ALAR LIGAMENT

Radiological work to visualize alar ligament on magnetic resonance imaging (MRI) has long started since the 1991 by Schweitzer, Hodler, Cervilla, and Resnick (16) and Krakenes, Kaale, Rorvik, and Gilhus (14) using a 1.5-Tesla MR scanner. They subsequently discussed the normal MRI appearance of craniovertebral junction including alar ligament, correlating them with the gross cadaveric dissection appearances. About ten years after that in early 2000's by Pfirmann, Binkert, Zanetti, Boos and Hodler (17) and Knackstedt, Krekenes, Bansevicius and Russell (6) also utilized 1.5-Tesla MR system and started recruiting healthy asymptomatic individuals. These studies proved that alar ligament can be visualized on MRI and is best seen on thin slice 2-mm proton-density sequence. Three different cross-sectional configurations were also identified by Krakenes, Kaale, Rorvik, and Gilhus (14) which were round, oval and wing-like appearances.

This is followed by another study the following year, again by Krakenes, Kaale, Moen, Nordli, Gilhus and Rorvik (6) which scrutinized alar ligament in patients with whiplash associated disorder (WAD) using a 4-tier grading system (grade 0 = low signal intensity across the whole cross section, 1 = high signal intensity in one third or less, 2 = high signal intensity in one-third to two thirds, and 3 = high signal intensity in two thirds or more across the cross-section). This is based on the ratio between the high signal area and the total cross-sectional area. Moderate to good intraobserver agreement was obtained with regards to detection of abnormal signal of alar ligament on MRI. However, this is strongly disagreed by Roy, Hol, Laerum, and Tillung (18) and Bitterling, St∆bler, and Brьckmann (7, 8) where they discovered marked intra-observer disagreement in analysing this ligament as well as a high range of normal signal variant.

Roy, Hol, Laerum, and Tillung (18) also found that there was poor concordance in visualizing alar ligament at different field strengths and concluded that MRI might not be the investigation of choice for subtle injuries of this ligament. Subsequent case-control studies carried out by Myran et al. (4) and Dullerud, Gjertsen, and Server (9) also found that there was lack of significant difference between alar ligament signal in WAD patients and asymptomatic subjects. Dullerud, Gjertsen and Server (9) suggested that this could be explained by magic angle phenomenon. Vetti, Krakenes, Eide, Rorvik, Gilhus, and Espeland (10) found that for acute WAD1-2 individuals without prior neck issues, hyperintense signal of the alar ligament immediately following damage did not alter outcome, making upper neck MRI of little utility for the initial assessment and monitoring of such patients. Further cross-sectional study by Myran et al. (4) found that alar ligament alterations in WAD patients were not significantly correlated with pain or functional impairment.

Concerning different magnetic fields of MR system, Lummet et al. (31) as well as Schmidt, Mayer, and Drescher (12) compared between 1-Tesla versus 1.5-Tesla versus 3-Tesla system and 1.5-Tesla versus 3-Tesla respectively. They concluded that higher magnetic field MRI systems improved the delineation of alar ligament due to greater signal-to-noise ratio, although the increased signal in alar ligament is already detected even at the lowest magnetic field. This is particularly true in coronal followed by sagittal views. While there was no discernible difference between 1.5 T and 3 T in sagittal view, delineation was substantially better on 3 T than on 1.5 T in coronal view. The 3 distinct field strengths did not significantly differ in terms of the alar ligament signal intensity in sagittal view among healthy volunteers.

Remarkable discovery by Wenz et al. (20) concluded that age, gender, and height all have a significant impact on the alar ligament signal hyperintensities in healthy people. They began to divide the signal intensities into fat-related hyperintensity (FH) and non fat-related hyperintensity (NFH) which may be attributed by variation in fibre compaction. With regards to FH, height and gender were determined to be the most important factors; while NFH was found more frequently in individuals more than 28.5 years old. Dyas, Niemeier, Mcgwin, and Theiss (11) attempted to assess the likelihood of alar ligament rupture in patients at risk of atlanto-occipital dissociation. Again, their findings indicated that interobserver and intraobserver reliability in the assessment of alar ligament injuries was inconsistent and inadequate. Most recently, Peters, Parizel, and Van Goethem (21) demonstrated that symptomatic individuals have varying degrees of signal intensity and alar ligament thickness as well as proposed a revised grading method for assessing variations in craniocervical ligaments in the general population.

MR MORPHOLOGY OF ALAR LIGAMENT IN VARIOUS STUDIES

Alar Ligament Visualization

In conjunction with cadaveric dissection anatomy, it was found that alar ligament is an important craniocervical junction ligament which is inevitably found in all human, emphasizing its great significance, most likely attributable to its function which is hardly replaced by any other ligaments. Its relevance is also demonstrable in its other mammalian counterparts as reported in Hecker's (1922) by Oakes, Sardi, Oskouian, and Tubbs (13) in a study of comparative anatomy between different species. Concordance of alar ligament configuration during cadaveric dissection and MRI images is also observed in a study by Debernadi, Daliberti, Talamonti, Villa, Piparo and Collice (1) whereby this ligament is a paired ligament with two portions each: the atlantoalar and the occipitoalar. The alar ligament is visualized well on the coronal and sagittal plane, as depicted by Krakenes, Kaale, Rorvik and Gilhus (14).

Alar Ligament Orientations

Dvorak and Panjabi (22) first described craniocaudal orientation of this ligament in 1987 which was observed in most of the cadaveric specimens. Krakenes, Kaale, Rorvik and Gilhus (14) subsequently described different orientations of alar ligament on MRI as superiorly oriented, horizontally oriented and inferiorly oriented. Then, Lummel, Zeif, Kloetzer, Linn, Brьckmann and Bitterling (19) characterized this ligament on MRI as laterally ascending, horizontal and laterally descending; which was adopted by many subsequent studies. Iwanaga, Sardi, Voin, Chapman, Oskouian and Tubbs (3) even described this ligament as being inverted 'V'-shaped in most of the cadaveric specimens dissected. When biomechanics of this ligament is of concern, horizontal orientation is essential in restricting rotational motions of the CVJ, which would be less efficient if it were orientated vertically. The horizontal disposition of the alar ligament fibre seems to be more precise than the conventional more angled vertical configuration. Table I presents alar ligament orientations observed in previous studies. Figure 1 shows different alar ligament orientations by different authors.

Alar Ligament Cross-Sectional Shapes

In terms of shape, there is no previous cadaveric studies which discuss regarding this aspect. Whereas different descriptions of alar ligament shape were presented by various studies. For instance, Krakenes, Kaale, Rorvik and Gilhus (14) and Lummel, Zeif, Kloetzer, Linn, Brückmann and Bitterling (19) adopted three different characterization of the shape viz. round, ovoid and wing-like. Other studies e.g. Pfirmann, Binkert, Zanetti, Boos and Hodler (17) and Schmidt, Mayer and Drescher (12) preferred to describe alar ligament shape as convergent, parallel and divergent. Finally, Wenz et al. (20) did analyse the shape of alar ligament but only mentioned the symmetry of the shape between the right and left ligaments in the literature while the exact shape characterization was unclear. Table II summarizes alar ligament shapes as observed on MRI in various studies.

Table 1: Different alar ligament orientations as described in previous literatures including cadaveric studies.

Study	Study Population & MRI System/ Sequences	Findings in Alar ligament Orientations
Dvorak and Panjabi (1987)	19 cadaveric upper cervical spine specimens	Most specimens showed craniocaudal direction. The fibre orientation is dependent on the height of dens axis.
Krakenes et al. (2001)	30 healthy volunteers; 11 men age range 28 ± 66 years; mean 46 years) and 19 women age range 29±62 years; mean 45 years Using 1.5-Tesla MRI, 2-mm, PD-weighted	A posterolateral orientation of less than 180 was found in the majority (23 of 30 cases), a straight lateral orientation in five cases and an anterolateral orientation more than 180° in two cases. On coronal images, 73% were horizontally oriented; 17% were superiorly oriented and 10% were inferiorly oriented. On axial images, 77% were posterolaterally oriented; 17% were laterally oriented and only 6% were anterolaterally oriented.
Pfirrmann et al. (2001)	50 healthy individuals (31 men, 19 women) with a mean age of 30 years (range, 19 – 47 years. Using 1.5-Tesla MRI, 3-mm, T1- and T2-weighted.	The orientation of the ligaments was caudocranial in 41% and 47%, horizontal in 52% and 47%, and craniocaudal in 7% and 5% on the left and right, respectively.
Lummel et al. (2011)	50 healthy volunteers (23 men, 27 women); average age was 24.1 years (range, 20–31 years) Using 1.5-Tesla MRI, 2-mm PD-weighted	On coronal images, ligaments were horizontally oriented in 40.5% and laterally ascending from the dens up to the condyles in 58.5%; laterally descending orientation in 1%. On axial view, a posterolateral orientation was found in 32.5%, a straight lateral orientation was found in 67.5%, and an anterolateral orientation was not found.
Schmidt et al. (2012)	36 healthy volunteers; mean age = 32.2 years; range 19-89 years Comparison between different magnetic field strengths of MRI (1.5-, 3-Tesla)	Cranial orientation was seen in 39-44%), horizontal orientation 56-61% and no caudal orientation observed.
Lummel et al. (2012)	50 healthy volunteers (23 men, 27 women; mean age = 24.1 year; range = 20–31 year; SD ± 2.7) Comparison between different magnetic field strengths of MRI (1-, 1.5-, 3-Tesla)	On coronal images, 58.5% were laterally ascending; 40.5% were in horizontal orientation.
Osmotherly, Rivett, and Mercer (2013)	11 cadaveric cervical spine specimens	Horizontal orientation in 7 specimens, slightly craniocaudal orientation in 4 specimens.
Wenz et al. (2015)	66 healthy volunteers separated into 2 groups (old vs young) using two approaches: dichotomization at the median age (40.0 years) and the calculated threshold (28.5 years) using receiver operating characteristics (ROC) Using 3.0-Tesla MRI, 2-mm PD-weighted	On coronal images, 62.1% were laterally ascending; 37.9% were horizontally orientated.
Iwanaga et al. (2017)	22 sides from 11, fresh frozen, cadaveric heads were used. The specimens included 8 males and 3 females that ranged in age from 67 to 99-years-old at death	Inverted V in nearly 54% of specimens, a transverse line in 40% and a normal V-shape in rare cases. When viewed from above, all the ligaments had a posterolateral insertion onto the dens that accounts for the nearly horizontal or slight posterolateral direction toward the condyles.

Figure 1: MRI images in T2-weighted sequence showing laterally ascending orientation of alar ligament in topmost images (19, 30); transverse or horizontal or lateral orientation in middle images (12, 14); and laterally descending orientation in lowermost images (19, 30).

Alar Ligament Signal Intensity

It is a generally known fact that on MRI study, ligamentous structures in the human body generally appear homogenously low signal intensity with few exceptions, due to the abundance of collagen fibres. This is in keeping with histopathological examination whereby Dvorak and Panjabi (22) discovered that the alar ligament almost exclusively consists of collagen fibres. However, the frequently observed signal intensity within alar ligament on MRI triggers further question of its actual histological constituent.

With regards to MR imaging, several prior studies pioneered by Krakenes, Kaale, Moen, Nordli, Gilhus and Rorvik (6) had adopted a 4-points grading system as their sole method in describing the alar ligament hyperintensity on axial view; from 0 to 3. The following table summarizes the 4-points scoring system of hyperintense signal in alar ligament.

However, in view of marked morphological variations especially in the signal intensity of the alar ligament, Myran et al. (4) and Dullerud, Gjertsen and Server (9) did not recommend utilization of this classification system in the routine evaluation of patients with WAD. Table III summarizes the findings of alar ligament signal intensity in previous studies.

Table II: Different alar ligament shapes on MRI as described by previous literatures.

Study	Study Population & MRI System/ Sequences	Findings in Alar Ligament Shapes
Krakenes et al. (2001)	30 healthy volunteers; 11 men age range 28±66 years; mean 46 years) and 19 women age range 29±62 years; mean 45 years Using 1.5-Tesla MRI, 2-mm PD-weighted	Round (23%); ovoid (54%); wing-like (23%).
Pfirrmann et al. (2001)	50 healthy individuals (31 men, 19 women) with a mean age of 30 years (range 19 – 47 years) Using 1.5-Tesla MRI, 3-mm T1- and T2-weighted	The shape of most ligaments was convergent to the periphery (76% left and 68% right). In 24% (left) and 32% (right) of the individuals, ligament borders were parallel. No divergent ligament forms were detected.
Lummel et al. (2011)	50 healthy volunteers (23 men, 27 women); average age was 24.1 years (range, 20–31 years) Using 1.5-Tesla MRI, 2-mm PD-weighted	Round in 41.5%; ovoid in 51.5%; wing-like in 6.5%.
Schmidt et al. (2012)	36 healthy volunteers; mean age = 32.2 years; range 19-89 years Comparison between different magnetic field strengths of MRI (1.5-, 3-Tesla)	Convergent shape was seen in 56-67%, parallel shape in 33-44%, divergent shape in 0-3%.
Wenz et al. (2015)	66 healthy volunteers separated into 2 groups (old vs. young) using 2 approaches: dichotomization at the median age (40.0 years) and the calculated threshold (28.5 years) using receiver operating characteristics (ROC) Using 3.0-Tesla MRI, 2-mm PD-weighted	Symmetry in terms of shape and size, was present in 91% of participants (60 of 66); asymmetrical AL was found in 9% of participants (6 of 66).

Alar Ligament Dimensions

There are several ways of measuring the alar ligament as portrayed by previous literatures. However, as any other ligaments, the most salient dimension of alar ligament is the length of the ligament from its origin towards the insertion site. Generally, the ligament varies in length from 8.8 to 15.0 mm. The next most important dimension of alar ligament is its thickness. This was measured in many previous studies, but a study by Iwanaga, Sardi, Voin, Chapman, Oskouian and Tubbs (3) showed that alar ligament is thinnest at its mid portion. Table IV lists the various alar ligament measurements from earlier investigations.

CLINICAL SIGNIFICANCE OF ALAR LIGAMENT

Trauma

In Malaysia, road traffic accidents (RTAs) have been a serious public health concern. According to statistics from the Road Transport Department, motorcyclists make up roughly half of all registered vehicles on the road. While it should be viewed as a hazard to Malaysians' quality of life, motorcycle riders are more vulnerable to chest and neck injuries during RTA. According to Ooi, Wong, Radin Umar, Azhar and Megat Ahmad (23), hyperflexion sprain, uni- or bilateral interfacetal dislocation, simple wedge (compression) fracture, flexion teardrop fracture, odontoid fracture, burst fracture, hyperextension fracture

Table III: Variable alar ligament signal intensity on MRI as described by previous literatures

Study	Study Population & MRI System/ Sequences	Findings in Alar Ligament Hyperintensity
Schweitzer et al. (1991)	Using 1.5-Tesla system, 4-mm spin-echo	Intermediate signal
Krakenes et al. (2001)	30 healthy volunteers; 11 men age range 28±66 years; mean 46 years) and 19 women age range 29±62 years; mean 45 years Using 1.5-Tesla MRI, 2-mm PD-, T1- and T2-weighted	Six cases showed low signal intensity (dark) all through the ligament. Seven had slightly higher signal intensity and appeared grey. The remaining 17 showed low signal laterally and higher signal medially. In 1 ligament, a high signal area covering nearly half of the cross-section in an otherwise low signal ligament structure. Higher signal towards dens seen in the majority of cases. Thin ligaments appeared dark, thicker ligaments appeared grey.
Pfirrmann et al. (2001)	50 healthy individuals (31 men, 19 women) with a mean age of 30 years (range, 19 – 47 years) Using 1.5-Tesla MRI, 3-mm T1- and T2-weighted	The signal intensity of alar ligaments was the same as that of the surrounding muscle tissue in most individuals on T1-weighted (64% left and 52% right) and T2-weighted images (67% left and right). Hyperintense and hypointense ligaments were less frequent on T1-weighted (21% left and right, 14% left and 21% right, respectively) and T2-weighted (24% left and 8% right, 9% left and 18% right, respectively) images.
Krakenes et al. (2002)	92 whiplash-injured (33 males and 59 females, mean age 40 years, mean time between injury and MRI is 6 years) and 30 uninjured individuals Using 1.5-Tesla MRI, 2-mm proton density-weighted	No grade 2 or 3 lesion in the uninjured group.
Dullerud et al. (2009)	28 patients with WAD compared with 27 healthy control subjects without neck trauma. Using 1.5-Tesla MRI, 2-mm PD-weighted	Signal alterations were found in 27 of 56 ligaments in 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 the patients. With fat suppression, the proportion of normal ligaments increased both among patients and control subjects.
Lummel et al. (2011)	50 healthy volunteers (23 men, 27 women); average age was 24.1 years (range, 20–31 years) Using 1.5-Tesla MRI, 2-mm PD-weighted	In a sagittal view, 6.5% of alar ligament appeared homogeneously dark. Hyperintense signal intensity in up to one-third of the cross-sectional area was present in 33% of cases; up to two-thirds of the cross-sectional area was hyperintense in 45% of the ligaments and 15% of the ligaments showed a hyperintense signal intensity in more than two-thirds of the cross-sectional area.
Lummel et al. (2012)	50 healthy volunteers (23 men, 27 women; mean age = 24.1 year; range = 20–31 year; SD ± 2.7) Comparison between different magnetic field strengths of MRI (1-,1.5-,3-Tesla).	No significant influence of the MRI field strength on the signal intensity of alar ligament.
Wenz et al. (2015)	66 healthy volunteers separated into 2 groups (old vs young) using 2 approaches: dichotomization at the median age (40.0 years) and the calculated threshold (28.5 years) using receiver operating characteristics (ROC). Using 3.0-Tesla MRI, 2-mm PD-weighted.	Two different AL patterns were observed: inhomogeneous (33.3%) and homogeneous (66.7%) whereby the latter pattern was mostly surrounded by a small dark rim (56.8%). Fat could be identified in 15.9% of all ALs (21 of 132 patients), and NFH was identified in 17.4% of all ALs (23 of 132 patients). Age 28.5 years was the preferred threshold, demonstrating a relatively high sensitivity for dichotomizing the population based on the ROC of NFH. Fat-related hyperintensities occurred significantly more frequently in men than women (OR 0.110 and p = 0.007 for women; OR 9.075 and p = 0.007 for men). Height was the second most significant factor: for every 1-cm increase, the odds of having fat lesions increased by approximately 10% (OR 1.102; p = 0.017).

of the posterior arch of the atlas, laminar fracture, intervertebral subluxation, and fracture of the uncinate process are among the cervical injuries.

The integrity of alar ligament is of utmost importance during the instance of trauma. Due to the wide lever-arm caused rostrally by the skull and the relative freedom of movement of the CVJ, it is particularly prone to injury because it is located in a very dynamic transition zone of the vertebral column (12). In relation to this, it is important to discuss specifically regarding the devastating atlantooccipital dissociation, the milder whiplash-associated disorder as well as occipital condylar fractures where alar ligament is usually afflicted.

Atlantooccipital dissociation (AOD) is known to be a rare but rather devastating injury. It can be identified by an atlantooccipital articulation widening of more than 4 mm and further classified using Traynelis Classification depending on whether craniocervical displacement takes place in anterior, posterior or longitudinal to the cervical spines (24, 25). This injury is more commonly observed in the paediatric population, in view of this age group has a less concave articulating surface of the atlas at this joint apart from an underdeveloped alar ligament (4). Management wise, traction is contraindicated in type 1 injuries. The affected patients, including those with spinal cord injuries, should undergo occipito-cervical fixation to make extubation and rehabilitation easier. Rigid fixation with an occipital plate and cervical screws is a standard way to do this.

The occipitocervical junction is known to have horizontally oriented facets with lack of intervertebral disc. Therefore, its stability is mostly dictated by the condition of the soft tissues and ligaments, notably the alar ligament. While debates continuously exist with

Table IV: Various measurements of alar ligament in previous literatures including cadaveric studies.

Study	Study Population & MRI System/ Sequences	Findings in Alar Ligament Dimensions
Dvorak and Panjabi (1987)	19 cadaveric upper cervical spine specimens	Approximately 10-13 mm long and elliptical in cross-section 3 X 6 mm in diameter.
Krakenes et al. (2001)	30 healthy volunteers; 11 men age range 28±66 years; mean 46 years) and 19 women age range 29±62 years; mean 45 years. Using 1.5-Tesla MRI, 2-mm PD	The median portion was flattened in all 30 cases. The mean ligament thickness at the mid-portion was 2.5 range 1.5 ± 3.5) mm. The mean craniocaudal height was 7 range 6 ± 9) mm. The mean ratio between height and thickness was 2.9 (range 2.0 ± 4.8). There was no correlation between ligament height and thickness.
Pfirrmann et al. (2001)	50 healthy individuals (31 men, 19 women) with a mean age of 30 years (range 19 – 47 years. Using 1.5-Tesla MRI, 3-mm T1 and T2.	The mean length of the alar ligament is 11mm cranially and 13mm caudally; the mean area is 3.2 x 6.0 mm with the larger diameter found in the craniocaudal direction.
Lummel et al. (2011)	50 healthy volunteers (23 men, 27 women); average age was 24.1 years (range, 20–31 years), Using 1.5-Tesla MRI, 2-mm PD.	10 to 13-mm length, 3 - 6 mm diameter.
Lummel et al. (2012)	50 healthy volunteers (23 men, 27 women; mean age = 24.1 year; range = 20–31 year; SD ± 2.7) Comparison between different magnetic field strengths of MRI (1-,1.5- and 3-Tesla)	The ligament has a length of about 10 mm, with a general variation of 2 mm; and a diameter varying from 2.9 ± 0.9 mm.
Osmotherly et al. (2013)	11 cadaveric cervical spine specimens	The length of alar ligaments between bony insertions ranged between 11 to 15 mm (mean length 12 mm, SD 1.25). The superior-inferior width of the ligaments viewed from the coronal plane ranged from 4 to 5 mm.
Cattrysse, Buzzatti, Provyn, Barbero, and Roy (2016)	20 cadaveric cervical spine fresh frozen specimens	The overall length of the ligaments was 8.8 mm (± 2.6 mm). The ligaments had a mean diameter of 7.3 mm (± 1.9 mm), ranging from 2 mm to 10 mm
Iwanaga et al. (2017)	11 cadaveric cervical spine fresh frozen specimens	Some asymmetry between the diameter of the left (8.7 ± 2.8 mm) and right sides (8.4 ± 2.5 mm). The anterior- posterior thickness showed mean diameter of 6.7 ± 2.0 mm (range 4.0 – 10.0 mm) in the left and 7.1 ± 1.8 mm (range 4.0 – 9.9 mm) in the right. The width lessened toward the middle portion of the ligament with a mean of 6.8±1.8 mm (range 3.8 – 8.7 mm) and 6.6±1.4 mm (range 4.8 – 9.0 mm) for the left and right sides, respectively.

regards to each craniovertebral ligament specific role in stability, alar ligament disruption has been theorised to occur in cases of clinically substantial instability of the occipitocervical area. Previous literatures (24, 25) suggested that the prognosis of AOD directly correlated with the time when the first diagnosis was made. It has been shown that all patients diagnosed with AOD earlier tend to survive without delayed neurological dysfunction, whereas delay in diagnosis resulted in an 89% of people dying within 90 days of an accident.

Having mentioned this, the diagnosis of AOD remains challenging since approximately 25% of them are missed on CT which over decades has supplanted the detection of cervical injuries with conventional cervical radiography. While previous research has shown that CT can identify relevant anatomic landmarks with 99% accuracy compared to lateral radiographs at 39%–84%, craniometric measurements like the Powers ratio, basion-dens interval, basion-axial interval, and condyle–C1 interval (CC1) continue to have low sensitivity for detecting AOD. This is the reason why MRI is so popular to directly visualize soft tissue injuries whereby CT and plain radiographs are only able to predict occipitocervical instability indirectly by solely relying on the craniometric measurements (11).

High impact trauma like whiplash injury significantly harms the CVJ ligaments. The definition of whiplash is an injury which is caused by hyperextension and subsequent cervical spine hyperflexion. This is related to the head experiencing abrupt acceleration and/ or deceleration, which is most frequently brought on by motor vehicle accidents. Plain films are typically normal in whiplash injury. On the other hand, the functional status of individuals with whiplash-associated disorder (WAD), a complicated illness influenced by numerous contributing factors, is affected. These include a variety of psychosocial factors as well as disability benefits. It is considered a minor disability-related soft tissue injuries due to a vehicle rear-end collision which has received a lot of attention (26).

According to Bitterling, Stäbler and Brückmann (7), medical experts frequently encounter WAD, which has tremendous knock-on effects for car insurance firms. Frequently, a diagnostic conundrum exists when there is a contradiction between strongly reported medical illnesses and the absence of objective data. However, motor control investigations discovered some motor control deficits that are particular to the WAD group. These deficiencies were also linked to high levels of discomfort, light-headedness, and depressed symptoms, which may affect the patients' functional status. According to a recent study, psychological characteristics may be more useful in predicting the duration and severity of symptoms in accident victims with WADs than collision severity (27). Therefore, there is a lot riding on diagnostic radiology to either validate or disprove this clinical illness with objective imaging results (7).

When compared to uninjured controls, chronic WAD has been shown to have more frequent high signal alterations of the alar ligament on high-resolution MRI. It started off when Krakenes, Kaale, Rorvik and Gilhus (14) found changes in alar ligament on MRI of alar and transverse ligament in WAD despite normal plain cervical radiograph. However, Vetti, Krakenes, Eide, Rorvik, Gilhus and Espeland (10) discovered that this high MR signal in alar ligament is not associated with real disability or neck pain in acute WAD 1-2 patients. As described by Pfirmann, Binkert, Zanetti, Boos and Hodler (17), large variations in fibre course, asymmetry, and ligament signal intensity tend to make it more difficult to distinguish between post-traumatic changes and typical physiological variations. Hence, MRI is of limited value for follow-up such lesions.

Occipital condyle fractures, which could be caused by inferior extension of skull vault fractures or reflect impacted fractures, can be a sign of high-energy trauma yet are simple to miss (24). The occipital condyle is also involved in alar ligament avulsion fractures. Using the Anderson and Montesano classification, it is divided into three types to depict various mechanisms and fracture patterns. A comminuted fracture without displacement is classified as a type 1 fracture. Type 2 fracture occurs when there is inferior extension from the occiput. However, because the tectorial membrane and alar ligaments are still intact, they usually remain stable. Avulsion at the point of alar ligament insertion characterises type 3 fracture, which is considered unstable, especially if bilaterally involved (29).

The presence or absence of CVJ instability heavily influences management. All patients must be externally immobilised with a hard collar for a minimum of 8 weeks due to the possibility of developing delayed lower cranial nerve impairments. When the more unstable bilateral fractures are considered, halo external orthosis is recommended. Occipital fixation is rarely required, usually in patients with contiguous C0/C1/C2 injuries, overt ligamentous instability, or neural compromise that necessitates decompression (12).

Other Pathologies Involving Craniocervical Junction

Apart from trauma, the CCJ and its ligaments including the alar ligament may get involved with multiple other pathologies. Obstructive hydrocephalus, neuronal or vascular impairment, and disruptions in the cerebrospinal fluid dynamics can all result from abnormalities in this area. According to Talukdar, Yalawar and Kumar (28), the commonest pathology involving CCJ is congenital anomaly and trauma which has been discussed previously. This is followed by CVJ tuberculosis and rheumatoid arthritis. They also found that males are more commonly affected than in CCJ pathologies than females. Since the upper cervical complex is a unique region of the spine, which depends heavily on the ligaments within for both mobility and stability, it is important to discuss regarding the pathologies which may compromise the ligament.

CONCLUSION

It has been presented in great detail regarding the alar ligament in terms of anatomical, embryological and biomechanical properties. It is now undeniable that though alar ligament is only a small structure, it plays a vital role in ensuring mobility, flexibility and survival of human being. It has also been outlined previously regarding how MR evaluation of alar ligament commenced, together with various reviews on the visualization, orientation, shape, signal intensity and dimensions. Radiological identification of alar ligament pathology may be difficult due to the high variety of the alar ligament in terms of its orientation, form and signal intensity. Regardless of whether hyperintensity or inhomogeneous signal inside the alar ligament indicates actual injury, it should be accompanied by significant clinical suspicion, especially in the case of trauma since a substantial degree of variance in this ligament is unquestionably present. The evaluation should be supplemented with additional techniques like computed tomography of the cervical region and plain radiography. Ultimately, the previous classification (14) for measuring alar ligament signal intensity should be replaced by a new classification; whereby the likelihood of an alar ligament damage can be determined objectively using clinicoradiological criteria that take into account results from multimodality approach using plain radiography, computed tomography and MR examination.

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