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Measurement of scapular prominence in symptomatic dyskinesis using a novel scapulometer: reliability and the relationship to shoulder dysfunction

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Background: No previous studies have investigated whether the extent of scapular dyskinesis is associated with shoulder dysfunction. This study aimed (1) to establish the reliability of a scapulometer in patients with shoulder pain and (2) to investigate the related factors associated with shoulder dysfunction.

Methods: One hundred participants with symptomatic scapular dyskinesis were recruited. Twenty-one participants were involved in the reliability study to test the intrarater and inter-rater reliabilities of the scapulometer in patients with shoulder pain. After demographic data and self-reported Flexilevel Scale of Shoulder Function (FLEX-SF) scores were recorded, all participants were measured with a scapulometer to determine the posterior displacement of the root of the spine (ROS) and the inferior angle (IFA) of the scapula from the thorax. Next, the participants performed 5 trials of bilateral scapular plane elevation for scapular kinematics and electromyographic (EMG) data collection. Stepwise multiple linear regressions were used to determine the relationships between self-reported FLEX-SF scores and potential factors. In addition to scapular displacement, pain level, scapular kinematics, and EMG data were included as independent variables.

Results: The intrarater and inter-rater reliabilities of the scapulometer were excellent (intraclass correlation coefficient [ICC] = 0.93-0.97) and moderate to good (ICC = 0.74-0.81), respectively. The Bland-Altman plots showed no systematic bias between raters in the ROS and IFA measurements. Final stepwise multiple regression models showed that more ROS distance, higher serratus anterior activity, and lower pain level during arm elevation were associated with higher shoulder function (total $R^2 = 0.253$).

Conclusion: The reliability of the scapulometer in patients with shoulder pain is moderate to excellent. Scapular dyskinesis may be a compensatory strategy to avoid shoulder pain and improve shoulder function.

Level of evidence: Level IV; Diagnostic Study

Keywords: Scapular dyskinesis; function; reliability; regression; kinematics; muscle activation

The National Taiwan University Hospital Human Subject Research Ethics Committee approved this study (no. 201712089RINC).

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Scapular dyskinesis is defined as altered scapular position and movement relative to the thoracic cage.[10,15] The prevalence rate of scapular dyskinesis ranges from 66%-100% in various shoulder disorders.[3,4,20,23,27,28] Although a

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recent meta-analysis showed that asymptomatic athletes with scapular dyskinesis have 43% greater risk to further develop shoulder pain compared to those without scapular dyskinesis,[6] the relationship between shoulder dysfunction and scapular dyskinesis is still unclear.

Quantitative assessment of scapular dyskinesis may clarify the mechanism between shoulder dysfunction and scapular dyskinesis. Previous studies have proposed visual-based assessments for classifying scapular dyskinesis patterns or severity.[11,15,27] These measurements are limited by their insufficient reliability (kappa coefficient = 0.31-0.61) and validity. On the other hand, the prominence of the scapular medial border and the inferior angle (IFA) can be quantitated with several tools developed to date.[5,19,22,25,29] Among these tools, a new scapulometer has been developed for measuring the root of spine (ROS), which is located at the most medial portion of the spine of the scapula, and the IFA of the scapula with reference to the posterior thoracic cage, unilaterally overcoming the stationed bilateral measurements affected by muscle mass asymmetry on the 2 sides.[5] In an asymptomatic population with scapular dyskinesis, the average ROS and IFA displacements were found to be 13.7 ± 5.0 mm and 12.5 ± 6.3 mm with excellent intrarater and inter-rater reliabilities, with intraclass correlation coefficient (ICC) = 0.88-0.99 and 0.95-0.99 (standard error of the mean = 0.7-0.8 mm), respectively. However, low correlations were found (0.35/0.19 for ROS and internal rotation/IFA and tilt) using a 3-dimensional motion tracking system to assess scapular internal rotation and posterior tilting. This tool should be further tested in a symptomatic population with scapular dyskinesis.

Recent results on the relationship between scapular dyskinesis and shoulder dysfunction have been conflicting.[7,13,26] Huang and colleagues found no differences in functional scores among scapular dyskinesis and normal pattern in patients with shoulder dysfunction.[7] However, Lopez and colleagues reported lower functional scores in an obvious dyskinesis group than in a no dyskinesis group in individuals with subacromial impingement syndrome.[13] Additionally, functional scores were significantly lower at the end than at the beginning of the season for collegiate pitchers with scapular dyskinesis.[26] Because of differences in the study design, populations, and functional scales among the studies, the impact of scapular dyskinesis on shoulder dysfunction remains unclear. In addition, no previous studies have investigated whether the extent of scapular dyskinesis is associated with shoulder dysfunction. Whether the extent of scapular dyskinesis is related to shoulder dysfunction or is a functional compensatory mechanism is unclear.

This study aimed (1) to establish the reliability of scapulometer measurement in symptomatic patients with scapular dyskinesis, and (2) to investigate the related factors, including the extents of medial border and inferior angle prominence, scapular kinematics, and muscle activation associated with shoulder dysfunction.

Material and methods

One hundred participants with symptomatic scapular dyskinesis (73 men, age: 26.8 ± 5.5 years, height: 171.8 ± 7.9 cm, weight: 67.4 ± 12.0 kg, Flexilevel Scale of Shoulder Function [FLEX-SF] score: 40.5 ± 5.3) were recruited from an outpatient clinic at a university hospital and through local Internet media. Participants were included if they (1) were 18-50 years old; (2) had unilateral glenohumeral region pain while performing functional activities, occupational tasks, or sports-specific movements; and (3) had scapular dyskinesis evaluated by a physical therapist. Scapular dyskinesis was characterized as inferior angle (pattern I) and/or medial border prominence (pattern II) of the scapula or mixed patterns during arm elevation.[8] A well-trained therapist used visual observation and palpation of the scapula during arm movements with weighted loads to investigate the scapular patterns. For the study, the participants read and signed informed consent approved by the hospital institutional review board. Additionally, participants were excluded if they (1) had a body mass index of <18 or >26; (2) had a diagnosis of long thoracic nerve or accessory nerve injury; (3) had cervical-related referred shoulder pain (shoulder pain results from cervical movement); (4) demonstrated more than moderate pain (visual analog scale [VAS] > 5) during arm elevation in the scapular plane.

The scapulometer in this study was modified from the Weon tool.[29] The modified scapulometer was positioned at one side to measure the distance from the root of the spine (ROS) and the inferior angle (IFA) of the scapula to the thoracic wall, respectively. For the measurement, right and left scapulometers were made for each side. This modified scapulometer has 2 parts: a digital caliper (Hanlin 1052, Hanlin Inc., New Taipei City, Taiwan) and a ruler body. The digital caliper, designed for up to 150 mm linear measurements with a minimum measurement error of 1 mm, is perpendicularly attached at the distal end of a 15-cm ruler body. Additionally, an inclinometer is attached to the ruler body to maintain the orientation of the scapulometer (Fig. 1).

The Polhemus 3Space FASTRAK system (Polhemus Inc., Colchester, VT, USA), an electromagnetic-based motion analysis system, was used for collecting 3-dimensional kinematic data of the scapula. The accuracy of the FASTRACK system is 0.8 mm and 0.15°. Sensors for the system are attached to the sternum and the flat bony surface of the acromion with adhesive tape. The third sensor is attached to the distal humerus with Velcro straps. Anatomic landmarks (sternal notch, xiphoid process, seventh cervical vertebra, eighth thoracic vertebra, acromioclavicular joint, root of the spine of the scapula, inferior angle of the scapula, lateral epicondyle, and medial epicondyle) are palpated and marked with a stylus. These marks are used for subsequent mounting of the receiver and digitization of landmarks. The transmitter serves as a global reference frame and is fixed to a rigid plastic base and oriented such that it is level and its coordinate axes are aligned with the cardinal planes of the human body.

Bipolar surface electromyography (EMG) electrodes (Ludlow Company LP, Chocopee, MA, USA), with an interelectrode (center-to-center) distance of 20 mm, were placed over the upper

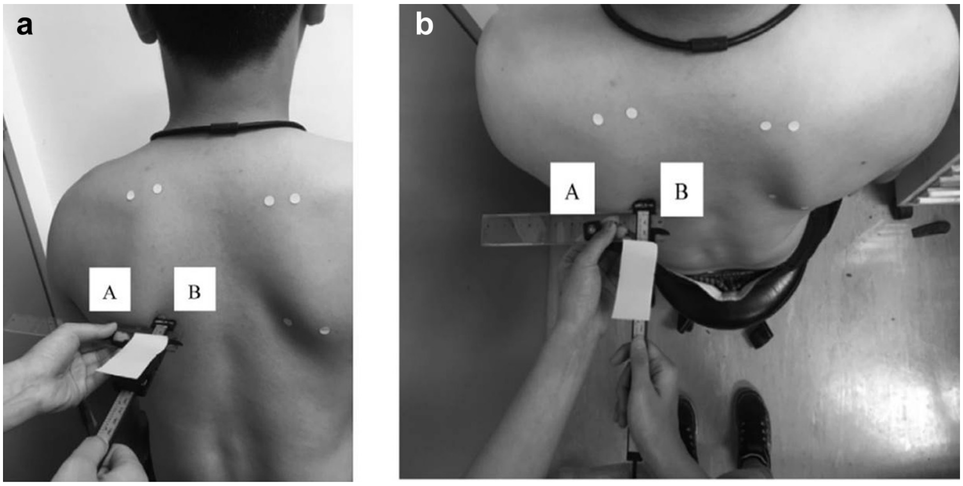

Figure 1 Landmarks and scapulometer measurement: (**a**) rear view; (**b**) superior view. The ruler was placed on the anatomic landmark and the digital caliper was placed on the parallel landmark. Posterior displacement of the scapula was measured by sliding the digital caliper toward the thorax until firm contact. *A*, inferior angle of scapular landmark; *B*, parallel landmark at the same level of the inferior angle of the scapula 1 cm medially to the scapular inferior angle.

trapezius (UT), lower trapezius (LT), and serratus anterior (SA) of the involved shoulder.[9] The UT electrodes were placed midway between the seventh cervical spinous process and the posterior tip of the acromion process, along the line of the trapezius. The LT electrodes were placed obliquely upward and laterally along a line between the intersection of the spine of the scapula and the vertebral border of the scapula and the seventh thoracic spinous process. The electrodes for SA were placed anterior to the latissimus dorsi and posterior to the pectoralis major. A reference electrode was placed at the ipsilateral clavicle. The electrodes were connected to a 16-channel EMG receiver and a Grass AC/DC amplifier (Model 15A12; Astro-Med Inc., Warwick, RI, USA). The surface EMG data were collected at 1000 Hz/channel using a 16-bit analog-to-digital converter (Model MP 150; Biopac Systems Inc., Goleta, CA, USA). An impedance meter (Model F-EZM5; Astro-Med Inc.) was used to measure the impedance between the electrodes over the muscle. The impedance of each electrode was controlled to less than 10 kΩ. All raw myoelectric signals were preamplified (overall gain, 1000; common rate rejection ratio of 86 dB at 60 Hz, and bandwidth [–3 dB] of 10-500 Hz).

Male participants were asked to remove their shirts, and females were asked to wear halter tops after the demographic data and self-reported FLEX-SF score were recorded. Twenty-one participants were involved in the reliability study to test the intrarater and inter-rater reliabilities of the scapulometer in patients with shoulder pain. Posterior displacement of the scapula was measured by 2 raters who had at least 6 months of experience in using a scapulometer for reliability analyses. One rater stood behind the participant and placed the ruler body of the modified scapulometer on the anatomic landmark and the digital caliper on the parallel landmark. The first rater held the modified scapulometer in place with one hand on the ruler body and slid the digital caliper anteriorly toward the parallel landmark until firm contact. During the measurement, the inclinometer attached to the ruler body was monitored to maintain the orientation of the scapulometer. Posterior displacement of the scapula was recorded by the second rater based on the digital caliper. Three measurements by each rater were performed with the participant in a sitting position with his or her arms at the sides. During the measurements, both raters were blinded to the results. For the other participants not involved in the reliability study, 3 measurements were performed in the same position by one tester.

Next, participants were instructed to practice arm elevation in the scapular plane and become familiar with the tempo of a metronome. The starting position was arms at the side of the body, elbow straight, and shoulder in neutral position. Participants were asked to elevate their arms, using the thumb-up position, to the end range over a 3-second count and then to lower them over a 3-second count. The dumbbells in each hand weighed 1 or 0.5 kg, depending on each participant's ability to elevate the arm with a VAS pain level of less than 5. After 1 minute of rest, the participants performed 5 trials of bilateral, active, and weighted arm elevation in the scapular plane for kinematics and EMG data collection.

Motion Monitor Software (Innovative Sports Training, Inc., Chicago, IL, USA) was used to calculate the humerus elevation, scapular upward/downward rotation, anterior/posterior tipping, and internal/external rotation. The International Society of Biomechanics guidelines were followed for constructing a shoulder joint coordinate system.[30] Raw kinematics data were low-pass filtered at a 6 Hz cutoff frequency and converted into anatomically defined rotations. The Euler angle sequence of rotation was used to describe scapular orientation relative to the trunk as rotation about Zs (protraction/retraction), rotation about Ys (downward/upward rotation), and rotation about Xs (posterior/anterior tipping). Humeral orientation relative to the scapula was described such that the first rotation represented the plane of elevation, the second rotation defined the amount of elevation, and the third rotation described the amount of axial rotation.

The EMG data for each muscle were averaged from the middle 3 trials of arm elevation/lowering. Full-bandwidth surface EMG data captured by data acquisition software (AcqKnowledge; Biopac Systems Inc.) were reduced using a root mean square algorithm to produce EMG envelopes with an effective sampling rate of 50 samples. Results were normalized to the maximal voluntary isometric contraction (MVIC) with a procedure reported in previous research.[9]

The Statistical Package for the Social Sciences, version 17.0, was used for data analysis. ICCs (3,1) were calculated based on a repeated measures analysis of variance to determine inter-rater reliability. The ICC (3,3) was calculated for intrarater reliability. ICC values less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 are indicative of poor, moderate, good, and excellent reliability, respectively.[12] Additionally, the minimal detectable change (MDC) was used to determine the measurement error. The method by Bland and Altman was used to determine systematic bias between raters.[2]

Stepwise multiple linear regressions were used to determine the relationships between FLEX-SF scores and ROS and IFA values, scapular kinematics, and EMG data. Pairwise associations among continuous variables were checked if any factors were strongly correlated ($r > 0.8$) to avoid multicollinearity. Related factors were entered into the model if they were associated with the FLEX-SF score ($P < .2$). The predictive factors were included in the final regression model if they were associated with the FLEX-SF score with $P < .05$.

Results

The average ROS and IFA distances of the participants overall were 10.8 ± 4.4 and 10.3 ± 4.2 mm, respectively. For the reliability study, the intrarater reliability of the ROS and IFA measurements were excellent (ICC = 0.93-0.95 and 0.96-0.97, respectively). The minimal detectable change (MDC) was calculated to be 1.0-1.4 mm and 1.2-1.3 mm for the ROS and IFA measurements, respectively. Additionally, the inter-rater reliability was moderate to good for the ROS and IFA measurements (ICC = 0.74 and 0.81, respectively). The Bland-Altman plots showed no systematic bias between raters in the ROS and IFA measurements (Fig. 2).

For the multiple regression analysis, a test for linearity showed that the pairwise association appeared linear. Additionally, multicollinearity, verified by correlation coefficient and variance inflation factor, revealed no collinear variables ($r > 0.8$ and variance inflation factor < 10) in the regression model. The variables associated with the FLEX-SF score were entered into the stepwise regression model ($P < .2$). These were ROS distance, IFA distance, pain level during arm elevation ($VAS_{elevation}$), posterior tipping at 30° of arm elevation (PT_{R30}), posterior tipping at 30° of arm lowering (PT_{L30}), upper trapezius activity during more than 120° of arm elevation (UT_{R120up}), serratus anterior activity during 0°-30° of arm elevation and lowering (SA_{R030} and SA_{L030}), and lower trapezius activity during 90°-120° of arm elevation and more than 120° of arm lowering (LT_{R90120} and LT_{L120up}). The final model revealed that ROS distance (standardized $\beta = 0.280$, $R^2 = 0.11$, $P = .004$), SA_{L030} (standardized $\beta = 0.322$, $R^2 = 0.072$, $P = .001$), and $VAS_{elevation}$ (standardized $\beta = -0.279$, $R^2 = 0.071$, $P = .005$) were all significantly associated with FLEX-SF score (total $R^2 = 0.253$). This model indicated that a higher FLEX-SF score may be associated with larger ROS distance, higher SA_{L030}, and lower $VAS_{elevation}$. These factors accounted for 25% of the variance of the FLEX-SF score (Table I).

Discussion

A scapulometer has been developed to measure the medial border and inferior angle prominence relative to the thorax, and the reliability of this tool has been established in healthy people. In the current study, we tested the intrarater and inter-rater reliabilities of the scapulometer in individuals with shoulder pain and scapular dyskinesis. The findings showed excellent intrarater reliability and moderate to good inter-rater reliability with no systemic bias. The MDC was calculated to be 1.0-1.4 mm for ROS and IFA distance. These can be reference values for therapists using the scapulometer in patients with shoulder pain. The inter-rater reliability was lower than the excellent reliability (ICC = 0.95-0.99) reported in a previous study.[5] The force applied by each tester may vary, influenced by sex, strength, and subjective feelings of end-feel. Modification of this type of scapulometer by adding a component for force detection can be further investigated.

This study was the first to investigate the relationship between the extent of altered scapular position and shoulder function. We hypothesized that more posterior displacement of the scapular medial border and inferior angle would be associated with a lower shoulder functional score. Interestingly, the current study reveals that greater posterior displacements of the ROS and IFA are associated with higher shoulder function. Because of the similar contribution for explaining shoulder function in the displacement of the ROS and IFA, IFA distance was not included in the final regression model. More displacement of the IFA was also significantly related to better shoulder function. The relationships among scapular dyskinesis, shoulder pathologies, and shoulder dysfunction are a complex condition. It has been proposed that scapular movement variability should be considered as a central nervous system optimization strategy instead of as a pathologic factor.[16] Based on dynamic movement theory, variability is evidence of flexibility and adaptability of the neuromuscular system in exploring new movement solutions to achieve the same goal.[24] Altered scapular position and movement may be compensatory ways to avoid shoulder pain and improve shoulder function, which is supported by the findings of the current study. The ROS and IFA values (10.8 ± 4.4 mm and 10.3 ± 4.2 mm, respectively) were also lower in patients with shoulder pain than were those (13.7 ± 5.0 mm and 12.5 ± 6.3 mm, respectively) in healthy people.[5]

The influence of scapular dyskinesis on shoulder function should depend on whether or not shoulder injuries are

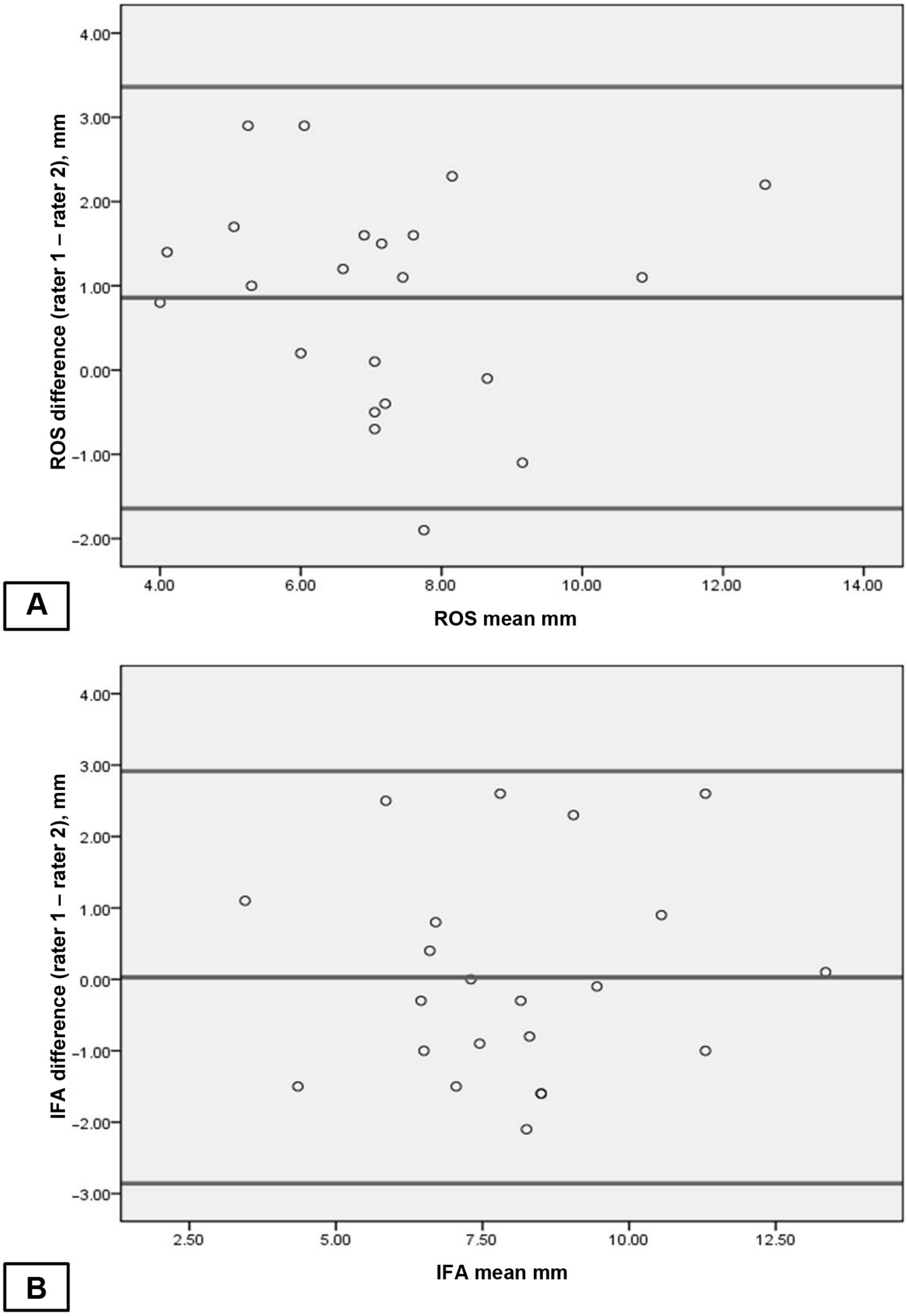

Figure 2 The Bland-Altman plots of (**A**) root of the spine (ROS) and (**B**) inferior angle (IFA) displacements measured by scapulometer between raters.

present and also on excessive loads on the shoulder region. It has been reported that asymptomatic patients with scapular dyskinesis have greater risk of developing shoulder pain and dysfunction, especially elite overhead athletes.[6,26] Evidence also supports that interventions focusing on correcting scapular dyskinesis can prevent further development of shoulder injuries in asymptomatic elite overhead athletes.[1] Scapular dyskinesis may not be a risk factor in isolation, but it increases the risk of shoulder pain in the presence of excessive increases of loads on the shoulder regions.[17] On the other hand, scapular dyskinesis may be a compensatory adaptation to avoid further injuries in a population with shoulder injuries.[7,16] Increased dyskinesis may be a strategy to meet the demand for scapular movements during functional activities in this population. Subsequently, whether scapular dyskinesis results in or

Table I Stepwise multiple linear regression for shoulder function

Independent variables	Potential variables ($P < .2$)	Significant factors	Standardized β	R^2	P value
ROS distance	ROS	ROS	0.280	0.110	.004
IFA distance	IFA	—			
$VAS_{elevation}$	$VAS_{elevation}$	$VAS_{elevation}$	−0.279	0.071	.005
Pain duration	—	—			
UR_{R30}/ UR_{R60}/ UR_{R90}/ UR_{R120}	—	—			
UR_{L30}/ UR_{L60}/ UR_{L90}/ UR_{L120}	—	—			
PT_{R30}/ PT_{R60}/ PT_{R90}/ PT_{R120}	PT_{R30}	—			
PT_{L30}/ PT_{L60}/ PT_{L90}/ PT_{L120}	PT_{L30}	—			
IR_{R30}/ IR_{R60}/ IR_{R90}/ IR_{R120}	—	—			
IR_{L30}/ IR_{L60}/ IR_{L90}/ IR_{L120}	—	—			
UT_{R030}/UT_{R3060}/UT_{R6090}/UT_{R90120}/UT_{R120up}	UT_{R120up}	—			
UT_{L030}/UT_{L3060}/UT_{L6090}/UT_{L90120}/UT_{L120up}	—	—			
LT_{R030}/LT_{R3060}/LT_{R6090}/LT_{R90120}/LT_{R120up}	LT_{R90120}	—			
LT_{L030}/LT_{L3060}/LT_{L6090}/LT_{L90120}/LT_{L120up}	LT_{L120up}	—			
SA_{R030}/SA_{R3060}/SA_{R6090}/SA_{R90120}/SA_{R120up}	SA_{R030}	—			
SA_{L030}/SA_{L3060}/SA_{L6090}/SA_{L90120}/SA_{L120up}	SA_{L030}	SA_{L030}	0.322	0.072	.001
Total R^2				0.253	

ROS, root of spine; *IFA*, inferior angle; *$VAS_{elevation}$*, pain level during arm elevation; *UR*, upward rotation; *PT*, posterior tipping; *IR*, internal rotation; *UT*, upper trapezius activity; *LT*, lower trapezius activity; *SA*, serratus anterior activity; *R30*, 30° of arm elevation in raising phase; *Lup120*, arm elevation angle interval from highest degree to 120° in lowering phase.

results from shoulder dysfunction should be clarified in patients with shoulder pain. Scapular assistance test screening to determine whether correcting the scapula position can alleviate symptoms and improve shoulder function may be an option that could provide clarification.[21] Additionally, changes in scapular prominence measured by scapulometer after scapular-focused interventions related to shoulder function will require further investigation.

In scapular dyskinesis, the serratus anterior and trapezius act as a force couple for scapular movement and should be assessed together, rather than as isolated muscles.[21] The serratus anterior muscle is reported to be involved in scapular upward rotation, posterior tipping, and external rotation.[14,18] Proper recruitment of the serratus anterior provides appropriate scapular movement to achieve shoulder function. In our findings, increased serratus anterior activity was associated with improved shoulder function. Reduced activity of the serratus anterior muscle has been observed in patients with shoulder impingement.[14] On the other hand, decreased upper trapezius activity and increased lower trapezius activity were found to be associated with higher shoulder function in patients with scapular dyskinesis.[7] Because scapular muscles act as a force couple to control scapular movement, different strategies may be used to activate part of the scapular muscles to accomplish the same shoulder task.

The variety of shoulder complex movements in daily living indicates that multidimensional factors influence shoulder function. Presumably, a lower pain level during arm elevation is related to higher shoulder function. However, the pain level during elevation only explained 7% of the variance of shoulder function in our results. Muscle flexibility, range of motion, and endurance may be other factors associated with shoulder function. Considering the 25% and 13%-16% of the variance of shoulder function explained by our results and in one previous study, more potential factors should be further investigated.[7]

Other limitations of the study should also be noted. First, it was a cross-sectional study designed to investigate the association between dyskinesis factors and shoulder function. A longitudinal study design was necessary to verify whether these factors can predict shoulder function. Second, we used surface EMG to detect the superficial scapular muscles. Deep muscles such as the rhomboids, levator scapulae, and rotator cuff muscles may also play vital roles in shoulder function. Third, the population in this study was generally young. The generalization of the results to elderly people should be carefully considered.

Conclusion

The intrarater and inter-rater reliabilities of using the scapulometer to measure dyskinesis demonstrated moderate to excellent values in individuals with shoulder pain. Greater ROS distance, higher serratus anterior activity, and lower pain level during arm elevation were associated with higher shoulder function. Altered scapular position and movement may be compensatory strategies to avoid shoulder pain and improve shoulder function. More potential factors need to be considered to explain shoulder function in populations with shoulder pain and scapular dyskinesis.

Disclaimer

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