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Toward Understanding Normal Craniocervical Rotation Occurring During the Rotation Stress Test for the Alar Ligaments

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Background. The rotation stress test is recommended for assessing alar ligament integrity. Although some authors, in the literature regarding the rotation stress test, accept that rotation will occur during testing, estimates of range occurring with a normal test response vary between 20 and 40 degrees. None of these estimates are based on formal examination of the test.

Objective. The purposes of this study were: (1) to examine the range of craniocervical rotation occurring during rotation stress testing for the alar ligaments in individuals who are healthy and (2) to investigate a measurement protocol for quantifying rotation.

Design. A within-subject experimental study was conducted.

Methods. Sixteen participants underwent magnetic resonance imaging in neutral and end-range rotation stress test positions. Measurements followed a standardized protocol relative to the position of the axis. A line connecting the transverse foramena of the axis created a reference plane. The position of the occiput in the head-neutral position was calculated as the angle formed between a line joining the foramena lacerum and the reference plane. Measurements were repeated at the end-range test position. Total rotation of the occiput was calculated as the difference in angles measured in neutral and test positions. Measurement was performed on 4 occasions, and reliability of measurements was assessed using the standard error of measurement (SEM) and the intraclass correlation coefficient (ICC).

Results. Measurement of rotation of the occiput relative to a stabilized axis ranged between 1.7 and 21.5 degrees ($\overline{X}$=10.6, SD=5.1, SEM=1.14, ICC=.96, 95% confidence interval=.90–.98).

Limitations. Sustaining the test position for imaging increased the potential for loss of end-range position and image quality. Testing could be performed only in the neutral position, not in 3 planes as commonly described.

Conclusions. The range of craniocervical rotation during rotation stress testing of intact alar ligaments should typically be 21 degrees or less. Rotation may be quantified using the method protocol outlined.

The rotation stress test has been proposed as a method for assessing alar ligament integrity prior to the application of manual procedures to the upper cervical spine.[1,2] Although this test has been cited in standard texts[3–5] as a component of premanipulative cervical spine screening, little examination of the properties or performance of this alar ligament test has been done. Although construct validity for this stress test has previously been demonstrated,[6] no reliability or validity data are available upon which to judge its diagnostic utility. Further investigation of the procedure is necessary to understand the mechanical effects of the test maneuver and to inform future studies assessing validity of this test in a patient population.

The rotation stress test may be performed in either the sitting position[5,7] or the supine position[1] and is repeated in positions of the upper cervical sagittal plane in neutral, flexion, and extension. The repetition of testing in these various positions is proposed to account for variation in ligament orientation in the sagittal plane.[8] Fixation of the axis is maintained by the grasping of the lamina with the thumb and index finger of one hand using a lumbrical grip. The head is then rotated to the end of available range, with the occiput simultaneously moving the atlas segment with it (Fig. 1). No lateral flexion is permitted throughout the movement.[2,5,7] A positive test finding is the detection of excessive rotation in all 3 positions of testing.[1]

The importance of rotation in assessing alar ligament integrity has been supported by the findings of Kaale et al,[9] who, using a variation of the rotation stress test performed in the sitting position, demonstrated that a passive manual examination assessing the degree of occipito-atlanto-axial rotation of the craniocervical segments for alar ligament incompetence produced moderate agreement with magnetic resonance imaging (MRI) gradings of detectable ligament injuries (kappa=.71 and .69 for right and left alar ligaments, respectively).

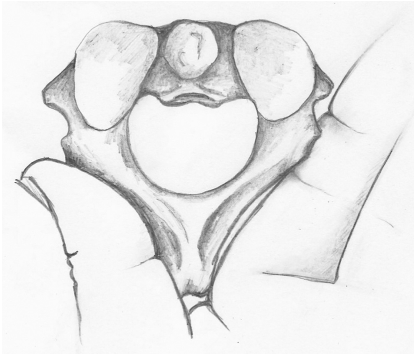

Figure 1.
Stabilization of the axis (view from superior aspect). The therapist's thumb and index finger provide broad contact around the neural arch of the axis. The hand is "cupped," and the thumb is adducted.

Interpretation of the test in the literature regarding the amount of movement that should be possible in the presence of intact alar ligaments is inconsistent. All authors agree that some rotation will occur during testing; however, the reported extent of rotation acceptable within the bounds of normal range varies considerably. Beeton[7] reported a normal range of rotation when testing of approximately 20 degrees, with a firm-end feel, provided effective stabilization of the axis is maintained. She recommended that more than 30 degrees of rotation is indicative of alar ligament compromise. Gibbons and Tehan,[3] Pettman,[5] and Torres-Cueco[10] agreed with this upper estimate of more than 30 degrees as indicative of contralateral ligament incompetence. Other authors have provided interpretations of the test that consider larger ranges of rotation to be within normal limits. Westerhuis[2] suggested 35 degrees should be considered the maximum value of normal motion, with a discrepancy of no more than 8 degrees between rotations in either direction. Hing and Reid[1] considered 35 degrees to 40 degrees of rotation with a solid end-feel to be the upper acceptable limits of normal range.

All of these reported ranges of movement are estimates of the range of rotation available to the occiput and atlas upon a manually stabilized axis, and interpretation of clinical test findings is predicated upon the consideration of the typical range of rotation available in individuals without alar ligament compromise. This variation in described normal range of available rotation presents a sizeable, as well as possibly clinically significant, variation in what is considered normal movement. Acceptance of wide and untested variation of up to 20 degrees (ie, 200% of the most conservative estimate) in suggested normal ranges of rotation elicited during the testing procedure causes a dilemma in our understanding of the range of rotation actually available during stressing of an intact craniocervical complex.

Furthermore, all estimates published in the literature regarding range of rotation available upon testing appear to be based solely on clinical observation. None of the estimates cited above have resulted from any formal examination of the rotation stress test in individuals with intact alar ligaments, nor are they the product of any systematic approach to measurement. No reference to any formally derived source of the estimate was provided in any publication examined.

The aim of this study was to examine the range of rotation elicited during the performance of the rotation stress test for the alar ligaments in a sample of individuals with no history of cervical spine injury or instability.

An understanding of the actual range of rotation normally available in the intact occipito-atlanto-axial complex in the test position is essential to inform subsequent investigations of the validity and interpretation of this clinical test. Through the provision of quantified and reproducible data obtained using a standardized and rigorous measurement protocol, a more accurate understanding of the maximum range of rotation occurring during a normal rotation stress test may be achieved.

Method

Participants

Sixteen skeletally mature participants, between 18 and 35 years of age, were recruited via advertisement from the population of the University of Newcastle, Australia. An upper age limit was imposed to minimize the effect of degenerative change on cervical spine movement during testing. Volunteers 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 men and 8 women satisfying all inclusion criteria consented to participate. The ages of the 16 volunteers ranged from 19 to 32 years (mean age=24.6, SD=5.3).

Rotation Stress Test

Each rotation stress test was conducted, with the participant in the supine position, by a single investigator, a physical therapist with 25 years of clinical experience. All tests were conducted within the confines of the MRI bore. The rotation imposed during the testing of each participant was directed to the right side only. All testing was performed in the neutral sagittal position. Repetition of the tests in flexed or extended positions was not undertaken because the required degree of sagittal-plane repositioning located the alar ligaments away from the posterior imaging coil, rendering the resultant images unclear.

Imaging of Participants

Images were acquired in the coronal plane using a SIEMANS MAGNETOM Verio syngo MR B17 MRI system with a 3-tesla magnet (Siemans AG, Erlangen, Germany). Participants were placed in the supine position within the MRI bore and enclosed in a phased array neck coil. A neutral position image was first acquired at the commencement of each participant's examination. The neutral head and neck position for each participant was determined using previously defined criteria.[11] Images were obtained for each participant on one occasion.

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

Analysis of MRI Images

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

The rotation stress test is described as movement of the occiput with respect to a stationary, manually stabilized axis. To account for this movement and permit accurate and reproducible measurement, each image was measured with reference to a rigorously standardized position of the axis established using multiplanar reconstruction of the image data. This standardization process has been described in detail in our previous publications.[6,12]

Calculation of the angle of rotation was made using a 2-step process. The first step involved measurement of the participants in the neutral position. With the axis viewed in axial section, the image was oriented along a line joining the transverse foramena (line 1). This plane was maintained while the view was moved superiorly to include the occiput such that the point where each internal carotid artery entered the foramen lacerum were contained within the viewed image. A line then was created joining both foramina (line 2). A reference angle was calculated between these lines (angle 1). This baseline measurement provided a pretest measurement of this angle to account for any individual anatomical variations inherent in each participant (Fig. 2). The second step repeated this measurement process using the images derived from the participants in the test position of end-range rotation, yielding a second angle between these lines (angle 2) (Fig. 3). Rotation of the occiput with respect to the axis was estimated as the difference between angle 2 (posttest) and angle 1 (pretest). All measurements for each imaged position for each participant were taken on 4 separate occasions to establish reliability of the measurement method.

Data Analysis

Analysis of all data was performed using Stata 11 statistical software (StataCorp LP, College Station, Texas).

Assessment of rotation of the occiput relative to the axis. Recorded measurements of the individual angles formed by the intersection of the lines connecting the transverse foramena and the foramena lacerum were aggregated as mean measurements and their dispersion presented as standard deviations. The estimate of rotation of the occiput relative to a stationary axis was calculated as the angle formed in the neutral position subtracted from the angle formed in the end-range rotation test position. These also were presented as mean estimates together with the standard deviation of the measurements. Distribution of the outcome variables was assessed for normality using standard procedures, including comparison of mean and median measurements, construction and inspection of a distribution histogram with superimposed normal curve, and construction of a normal probability plot.

Estimates of reliability. Reliability of measurements for each participant's test was assessed by estimation of standard error of measurement (SEM) and intraclass correlation coefficient (ICC) (2,1) between the recorded measurements of the images taken on 4 separate occasions.

Role of the Funding Source

This research was supported by a Physiotherapy Research Foundation grant.

Results

In the neutral position, the mean angle formed by the intersection of the lines joining the transverse foramena and foramena lacerum was 0.74 degrees. In the test position of end-range rotation, the mean angle formed by the lines of intersection was 11.32 degrees. The resultant mean difference in angle representing magnitude of rotation of the occiput relative to a stationary axis was 10.58 degrees. Details of the mean measurements and the dispersion of the data are provided in Table 1. Upon completion of exploratory data analysis, the distribution of occipital rotation measurements relative to the stationary axis was deemed to satisfy the requirements for normality.

The reliability of angle measurement ranged from moderate to substantial according to accepted criteria.[13] The SEM and ICC for angles measured in both the neutral and test positions, the calculated range of occipital rotation with respect to the axis, and the 95% confidence intervals for the ICC are given in Table 2.

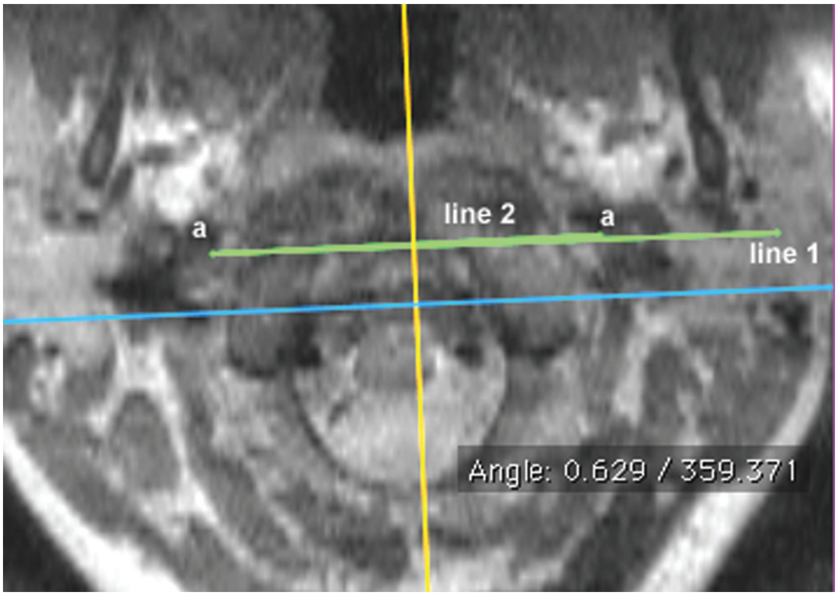

Figure 2.
Neutral position: angle formed by the intersection of line 1 indicating the superimposed position of the line joining the transverse foramena and line 2 between the internal carotid arteries entering the foramena lacerum (a).

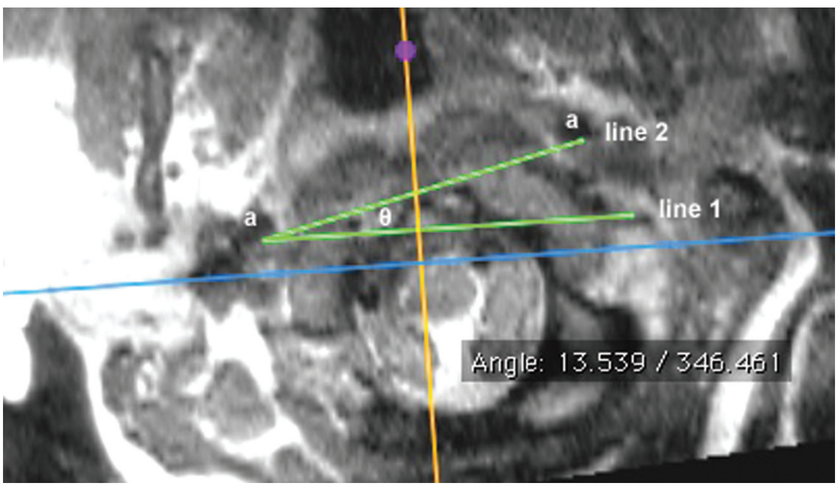

Figure 3.
Rotation stress test position: angle formed (θ) by the intersection of line 1 indicating the superimposed position of the lines joining the transverse foramena and line 2 between the internal carotid arteries entering the foramena lacerum (a).

Table 1.
Angles (in Degrees) Formed by the Intersection of the Lines Joining the Transverse Foramena and the Foramena Lacerum[a]

Position Measured	Mean Angle	SD	Range
Neutral position	0.74	1.31	−3.74 to 3.29
End-range rotation	11.32	5.39	1.12 to 21.54
Occipital rotation	10.58	5.12	1.69 to 21.54

[a] Angles formed by the intersection of the lines joining the transverse foramena (line 1) and foramena lacerum (line 2), as illustrated in Figures 1 and 2, indicate rotation of the occiput with respect to the axis in neutral and rotation stress test positions.

Table 2.
Estimates of Reliability for the Angular Measurements in Neutral and Rotation Stress Test Positions[a]

Measurement	ICC	95% CI	SEM (°)
Angle in neutral position	.75	.56–.89	0.65
Angle in end-range rotation	.96	.93–.99	1.07
Rotation of occiput relative to stationary axis	.95	.90–.98	1.14

[a] ICC=intraclass correlation coefficient, 95% CI=95% confidence interval for ICC, SEM=standard error of measurement.

Discussion

This is the first in vivo study to quantify the range of rotation occurring during a normal response to the rotation stress test for alar ligament integrity, developing an accurate and reliable method for determining the magnitude of rotation between the occiput and the axis. Although the sample was sufficient to establish normative values, the rotation ranges measured in this study are consistent with the lower estimates of movement that have been suggested previously in the literature. However, they are substantially less than the 35- to 40-degree estimates of rotation that have been proposed by some authors. The method developed to assess the segmental rotation also may be suitable for future studies exploring the validity of the rotation stress test for alar ligament integrity utilizing a population with demonstrable alar ligament compromise.

The mean range of rotation measured in this sample was 10.58 degrees, and the maximum range achieved was 21.54 degrees. These findings strongly suggest that there is considerable variation in the amount of craniocervical rotation occurring as a result of the imposition of this clinical stress test. Applying a conventional statistical approach to these data, we may infer that because these data satisfy the requirements for being normally distributed, we may be 95% confident that the range of maximum rotation occurring in the craniocervical segments in young adults without alar ligament compromise is 21 degrees or less, this range being within 2 standard deviations or 10.2 degrees of the calculated mean. Although we may consider movement in this range to include that of nearly all individuals whose alar ligaments are unimpaired, it cannot be inferred that all test findings falling into this range are consequently negative. In addition to the tension developed in the alar ligaments, limitation to movement may be influenced by lateral translation of the lateral mass of the atlas and variation in the geometry of the articulations themselves.[14] It also should be noted that the range of rotation elicited in many individuals was considerably less than 21 degrees. Given cadaveric research demonstrating a 30% increase in the range of contralateral rotation following unilateral alar ligament transection,[15] it is possible that a person without alar ligament integrity may have movement within this range. This possibility presents difficulties in the interpretation of a test finding based upon range of rotation alone and should be considered in subsequent research examining the validity of this clinical test.

The finding that the ranges measured during testing were considerably lower than the less conservative published estimates of rotation should not be surprising. Total ranges of unrestricted axial rotation at the atlantoaxial joint have been estimated between 38.9 degrees and 47 degrees during cadaveric examinations[16–18] and between 31.4 degrees and 46 degrees with radiological analysis.[19–22] These ranges would place the less conservative estimates of a rotation occurring during this test for individuals with uncompromised alar ligaments at the extremes of normal joint movement. Moreover, unlike the stress testing performed in this study, unrestricted atlantoaxial rotation occurs in the presence of the normal coupling of movements in the occipito-atlanto-axial joint complex. In order for maximum rotation to be achieved at these levels, lateral flexion of the occiput on the atlas and a lateral displacement of the odontoid process must occur.[23,24] Effective stabilization of the axis and monitoring for the occurrence of side bending during the rotation stress test effectively minimizes the coupling of movements, hence limiting available rotation range.[5] Due to the posterior attachment of the alar ligaments onto the odontoid process, rotation of the axis beneath a fixed occiput will result in tensioning of the alar ligament ipsilaterally by winding the ligament around the odontoid process. Further rotation would draw the ipsilateral occipital condyle toward the odontoid process resulting in atlanto-occipital lateral flexion in the same direction as the axis rotation.[25,26]

Manual stabilization to eliminate the occurrence of coupled lateral flexion, therefore, will limit the range of rotation available at the atlantoaxial joint in the presence of intact alar ligaments. Furthermore, because the accepted function of the alar ligaments is to limit axial rotation of the occipito-atlanto-axial complex, it would seem reasonable that the range of rotation they permit should be less than the range permitted by articular configuration alone.

Implications of the need to sustain the test position in excess of 3 minutes to accomplish the imaging include the potential for loss of the end-range position and loss of image quality due to vibration. Hence, the estimates of axial rotation range provided in this study could be considered conservative. However, the reliability of the angles measured in both neutral and end-range stress test positions suggests that any error introduced by vibration or loss of end-range position was minimal. Therefore, these results may be considered reasonable estimates of the actual range of craniocervical axial rotation available in asymptomatic individuals upon application of the rotation stress test for the alar ligaments.

It also should be considered that the range of rotation described in this study was the result of stress testing performed in the neutral plane alone. Testing in a patient population would be performed in the planes of neutral, flexion, and extension to account for variation in alar ligament orientation.[7,8] This approach may potentially change the available excursion of the atlantoaxial joint as a result of articular geometry and altered coupling of movements in these positions. The effects of the plane of testing on the available range of rotation is currently under investigation as part of our ongoing work in this area.

Conclusion

The range of craniocervical rotation occurring during performance of the rotation stress test for the alar ligaments should be considered to be as much as 20 degrees in individuals with alar ligament integrity. Previously published estimates of rotation of up to 40 degrees on testing appear to be of a magnitude unlikely to include a typical test response in an intact craniocervical segment. Our findings suggest that the normal range of rotation occurring during performance of the rotation stress test is consistent with the lower published estimates. Clinicians should exercise caution in their determination of a negative alar ligament test when interpreting the result using the larger clinically estimated ranges of rotation reported in the literature. Improved understanding of normal motion during testing and the development of a reliable method for quantifying craniocervical rotation will assist in the design of, and interpretation of results from, future studies examining the diagnostic utility of this clinical screening test.

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

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

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