Clinical and Radiological Investigation of Thoracic Spine Extension Motion During Bilateral Arm Elevation

Clinical examination of patients who present with mechanical shoulder pain often includes assessment of the posture and mobility of the shoulder girdle and the thoracic spine.\(^1,3\) Thoracic spine extension motion is considered important for normal shoulder girdle function,\(^3\) and an impairment of this movement may contribute to the development of subacromial impingement and shoulder pain.\(^3\) Constraining thoracic extension motion through posture modification has been shown to reduce the available range of arm elevation in asymptomatic individuals.\(^4\) Conversely, facilitating extension motion in the thoracic spine may increase the acromiohumeral distance and range of arm elevation, and delay the onset of pain, in patients with subacromial impingement disorders.\(^1,3,15\) Short- and long-term benefits of thoracic spine manipulation have been described for the management of patients with shoulder impingement disorders.\(^2,6\) This suggests that impairments of thoracic spine mobility may have an adverse impact on shoulder girdle function. Though changes in thoracic spine mobility in response to manipulation treatment were not reported in those studies, it may be assumed that the positive treatment outcome was, in part, due to improvement in the sagittal plane mobility of the thoracic spine during arm movement.

An understanding of the role of thoracic spine motion during arm elevation requires knowledge of the expected range of movement and the factors that may contribute to variability in this movement among individuals. Movement of the thoracic spine during unilateral and bilateral arm elevation has been examined in a number of studies, the results of which are summarized in Table 1. Previous studies\(^6,7,28,32\) have only examined female par...
participants, across which there have been consistent results in relation to the mean range of thoracic extension motion. Variability within each study cohort might have been due to differences in the age of the participants or to the inherent differences in spinal mobility among individuals. In young, asymptomatic individuals, the total range of thoracic spine extension motion has been reported to be between 2° and 19°, with slightly greater mobility in men.10 The magnitude of the thoracic kyphosis present in neutral standing has been shown to correlate with the magnitude of the kyphosis measured in the extreme of thoracic spine extension.10 Therefore, the sagittal curvature of that region of the spine may influence the capacity for thoracic spine extension motion. This influence may also explain the decrease in thoracic spine extension mobility that has been reported in asymptomatic individuals older than 60 years,11,22 as the magnitude of the thoracic kyphosis tends to increase with age.11

A variety of external measurement systems have been used to measure thoracic extension motion, including inclinometers, kypometers, electrogoniometers, ultrasound topometry, and 3-D motion analysis systems.11,23,24,31,24 Recent studies have used 2-D photographic image analysis, which may be a method of spinal analysis suited to both research and clinical practice.15,28 Photographic analysis is quick, inexpensive, and has been shown to have good reliability for the analysis of thoracolumbar sagittal mobility.5,26 However, to our knowledge, the validity of external measurement systems of thoracic spine posture and movement, including photographic measurement, by comparison with radiographic analysis, has not been reported. Functional radiography has been used to examine sagittal mobility in the cervical and lumbar regions but has not been described in the thoracic region.23,27 External measurements of thoracic kyphosis using an electrogoniometer have been shown to be strongly correlated (r = 0.81) with Cobb angle measurements from thoracic spine radiographs.24

The primary objective of this study was to measure thoracic spine extension motion during bilateral arm elevation in asymptomatic male subjects using functional radiographic analysis. Secondary objectives were to examine the validity of photographic measurements of thoracic extension motion through comparison with the radiological measurements, and to examine the relationship between the amount of thoracic kyphosis measured in neutral posture and in full arm elevation.

**METHODS**

Twelve asymptomatic male participants were recruited through poster advertising at Curtin University in Western Australia. The mean ± SD (range) age, height, and weight were 22.6 ± 3.2 (18-28) years, 177 ± 7.0 (163-190) cm, and 72.6 ± 8.1 (57-85) kg, respectively. The age range of participants was restricted within 18 to 30 years to limit the influence of age-related changes on spinal morphology and thoracic mobility. The exclusion criteria were the presence of a visible thoracolumbar scoliosis, Scheuermann disease, a history of spinal or shoulder pain in the previous 3 months, a body mass index of greater than 25 kg/m², radiographic or computerized tomography scan examination of the spine in the previous 12 months, and chronic respiratory disorders. All participants were provided with information explaining the study procedures, including the requirement for radiographic imaging and related radiation exposure. Signed informed consent was obtained prior to testing. Approval for the study was granted by the Radiation Safety Committee and the Human Research Ethics Committee of Curtin University.

Pyramidal reflective markers (height, 40 mm; base, 15 × 15 mm) containing 5-mm ball bearings in the base were fixed over the spinous processes of T1, T4, T8, and T12, using nonallergenic tape. To minimize the potential source of error in measurement of spinal movement with skin markers, 1 experienced physical therapist identified the relevant spinous processes on all participants. The spinous processes were identified through surface palpation, using scapula landmarks as a reference.5 A second investigator confirmed the marker location using the similar anatomical landmarks, prior to adhering the markers to the skin.

**TABLE 1**

**Summary of Studies That Have Examined Movement of the Thoracic Spine During Arm Elevation**

<table>
<thead>
<tr>
<th>Author</th>
<th>Subjects</th>
<th>Measurement Technique</th>
<th>Method*</th>
<th>Thoracic Spine Extension Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crawford and Jul†</td>
<td>Females; age, 18-30 y; n = 30</td>
<td>Myrin goniometer</td>
<td>Bilateral</td>
<td>Total: 15° ± 8†</td>
</tr>
<tr>
<td></td>
<td>Females; age, 19-74 y; n = 30</td>
<td>Myrin goniometer</td>
<td>Bilateral</td>
<td>Total: 13° ± 8†</td>
</tr>
<tr>
<td>Stewart et al‡</td>
<td>Females; age, 18-33 y; n = 20</td>
<td>FASTRAK 3-D motion analysis</td>
<td>Unilateral</td>
<td>Upper (T1-5), 3.1° ± 2.3°; lower (T7-12), 5.8° ± 3.2°‡</td>
</tr>
<tr>
<td>Theodoridis and Ruston‡</td>
<td>Females; age, 45-64 y; n = 25</td>
<td>FASTRAK 3-D motion analysis</td>
<td>Unilateral</td>
<td>Upper (T2-7), 4.0° ± 1.5†</td>
</tr>
<tr>
<td>Crosbie et al†</td>
<td>Females; age, 19-74 y; n = 32</td>
<td>Motion Star 3-D motion analysis</td>
<td>Unilateral</td>
<td>Upper (T1-5), 2° (1°-3°); lower (T7-12), 6° (4°-8)‡</td>
</tr>
<tr>
<td></td>
<td>Females; age, 19-74 y; n = 32</td>
<td>Motion Star 3-D motion analysis</td>
<td>Bilateral</td>
<td>Upper (T1-5): 3° (2°-5°); lower (T7-12): 5° (7°-12)‡</td>
</tr>
</tbody>
</table>

*Unilateral or bilateral arm elevation. †Values are mean ± SD. ‡Values are mean (range).
A spherical reflective marker (10 mm in diameter) was placed over the lateral epicondyle of the right humerus.

Prior to image acquisition, each participant was shown the required neutral standing position and the position of full bilateral arm elevation. To achieve the neutral starting position, the participant stood with the hands at the level of the navel, holding a midline support. The participant then reached forward, with the arms straight, to obtain a protracted shoulder position (approximately 30° of shoulder elevation) (FIGURE 1A). To achieve full arm elevation, participants were then asked to lift the arms as high as possible in the sagittal plane, until a comfortable end-range position was achieved (FIGURE 1B). One investigator provided the instructions and movement guidance to all participants to ensure consistent performance of movements for both the photographic and radiographic imaging procedures. For the photographic analysis, a digital camera (Tough with 5× optical zoom; Olympus Imaging Australia Pty Ltd, Macquarie Park, Australia) was mounted on a tripod 2.5 m from the participant, and photographs (2592 × 1944 pixels) were taken in the neutral and fully elevated arm positions. For all participants, the photographic images were obtained first, followed immediately by radiographic image acquisition.

All thoracic spine radiographs were conducted in the Department of Imaging and Applied Physics of Curtin University. Radiographic exposure settings and X-ray beam collimation and filtration were in accordance with best-practice principles. Prior to performing the lateral thoracic spine radiographs, the participant was fitted with lead aprons around the pelvic girdle. Each participant stood with the left side immediately adjacent to a radiographic Bucky device (with a 35 × 43-cm portrait-orientated computed radiography cassette enclosed). The X-ray beam was centered on T7, and a standard focal film distance of 100 cm was used for all radiographs. Collimation was restricted to the skin edges posteriorly and was no larger than 13 to 15 cm in diameter (depending on the subject’s size). The subject was asked to remain still and hold the breath at end expiration while the radiographic image was obtained. One lateral thoracic radiograph was obtained in the neutral standing posture (starting position) and 1 in the fully elevated shoulder posture (end position).

To minimize the radiation exposure risk, preliminary phantom studies were conducted to optimize the minimum radiation dose required to obtain an image of acceptable spatial resolution and quality for the motion analysis. The X-ray exposure parameters were 1.6 mAs and 70 kVp, and effective radiation dose was estimated to be 0.2 mSv. The imaging protocol was approved by the institutional Radiation Safety Committee.

Photographic image analysis was performed on a personal computer using ImageJ software (National Institutes of Health, Bethesda, MD). To calculate the thoracic angle (kyphosis) in the neutral and fully elevated positions, lines were drawn through the T1 and T4 markers.
and through the T8 and T12 markers. The angle formed by the intersection of these lines was used to define the thoracic angle (FIGURE 2B). To measure upper and lower thoracic movement, 2 additional angles were calculated: the upper thoracic angle formed by the intersection of lines connecting the T1 to T4 and the T4 to T8 markers, and the lower thoracic angle formed by the intersection of lines connecting the T4 to T8 and the T8 to T12 markers (FIGURE 2B). The difference in thoracic kyphosis angle obtained in neutral and fully elevated arm positions was used to define the range of thoracic extension (in degrees). The position of the arms in full shoulder elevation was defined by the intersection of a line connecting the lateral epicondyle marker and the base of the T1 marker, and by a vertical reference line (FIGURE 2C).

The radiographic images obtained in the neutral and full arm elevation positions were also imported into a personal computer and analyzed using ImageJ software (National Institutes of Health). Adjustment of the image brightness and contrast was performed as required to obtain optimal visualization of the vertebral body boundaries. The thoracic angle in each position was determined using the vertebral centroid angle technique.3 To obtain this measurement, a vertebral centroid angle was determined by measuring the intersection angle of 2 lines, each of which passed through a pair of contiguous vertebral centroid points within selected vertebral bodies. Vertebral centroids used to define the global kyphosis were located in the vertebral bodies of T3 and T4 superiorly, and T10 and T11 inferiorly. To locate the vertebral centroid, the vertebral body corners were marked as reference points. The point of intersection of diagonal lines connecting the corner reference points was defined as the vertebral centroid.3 For the radiographic analyses, the thoracic angle was measured with subjects in the neutral and fully elevated arm positions (FIGURES 3A and 3B). The difference between these 2 thoracic kyphosis angles was used to define the range of thoracic extension motion. We were not able to consistently visualize thoracic vertebral bodies above T3 and below T11 in the radiographs of all participants. Consequently, we chose to standardize the analysis of thoracic kyphosis by performing this analysis between T3 and T11 for all participants.

Prior to testing, a pilot study was completed to examine the variability in thoracic kyphosis angle for the neutral and fully elevated arm positions when these were performed repeatedly by the same participant. Photographic analysis of 5 participants in the neutral and end-range positions was repeated 5 times within a single session. The participants were required to move and then to resume the required position prior to each image acquisition. For repeated analysis of the same photographic image, the coefficients of variation ranged from 0.60% to 1.80% and 0.60% to 1.90%, with standard errors of measurement of 0.4° to 1.3° and 0.4° to 1.5°, for thoracic kyphosis measured in the neutral posture and in full arm elevation, respectively. The intraexaminer reliability for the radiographic image analysis was examined through 5 repeated measurements of 5 neutral and 5 end-range radiographs by a single examiner. For repeated analysis of the same radiographic image, the coefficients of variation were 6.10% and 8.60%, with standard errors of measurement of 0.7° and 0.6°, for thoracic kyphosis measured in the neutral posture and in full arm elevation, respectively.

Statistical Analysis
For the photographic and radiographic data, descriptive statistics were calculated...
for the thoracic kyphosis angle in neutral posture and in end-range shoulder elevation, and for the range of thoracic extension associated with end-range shoulder elevation. Descriptive statistics for the regional ranges of motion were calculated for the photographic measurements. Linear regression analysis was then used to examine the relationship between radiographic and photographic measures of thoracic kyphosis (angle) in neutral posture and in end-range arm elevation. Bland-Altman plots were used to examine the extent of agreement, the amount of random error, and any systematic bias between the 2 measurement techniques. To interpret the difference between measurement techniques, the 95% limits of agreement were determined by calculating the mean and standard deviation of the difference. The relationship between the magnitude of the thoracic kyphosis in neutral posture and the thoracic kyphosis in end-range arm elevation was also examined using linear regression analysis. For all statistical analyses, the criterion for statistical significance was set at \( P < .05 \).

RESULTS

The mean ± SD amount of arm elevation measured from the photographic images was 156.3° ± 8.7°. The amount of thoracic kyphosis measured in both the neutral and full arm elevation positions is summarized in **TABLE 2**. The mean ± SD change in thoracic kyphosis associated with full arm elevation was 12.8° ± 7.6° and 10.5° ± 4.4°, as measured from the radiographs and photographs, respectively. Among all subjects, the change in thoracic kyphosis with arm elevation varied from 0° to 26° when measured from the spinal radiographs. There was a significant correlation between the thoracic kyphosis angles obtained from the 2 measurement techniques for both the neutral \( (r = 0.79, P < .001) \) and full arm elevation \( (r = 0.79, P < .001) \) postures (**FIGURE 4**). Bland-Altman analysis showed mean differences between measurement techniques being close to zero for both postures (**FIGURE 5**). The mean difference between measurements (95% limits of agreement) was –2.8° (–19.6°, 13.9°) for the kyphosis measured in neutral posture and –0.5° (–11.6°, 10.5°) for the kyphosis measured in full arm elevation. Differences between measurement methods appeared random, with no evidence of a systematic bias (one method giving consistently higher or lower measurements).

Regional changes in thoracic kyphosis measured from the photographs demonstrated greater mean ± SD movement toward thoracic extension in the lower thoracic region \( (7.0° ± 3.2°) \) than in the upper thoracic region \( (3.7° ± 2.3°) \) when the arms were fully elevated (**TABLE 3**).

There was a significant correlation between the magnitude of the thoracic kyphosis measured in neutral posture and that measured at end-range bilateral arm elevation with radiographs \( (r = 0.80, P < .001) \) and with photographs \( (r = 0.84, P < .001) \) (**FIGURE 6**).

**DISCUSSION**

Radiological analysis is considered the gold standard for measuring spinal posture and movement. This is the first study to use functional radiography to examine the extension motion of the thoracic spine associated...
Photographic Measures of Regional Thoracic Extension Motion (n = 21)

<table>
<thead>
<tr>
<th>Region</th>
<th>Outcomes*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper thoracic</td>
<td>37 ± 2.3 (-4.7-77)</td>
</tr>
<tr>
<td>Lower thoracic</td>
<td>70 ± 3.2 (18-141)</td>
</tr>
<tr>
<td>Total</td>
<td>10.5 ± 4.4 (2.7-16.8)</td>
</tr>
</tbody>
</table>

*Values are mean ± SD (range) degrees.

TABLE 3

with bilateral arm elevation. The results confirm that motion of the thoracic spine does occur during arm elevation in standing, and that the amount of movement is variable in young, asymptomatic men. The mean ranges of thoracic spine extension of 12.8° and 10.5° measured from the spinal radiographs and photographs, respectively, are similar to the data of previous studies performed on women using external measurement systems. In young, asymptomatic women, thoracic spine extension motion of 15° during bilateral arm elevation was measured using inclinometers. Similarly, Crosbie and colleagues reported a mean range of thoracic spine extension of 12° during bilateral arm elevation in asymptomatic women using 3-D motion analysis. Together with the results of the present study, these findings support the concept of examination of thoracic spine extension motion in patients who present with shoulder pain, particularly when the pain is provoked by arm elevation movement.

Within the homogeneous group of participants in the present study, the amount of thoracic extension motion associated with arm elevation was highly variable. This is consistent with previous studies reporting spinal mobility in asymptomatic adults, including mobility of the thoracic spine. Because all participants in the present study were young, asymptomatic men who received identical instructions during the measurement procedure, the variability in thoracic extension motion between subjects cannot be explained by pain or age-related changes in spinal morphology. Rather, the variability between individuals could be due to differences in motion segment morphology and stiffness characteristics, or to differences in spinal curvature or regional movement patterns. Lifestyle factors such as occupation or participation in sport and physical activity may also influence posture and mobility of the thoracic spine. Consideration of individual differences in thoracic extension motion during arm elevation and of factors that may contribute to these differences is important in the interpretation of clinical assessments of shoulder and spinal mobility.

In asymptomatic women, Crawford and Jull described extension motion of the thoracic spine associated with bilateral arm elevation as being 50% of the available range of thoracic motion. However, the mean thoracic extension motion associated with full bilateral arm elevation identified in the present study (radiographs, 12.8°; photographs, 10.5°) is similar to the total range of thoracic extension motion previously reported in young, asymptomatic men (mean, 11.3°). These contrasting results are probably explained by differences in measurement technique, as gender differences in thoracic spine extension mobility are typically small. Consequentially, bilateral end-range arm elevation appears to require close to the full available range of extension motion in the thoracic spine when the movement is performed in standing. The requirement of optimal thoracic spine extension to achieve full-range arm elevation has been demonstrated through thoracic posture modification in patients with subacromial impingement pain. Minor impairments of thoracic spine extension mobility may have a negative impact on shoulder girdle mechanics and may contribute to the development of subacromial impingement disorders. Conversely, spinal manipulation and exercises that promote thoracic mobility have been shown to decrease pain and improve mobility in patients with subacromial impingement disorders.

A significant correlation between the magnitude of the thoracic kyphosis measured in a neutral standing posture and kyphosis in full arm elevation was identified with both the radiographic and photographic analyses. Individuals with a more kyphotic thoracic spine in normal neutral standing were more likely to have a more flexed thoracic spine in full arm elevation than those who were less kyphotic. Interpretation of clinical observations of the thoracic spine kyphosis in full arm elevation should account for the spinal posture from which the movement is initiated. These findings suggest that...
the “extreme of motion”4 of the thoracic spine in full arm elevation may be attributed in part to the magnitude of the thoracic kyphosis when standing in a relaxed posture. Because a more extended end-range position of the thoracic spine will enhance arm elevation,4 evaluation of the extreme-range position of the thoracic spine in this position appears to be more clinically relevant than an evaluation of the range of motion.

Photographic analysis has been used in clinical research to measure sagittal posture and mobility of the thoracic spine.5,6,12 However, the extent to which these external measurements reflect the true movement of the spine is not known. The validity of external measurement systems for the measurement of sagittal spinal motion has been tested through comparisons with radiographic measurements in the lumbar spine and cervical spine.25,37 In the present study, a method of functional radiography was used to examine the validity of photographic analysis of thoracic kyphosis in neutral posture and in end-range arm elevation. There was a moderate correlation and no evidence of a systematic difference between the radiological and photographic measurements of thoracic kyphosis in both postures. In previous studies,27 lumbar spine extension measured using an inclinometer has been shown to correlate moderately \((r = 0.75)\) with the extension range measured from functional radiographs. The findings of the present study support the use of photographic analysis of surface markers as a valid method of measuring thoracic spine motion during arm elevation. Future applications of this method may include evaluation of changes in thoracic spine posture and mobility response to physical treatment. Evaluation of medical disorders affecting the spine, such as osteoporosis and ankylosing spondylitis, and monitoring spinal mobility following surgery may also be applications of the photographic analysis technique evaluated in this study.

Specific regional differences in thoracic extension motion associated with full bilateral arm elevation were identified from the photographic analysis in the present study. On average, extension motion was greater in the lower thoracic region \((7.0^\circ)\) than in the upper thoracic region \((3.7^\circ)\). This finding is consistent with results from previous studies that have examined regional differences in thoracic spine movement during arm elevation in asymptomatic women (TABLE 1). The lower thoracic region appears to provide the majority of the spinal contribution to arm elevation, and changes in spinal function that result in an impairment of motion in this region may impact the normal mechanics of the shoulder girdle. These findings support the routine examination of total and regional thoracic spine extension motion in patients with shoulder pain and limited arm elevation.

Inherent errors in both methods of measurement make high levels of agreement unlikely. Although the number of participants examined in this study was relatively small, it was adequate to show significant correlations between variables. Given the requirement for exposure of asymptomatic individuals to ionizing radiation, it was considered appropriate to limit the number of participants recruited to the study to the minimum required to address the research objectives. However, the participants appear to be representative of the normal population of individuals of this age, based on population-based studies of thoracic kyphosis.38 Only male participants were recruited into this study, which may limit extrapolation of the results to women. However, the ranges of thoracic spine movement reported in the present study are consistent with those reported in previous similar studies of female participants. Age-related changes in spinal morphology may influence thoracic mobility, which would limit the extrapolation of the results of this study to older individuals.9 A further potential source of error is the correct identification of thoracic spinal levels through palpation. However, palpatory accuracy to within 1 level of the required segment would be expected when performed by an experienced clinician.2 Because consistent visualization of thoracic spinous processes was not possible using the radiographic imaging protocol, the present study was unable to examine palpatory accuracy. The primary objective of the radiographic protocol was to obtain optimal resolution of the vertebral bodies while minimizing participant radiation exposure.

**CONCLUSION**

Functional radiographic analysis was used to measure the extension motion of the thoracic spine associated with bilateral arm elevation. When referenced to the thoracic kyphosis measured in a neutral standing posture, the mean range of thoracic spine extension...
in end-range bilateral shoulder elevation was 12.8°, with considerable variability among participants. The amount of thoracic extension motion associated with shoulder elevation was greater in the lower than in the upper thoracic region. The amount of thoracic spine kyphosis in end-range arm elevation was significantly correlated with the magnitude of the thoracic kyphosis measured in a neutral standing posture. The significant correlation between the radiographic and photographic measurements of thoracic kyphosis confirms the validity of the photographic technique for the analysis of thoracic spine posture. The findings of this study support the concept of examination of thoracic spine mobility as part of the physical examination of patients with shoulder pain.

**KEY POINTS**

**FINDINGS:** Functional radiographic analysis was used to demonstrate movement of the thoracic spine toward extension with end-range bilateral arm elevation. The amount of movement varies among individuals, and the magnitude of the thoracic kyphosis in bilateral arm elevation is associated with the magnitude of the thoracic kyphosis measured in a neutral standing posture.

**IMPLICATIONS:** These results support the concept of examination of thoracic spine mobility as part of the physical examination of patients with shoulder pain related to arm elevation.

**CAUTION:** Results of this study may not be transferable to older individuals or to individuals with shoulder or spinal pain.

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**REFERENCES**

30. Tate AR, McClure PW, Young IA, Salvatori R,


