Construct Validity of Clinical Tests for Alar Ligament Integrity: An Evaluation Using Magnetic Resonance Imaging
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Construct Validity of Clinical Tests for Alar Ligament Integrity: An Evaluation Using Magnetic Resonance Imaging

Peter G. Osmotherly, Darren A. Rivett, Lindsay J. Rowe

Background. The alar ligaments are integral to limiting occipito-atlanto-axial rotation and lateral flexion and enhancing craniocervical stability. Clinical testing of these ligaments is advocated prior to the application of some cervical spine manual therapy procedures. Given the absence of validation of these tests and the potential consequences if manipulation is applied to an unstable upper cervical spine segment, exploration of these tests is necessary.

Objective. The purpose of this study was to examine the direct effect of the side-bending and rotation stress tests on alar ligaments using magnetic resonance imaging (MRI).

Design. This was a within-participant experimental study.

Methods. Sixteen participants underwent MRI in neutral and end-range stress test positions using proton density-weighted sequences in a 3-Tesla system. Measurements followed a standardized protocol relative to the position of the axis. Distances were measured from dens tip to the inferior margin of the foramen magnum and from midsubstance of the dental attachment of the ligament to its occipital insertion. Between-side differences were calculated for each measurement to account for inherent asymmetries in morphology. Differences were compared between the test and neutral positions using a Wilcoxon signed rank test.

Results. Side-bending stress tests produced a median between-side difference in ligament length of +1.15 mm. Rotation stress tests produced a median between-side difference in ligament length of +2.08 mm. Both results indicate increased measurement of the contralateral alar ligament.

Limitations. Assessment could be made only in the neutral position due to imaging limitations. Clinical texts state that tests should be performed in 3 positions: neutral, flexion, and extension.

Conclusions. Both side-bending and rotation stress testing result in a measurable increase in length of the contralateral alar ligament. This finding is consistent with mechanisms that have been described to support their use in clinical practice.
The lack of established validity of the tests of ligamentous stability of the upper cervical spine brings into question their ability to detect instabilities in this region. There is potential for an adverse outcome for a patient with an upper cervical spine instability undergoing treatment with manipulative techniques. Given this possibility, this area warrants further research to improve both the safety and treatment outcomes for patients undergoing physical therapy management of upper cervical spine disorders. An early step in the validation process for these clinical tests is the establishment of construct validity to assess whether the tests are capable of influencing the alar ligaments.

The alar ligaments have been described primarily as limiting occipito-atlanto-axial rotation and lateral flexion. They pass from the superolateral aspect of the dens to the medial surface of the occipital condyles. Loss of integrity of the alar ligaments removes a primary passive restraint to rotation in the upper cervical spine. A loss of control of rotation is associated with increased likelihood of adverse neurovascular events that have been associated with high-velocity thrust and end-range techniques used in the upper cervical spine.

Both the side-bending and rotation stress tests for the alar ligaments are based on preventing the inherent coupling of rotation and lateral flexion in the occipito-atlanto-axial complex. That is, lateral flexion of the occiput on the atlas is accompanied by immediate ipsilateral rotation of the axis beneath the atlas. This rotation was proposed by Dvorak and Panjabi to result from tension generated in the alar ligaments.

The side-bending stress test, first proposed by Aspinall, has been described for both sitting and supine positions. In performing this test, the spinous process and lamina of the axis are stabilized by the therapist to prevent both side bending and rotation of the segment. Slight compression is applied through the crown of the head to facilitate atlanto-occipital side bending. Passive side bending then is applied using pressure through the patient’s head; in effect, directing the patient’s ear toward the opposite side of the neck. If fixation of the axis is adequate, the normal coupled movement will not be permitted to occur. Hence, no lateral flexion should occur. Testing is recommended to be performed in 3 planes (neutral, flexion, and extension) to account for variation in alar ligament orientation. For a side-bending stress test to be considered positive for an alar ligament lesion, excessive movement in all 3 planes of testing should be evident.

The rotation stress test is regarded as primarily stressing the contralateral alar ligament in accordance with the biomechanical description of Dvorak et al. Again, the test is described for both sitting and supine positions. The axis is stabilized around its laminae and spinous process using a lumbrical grip. The cranium is grasped with a wide hand span and then rotated, the occiput taking the atlas segment with it, to the end of available range. No lateral flexion is permitted. Some rotation will occur during the test, but the extent of rotation within the bounds of normal is subject to some variation. Estimates of the range of normal rotation vary between 20 and 40 degrees. As with the side-bending test, the test is repeated in 3 positions in the sagittal plane, with laxity in all 3 positions necessary to establish a positive test finding.

The aim of the study was to examine through magnetic resonance imaging (MRI) the direct effect of clinical stress tests described for the alar ligaments to assess whether these tests are capable of demonstrating abnormalities of these structures.

Method
Participants
Sixteen skeletally mature participants were recruited sequentially via advertisement from the population of The University of Newcastle, Newcastle, New South Wales, Australia. To be eligible for inclusion, participants had to be between the ages of 18 and 35 years. The upper age limit was imposed to mitigate the effect of degenerative change on cervical spine movement during testing. Potential participants were excluded if they had a history of cervical spine trauma or recurrent pharyngeal infection, had been diagnosed with an inflammatory disease or an instability of the craniovertebral region, had any congenital disorder recognized to have the potential for instability of the craniovertebral region, or experienced claustrophobia or discomfort in confined spaces.

Eight male and eight female individuals satisfying all criteria for inclusion volunteered to participate. The average age of the female participants was 23 years 10.6 months (SD=72.3 months). The average age of the male participants was 25 years 4.6 months (SD=57.6 months).

Clinical Stress Tests Examined
The stress tests examined in this study were the side-bending stress test and the rotation stress test. Each test was administered by a
single investigator with the participants in a supine position. The side-bend or rotation movement imposed during each test was directed to the right in each case. Testing was not performed away from neutral in the sagittal plane because the required degree of sagittal-plane positioning would move the alar ligaments away from the posterior imaging coil, rendering them unclear on the resultant images.

**Imaging of Participants**

Images were acquired in the coronal plane using a Siemens Magnetom Verio Syngo MR B17 MRI system with a 3-Tesla magnet (Siemens AG, Erlangen, Germany). All ligament tests were performed consecutively in a supine position within the MRI bore, with participants enclosed in a phased array neck coil (Fig. 1). A neutral image was acquired as a reference study at the commencement of each participant’s examination. The neutral head and neck position for each participant was defined using criteria published previously, whereby the participant was positioned such that a line between the forehead and chin was horizontal and parallel to the examination table and an imaginary line running parallel to the table extended from the tragus of the ear would pass along the axis of the neck longitudinally.\(^\text{17}\)

A proton density-weighted turbo spin echo sequence was used with the following parameters: repetition time = 1,000 milliseconds, echo time = 38, field-of-view = 150 × 150 mm, image matrix = 320 × 320, image resolution = 0.5 × 0.5 × 1.5 mm (phase encoding direction right to left). Sixty slices were generated with a slice thickness of 1.5 mm. The total acquisition time for each sequence was 3 minutes 20 seconds.

**Measurement of MRI Images**

Viewing and analysis of all images were performed using OsiriX 3.5 image processing software (Osirix Foundation, Geneva, Switzerland).

**Method of standardizing reference position.** Each test examined has been described as movement of the atlas or occiput with respect to a stationary, manually stabilized axis. To ensure consistency with the test description and permit accurate and reproducible measurement, each image was measured with reference to a standardized position of the axis.

To create anatomically based scan planes to standardize axis position, each data set was displayed using a multiplanar reconstruction. In the sagittal reconstruction, a section passing parallel to the longitudinal axis of the odontoid process and orthogonal to the plane of the interbody joint of C2–3 was selected. In the coronal reconstruction, a section passing longitudinally down the midline of the odontoid process and bisecting the body of the second cervical vertebra was selected. In horizontal reconstruction, a section centered on the center point of the cross-section of the odontoid process was selected. To account for any rotation of the axis present, the image was rotated when necessary such that the plane of the section contained the transverse foraminae of the axis in alignment.

**Methods of measurement for each ligament test position.** Each image was measured on 2 separate occasions to establish reliability of measurement according to the protocol that follows.

The effectiveness of the tests in tensioning the alar ligaments was measured in the coronal plane using both direct and indirect techniques. In the absence of validated published methods to assess alar ligament length, indirect estimation was used to provide concurrent measurement.
of change in the relationship between points of bony prominence adjacent to the attachment sites of the ligaments. To estimate displacement of the occiput from the stabilized axis, the distance from the tip of the odontoid process to the inferior aspect of the foramen magnum was measured bilaterally. Direct estimation was performed by first selecting the midpoint of the dental attachment of the alar ligament. A line corresponding to the axis of the ligament (indicated by the arrow) is generated and measured between origin midpoint and insertion into the occiput.

Data Analysis
Analysis of all data was performed using Stata 11.0 statistical software (Stata Corporation, College Station, Texas). Due to the inherent asymmetries of the morphology of the region, including variation in orientation of the odontoid process and the individual ligaments in all 3 anatomical planes, analysis of the alar ligament tests was undertaken using the difference between left-sided and right-sided measurements as the base variable of analysis. A variable representing the difference in measured distance between bony landmarks and between alar ligament lengths was generated for each measure in all test positions as the measure of the right side subtracted from the measure of the left side.

Exploratory data analysis was used to describe the difference and spread of data representing the generated variables of the left to right difference for each measure. The distribution of each variable was assessed both visually using histograms of the data and normal probability plots and statistically using the Shapiro-Wilk test for normality. Hypothesis testing comparing the left to right differences in both measured distance between bony landmarks and actual ligament length was done by analyzing the difference estimates in the test positions compared with the difference estimates in the neutral position. Each hypothesis test was performed using the nonparametric Wilcoxon signed rank test for paired variables. Reliability of measurements for each image was assessed by estimation of intraclass correlation coefficients for the recorded measurements of the image taken on 2 separate occasions.

Role of the Funding Source
This research was supported by a Physiotherapy Research Foundation grant.

Results
The measured lengths of the distance between the tip of the odontoid process and the foramen magnum and the direct measurements of the alar ligaments for each side and for each position are given in Table 1. After application of each stress test for the alar ligament, an increase in left-sided length was evident in each participant (Fig. 3).

Figure 2.
(A) Measurement from the tip of the odontoid process to the inferior margin of the foramen magnum indicated by the arrow. (B) Direct estimation of alar ligament length. A line corresponding to the axis of the ligament (indicated by the arrow) is generated and measured between origin midpoint and insertion into the occiput.
Bony Estimation: Tip of the Odontoid Process to the Foramen Magnum
In the neutral position, the median left-right difference in this measure was 0.02 mm (interquartile range [IQR]=−0.05 to 0.23). After imposition of the side-bending stress test, the median left-right difference was calculated as 0.85 mm (IQR=0.10 to 2.52), indicating a lengthening of the interval on the left side compared with the neutral position. On rotation stress testing, the median left-right difference was calculated as 1.44 mm (IQR=0.76 to 1.90), again indicating an increased distance between landmarks on the left side. Between-position comparisons using the neutral and test position measurements were statistically significant for each alar ligament stress test (Tab. 2).

Direct Measurement of Alar Ligament Length
The median left-right difference in alar ligament length in the neutral position was −0.05 mm (IQR=−0.17 to 0.36). With the imposition of the side-bending stress test, the median left-right difference increased to 1.15 mm (IQR=0.58 to 1.67), indicating a greater length of the left-sided alar ligament. Upon rotation stress testing, the median left-right difference increased to 2.08 mm (IQR=1.09 to 2.60), again indicating an increase in measurable length of the left-sided alar ligament. Comparisons between the stress test position and the neutral position were statistically significant for each stress test examined (Tab. 2).

Intraclass correlation coefficients for the estimation of left-right difference for each measurement in each position are given in Table 3. Reliability of measurement ranged from moderate to substantial according to accepted criteria.18

Discussion
This is the first study to demonstrate a direct effect of these clinical tests on the alar ligaments, providing support for the construct validity of these screening tests. The use of a detailed, standardized protocol to orient and measure the images of the testing procedures provides considerable rigor and consistency to the findings of this study. This consistency is underscored by the magnitude of the intraclass correlation coefficients assessed for each measurement in each position imaged. This standardized protocol, using 3-dimensional reconstructions to create a reference position for the axis, accounted for movements occurring across all 3 planes during the testing procedures.

The observed direct effect of testing on the alar ligaments has been corroborated by changes measured con-

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**Table 1.**
Measurements of Indirect and Direct Methods of Ligament Length for Left and Right Alar Ligaments

<table>
<thead>
<tr>
<th>Position</th>
<th>Left Side</th>
<th></th>
<th>Right Side</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bony Measurement</td>
<td>Ligament Measurement</td>
<td>Bony Measurement</td>
<td>Ligament Measurement</td>
</tr>
<tr>
<td></td>
<td>Mean Length (mm)</td>
<td>SD (mm)</td>
<td>Mean Length (mm)</td>
<td>SD (mm)</td>
</tr>
<tr>
<td>Neutral</td>
<td>9.85</td>
<td>0.99</td>
<td>6.38</td>
<td>0.83</td>
</tr>
<tr>
<td>Side bending</td>
<td>10.64</td>
<td>1.24</td>
<td>6.76</td>
<td>1.06</td>
</tr>
<tr>
<td>Rotation</td>
<td>10.51</td>
<td>1.53</td>
<td>7.18</td>
<td>1.23</td>
</tr>
</tbody>
</table>

---

**Figure 3.**
The alar ligaments (circled) following imposition of the side-bending stress test.
currently in the distance between the tip of the odontoid process and the foramen magnum. This finding indicates that the method of alar liga-
mament measurement used is a valid representation of its length.

The substantial reliability of image measurement demonstrated that the inherent inaccuracies in measure-
ment due to vibration while sus-
taining end-range positions were minimized, despite the subsequent reduction in image quality. The main undesirable effect of sustaining each test position in excess of 3
minutes would be to lose the end-
range position and hence reduce the measured differences between the neutral and test positions. Thus, the changes shown in this study may possibly be considered an underesti-
mate of the potential displacement occurring during these tests. The consistent findings of a measurable displacement thus should be consid-
ereg to be a conservative estimate of
the true displacement that may be achieved during the application of
these stress tests.

In the neutral position, no significant difference was noted in the ligament lengths measured or the bony esti-
mations of ligament attachment. Thus, any left-right difference found on testing may be attributed to
the application of the test proce-
dure. Both the side-bending and the rotation stress tests resulted in a measurable change in the distances assessed. In each case, the left-side measurements increased relative to the right side, indicating a direct lengthening of the left, that is, contralateral alar ligament. This finding indicates that the 2 stress tests
applied in this study both demon-
strated a direct effect on the alar
ligaments.

Aspinall11 proposed the side-bending stress test as a mechanism for testing the contralateral alar ligament. These
findings are consistent with the testing mechanism as described by Aspinall. However, based on the descriptions of Dvorak and Panjabi,3 it also has been suggested that testing in both directions is necessary to infer instability due to both alar
ligaments tensioning bilaterally during side bending.16 In the current study, a clear difference between sides was evident during side-bending testing. This finding indicates that within the ranges in which these ligaments were tested, a bilateral effect on the alar ligaments is not evident and the need for a finding of laxity in both directions is not neces-
sary to infer instability.

The mechanism attributed to the rotation stress test is the prevention of coupled movement within the occipito-atlanto-axial complex. Rotation of the occiput over a stationary axis results in the contralateral alar ligament being wound around
the odontoid process due to its pos-
terior attachment on the odontoid.6 Under normal biomechanical cir-
cumstances, the odontoid would be permitted to shift laterally, thus ten-
sioning the ipsilateral ligament. However, if the maintenance of the axis position is effective and cranio-
cervical side bending is effectively
minimized through manual stabiliz-
ation, the limiting feature of the rotation movement should be the
tension developed in the contrala-
teral alar ligament. The findings of
the current study are consistent
with this mechanism. A clear differ-
ence in length developed between the alar ligaments in each partici-
Oodontoid Process to Foramen Magnum (mm)
<table>
<thead>
<tr>
<th>Position</th>
<th>Left-Right Difference Assessed</th>
<th>ICC</th>
<th>95% CI*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral</td>
<td>Odontoid process to foramen magnum</td>
<td>.85</td>
<td>.63 to .95</td>
</tr>
<tr>
<td>Neutral</td>
<td>Direct measurement of ligament length</td>
<td>.81</td>
<td>.54 to .93</td>
</tr>
<tr>
<td>Side bending</td>
<td>Odontoid process to foramen magnum</td>
<td>.63</td>
<td>.24 to .86</td>
</tr>
<tr>
<td>Side bending</td>
<td>Direct measurement of ligament length</td>
<td>.83</td>
<td>.58 to .94</td>
</tr>
<tr>
<td>Rotation</td>
<td>Odontoid process to foramen magnum</td>
<td>.68</td>
<td>.29 to .88</td>
</tr>
<tr>
<td>Rotation</td>
<td>Direct measurement of ligament length</td>
<td>.62</td>
<td>.22 to .85</td>
</tr>
</tbody>
</table>

* CI=confidence interval.
Construct Validity of Clinical Tests for Alar Ligament Integrity

measurements of 1.24 mm and an increase in direct ligament measurement of 1.22 mm. Hence, both indications of ligament length are consistent and strongly correlated \( (r = .76) \). Rotation stress testing resulted in a mean increase in ligament approximation by skeletal measurement of 1.60 mm and a direct ligament measurement of 1.88 mm. Again, the measured effect on ligament length was consistent in direction, with moderate correlation between these measures \( (r = .65) \). From these findings, it may be considered that the rotation stress test produces a greater measurable effect on the contralateral alar ligament than the side-bending stress test.

Although assessment of the alar ligaments was undertaken only in the neutral plane for imaging reasons as described previously, testing into both flexion and extension should exhibit the same findings, considering the mechanism of the clinical tests applied. Moreover, the majority of alar ligament specimens examined in previous dissection\(^7\) and radiological\(^8\) studies were oriented in the horizontal plane. Where caudal or cranial orientation was noted, the angles were smaller than illustrated in standard texts.\(^21\) Hence, findings in the neutral position will be transferable to the majority of alar ligaments in the adult population.

Previous studies also have indicated that a proportion of alar ligaments either have anterior portions that do not attach to the odontoid process or may even bypass the odontoid process entirely.\(^22,23\) It is not possible to identify people whose ligament arrangement might reflect this morphology under clinical examination. Hence, some radiologically demonstrable ligament injuries may not be perceptible in some individuals using these standard clinical stress tests.

Although clinical texts suggest that the alar ligament tests should be performed in 3 positions (neutral, flexion, and extension), we assessed these procedures only in the neutral position. Pretrial piloting of the techniques showed that retesting in further positions in the sagittal plane resulted in extensive loss of MRI signal due to the separation of the patient from the anterior portion of the head coil, rendering the images acquired unreadable.

Although the findings of this study provide support for the construct validity of these 2 clinical tests by demonstrating a direct effect on alar ligaments in an asymptomatic population, it should be noted that neither the validity nor the reliability of these tests has yet been established in a clinical population. In the only article published previously examining alar ligament testing, Kaale and colleagues\(^24\) demonstrated high specificity and moderate sensitivity for detecting alar ligament lesions in a mixed population dominated by people with a history of chronic whiplash-associated disorder based on an assessment of the quality of occipito-atlanto-axial rotation performed by one examiner. Assessment of tests under conditions of pain and muscle spasm and in the presence of other induced symptoms is necessary to evaluate their clinical utility.

Conclusion

This study has established successfully a reproducible method for the assessment of the clinical stress tests of the upper cervical spine ligaments. By using rigorously defined methods of standardization of the axis as a reference position and a clearly defined measurement protocol, the measurements produced have been demonstrated to be highly reliable. This study has addressed an important limitation of previous studies using MRI and will permit more accurate examination of the alar ligaments in future research.

Both the rotation and the side-bending stress tests for the alar ligaments have been demonstrated to increase the length of the contralateral alar ligament during testing. In contrast to the opinions of some authors, no bilateral effect was observed.

Mr Osmotherly and Dr Rivett provided concept/idea/research design and writing. All authors provided data collection and fund procurement. Mr Osmotherly and Mr Rowe provided data analysis. Dr Rivett provided project management. Mr Osmotherly provided participants. Dr Rowe provided facilities/equipment, institutional liaisons, and consultation (including review of manuscript before submission).

Ethical approval for this study was granted by the Hunter New England Human Research Ethics Committee.

An oral presentation of this research was given at the Australian Physiotherapy Association Conference; October 27–30, 2011; Brisbane, Queensland, Australia.

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