Normal kinematics of the upper cervical spine during the Flexion-Rotation Test – in vivo measurements using Magnetic Resonance Imaging

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Abstract

The Flexion-Rotation Test (FRT) is proposed to assess mobility primarily at C1-C2. However, there is no in vivo measurement investigating the validity of the FRT. The purpose of this study was to investigate the validity of the FRT by evaluating kinematics of the upper cervical spine during the FRT using MRI. A secondary purpose was to examine measurement reliability. Nineteen asymptomatic female subjects (mean age: 22.2 years) were evaluated with a 0.2-T horizontally open MRI unit. The segmental rotation angles from Occiput-C1 to C3-C4 and the C4 vertebra were assessed with the head maximally rotated to both the right and the left in two conditions – neck in neutral and in flexion. A repeated measures ANOVA revealed an interaction between the two different neck starting positions and segment levels ($P < 0.0001$). Post-hoc analysis revealed that there were significant reductions in the flexed position ($P<0.0001$) except for at Occiput-C1. While there was only a 16.3% reduction in rotation range at C1-C2, the reduction was 68.1% at C2-C3, 61.4% at C3-C4, and 76.9% at segments below C4, respectively. The inter- and intra-observer measurement reliability were substantial. These results support the validity of the FRT as a clinical measure of atlanto-axial mobility.

Keywords

In vivo, MRI, Segmental rotation, Upper cervical spine

Introduction

Restriction of range of motion appears to be a generic feature of neck pain disorders, and it is routinely assessed in the clinical evaluation of patients (Dall'Alba et al., 2001; Woodhouse and Vasseljen, 2008). Clinical examination of primary plane movements provides overall information about movement of the spinal segments collectively, but some tests reportedly are biased toward a certain cervical segment (Edwards, 1992; Dvorak et al., 2008).

The Flexion-Rotation Test (FRT) described by Dvorak et al (1998) is commonly used as an assessment of mobility in the upper cervical region. The cervical spine is placed in end-range flexion, in an attempt to block rotation of all vertebrae below C2. It is postulated that rotation in end-range cervical flexion occurs predominantly at the atlantoaxial joint (C1-C2) (Hall and Robinson, 2004; Ogince et al., 2007; Dvorak et al., 2008; Hall et al., 2008b). Proponents of this test report its relative ease of use with minimal practitioner skill required (Hall et al., 2008b), which is in contrast to other passive segmental mobility tests (Jull et al., 1988; Jull et al., 1997). Normal range of motion is approximately 45° to both sides (Hall and Robinson, 2004; Hall et al., 2008b). Range of motion less than 33° to one side is rated as abnormal (Ogince et al., 2007; Hall et al., 2008b). In addition, range of motion recorded during the FRT is stable over time (Hall et al., 2010b). Hence, the FRT has been used clinically in cervicogenic headache diagnosis and as a treatment outcome measure after physical therapy interventions to the upper cervical spine (Hall et al., 2007; Hall et al., 2008a; Hall et al., 2010a). However, to date there has been no in vivo study to measure cervical segmental movements during the FRT to confirm the validity of the FRT.

The purpose of this study was two-fold. The first purpose was to investigate the validity of the FRT as a test of predominantly C1-C2 motion. This was achieved by measuring and comparing segmental rotation from Occiput-C1 to C3-C4 and rotation of the C4 vertebra, which indicates total rotation of segments distal to C4, with the neck in neutral position and in flexion position, using Magnetic Resonance Imaging (MRI). The second purpose was to examine measurement reliability of rotation angles derived from MRI data.

Materials and Methods

Participants

Subjects were volunteers recruited from advertising in the Sapporo Medical University. Forty-five asymptomatic subjects who were less than 145cm tall, without any history of significant cervical spine or shoulder girdle disorders were included. Twenty-two subjects were immediately excluded as they could not achieve end-range cervical flexion in the narrow space within the MRI unit. To identify potential cervical spine disorders, all remaining volunteer subjects were screened by sagittal T2-weighted and axial T2*-weighted MRI of the neck and by a routine physical examination of range of motion of the neck and upper limbs. Two orthopedic surgeons experienced in MRI evaluations, inspected all MRI images for abnormalities on the sagittal T2-weighted images (FSE, FOV: 250, TR/TE: 2570/140msec, Thickness: 5.0mm, Interval: 6.0mm, Scan time 5:39) and the axial T2*-weighted images (GE, FOV: 200, TR/TE: 900/20msec, Thickness: 5.0mm, Interval: 5.0mm, Scan time 5:24). Four subjects were found to have potential evidence of musculoskeletal disorders (non-symptomatic disc bulging) and were thus excluded. As a result, 19 females of the original 45 volunteer subjects completed the study. The mean height of the 19 subjects was 141.2cm (range, 136-145cm) and mean age 22.2 years (range, 19-27 years).

All subjects were informed of the study design and the procedures to be used and all provided informed consent prior to data collection. Data collection was conducted in the Shinoro Orthopedic, Sapporo, Japan. Approval for this study was granted by the Society of Physical Therapy Science.

Measurement method

Equipment

MRI of the cervical spine was performed with a 0.2-T horizontally open unit (AIRISmate, HITACHI Inc., Sapporo, Japan). The participants were placed in the supine position on a custom-made positioning device that was designed and constructed to fit into the MRI unit and attach to the examination table. It was located beneath the flexible receiver surface coil (MR-JCL-72 separate type, HITACHI Inc. Sapporo, Japan) and used to guide the movements of neck rotation from neck in neutral position and end-range flexion position. Both shoulders and chest were fixed firmly by belts (Figure 1).

Data acquisition method

The range of vertebral rotation was assessed at each level from the occiput to the C4 vertebra under two conditions: head rotation with the neck in neutral position (lying without a pillow) and in a flexed position. The angle of the spinal column in the sagittal plane in the neutral and flexed positions was measured and calculated from the angle of bisection of the lines drawn parallel to the inferior end-plates of the C2 and C7 vertebra. This measurement has previously been shown to be reliable (Takasaki et al., 2009a). It was described as positive if it rotated anteriorly relative to the line described by C7, from sagittal T1-weighted images (GE, FOV: 250, TR/TE: 90/12msec, Thickness: 5.0mm, Interval: 9.0mm, Scan time 0:35). The sagittal T1-weighted image was captured before the measurements of head rotation in each neck position.

For each measurement of the vertebral rotations (neutral and in flexion), an examiner passively maintained the end-range head rotated position during scanning. The order of testing (neck in neutral or in flexion) was randomized between subjects.

Measurement angles

Segmental rotation angles (Occiput-C1, C1-C2, C2-C3 and C3-C4) were calculated from the vertebral rotation angles as follows. Firstly, each vertebral rotation from the occiput to C4 vertebra was measured from axial T1-weighted images (GE, FOV: 260, TR/TE: 450/15msec, Thickness: 2.5mm, Interval: 2.5mm, Scan time 2:56). Rotation of the occiput was measured by drawing a line from the midpoint of the foramen magnum to the nasal septum on the T1-waighted axial image (Figure 2) and defining the rotation value between that line and sagittal plane (vertical image frame). The rotations of C1 and C2 were defined using a line drawn through the lateral masses of the atlas dividing C1 symmetrically into anterior and posterior parts (Figure 3), and a line drawn parallel to the posterior border of the body of C2 (Figure 4). The rotation values of the C1 and C2 vertebrae were defined between those lines and coronal plane (horizontal image frame). The angles of the C3 and C4 vertebrae were defined using a line drawn from the midpoint of each spinous process to the center of each vertebral body (Figure 5). The sagittal plane (vertical image frame) was used as a reference. Secondly, segmental rotation angles were calculated by subtracting the rotation values of the lower vertebrae from those of the upper vertebrae. Each measurement was taken on two occasions and for analysis and presentation of results, the averaged values of two measurements were used. In addition, the angles of rotation to the left and right at each segment were summed.

To examine inter- and intra-observer variation of the measurement of the segmental rotations and the C4 vertebral rotation, two examiners experienced in the measurement of MRI data were included. The two different examiners, blind to each other's assessment, measured the same series to study inter-observer variation. To investigate intra-observer variation, one of the two examiners measured the images twice on two separate occasions. On the second occasion, the examiner was blind to the results of the first measurement session.

Statistics

A repeated measures ANOVA was used to compare movement patterns of the segmental rotation angles and the C4 vertebral rotations (combined rotation from segments below the C4 vertebra) between the neutral position and the flexed position. The Shapiro-Wilk's test was used to examine for normal distribution of data and post-hoc analysis employed paired t-tests and/or Mann-Whitney U tests to examine mean differences of segmental rotations and the C4 vertebral rotations between the two neck starting positions. Statistical analysis was performed using SPSS version 18.0 (SPSS Inc., Tokyo, Japan). Statistical significance was set at $P < 0.05$.

The intraclass correlation coefficients (ICC) were calculated with the use of $ICC_{(1,1)}$ and $ICC_{(2,1)}$ to examine inter- and intra-observer accuracy of MRI data measurements and to estimate the minimum number of measurement repetitions to achieve good measurement repeatability (ICC > 0.8). The standard error of measurement (SEM) of the segmental rotation angles from Occiput-C1 to C3-C4 and C4 rotation was also calculated for each investigator to examine measurement accuracy of MRI data.

Results

The total ranges of head rotation in the neutral and flexed positions were 163.0° ± 8.3° and 88.4° ± 7.6°, respectively. The mean sagittal angles of the cervical spinal column when the head was rotated in the neutral and flexed positions were -3.3°± 3.5° and 52.4°± 10.8°, respectively.

Preparatory analysis confirmed that the data for Occiput-C1, C1-C2, and C3-C4 were normally distributed. Mean segmental rotation angles (left and right summed) at each cervical motion segment in each neck position (neutral and flexion) are presented in Table 1. Notably, the range of rotation at the C1-C2 level was 51.9% of total head rotation in the neutral position and 73.5% of available range in the flexed position. A repeated measures ANOVA revealed an interaction between the two different neck starting positions and segment levels ($P < 0.0001$). Post-hoc analysis revealed that except for the Occiput-C1 segment, there were significant reductions ($P < 0.0001$) in the segmental rotation ranges with the neck in flexion compared with the neutral neck position.

The intra- and inter-observer-ICC and the SEM of the vertebral rotation angles are shown in Table 2. Substantial intra- and inter-observer reliability of the measures was demonstrated and the magnitude of measurement error was low. Based of the results of the $ICC_{(1,1)}$, it was determined that the average value of two measurements, rather than a single measurement, provided higher levels of repeatability (ICC > 0.8).

Discussion

This study supports the validity of the FRT, described by Dvorak et al (1998), as a test which predominately tests rotation of the atlanto-axial joint. In considering the distribution of segmental rotation between the neutral and flexed neck positions, the segmental rotation between the occiput and C1 was negligible in both test positions, which is consistent with the known kinematics of this motion segment (Bogduk and Mercer, 2000). At the atlanto-axial joint, there was a 16.3% reduction in range of rotation in the flexed compared to the neutral position, but this was minimal compared to the reduction which occurred at the other cervical segments: 68.1% at C2-C3, 61.4% at C3-C4 and 76.9% collectively at the cervical segments distal to C4. Thus, flexing the cervical joints and pre-tensioning the posterior cervical articular and other soft tissues in the neck flexion position has an apparent greater effect on the segments distal to C1-C2. The 16.3% reduction in C1-C2 motion measured in this study might reflect changes in tension of the soft tissue structures local to this joint including the alar ligaments and tectorial membrane in the FRT (Crisco et al., 1991; Oda et al., 1992). The C1-C2 segment provided 73.5% of the total rotation in the flexed position. This lends supports to the validity of the FRT as an assessment of predominantly atlanto-axial joint rotation.

To our knowledge this is the first study to measure segmental range of cervical rotation during the FRT. All previous reports that have investigated the FRT have used external measurement devices. In the present study, the total range of head rotation in the FRT position was 88.4° ± 7.6°. Walmsley et al (1996) and Amiri et al (2003) used an external electromagnetic device, the 3Space Tracker system, and reported ranges of 100.8°±12.9° and 81.1°±10.3° respectively for total head rotation in the FRT position. Hall et al (2008b) used a Cervical Range of Motion goniometer and recorded 89° of rotation in the FRT. The small differences between our and other studies likely arise from different measurement methods as well as different FRT procedures (Walmsley et al., 1996; Amiri et al., 2003) but the comparability between the MRI and external measures supports the latter’s use for a clinical evaluation.

MRI is a highly accurate means of measuring rotation range that has been used extensively in other kinematic studies of the cervical spine (Karhu et al., 1999; Gradl et al., 2005; Ishii et al., 2006; Takasaki et al., 2009b). Despite the number of studies to have used MRI to investigate cervical rotation range, ours is the first to report the reliability and measurement error for this technique. We found good levels of inter- and intra-observer reliability for the measurement technique. ICCs were greater than 0.7, with narrow 95% confidence interval values for mean range of rotation. Furthermore the largest standard error of measurement was only 0.4˚. Hence the ranges reported in our study can be interpreted with a reasonable level of confidence.

The present study had two potential limitations. Firstly, the study included only a small number of subjects and all were female (because of the height restriction to fit in the narrow space of the MRI unit), young and healthy without cervical spine disorders. Nevertheless, Walmsley et al (1996) found no significant differences between genders for head rotation from a cervical neutral or maximally flexed position, but there were significant differences with age. Therefore, our angular data cannot be extrapolated to older subjects and further study of this age group is required. The second limitation was that segmental movement of the lower cervical segments was not assessed because of technical limitations. Further studies are required to assess rotation at all cervical segments during the FRT.

Conclusion

MRI is a reliable and accurate method of measuring cervical segmental rotation. Head rotation when the neck is in a flexed position occurs primarily at the atlanto-axial joint whereas rotation is markedly restricted at all other cervical motion segments. These data lend support to the FRT as a valid clinical test of atlanto-axial mobility. There can be some confidence that the predominant location of the restriction is at the atlanto-axial joint when side to side differences of rotation are found in the FRT in the clinical assessment of patients with cervical disorders.

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