Original Article

Ability of magnetic resonance imaging to accurately determine alar ligament integrity in patients with atlanto-occipital injuries

ABSTRACT

Objective: The objective of this study is to evaluate the the reliability of magnetic resonance imaging (MRI) in diagnosing alar ligament disruption in patients with potential atlanto-occipital dissociation (AOD).

Materials and Methods: Three-blinded readers performed retrospective review on 6 patients with intra-operative confirmed atlanto-occipital dissocation in addition to a comparison cohort of patients with other cervical injuries that did not involve the atlanto-occipital articulation. Ligament integrity was graded from 1 to 3 as described by Krakenes *et al.* The right and left ligaments were assessed separately. Inter-observer agreement by patient, by group (AOD vs. non-AOD), and intra-observer agreement was calculated using weighted Cohen's kappa.

Results: Interobserver agreement of alar ligament grade for individual patients ranged from slight to fair (κ = 0.05–0.30). Interobserver agreement of alar ligament grade for each group (AOD vs. non-AOD) ranged from fair to substantial (κ = 0.37–0.66). No statistically significant difference in categorical analysis of groups (AOD vs. non-AOD) and grade (0–1 vs. 2–3) was observed. Intraobserver agreement of individual patient's alar ligament grade ranged from moderate to substantial (κ = 0.50–0.62).

Conclusion: The use of MRI to detect upper cervical ligament injuries in AOD is imperfect. Our results show inconsistent and unsatisfactory interobserver and intraobserver reliability in evaluation of alar ligament injuries. While MRI has immense potential for detection of ligamentous injury at the craniovertebral junction, standardized algorithms for its use and interpretation need to be developed.

Keywords: Atlanta-occipital dissociation, cervical spine, cervical trauma

INTRODUCTION

Atlanto-occipital dissociation (AOD) is a rare but devastating injury that accounts for 6%–8% of all traffic fatalities.[1-3] The prognosis of AOD has been shown to directly correlate with the timing of initial diagnosis.[4,5] At a major trauma center in the United States, all patients diagnosed with AOD on initial evaluation survived without delayed neurologic dysfunction; whereas, delayed diagnosis correlated with an 89% death rate within 90 days of injury.[4]

Despite standardized trauma evaluation protocols, clinical and radiographic diagnosis of AOD remains challenging.[6] In recent decades, computed tomography (CT) has supplanted the use of cervical radiographs in the setting of acute cervical trauma.[7] Past work has demonstrated 99% identification of relevant anatomic landmarks with CT in comparison to only 39%–84% with lateral radiographs.[8] Nonetheless, craniometric measurements, such as Powers ratio, basion–dens interval, basion–axial interval and condyle-C1 interval (CCI), continue

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to show poor sensitivity in diagnosing AOD regardless of imaging modality[8-15] with approximately 25% not diagnosed with CT scans.[4]

MRI evaluation is popular due to the ability to directly visualize soft-tissue injuries[16] whereas CT and radiographs rely on craniometric measurements as a predictor of occipitocervical stability, MRI has the advantage of high soft-tissue contrast and multi-planar imaging capabilities.[17] To date, MRI is used in diagnosis and treatment algorithms for AOD, however, little data exist in regards to its validity. Critical to diagnosing subtle cases of AOD is the integrity of the alar ligaments which have been described as perhaps the main stabilizer of the occipitocervical junction. The current study was designed to evaluate the reliability of MRI in diagnosing alar ligament disruption in patients with potential AOD.

MATERIALS AND METHODS

Following Institutional Review Board approval, patients with acute AOD from a single institution from 2008 to 2016 were identified using International Classification of Diseases (ICD)-9 and ICD-10 coding. The study population consisted of patients with acute AOD diagnosed with routine imagining including MRI and confirmed intraoperatively. A cohort of an equal number of patients was created that consisted of other upper cervical injuries that did not include the atlanto-occipital articulation. Patient' demographics, including age and mechanism of injury, were recorded for all patients with acute AOD.

AOD was defined as widening of the atlanto-occipital articulation of greater than 4 mm on CT imaging with instability noted on intraoperative physical examination as defined by Bellabarba *et al*.[5] Patients with AOD with preoperative cervical MRI were included in the study. Patients with suspected AOD but without documented instability noted on intraoperative examination or without preoperative cervical MRI were excluded from the study.

Three independent observers, consisting of two attending orthopedic spine surgeons and one musculoskeletal radiologist, read the preoperative MR imaging specifically to assess the integrity of the alar ligaments. Each observer was blinded to the patient's diagnosis and to the other observer reads. Each reviewer independently read the MRIs on two separate occasions with at least 1 month in between reads. All MRIs included sagittal, coronal, and axial T1 and T2 weight images as well as sagittal STIR images. MRIs were obtained using both 1.5 and 3 Tesla magnets.

Ligament integrity was graded using the Krakenes *et al*. scale with low signal strength denoting uninjured ligaments.[18,19] The grading scheme was 0 = low-signal strength throughout, 1 = high signal strength in <1/3 of ligament cross section, 2 = high-signal strength from 1/3 to 2/3 of ligament cross-section, and 3 = high-signal strength in >2/3 of ligament cross-section. The right and left ligaments were assessed separately.

Statistical methods

Interobserver agreement by patient and by group (AOD vs. non-AOD) and intra-observer agreement by patient and by group (AOD vs. non-AOD) was calculated using weighted Cohen's kappa, and degree of agreement was categorized using Landis and Koch's classification: <0: no agreement, 0–0.20: slight, 0.21–0.40: fair, 0.41–0.60: moderate, 0.61–0.80: substantial, and 0.81–1: almost perfect agreement. Chi-square and Fisher's exact tests were used for statistical comparisons between the AOD vs. non-AOD groups and Grade 0–1 ligament vs. Grade 2–3 ligament. All statistical analyses were performed in SAS 9.4 (SAS Institute, Inc., Cary, NC, USA) and level of significance (two-sided) was set at 0.05.

RESULTS

Eight patients with acute AOD were identified with six patients met the inclusion and exclusion criteria. Six patients with upper cervical injuries not involving the occipitocervical articulation were used as a control group [Table 1]. Mechanism of injury of the AOD group included MVA (5 patients) and fall from height (1 patient). No cases of low energy acute AOD were observed. The weighted kappas, 95% confidence

Table 1: Patient characteristics

Median age (range)	39 (26-66)
Gender	
Males	4
Females	2
Median time to MRI in hours (range)	
Transfer from outside hospital (n=2)	236.8 (93.4-380.2)
Initially presented to our institution (n=4)	11.7 (5.7-14.7)
Overall (n=6)	14.5 (5.7-380.2)
Mechanism of injury	
MVA	5
Fall from height	1
Magnet quality	
1.5T	6
3.0T	0
Control group injuries	
Lower cervical dislocation	3
Lower cervical fracture	1
Lower cervical distraction injury	2

MRI - Magnetic resonance imaging; MVA - Mitral valve area intervals, and agreement classifications for interobserver agreement by patient, interobserver agreement by group (AOD vs. non-AOD), and intra-observer agreement by patient can be shown in Tables 2 and 3.

Interobserver agreement of alar ligament grade for individual patients ranged from slight to fair (weighted kappa range: 0.05–0.30). Interobserver agreement of alar ligament grade for each group (AOD vs. non-AOD) ranged from fair to substantial (weighted kappa range: 0.37–0.66).

Intraobserver agreement of individual patient's alar ligament grade ranged from moderate to substantial (weighted kappa range: 0.50–0.62). Intraobserver agreement of alar ligament grade for each group (AOD vs. non-AOD) ranged from no agreement to perfect agreement (weighted kappa range: −0.20–1.00).

Although each observer graded more ligaments 2–3 in the AOD than the non-AOD group for both reads, no statistically significant difference in categorical analysis of groups (AOD vs. non-AOD) and grade (0–1 vs. 2–3) was observed, regardless of individual observer or read (Fisher's exact test range: $0.07 \leq P \leq 0.84$).

DISCUSSION

Anatomically, the ligamentous complex of the craniovertebral junction has been studied meticulously in cadavers.[20] As the occipitocervical junction has horizontally oriented facets and lacks intervertebral discs, the stability of the craniovertebral junction is primarily dependent on the integrity of the ligaments and soft tissues.[21,22] The alar ligaments are a paired structure that extends from the medial surface of the occipital condyles inferiorly to the tip of the dens.[23-25] Biomechanical cadaveric studies have shown the alar contribute significantly to the stability of the atlanto occipital articulation.[23,24] In 1991, Panjabi *et al*. showed that unilateral transection of the alar ligaments equated to an increase in 25% of rotation to the contralateral side.[25] While debate exists in regards to each craniovertebral ligaments specific role in stability,[22] clinically significant instability of the occipitocervical region has been hypothesized to demonstrate disruption of the alar ligaments.[5,20]

Table 2: Analysis of magnetic resonance imaging interobserver agreement of alar ligament grade

	Weighted κ	95% CI	Landis and Koch's guidelines
Interobserver agreement by the patient			
Observers A and B			
First, read	0.30	−0.16-0.76	Fair
Second read	0.10	−0.30-0.50	Slight
Observers B and C			
First read	0.28	−0.05-0.60	Fair
Second read	0.05	−0.27-0.37	Slight
Observers A and C			
First read	0.17	−0.09-0.43	Slight
Second read	0.27	−0.05-0.58	Fair
Interobserver agreement by group			
AOD			
Right alar ligament	0.66	0.37-0.95	Substantial
Left alar ligament	0.53	0.19-0.86	Moderate
Non-AOD			
Right alar ligament	0.52	0.23-0.81	Moderate
Left alar ligament	0.37	0.00-0.74	Fair

AOD - Atlantooccipital dissociation; Non-AOD - Upper cervical injuries not involving atlanto-occipital articulation; CI - Confidence interval

Despite the widespread use of MRI in cervical spine trauma, its validity has not been verified. To date, current cervical guidelines lack sufficient evidence to support MRIs use in evaluating injuries to the craniovertebral junction.[26-28] In the current study, we found limitations in the use of MRI in evaluating alar ligament injury in patients with acute, traumatic atlanto-occpital injuries. Our results suggest that MRI evaluation of the alar ligaments has unsatisfactory inter and intra-observer reliability which significantly limits its usefulness in diagnosing atlanto-occipital injuries.

To the author's knowledge, this is the first study to evaluate the reliability of MRI in diagnosing AOD in adults. Prior research in normal adults and patients with whiplash has established MRI as an effective tool in visualizing the ligamentous complex of the cranioverterbral junction.[19,29] In 2006, Bellabarba *et al*. published a treatment algorithm of AOD that based stability on the integrity of the craniovertebral ligament as judged by MRI.[5] They concluded that unilateral disruptions or sprains to the alar ligaments represent stable injuries that can be adequately treated non-operatively; whereas, disruption of the alar ligaments or other craniocervical stabilizers indicates a clinically unstable injury that requires surgical treatment.[5]

In the current study, interobserver agreement of alar ligament grades for individual patients ranged from slight to fair-depending on laterality (weighted kappa range: 0.05–0.30). Our result of inconsistencies in rating the degree of injury to the alar ligaments is not unlike past studies by Krakens, Roy, Kaale and Schmidt.[18,21,30,31] Pfirrman *et al*. demonstrated structural alterations in the alar ligaments including asymmetry in up to 58% and fluid detected in 8% in asymptomatic individuals.[32] In evaluating patients with whiplash, Bitterling *et al*. concluded that MRI signal

Table 3: Analysis of magnetic resonance imaging intraobserver agreement of alar ligament grade

	Weighted κ	95% CI	Landis and Koch's guidelines
Intraobserver agreement by patient			
Overall			
Right alar ligament	0.62	0.42-0.82	Substantial
Left alar ligament	0.50	0.27-0.74	Moderate
Observer A			
Right alar ligament	0.84	0.55-1.00	Almost perfect
Left alar ligament	0.74	0.38-1.00	Substantial
Observer B			
Right alar ligament	0.24	−0.06-0.54	Fair
Left alar ligament	−0.03	−0.33-0.27	No agreement
Observer C			
Right alar ligament	0.68	0.22-1.00	Substantial
Left alar ligament	0.57	0.12-1.00	Moderate
Intraobserver agreement by group			
AOD			
Observer A			
Right alar ligament	1.00	1.00-1.00	Perfect
Left alar ligament	1.00	1.00-1.00	Perfect
Observer B			
Right alar ligament	0.38	0.05-0.70	Fair
Left alar ligament	0.10	−0.08-0.28	Slight
Observer C			
Right alar ligament	0.67	0.10-1.00	Substantial
Left alar ligament	0.43	−0.12-0.97	Moderate
Non-AOD			
Observer A			
Right alar ligament	0.70	0.23-1.00	Substantial
Left alar ligament	0.47	−0.14-1.00	Moderate
Observer B			
Right alar ligament	0.19	−0.13-0.52	Slight
Left alar ligament	−0.20	−0.77-0.37	No agreement
Observer C			
Right alar ligament	0.00	0.00-0.00	No agreement
Left alar ligament	N/A	N/A	N/A

AOD - Atlantooccipital dissociation; Non-AOD - Upper cervical injuries not involving atlanto-occipital articulation; N/A - Not applicable; CI - Confidence interval

differences in the alar ligaments could not be differentiated from normal variants.[33]

In the current study, there was a trend for patients with AOD to have higher alar ligament grades (2–3) in comparison to the non-AOD group; however, this did not meet statistical significance ($0.07 \leq P \leq 0.84$). In addition on reviewer reevaluation, intraobserver agreement was unacceptably low (kappa 0.50–0.62). These results suggest that MRI is not a reliable tool in evaluating injury to the alar ligaments. Furthermore, the authors advocate that abnormal MRI signal of the alar ligaments does not readily correlate with clinical stability and thus caution is advised when abnormal findings are encountered on MRI.

Due to the strict diagnostic inclusion criteria and the rarity of the condition, this study's primary limitation is its small sample size. In addition, while the alar ligament grading scale utilized in this study developed by Krakenes *et al*. was described utilizing a 1.5-T MRI magnet, the current study utilized MRI studies with both 1.5-T and 3-T magnetic qualities;[18] however, all patients in the AOD cohort underwent MRI with a 1.5-T magnet. This potentially serves as a source of study bias as recent work by Schmidt *et al*. has shown improved visualization of the alar ligaments utilizing a 3-T magnet in comparison to 1.5-T magnet in normal, healthy patients.[21]

CONCLUSION

Our study shows that the use of MRI to detect upper cervical ligament injuries in AOD is imperfect. We found inconsistent and unsatisfactory interobserver and intraobserver reliability in evaluation of alar ligament injuries. While MRI has immense potential for the detection of ligamentous injury at the craniovertebral junction, standardized algorithms for its use and interpretation need to be developed.

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Conflicts of interest

There are no conflicts of interest.

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