ORIGINAL ARTICLE

Characterization of Alar Ligament in Young Adult on 3.0T MRI: A Cross-sectional Study in IIUM Medical Centre, Kuantan

Raihanah Haroon[1], Siti Kamariah Che Mohamed[1], Karimah Hanim Abd. Aziz[2]

[1] Department of Radiology, Kulliyyah of Medicine, International Islamic University of Malaysia (IIUM), Jalan Sultan Ahmad Shah, 25200 Kuantan, Pahang
[2] Department of Community Medicine, Kulliyyah of Medicine, International Islamic University of Malaysia (IIUM), Jalan Sultan Ahmad Shah, 25200 Kuantan, Pahang

ABSTRACT

Introduction: Alar ligament is a paired craniocervical junction ligaments which stabilizes the atlantooccipital and atlantoaxial joints. The main purpose of the study was to compare the normal anatomy of alar ligament on MRI between male and female. The prevalence of alar ligament visualized on MRI and its characteristics were also studied apart from determining the association between the heights of respondents with alar ligament signal intensity and dimensions. **Methods:** Fifty healthy volunteers were studied using 3.0T MR scanner (Siemens Magnetom Spectra) by 2-mm proton density, T2 and fat-suppression sequences. Alar ligament visualization, dimensions and variability of the ligament courses, shapes and signal intensity characteristics were determined. **Results:** The orientation of the ligament was laterally ascending in most of the subjects (60%), predominantly oval in shaped (54%) and 67% showed inhomogenous signal. Females are 70% less likely to exhibit alar ligament signal inhomogeneity than males. There were positive correlation between height and the craniocaudal diameter of the alar ligament as well as the antero-posterior diameter, which were statistically significant ($r = 0.25$, $n = 100$, $p = 0.01$ and $r = 0.201$, $n = 100$, $p = 0.045$ respectively). **Conclusion:** Tremendous variability of alar ligament shows that clinical and multimodality correlation needs to be exercised, especially in evaluating alar ligament MR signal in male. Taller individuals otherwise tend to have longer and thicker ligaments. Future studies with larger samples of alar ligaments including trauma cases are also recommended to supplant a new classification system of alar ligament injury.
Malaysian Journal of Medicine and Health Sciences (2023) 19(1):149-157. doi:10.47836/mjmhs19.1.21

Keywords: Alar ligament, MRI, Atlantoaxial joint, Male female, Healthy respondents

Corresponding Author:
Raihanah Haroon, MMed (Radiology)
Email: raihanahharoon@iium.edu.my
Tel: +6013-7413649

INTRODUCTION

Alar ligament is one of the several craniocervical junction (CCJ) ligaments; one of the most important and most detrimental if injured, as a matter of fact. It is a paired ligament forming an angle greater than 108°, which originates from the distal lateral ends of odontoid of 2nd cervical vertebra (C2) with two sites of attachments; the medial side of occipital condyles as well as the axis bilaterally (1). The CCJ ligamentous complex is meant to stabilize the atlanto-occipital joint along with the atlanto-axial joint and the ligaments are classified into intrinsic and extrinsic ligaments (2).

Along with apical ligament, their combination is termed as odontoid ligament and serves as one of the intrinsic ligament that stabilizes the CCJ apart from tectorial membrane and cruciate ligament (3). Biomechanical cadaveric studies have shown that this small ligament also serves as primary restraints to axial rotation and lateral flexion; the right becoming taut on rotation to the left and vice versa. Apart from this, this ligament also supports flexion and limits extension of the neck as well as prevents dislocation of the odontoid in longitudinal direction. Having said this, it allows for adequate mobility and stability as provided by the transverse ligament, while safeguarding the neurovascular structures entering and exiting the skull at the CCJ (4).

Alar ligament and other CCJ ligaments may be involved in various pathological processes. These can be further divided into primary and secondary. Primary CCJ pathologies include basilar invagination, platybasia, occipitalisation of atlas, atlanto-occipital dislocation, atlanto-axial dislocation, hypoplastic clivus, Chiari I-III malformations, cervicomedullary junction compression, syrinx, Kippel-Feil syndrome, os odontoideum and many others. Pathologies of the CCJ ligaments can also be secondarily acquired, most commonly in traumatic injuries, followed by CCJ tuberculosis, rheumatoid arthritis etc. (5).

Tribute to the advent of magnetic resonance imaging (MRI) which provides high resolution and increased tissue characterization, attempts to visualize the alar ligament had long started since the early 2000's. This is particularly true with regards to stronger magnetic field MRI scanner, whereby it is now possible to evaluate small CCJ ligamentous complex including alar ligament to its intricate features. Hence, MRI evaluation is commonly performed; especially concerning traumatic injuries since it has been known as an important adjunct to conventional radiography and computed tomography to detect a wide range of severe cervical spine injuries namely cord injury and disc herniation. MRI is also advisable for treatment planning of unstable cervical spine, including patients with neurological deficit. For patients in whom ligamentous injury is suspected and those who cannot be clinically assessed for more than 48 hours due to altered level of consciousness, MRI will also be of benefit (3). 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 no structural difference other than age-related degenerative disc diseases have been reported.

Having observed the widespread use of MRI in cervical spine trauma, several limitations are identified. Routine MR examinations performed are usually not focused on the CCJ ligaments which require special MR sequences to delineate them. To date, the most proposed MRI sequence to visualize this ligament is multiplanar 2-mm proton density (6, 7). To our knowledge, no previous study on MRI of the alar ligament has ever been performed in Malaysian population. Despite the vast analysis of the alar ligament morphology, no previous study attempts to seek for the difference of this ligament between different genders. This study thus aims to address this gap by comparing the normal anatomy of alar ligament on MRI between male and female of asymptomatic individuals in IIUM Medical Centre and to further understand the morphology of alar ligament on MRI, especially with regards to its variations.

The study of the alar ligament variations in terms of its visualization, orientations, shapes and sizes not only gives advantage to the reporting radiologist, but also to neurosurgeons and orthopaedic spine surgeons. This is particularly true especially when determining an injured alar ligament in traumatic scenario. With regards to craniovertebral junction with such a small space housing several minute important structures, this anatomical region has also been a challenging territory for the operating surgeons.

MATERIALS AND METHODS

Study Design and Setting

This research employs a cross-sectional descriptive design regarding alar ligament morphology and this is achieved using a 3.0T MRI. The study took place at IIUM Medical Centre, Jalan Sultan Ahmad Shah, 25200 Kuantan, Pahang from a period of February 2018 until January 2020.

Study Population and Subject Recruitment

A total of fifty (50) normal healthy respondents among IIUM students and IIUM Medical Centre staff were recruited. They all passed the inclusion and exclusion criteria and subsequently included in this study as a sample.

Subject inclusion criterion includes young adults aged 18-25 years old. Subject exclusion criteria are as follows:

i. Known cervical spine pathology.
ii. History of traumatic brain injury.
iii. Previous head and/ neck surgery.
iv. Chronic neck pain.
v. Restricted mobility of cervical spine.
vi. Pregnancy.
vii. Chronic debilitating disease e.g. rheumatoid arthritis, Marfan's syndrome, Ehler-Danlos syndrome.
viii. Contraindications to MRI e.g. ferromagnetic implant/ foreign body, claustrophobia.

Purposive sampling was applied for sampling method. Any student, staff or any individual who meets the inclusion and exclusion criteria were invited to participate in this study. A thorough explanation was given, taking into consideration the inclusion and exclusion criteria. The formal radiological examination form was filled up, including the MRI checklist. Eventually each respondent was required to provide a written consent prior to the MRI study. Printed brochures containing information of the study was also given to the participants for further read-up prior to the study.

Sampling Size Calculation

Sample size calculation was based on the prevalence of inhomogenous signal intensity of alar ligament on 3-T MRI systems of 33.0% (38). It was estimated using a single proportion formula, with 10% expected non-response rate, power set at 80% and significance level set at 5%. The minimum sample size required for this study was 135 alar ligaments. However, a total of 100 alar ligaments sampled from 50 healthy respondents were obtained. This was decided after considering the cost of conducting MRI which was about RM800 per respondent apart from time constraints during the study.

MRI Protocol

MRI was acquired using a 3.0-Tesla magnetic field scanner (Magnetom Spectra, Siemens Healthcare). A standard 12-channel head and neck coil was used, and all images were obtained while the participants' head and neck in neutral position. The coronal and axial images were planned using a sagittal plane image. The coronal image was planned to follow the angulation of the dens, whilst the axial image was planned perpendicular to this.

The imaging protocol utilized 2-mm proton density (PD), T2 and fat-suppression sequences. Three-dimensional multiplanar reconstruction image was also obtained as T2-SPACE (sampling perfection with application optimized contrast) as shown in Table I.

Table I: MRI Parameters for Each Sequence Employed in This Study

Parameters	T2-SPACE	PD-T2-TSE	PD-T2-TSE-FS
Voxel size (mm)	0.8 x 0.8 x 0.9	0.7 x 0.7 x 2.0	0.7 x 0.7 x 2.0
Field of view-read (mm)	266	180	180
Field of view-phase (%)	90	100	100
Base resolution (pixel)	320	256	256
Slices	56	26	26
Slice thickness (mm)	0.9	2	2
Averages	1.4	2	2
Repetition time, TR (msec)	1500	4490	5540
Echo time, TE (msec)	120	29	29
Flip angle (°)	140	150	150
Echo-train length		26	26
Fat saturation	No	No	Yes
Acquisition time, TA (min)	5:00	3:59	5:01
Parallel acquisition technique, PAT	2	2	2

The MRI study was only started after getting the approval from IIUM Research Ethics Committee (IREC). The department and MRI technicians were informed regarding the whole study, specifically the MR techniques and sequences. A printed manual/ guideline with detailed information regarding the techniques was placed in the MRI console for reference. The MRI studies were performed once a volunteer was obtained at a particular time. The details of the volunteer and the MRI study were immediately recorded. The research investigator was always present during the MRI study to review the images and to make sure that the MR study was carried out as per guidelines in order to get optimum images. Finally, the images were sent to Picture Archiving and Communication System (PACS) and SIEMENS workstation (*syngo®*.via).

Image Evaluation

Image evaluation and data collection were performed by a radiologist during a period of December 2019 till January 2020. This person, blinded from all related sociodemographic and clinical data, analysed each data set independently. All viewing and image evaluation were electronically performed on a DICOM formatted SIEMENS workstation (*syngo®*.via). The window/ level settings were freely adjusted, but no automatic pre-processing was applied. The data were tabulated into a Microsoft Excel worksheet for the purpose of data collection. Transfer of data was then performed from Microsoft Excel to IBM SPSS© software (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.) for analysis.

Alar Ligament Morphological Evaluation

Concerning alar ligament morphology, parameters such as alar ligament visualization, orientation and shape were evaluated. Visualization of alar ligament was assessed in all planes and sequences, whilst the orientation of alar ligament was evaluated on a coronal plane; either laterally ascending, horizontal or laterally descending as depicted in Fig. 1. The cross-sectional shape of the alar ligament was determined on a sagittal plane, and further confirmed on multiplanar reconstructed images; either round, oval or wing-like as represented in Fig. 2.

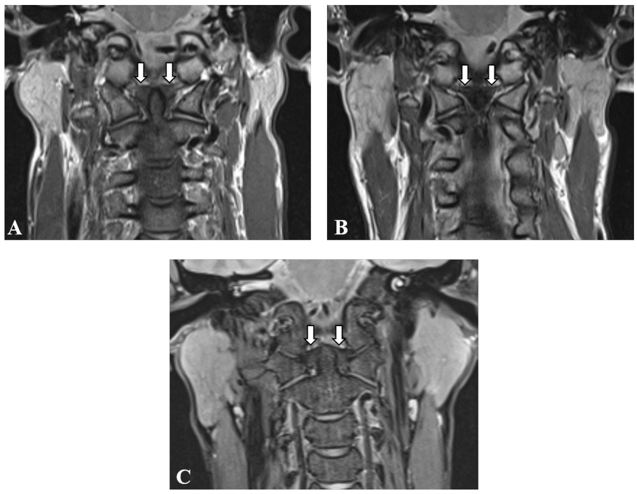

Fig. 1: Proton density-weighted images in coronal planes showing different orientations of alar ligament as demonstrated by the arrows; (A) laterally ascending, (B) horizontal and (C), laterally descending.

Alar Ligament Signal Characteristics

Regarding alar ligament signal characteristics, signal homogeneity was categorized on coronal T2- and PD-weighted images as homogenous and inhomogenous patterns as depicted in Fig. 3. Homogenous patterns are further subdivided into complete and incomplete with dark rim. In contrast, inhomogenous patterns are further subdivided into fat-suppressed and non-fat suppressed as subsequently determined by fat-suppression sequence.

Performing Alar Ligament Measurements

Concerning alar ligament dimensions, the measurements taken include anteroposterior (AP) diameter, length and craniocaudal diameter. The anteroposterior diameter was measured on a sagittal plane. The length and craniocaudal diameter were measured on multiplanar reconstruction image while adjusting the image mainly in oblique reconstruction so as to get the maximal length and craniocaudal diameter depending on the orientation of the ligament.

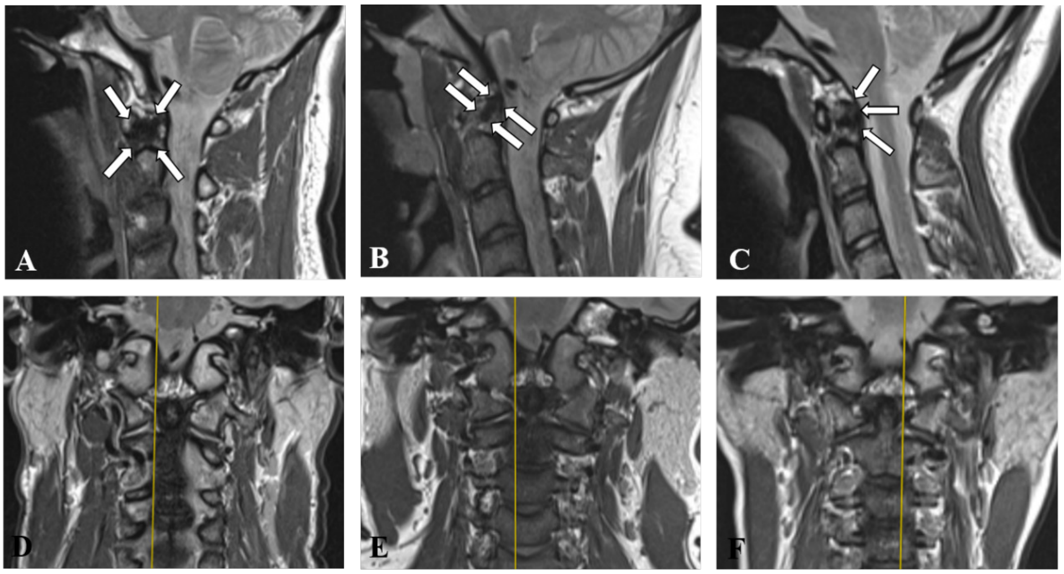

Fig. 2: Proton density-weighted images in sagittal planes (A, B and C) with corresponding coronal planes (D, E and F) showing different shapes of alar ligament as demonstrated by the arrows; (A) round, (B) oval, and (C) wing-like.

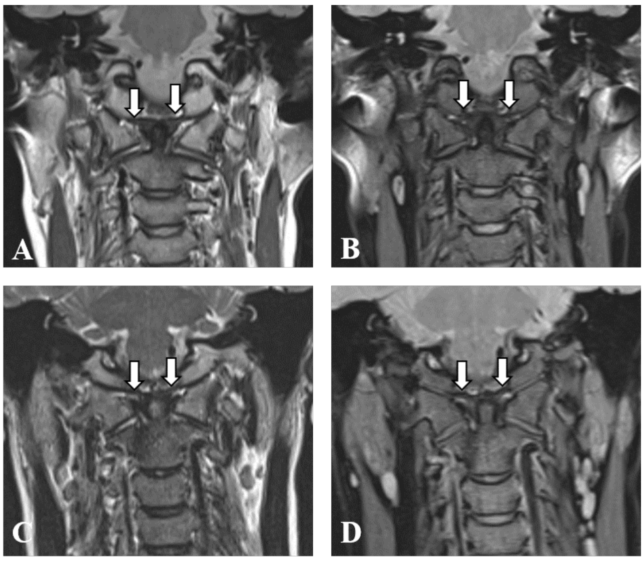

Fig. 3: Proton density-weighted images with fat suppression in the coronal plane showing (A), (B) homogenous; and (C), (D) inhomogenous signal intensity within alar ligament.

Statistical Analysis

The statistical analysis was described and performed using SPSS software Version 19.0 (IBM Corp. Released 2010. IBM SPSS Statistics for Windows, Version 19.0. Armonk, NY: IBM Corp.). The sociodemographic characteristics such as age, gender, height and weight were described using mean (SD) and frequency (%). Numerical variables were tested as normal distributions using histogram. Fifty pairs of alar ligaments were obtained resulting in a total of 100 ligaments, which were analysed independently. Multiple logistics regression was used to determine the association between gender and height of the subjects with signal intensity. Other variables such as age, height and weight were considered as confounders. The Pearson's correlation was run to determine the relationship between the height of the subjects and alar ligament dimensions.

Ethical Approval

Ethical approval from IIUM Research Ethics Committee (IREC) was obtained as a clearance prior to the commencement of the study (IREC 2018-004).

RESULTS

Baseline Characteristics of Respondents

The total numbers of subjects were 50, aged between 22.6-24.4 years and the mean age was 23.5 ± 0.9 years. The mean age for male subjects was 23.4 ± 0.7 years, while the mean age for female subjects was 23.6 ± 1.0 years. The mean height was 159.6 ± 10.8 cm. The mean weight of the respondents was 63.8 ± 15.2 kg.

Visualization, Orientation, Shape and Signal Intensity of Alar Ligament

The total number of 50 subjects had led to a total number of 100 alar ligaments to be evaluated since alar ligament is paired in configuration. These ligaments are analysed independently and the results for visualization, orientation and shape are shown in Table II. In terms of signal characteristics, a total of 33 ligaments (33.0%) showed homogenous signal intensity, which consisted of 2 ligaments showing complete homogeneity and 31 ligaments showing incomplete homogeneity with dark rim. A total of 67 ligaments showed inhomogeneity of signal which solely consisted of those which were non-fat suppressed.

Further subanalysis shows that in male subjects, 12 ligaments (24%) showed homogenous signal, but this was exclusively incomplete with dark rim. No complete homogeneity of alar ligament was observed. 38 ligaments (76%) demonstrated inhomogenous signal

Table II: Visualization, Orientations and Shapes of Alar Ligament (n = 100)

	Total (N = 100)
Visualization of Alar Ligament*	100 (100.0)
Alar Ligament Orientations*	
Laterally ascending	60 (60.0)
Horizontal	37 (37.0)
Laterally descending	3 (3.0)
Alar Ligament Shapes*	
Round	11 (11.0)
Ovoid	54 (54.0)
Wing-like	35 (35.0)

* Frequency, n (Percentage, %)

which were non-fat suppressed. In female subjects, homogenous signal was seen in 21 ligaments; 2 ligaments (4%) showing complete homogeneity while the other 19 ligaments (38%) showed incomplete homogeneity with dark rim. The remaining 29 ligaments (58%) showed signal inhomogeneity which again, were non-fat suppressed.

Alar Ligament Dimensions

The mean anteroposterior diameter of alar ligament is 7.6 ± 2.0 mm and ranged between 5.6 mm – 8.6 mm. The mean length of alar ligament is 13.3 ± 2.3 mm and the value ranged between 11.0 mm – 15.6 mm. The mean craniocaudal diameter on coronal plane of alar ligament is 11.8 ± 1.6 mm and the value ranged between 10.2 mm – 13.4 mm. The mean craniocaudal diameter on sagittal plane of alar ligament is 11.5 ± 1.7 mm and the value ranged between 9.8 mm – 13.2 mm. The midportion craniocaudal diameter of alar ligament on coronal plane is 5.2 ± 1.4 mm and the value ranged between 3.8 mm – 6.6 mm

Association between Gender and Height with Alar Ligament Signal Intensity

As depicted in Table III, a multiple logistic regression was performed to ascertain the effects of gender and height on the likelihood of alar ligament inhomogeneity. The logistic regression model was statistically significant, $\chi^2(4) = 27.402$, $p < .0005$. The model explained 11.5% (Nagelkerke R^2) of the variance in alar ligament signal homogeneity and correctly classified 69.0% of cases. Table III shows factors associated with alar ligament signal intensity. Females are 70% less likely to exhibit alar ligament signal inhomogeneity than males ($p < 0.05$). For height, there was no significant association observed between the height of the subjects and alar ligament signal intensity ($p = 0.42$).

Association between Height and Alar Ligament Dimensions

A Pearson correlation test was run to determine the relationship between height of subjects and alar ligament dimensions. As demonstrated in Table IV, there was a positive correlation between height and the craniocaudal diameter of the alar ligament on coronal and sagittal planes as well as the anteroposterior diameter, which was statistically significant ($p < 0.05$). In other words, subjects with increased height are more likely to have thicker alar ligament specifically the anteroposterior and craniocaudal diameters. No significant correlation is observed between respondent's height and the length or midportion craniocaudal diameter of alar ligament ($p > 0.05$).

Table III: Factors Associated with Alar Ligament Signal Intensity

Gender	Alar Ligament Signal Homogeneity (n, %)		p-value	Odds Ratio	95% CI
	Homogenous	Inhomogenous			
*Gender			0.02	0.291	0.10-0.82
Male	12 (24)	38 (76)			
Female	21(42)	29 (58)			
#Height	33	67	0.419	0.979	0.93-1.03

*After adjusting for height, age and weight.
#After adjusting for gender, age and weight.

Table IV: Correlation between Height of Respondents with Alar Ligament Dimensions

Alar Ligament Dimensions	Height
Anteroposterior Diameter	
r	0.201
p-value	0.045
Length	
r	-0.31
p-value	0.762
Craniocaudal Diameter on Coronal Plane	
r	0.254
p-value	0.011
Craniocaudal Diameter on Sagittal Plane	
r	0.248
p-value	0.013
Midportion Craniocaudal Diameter on Coronal Plane	
r	0.082
p-value	0.417

DISCUSSION

Alar Ligament Visualization

In our study, MRI provides excellent visualization of alar ligament which agrees with Bitterling, StΔbler, and Brьckmann (8) and many other studies. As stated in the preceding chapter, alar ligament was visualized as a paired ligament in all the subjects. This is contrary to previous study finding which discovered right alar ligament visualization in only about 76% and left alar ligament visualization in only about 84% of

50 subjects (6). Although this ligament may appear asymmetrical (6, 9), this is not the main concern in this research though we noted some asymmetry in certain subjects as we performed image evaluation and data collection. Complete MRI visualization of alar ligament in all subjects of this study is also in keeping with previous cadaveric dissection studies (10). This finding emphasizes the importance of alar ligament for human evolutionary survival as one crucial ligament amongst the many CCJ ligaments. The role of alar ligament is undeniably fundamental, acting as stabilizers of CCJ, limiting axial rotation and limiting extension of the neck. With regards to other mammalian counterparts, alar ligament is inevitably present across species (11), attributed by the fact that the function of this ligament is hardly replaced by others.

Alar Ligament Orientations

This study discovered that the predominant orientation is laterally ascending which accounts for 60%, followed by 37% in horizontal orientation and 3% demonstrating laterally descending orientation. No significant difference in alar ligament orientations is noted between different genders. This corresponds to previous literature which showed a majority of 58.5% of laterally ascending orientation in 50 asymptomatic volunteers (12). Another study also described 62.1% of laterally ascending alar ligament in 66 healthy volunteers (9). However, conflicting to this finding, Krakenes, Kaale, Rorvik, and Gilhus (7) found a predominating 73% of alar ligament demonstrating horizontal orientation. In addition, previous cadaveric study also stated that when biomechanics of this ligament is of concern, horizontal orientation of the alar ligament fibre seems to be more accurate than the traditionally believed vertical configuration since horizontal orientation is crucial in restricting rotational movements of the CVJ (13). This would be less efficient if the ligament is oriented vertically.

Alar Ligament Shapes

Alar ligament shape is mainly evaluated on a sagittal plane and consists of its cross-sectional shape. This study identifies an oval shape in the majority of the ligament (54%), followed by wing-like configuration (35%) and round shape (11%). In concordance to previous literatures, Krakenes et al. (7) and Lummel et al. (12) also depicted oval shape in the majority of the ligaments, each represented by 54% and 51.5% respectively. Krakenes et al. (7) also noted wing-like configuration of this ligament as the second most common shape, comprising 23%. However Lummel et al. (12) found only a small number of wing-like configurations, which is less a quarter of what we found (6.5%), rendering it the least frequent shape observed. We postulate that the different shapes of alar ligament are somewhat connected to its signal intensity since determination of alar ligament shape is mainly by outlining the hypointense part of the ligament on sagittal plane, leaving out the hyperintense portion as the possible surrounding fatty connective tissue.

Alar Ligament Signal Characteristics

Numerous previous literatures have highlighted the MR appearances of alar ligament which could be inhomogenous unlike many other ligaments in the body. We do not evaluate the alar ligament signal characteristics according to the 4-points scoring system which was first introduced by Krakenes et al. (14). This is owing to the subsequent research produced by Myran et al. (15) and Dullerud, Gjertsen, and Server (6) which give rise to the scoring system being questionable. However, it is at the point of interest that Wenz et al. (9) started looking at the inhomogenous signal as being dispositional i.e. fat-related hyperintensity or degenerative changes i.e. non fat related hyperintensity. This is preceded by Dullerud et al. (6) which discovered that with fat suppression sequence, the proportion of normal ligaments increased both among whiplash-associated disorder patients and control subjects.

For that purpose, we do not include respondents older than 25 years old to prevent getting degenerative changes in the cervical region including the alar ligament as portrayed in the previous studies. As such, this study presents a greater number of alar ligaments with inhomogenous signal intensity, which is a whopping 67%. A noticeable difference is observed with other studies whereby this contrasts with a study by Wenz et al. (9) which was performed using similar 3-Tesla MR scanner. They found that only a minor of 33.3% of the ligaments which appear inhomogenous. They also found out that fat could be identified in about 6% of the ligament, whereas contrary to our findings, no fat-related hyperintensity is detected. This noticeable difference may reflect a true representation of alar ligament inhomogeneity in the study population. However, this could also be attributed to technical factors employed in this study.

There are several explanations to justify the presence of hyperintensity within alar ligament. Firstly, this could be attributed by partial volume effects from surrounding fatty tissue which causes misinterpretation during image evaluation. Secondly, it may be caused by real injury or tear to the ligament, usually from a severe trauma to the CCJ. However, this is not the case in our study since we only recruited healthy asymptomatic individuals. Thirdly, the ligament hyperintensity may represent dispersed interstitial fat as proven by Koch (12) in previous autopsy study.

Most recently, Wenz et al. (9) considered interposed fat between alar ligament fibres as dispositional and an intrinsic feature of the ligament and started investigating possible degenerative changes in alar ligament. This was done by proving the existence of non fat-suppressed hyperintensity within the ligament. They found that older age groups more than 28.5 years old have a higher tendency to develop degenerative changes of the ligament. They also discovered that men and taller individuals are more likely to demonstrate fat hyperintensity in alar ligament.

With regards to histological constituents of alar ligament, Dvorak and Panjabi (10) initially found that alar ligament consists almost exclusively of collagen fibres which compose the central core of the ligament with a few elastic fibres peripherally. Elastic fibres may tolerate elongation of the ligament up to 200%, whereas only about 8% in collagen fibres. Hence, elastic fibres are the ones preserving the continuity of alar ligament when severely injured.

However, the frequently observed signal intensity within alar ligament on MRI triggers further question of its actual histological constituent. According to Krakenes et al. (14), the hyperintense signal within the ligament is probably attributed by atrophy of fibres with subsequent fat replacement. In view of the feeding vessels penetrate at the site of ligament insertion; ligament usually has uniform microvascularity as explained by Woo et al. (16). Since alar ligament lesions occur in the ligament-bone transition zone which we also notice in this study, impaired nutrition may be a cause of atrophy. In addition, Debernadi et al. (1) explained that variation in fibre compaction may explain these differences because fat and connective tissue interposed between the fibres have higher proton density than the fibres themselves.

Alar Ligament Dimensions

This study found that the alar ligament is thinner at its mid portion diameter in comparison to its origin at the lateral aspect of odontoid peg and its insertion site at medial occipital condyle and atlas. Likewise, Krakenes et al. (7) and Iwanaga et al. (13) also commented on similar observations in all subjects. Otherwise, not many previous literatures performed extensive measurement of alar ligament, especially those concerning MRI studies of alar ligament. Several measured dimensions in this study do resemble values from previous literatures, especially studies which involved cadaveric cervical spine specimens. The mean AP diameter of alar ligament in this study closely resembles the findings by Iwanaga et al. (13). The mean length of the alar ligament in this study is in close approximation with the measurement by Dvorak et al. (10) and Osmotherly, Rivett, and Mercer (17). Finally, the midportion craniocaudal diameter of the alar ligament in this study is almost similar to values from Iwanaga et al. (13). Other measurements are not comparable with our study. These findings may reflect different technical aspect whereby different person-to-person ways of measuring the alar ligament is observed. Hence, it is crucial to standardize the measurement for future reference. Apart from this, our findings could be a genuine representation of the study population since the measurements resemble that of most of the cadaveric studies.

Association between Gender and Alar Ligament Signal Intensity

A multiple logistic regression test performed revealed that females are 70% less likely to exhibit alar ligament signal inhomogeneity than males ($p = 0.02$). This makes male subjects 30% more likely to demonstrate alar ligament signal inhomogeneity compared to females. Hence, this finding is in concordance to previous literature which found that alar ligament hyperintensities occurred more significantly in men than women ($p = 0.007$) (9). However, this is particularly true in relation to fat-related hyperintensities where they found dispositional interspersed fat more frequent in males, while our study depicted only non fat-related hyperintensities with no fat-related hyperintensity identified. No matter how different our result from the previous studies is, it is possible that our result is a true representation of alar ligament signal intensity in our study population since this study and that of Wenz et al. (9) employed similar sample size. Apart from that, the reason for the discrepancy is due to different sociodemographic background where we recruited subjects of younger age group, which is less than 25 years old, whereas Wenz et al. (9) recruited subjects with a median age of 40 years old. This study shows that our population sample manifested degenerative hyperintense signal of alar ligament at an earlier age. Another possible reason for this difference could be due to technical factors e.g. magic angle phenomenon.

Association between Height and Alar Ligament Signal Intensity

No significant association between the height of the subjects and alar ligament signal homogeneity ($p = 0.42$), which is opposite to the discovery by Wenz et al. (9) who found that with every 1 cm increased in height of the respondents, the odds of having a fat-lesion within alar ligament significantly increased by 10%. This is pertinent to the fact that no native fat-related hyperintensity was found in our study. Again, this could be attributable to different age group of the study subjects in this study as compared to Wenz et al. (9).

Association between Height and Alar Ligament Dimensions

Only the anteroposterior and craniocaudal diameter of alar ligament show association with individual's height in this study, with $p = 0.045$ and $p = 0.01$ respectively. In other words, the taller a person is, the thicker and longer is the alar ligament. To date, no other previous study that evaluated the relationship of the individual height with alar ligament dimensions. The relationship of ligament length and its durability is not generally known, and this includes other ligaments in the body. However, a study carried out by Mahajan, Chandra, Negi, Jayaram, and Hussein (18) regarding the anterior cruciate ligament of the knee found that the maximum diameter of anterior cruciate ligament in injured subjects were significantly smaller than non-injured ones. Whether or not the alar ligament thickness would determine the likelihood of an individual to develop injury is open to debate considering the fact that the anterior cruciate ligament is different from alar ligament in biomechanical point of view. Hence, this is one aspect that could be explored in future research.

Clinical Implications of Study Findings

While the predominant inhomogenous alar ligament signal in our study reflects the normal asymptomatic population, we believe that if the previous 4-points scoring system of alar ligament hyperintensity was to be utilized, grade 1-2 acute whiplash-associated disorder (WAD) should not be considered as real disability or injury since it is commonly encountered in asymptomatic subjects (19). However, in atlantooccipital dissociation (AOD), high index of suspicion towards alar ligament injury should be exercised since plain radiography and computed tomography alone may miss this injury with a potential of causing grave neurological deficit and high rate of death if not detected early (20).

This research has several limitations, amongst which is the use of convenience sampling, which was used considering time and logistic constraints. Some discrepancy between our data with previous literatures, especially the presence of fat related hyperintensity; could be due to slightly smaller sample size employed in this study when compared to some of the earlier publications. Technical factors could also explain the discrepancies whereby some previous studies utilized different magnetic strength of MRI scanner and different MRI sequences on top of the occurrence of the magic angle phenomenon which is a common MRI artefact. After all, the results of this study could still be a true representation of the study population. In trauma setting, the sample of injured subjects is required if the result were to represent the whole population.

Since alar ligament is relatively small with subcentimetric measurement and possible partial volume effects, the image often needs to be enlarged hence may reduce its spatial resolution. However, this is mainly done while measuring the ligament but not during other aspects of the ligament evaluation such as evaluating the signal intensity for fear of misinterpretation.

Though MRI is known to have superior soft tissue resolution, other evaluations such as the craniometric measurements are best done using bone interface hence plain radiograph or computed tomography should be complementarily utilized. For example, dens lateralization is the most important finding on CT in unilateral alar ligament injury. The stability of CCJ needs to be evaluated by ruling out other ligamentous injuries which commonly accompanies alar ligament injury, hence flexion-extension CT is crucial (35). This is These are in accordance with the patient's clinical information and evaluating the CCJ as an entire system is necessary.

CONCLUSION

High variability of alar ligament in terms of its orientation, shape and signal intensity could pose a challenge in radiological diagnosis of alar ligament pathology. Despite the fact that no dispositional fat-related hyperintensity was detected in any of the ligaments as well as no significant association between individual's height and alar ligament signal intensity was identified, the fact remains that males are more likely to develop signal inhomogeneity in alar ligament compared to female. A taller person is also more likely to have a longer and thicker alar ligament. This study could benefit the radiologists, neurosurgeon and orthopaedic surgeon by thorough description of alar ligament in terms of its morphology, dimensions and evidence of injury. Whether or not hyperintensity or inhomogenous signal within the alar ligament points to real injury, it should be accompanied by strong clinical suspicion; especially in the case of trauma since a high amount of variation in this ligament is undoubtfully present. Other modalities such as plain radiography and computed tomography of the cervical region should supplement the evaluation. Finally, other centres could adopt the data from our study as references if the need arises for the reason that there is lack of other local data.

A new classification should supplant the previous classification introduced by Krakenes et al. (2002) for evaluating alar ligament signal intensity. Local data on alar ligament variations and signal intensity of trauma cases involving the cervical region should also be collected and analysed. Objective clinicoradiological criteria including findings from plain radiography and computed tomography can be devised to measure the probability of alar ligament injury hence the need for MRI study. The association between alar ligament thickness and the likelihood of developing alar ligament injury can be explored. Further research on alar ligament on a larger sample size is required.

ACKNOWLEDGEMENT

The authors of this study would like to thank IIUM Research Ethics Committee (IREC) for the ethical approval, staff of Radiology Department, Sultan Ahmad Shah Medical Centre (SASMEC @IIUM) and Radiology lecturers for their endless guidance. Special thanks to IIUM and WIDAD University medical students who consented to participate in this study.

REFERENCES

1. Debernardi A, Daliberti G, Talamonti G, Villa F, Piparo M, Collice M. The craniovertebral junction area and the role of the ligaments and membranes. Neurosurgery. 2011;68(2):291–301. Italy. doi: 10.1227/neu.0b013e3182011262
2. Riascos R, Bonfante E, Cotes C, Guirguis M,

Hakimelahi R, West C. Imaging of atlanto-occipital and atlantoaxial traumatic injuries: what the radiologist needs to know. RadioGraphics. 2015;35(7):2121–2134. United States. doi: 10.1148/rg.2015150035
3. Pfirmann CW, Binkert CA, Zanetti M, Boos N, Hodler J. MR morphology of alar ligaments and occipito-atlantoaxial joints: study in 50 asymptomatic subjects. Radiology Society of North America. 2001;218(1). doi: 10.1148/radiology.218.1.r01ja36133
4. Offiah CE, Day E. The craniocervical junction: embryology, anatomy, biomechanics and imaging in blunt trauma. Insights Imaging. 2017;8:29–47. United Kingdom. doi: 10.1007/s13244-016-0530-5
5. Talukdar R, Yalawar RS, Kumar M. Imaging in craniovertebral junction (CVJ) abnormalities. IOSR Journal of Dental and Medical Sciences. 2015;14(12):33–49. India. doi: 10.9790/0853-141223349
6. Dullerud R, Gjertsen Ш, Server A. Magnetic resonance imaging of ligaments and membranes in the craniocervical junction in whiplash-associated injury and in healthy control subjects. Acta Radiologica. 2010;51(2):207–212. Norway. doi: 10.3109/02841850903321617
7. Krakenes J, Kaale B, Rorvik J, Gilhus N. MRI assessment of normal ligamentous structures in the craniovertebral junction. Neuroradiology. 2001;43(12):1089–1097. Norway. doi: 10.1007/s002340100648
8. Bitterling H, StΔbler A, Brьckmann H. Mystery of alar ligament rupture: value of MRI in whiplash injuries - biomechanical, anatomical and clinical studies. PubMed. 2007;179(12):1242. Germany. doi: 10.1055/s-2007-963426
9. Wenz H, Kerl HU, Maros ME, Wenz R, Kalvin K, Groden C, et al. Signal changes of the alar ligament in a healthy population: a dispositional or degenerative consequence? Journal of Neurosurgery: Spine. 2015;23(5):544–550. Germany. doi: 10.3171/2015.1.spine141214
10. Dvorak J, Panjabi MM. Functional anatomy of the alar ligaments. Spine. 1987;12(2):183–189. Switzerland. doi: 10.1097/00007632-198703000-00016
11. Oakes PC, Sardi JP, Oskouian RJ, Tubbs RS. Translation of Hecker's 1922 "The occipital-atlanto-axial ligament system: a study in comparative anatomy. 2017. Grenada. doi: 10.1002/ca.22853
12. Lummel N, Zeif C, Kloetzer A, Linn J, Brückmann H, Bitterling H. Variability of morphology and signal intensity of alar ligaments in healthy volunteers using MR imaging. AJNR Am J Neuroradiol. 2011;32:125-130. Neuroradiologie Scan. 2011;1(01):19-20. Germany. doi:10.1055/s-0030-1256915
13. Iwanaga J, Sardi J, Voin V, Chapman JR, Oskouian RJ, Tubbs RS. Anatomy of alar ligament Part I: morphometrics and variants. World Neurosurgery. 2017;107:1001–1006. United States. doi: 10.1016/j.wneu.2017.07.187
14. Krakenes J, Kaale BR, Moen G, Nordli H, Rorvik J, Gilhus NE. MRI assessment of the alar ligaments in the late stage of whiplash injury – a study of structural abnormalities and observer agreement. Neuroradiology. 2002;44:617–624. Norway. doi: 10.1007/s00234-002-0799-6
15. Myran R, Kvistad KA, Nygaard OP, Andresen H, Folvik M, Zwar, JA. Magnetic resonance imaging assessment of the alar ligaments in whiplash injuries. Spine. 2008;33(18):2012–2016. Norway. doi: 10.1097/brs.0b013e31817bb0bd
16. Woo SLY, An KN, Arnoczky SP, Wayne JS, Fithian DC, Myers BS. Anatomy, biology, and biomechanics of tendon, ligament, and meniscus. In: Simon SR (Ed.). Orthopedic Basic Science. American Academy of Orthopaedic Surgeons, Columbus, Ohio. Philadelphia; Lippincott Williams & Wilkins: 1994
17. Osmotherly PG, Rawson OA, Rowe LJ. The relationship between dens height and alar ligament orientation: a radiologic study. Journal of Manipulative and Physiological Therapeutics. 2011;34(3):181–187. Australia. doi: 10.1016/j.jmpt.2011.02.006
18. Mahajan PS, Chandra P, Negi VC, Jayaram AP, Hussein SA. Smaller anterior cruciate ligament diameter is a predictor of subjects prone to ligament injuries: an ultrasound study. BioMed Research International. 2015;1–8. Qatar. doi: 10.1155/2015/845689
19. Vetti N, Krakenes J, Eide GE, Rorvik J, Gilhus NE, Espeland A. Are MRI high-signal changes of alar and transverse ligaments in acute whiplash injury related to outcome? BMC Musculoskeletal Disorders. 2010;11:260. Norway. doi:10.1186/1471-2474-11-260
20. Dyas A, Niemeier T, Mcgwin G, Theiss S. Ability of magnetic resonance imaging to accurately determine alar ligament integrity in patients with atlanto-occipital injuries. Journal of Craniovertebral Junction and Spine. 2018;9(4):241. United States. doi: 10.4103/jcvjs.jcvjs_81_18