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Original Article

# Assessing validity of thoracic spine rotation range of motion measurement methods: comparison of magnetic resonance imaging and clinical measurements

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**Abstract.** [Purpose] This work was designed to establish criteria for assessing common clinical measurement methods for thoracic spinal rotation angles by comparing their results with magnetic resonance imaging measurements. [Participants and Methods] Twenty-six healthy participants underwent thoracic rotation angle assessments using an electronic goniometer in three positions: lumbar-locked, seated, and half-kneeling. We compared these results with measurements obtained by magnetic resonance imaging. [Results] A moderate but significant positive correlation was observed between the thoracic rotation angle measured by magnetic resonance imaging and the lumbar-locked rotation test. The respective 95% confidence intervals of these correlation coefficients were 0.09 and 0.72. Bland–Altman analysis revealed a fixed error in the lumbar-locked rotation test, suggesting that the test tended to overestimate thoracic rotation compared with magnetic resonance imaging, but proportional errors could not be definitively identified. [Conclusions] Thoracic spine rotation angles measured using magnetic resonance imaging aligned closely with previously reported results. Notably, although measurements obtained by the lumbar-locked rotation test correlated with magnetic resonance imaging results, they exhibited fixation errors. Functional tests (seated and half-kneeling) showed limited correlations with magnetic resonance imaging results. The influence of adjacent joints on clinical measurements should be considered.

**Key words:** Range of motion, Thoracic spine, Validity

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## INTRODUCTION

The thoracic spine possesses a distinct shape, featuring ribs that serve as protective shields for vital organs, such as the lungs and heart[1, 2)]. This spinal region is less mobile than other spinal segments, such as the cervical and lumbar spines[2, 3)]. Reduced mobility in a specific spinal column segment could increase the range of motion (ROM) in adjacent parts, causing pain and instability[4, 5)].

Therefore, understanding that this restricted ROM in the thoracic spine can serve as a compensatory mechanism is essential. In addition, this compensatory mechanism influences the shoulder joints[6)]. When the thoracic spine has limited rotational ROM, substantial movement from the scapulothoracic and glenohumeral joints is required, causing muscle and strength imbalances and an elevated risk of injury[7)]. Furthermore, there are documented cases of thoracic spine hypomobility contributing to neck symptoms[8, 9)] and low back pain[10)]. These findings emphasise the interconnectedness of spinal health and potential ripple effects throughout the musculoskeletal system. Similarly, changes in pain and ROM in the lumbar spine are reportedly a consequence of interventions in the thoracic spine[11)].

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ROM measurements are commonly used in clinical practice to evaluate joint mobility. However, assessing the ROM of the thoracic spine, which comprises multiple segments, is challenging[12, 13)]. Consequently, various measurement methods have been used to quantify the ROM of the thoracic spine. In addition to goniometers and inclinometers, tape measures are used to assess flexion-extension and lateral flexion of this complex spinal region[13–15)].

Studies have confirmed the inter- and intra-examiner reliability of measurement methods for thoracic spine rotation[13, 16, 17)]; however, whether the measured angles accurately reflect the degree of thoracic spine rotation remains unconfirmed. Many measurement methods may provide the ROM for the lumbar and thoracic spines. The joint ROM measurement method recommended by the Japanese Orthopaedic Association and the Japanese Association of Rehabilitation Medicine involves assessing the ROM of thoracolumbar rotation, which is evaluated with lumbar rotation. In addition, the Selective Functional Movement Assessment process requires that the range of trunk rotation measured in the lumbar-locked position be greater than 50° to consider whether thoracic rotation movements are functional. If the measurement is not greater than 50°, it is considered a functional impairment[18)]. However, the validity of the 50° thoracic rotation criterion remains unproven[19)].

Consequently, whether thoracic spine rotation measurements commonly used in clinical practice reflect the pure movement of the thoracic spine remains uncertain. Since evidence-based practices are currently needed in physiotherapy, establishing an assessment method that can be feasibly implemented in clinical settings within limited time constraints is crucial.

This study aimed to investigate the criterion-related validity (comorbid validity) of joint mobility measurements of thoracic spine rotation angles. This study aimed to investigate the criterion-related validity (comorbid validity) of joint mobility measurements of thoracic spine rotation angles. Hypothesis of this study, clinical tests reflecting the thoracic spine range of motion can be confirmed by comparing the rotation angles obtained from thoracic spine joint mobility tests commonly used in clinical practice with those derived from magnetic resonance imaging (MRI), which is considered the gold standard for such measurements.

## PARTICIPANTS AND METHODS

Twenty-six healthy volunteers (12 males and 16 females) participated in the study. The required sample size was calculated as N=26 using G*Power (Heinrich Heine University, Düsseldorf, Germany), with effect sizes of d=0.5, alpha=0.05, and power=0.80. Participants were healthy adults recruited by using posters at a university. The inclusion criteria for this study were a participant age of over 18 years, absence of thoracic spine injury within the last six months. The exclusion criteria encompassed individuals with spinal injuries or diseases, those incapable of spine rotation, those with metal implants, and those with claustrophobia. The study was approved by the Tokyo Metropolitan University Arakawa Campus Research Safety Ethical Review committee (No.22007), and all participants provided informed consent by completing a consent form.

For thoracic rotation angle measurements using MRI, markers were affixed to the first and twelfth thoracic vertebrae of the participants. These individuals were positioned on their sides within a gantry. T2-weighted images of the thoracolumbar spine were captured, starting from a 0° thoracic flexion-extension position and passively positioning the maximum rotation of the thoracolumbar spine. The participants' limbs were secured using fixation bands, towels, and pelvic and hip immobilization devices to ensure immobilization (Fig. 1).

Furthermore, the acquired images were processed into axial images, following the curvature of the thoracic spine (curved multiplanar reconstruction [MPR]) and allowing for the observation of transverse sections of each vertebra. These images were loaded into OsiriX Ver13.0. (Newton Graphics, Inc., Sapporo, Japan) to retrieve superior transverse plane images of each vertebral body. MRI scans were conducted using an Achieva 3.0T system (GE Healthcare, Tokyo, Japan), supervised by a collaborator. Approximately 47 horizontal slices were obtained using T2-weighting, with the following specific parameters: imaging field of view, 200 mm; slice thickness, 4.0 mm; and scan time, 3 min 47 s. Before scanning, precautions were taken to ensure that trunk flexion and lateral bending compensation were not introduced. Subsequently, a slice image displaying the spinous process of each vertebral body was extracted using the DICOM Viewer OsiriX (Newton Graphics Ltd).

**Fig. 1.** Thoracic rotation angle measurement using magnetic resonance imaging.

According to previous research, the rotation angle was defined as the angle formed by the intersection of a line connecting the centers of the vertebral body and the spinous process with a vertical line[20)]. This measurement is deemed reliable. The lumbar rotation angle between adjacent vertebrae was determined as the difference between the rotation angles of the upper and lower spines. Finally, ImageJ (NIH, Bethesda, MD, USA) was used to analyze the extracted images and calculate the angles spanning from T1/2 to T11/12 (Fig. 2).

For the lumbar-locked rotation test, we followed the method described by Johnson et al. The intraclass correlation coefficient (ICC) values for the within-day intratester reliability (ICC [1,3]) of this test were between 0.81 and 0.94[17)]. This indicates that the lumbar-locked rotation test is a consistent and reliable measurement test. The participants were placed in a quadruped position (Fig. 3A). This limb posture ensures maximum flexion of the hips and lumbar spine, restricting the movement of the pelvic and lumbar spines during thoracic rotation.

Examiner A placed an electronic goniometer between the scapular spines at the TI–T2 level (Fig. 3B). The participant positioned their hand in the direction of rotation on the posterior side of the neck and rotated the thoracic spine while keeping the knees and lumbar spine flexed. Once the participant reached the final ROM, Examiner B rotated and stabilized the trunk, passively preventing compensatory motion. Examiner A saved the measurements by pressing the main button on the electronic goniometer, and Examiner B recorded the measurements. This sequence of measurements was repeated for three right rotations.

For the seated rotation test, we followed the method described by Johnson et al. The ICC values for the within-day intratester reliability (ICC [1,3]) of this test were between 0.76 and 0.93[17)].

The participants were seated in a 90° hip-knee flexion position with a ball between their legs. This position minimizes the pelvic and lumbar movements during thoracic spine rotation. The upper limb position was marked with a tape in the middle of the bar, and the participants were instructed to cross their arms at that point (Fig. 4A).

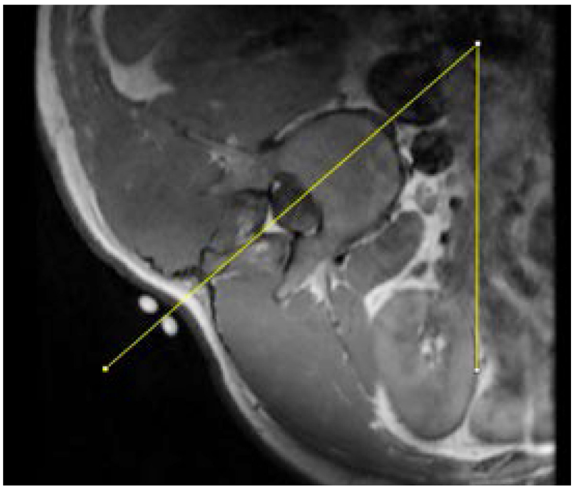

**Fig. 2.** Thoracic rotation angle. The angle was defined as the angle formed by the intersection of a line connecting the centers of the vertebral body and the spinous process with a vertical line.

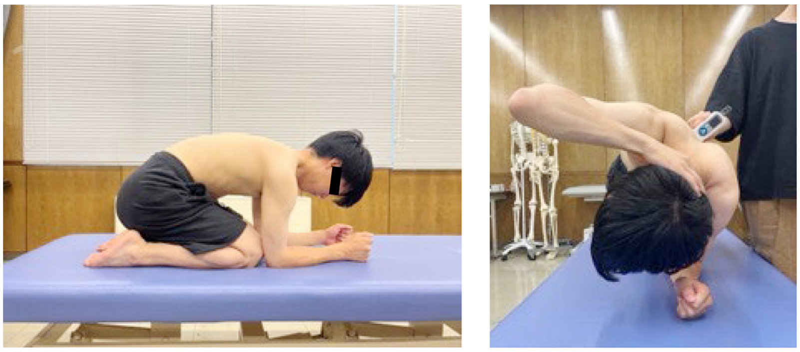

Fig. 3A Fig. 3B

**Fig. 3.** Lumbar-locked rotation test. A: Starting position, B: Right rotation.

Examiner A placed an electronic goniometer between the scapular spines at the TI–T2 level. The participant was instructed to rotate the thoracic spine while ensuring that the bar remained parallel to the floor (Fig. 4B). When the participant reached the final ROM, Examiner B rotated and passively stabilized the trunk to prevent compensatory motion. Examiners A and B recorded the measurements by pressing the main button on the electronic goniometer. This sequence of measurements was repeated three times.

For the half-kneeling rotation test, we followed the method described by Johnson et al. The ICC values for the within-day intratester reliability (ICC [1,3]) of this test were between 0.86 and 0.96[17]. The participants were positioned in a half-kneeling (lunge) stance, as illustrated in Fig. 5A. The placement of the bar at the front and the alignment and measurement methods using the goniometer mirrored those used in the seated rotation test. The rotation direction was right, with the right leg positioned forward in the lunge (Fig. 5B). Three measurements were taken for the right rotations.

To assess the relationship between thoracic rotation angles measured using MRI and those measured using an electronic goniometer, we calculated Pearson's correlation coefficients. Subsequently, we used Bland–Altman analysis to evaluate the agreement between the two measurement methods. IBM SPSS version 29 (IBM, Armonk, NY, USA) was used for the statistical analysis.

## RESULTS

Table 1 shows the results of right thoracic spine rotation ROM.

The mean age, height, and weight of the 26 participants were 24.4 (range, 21–39) years, 163.2 (range, 149–180) cm, and 57.3 (range, 45–85) kg, respectively. The Shapiro–Wilk test results indicated that for all items, p was ≥0.05, suggesting that they followed a normal distribution. Consequently, Spearman's rank correlation coefficients were calculated. The correlation coefficients for these items and others are listed in Table 2.

Fig. 4A Fig. 4B

**Fig. 4.** Seated rotation test. A: Starting position, B: Electronic goniometer placement during right rotation.

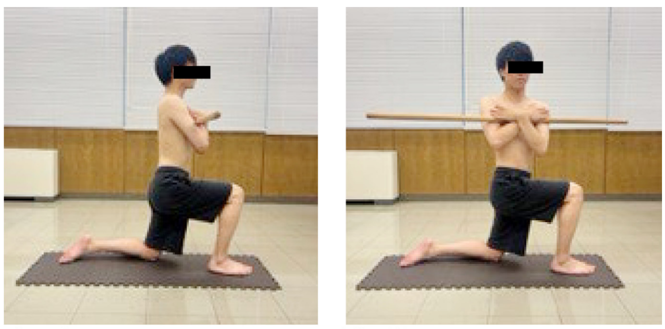

Fig. 5A Fig. 5B

**Fig. 5.** Half-kneeling rotation test. A: Starting position, B: Right rotation toward the forward leg.

There was a significant and moderately positive correlation, at $p<0.05$, between the thoracic rotation angle measured using MRI and the lumbar-locked rotation test (95% confidence intervals: 0.09, 0.72).

Bland–Altman analysis was used for correlated items to assess the agreement between the two measurement methods. The analysis was conducted by initially constructing a Bland–Altman plot, with the difference between the two measurements (d) represented on the y-axis and the mean of the two measurements on the x-axis (Fig. 6). Given that chance errors are random and follow a normal distribution pattern, the limits of agreement (LOA) for errors in both measurement methods were determined. LOA are calculated as 'mean of the difference ± 1.96 × standard deviation of the difference', representing the range within which differences between the two measurements are considered acceptable errors. If the errors adhere to a normal distribution, 95% fall within this range. The LOA result was 14.77° (LOA −5.48°, +9.29°). Consequently, if the difference between two measurements falls within these limits, the two measurement methods are deemed equivalent (concordant). Fixed errors were assessed using t-tests, whereas proportional errors were examined using regression analysis.

Figure 6 shows that when systematic errors with a fixed component were present, the distribution displayed a negative bias away from the x-axis, suggesting that fixed errors exist. Fixed error assessment via the t-test yielded a significant difference, with a significance probability of $p=0.001$ ($p<0.05$). However, the 95% confidence interval for the difference ranged from −8.53 to −2.44, with the interval excluding 0, indicating the presence of a fixed error in the negative direction. Conversely, it was suggested that the results of the lumbar-locked rotation test were larger than those of the MRI.

Regarding verifying the proportional errors through regression analysis, the significance probability was $p=0.348$, suggesting insignificant differences. As the regression coefficient incorporated into the regression equation could not be ruled out as zero, it was concluded that a proportional error could not be definitively identified.

**Table 1.** Right thoracic spine rotation range of motion

| Measurement methods | Mean ± SD |
|---|---|
| MRI (°) | 29.91 ± 6.57 |
| Lumbar-locked rotation test (°) | 35.40 ± 7.81 |
| Seated rotation test (°) | 42.13 ± 12.05 |
| Half-kneeling rotation test (°) | 50.83 ± 11.85 |

SD: standard deviation; MRI: magnetic resonance imaging.

**Table 2.** Correlation coefficients for correlations with MRI measurements

| | Lumbar-locked rotation test | Seated rotation test | Half-kneeling rotation test |
|---|---|---|---|
| MRI | 0.461* | 0.348 | 0.309 |

*p<0.05
MRI: magnetic resonance imaging.

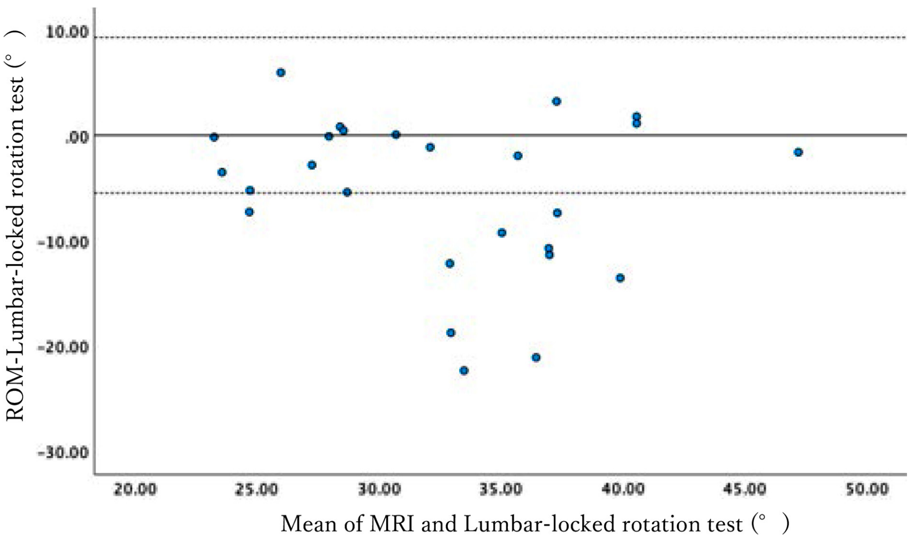


**Fig. 6.** Bland–Altman plot.
ROM: range of motion; MRI: magnetic resonance imaging.

## DISCUSSION

The thoracic spine rotation angle was measured using MRI and was found to be 29.91 ± 6.57°. This value is closely consistent with those in previous studies, and similar results have been reported for *in vivo* and *in vitro* studies. For example, Fujimori et al.[21] reported a unidirectional thoracic spine rotation angle of 24.9 ± 4.9° using 3D computed tomography. Similarly, Liebsch and Wilke[22] studied eight fresh human thoracic spine samples and reported an axial rotation angle of 28.8° (23.9, 45.0) for T1–12, presented as [median (min, max)].

A study by White and Panjabi[23] is typically cited for thoracic spine rotation and segment-specific angles; a comparison with our study revealed significantly larger values. In their systematic review of the thoracic spine joint ROM, Borkowski et al.[12] noted that the estimated ROM for axial rotation (left and right) was 45° in their study. In contrast, White and Panjabi[23] reported a ROM of 108°–198°. Studies reporting smaller values may have been based on newer equipment or more recent findings. Therefore, our results could likely provide a more accurate reflection of thoracic spine ROM.

Although the MRI-measured and lumbar-locked rotation test values correlated, the Bland–Altman analysis revealed a fixation error. This analytical approach indicates that a high correlation does not necessarily imply perfect agreement between the two methods[24]. The t-test and Bland–Altman plot results suggest that the values obtained from the lumbar-locked rotation test tend to be higher than those obtained from MRI. Hence, to accurately assess the ROM of the thoracic spine, considering the influence of adjacent joints (e.g., scapulothoracic, lumbar, and hip joints) is essential. The lumbar measurements yielded smaller values than those obtained in previous studies. Common compensatory movements include trunk extension, pelvic side shifts, and horizontal abduction of the shoulder joint[25]. The examiners performed passive measurements to minimize changes in trunk extension and hip flexion angles. However, the horizontal abduction of the shoulder joint and scapular abduction movements may increase the rotation angle. In this limb position, fixating the scapula and elbow is challenging, which could contribute to larger values than those of MRI.

However, as the correlation coefficients for correlations with the angles measured on MRI were statistically significant, the lumbar-locked rotation test may be more suitable in clinical practice. Two potential reasons for the inadequately confirmed correlation between the seated and half-kneeling rotation tests and MRI measurements are as follows. First, the correlation coefficients for the seated and half-kneeling rotation tests were statistically insignificant. Second, the seated rotation test required the participants to use a ball between their legs to stabilize their posture, and the half-kneeling posture may have complicated balance maintenance in some participants. It is possible that the participants encountered challenges in performing thoracic spine rotation while simultaneously maintaining balance and stabilizing the lumbar spine.

Furthermore, we used established MRI measurements for the cervical spine; however, the validity of these measures for the thoracic spine remains uninvestigated. Although MRI effectively captures the thoracic spine angles, the clinical measurement method does not account for the potential influence of other joints on thoracic spine motion. Notably, shoulder joint and girdle movements may affect the thoracic spine measurements, and strategies for minimizing these compensatory movements should be explored.

However, the significance of this study lies in establishing a method for measuring thoracic spine rotation ROM. This method facilitates data collection regarding thoracic spine rotation angles in future studies. Furthermore, it serves as a valuable outcome measure in investigations aimed at identifying effective treatments and exercises to enhance thoracic spinal mobility, contributing to evidence accumulation in the field of physiotherapy.

We measured the thoracic spine rotation angles using MRI, closely aligning with previous studies. Notably, the lumbar-locked rotation test results, although correlated with MRI measurements, exhibited fixation errors. Functional tests (seated and half-kneeling) showed limited correlations with MRI. The influence of the adjacent joints should be considered. While our study facilitates the understanding of thoracic spine mobility, further research is needed to refine the measurement techniques for clinical use, acknowledging potential compensatory movements and joint influences.


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### *Conflict of interest*

None.

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