Archives of Physical Medicine and Rehabilitation

journal homepage: www.archives-pmr.org

Archives of Physical Medicine and Rehabilitation 2015;96:298-306

ORIGINAL ARTICLE

Visual Scapular Dyskinesis: Kinematics and Muscle Activity Alterations in Patients With Subacromial Impingement Syndrome

Andrea Diniz Lopes, DSc,[a,b,d] Mark K. Timmons, PhD, ATC,[c] Molly Grover, BS,[d] Rozana Mesquita Ciconelli, PhD, MD,[a] Lori A. Michener, PhD, PT, ATC[d,e]

From the [a]Translational Medicine Program, Department of Medicine, Federal University of Sao Paulo, Sao Paulo, SP, Brazil; [b]Research Support, Center for Clinical Outcomes Studies, A.T. Still University, Mesa, AZ; [c]School of Kinesiology, Marshall University, Huntington, WV; [d]Department of Physical Therapy, Clinical Biomechanics, Orthopedic and Sports Outcomes Research Laboratory, Virginia Commonwealth University, Richmond, VA; and [e]Division of Biokinesiology and Physical Therapy, University of Southern California, Los Angeles, CA.

Abstract

Objective: To characterize scapular kinematics and shoulder muscle activity in patients with subacromial impingement syndrome, with and without visually identified scapular dyskinesis.

Design: Cross-sectional study.

Setting: Laboratory.

Participants: Participants with subacromial impingement syndrome (N=38) were visually classified using a scapular dyskinesis test with obvious scapular dyskinesis (n=19) or normal scapular motion (n=19).

Interventions: Not applicable.

Main Outcome Measures: An electromagnetic motion capture system measured 3-dimensional kinematics of the thorax, humerus, and scapula. Simultaneously, surface electromyography was used to measure muscle activity of the upper, middle, and lower trapezius; serratus anterior; and infraspinatus during ascending and descending phases of weighted shoulder flexion. Separate mixed-model analyses of variance for the ascending and descending phases of shoulder flexion compared kinematics and muscle activity between the 2 groups. Shoulder disability was assessed with the Pennsylvania Shoulder Score (Penn).

Results: The group with obvious dyskinesis reported 6 points lower on Penn shoulder function (0–60 points), exhibited a main group effect of less scapular external rotation of 2.1° during ascent and 2.5° during descent, and had 12.0% higher upper trapezius muscle activity during ascent in the 30° to 60° interval.

Conclusions: Patients with obvious dyskinesis and subacromial impingement syndrome have reduced scapular external rotation and increased upper trapezius muscle activity, along with a greater loss of shoulder function compared with those without dyskinesis. These biomechanical alterations can lead to or be caused by scapular dyskinesis. Future studies should determine if correction of these deficits will eliminate scapular dyskinesis and improve patient-rated shoulder use.

Archives of Physical Medicine and Rehabilitation 2015;96:298-306

Subacromial impingement syndrome (SAIS) accounts for 44% to 65% of all complaints of musculoskeletal shoulder pain.[1-3] The mechanisms of this syndrome are not well understood because of the multifactorial nature and lack of a consistent identifiable tissue pathology.[4] SAIS has been linked to altered scapular motion and muscle activity.[5-7]

The 3-dimensional kinematic general pattern of normal scapular motion during active arm elevation is scapular upward rotation and posterior tilting, along with clavicular elevation and retraction.[8] Scapular external/internal rotation varies depending on the plane and degree of arm elevation.[5,9] During sagittal plane

Supported in part by the Coordination for the Improvement of Higher Education Personnel (CAPES), Brazil, and Interprofessional Polytrauma and Traumatic Brain Injury Rehabilitation Research Fellowship, VA Advanced Fellowships & Professional Development, Office of Academic Affiliations, Department of Veterans Affairs.

Disclosures: none.

0003-9993/14/$36 - see front matter © 2015 by the American Congress of Rehabilitation Medicine

http://dx.doi.org/10.1016/j.apmr.2014.09.029

Table 1 Participant demographics and characteristics

Variable	DYSK (n=19)	NO DYSK (n=19)	*P*
Age (y)	40.2±13.8	46.4±10.9	.13
Weight (kg)	80.2±13.7	81.1±19.6	.88
Height (cm)	173.7±15.4	174.5±10.0	.85
Sex: male	12 (63.2)	11 (57.9)	.50
Arm dominance: dominant	12 (63.2)	12 (63.2)	.63
Duration of symptoms			.15
6–12wk	0 (0)	2 (10.5)	
>12wk	19 (100)	17 (89.5)	
Penn			
Total score (0–100, 100=no disability)	59.8±10.8	68.9±8.7	.01*
Penn pain subscale (0–30, 30=no pain)	17.7±5.7	19.7±4.6	.23
Penn satisfaction subscale (0–10, 10=fully satisfied)	3.6±2.3	4.6±3.0	.26
Penn function subscale (0–60, 60=full function)	38.5±6.4	44.5±6.2	.01*

NOTE. Values are mean ± SD, n (%), or as otherwise indicated.
Abbreviations: DYSK, obvious scapular dyskinesis group; NO DYSK, normal scapular motion group.
* Significant difference between groups.

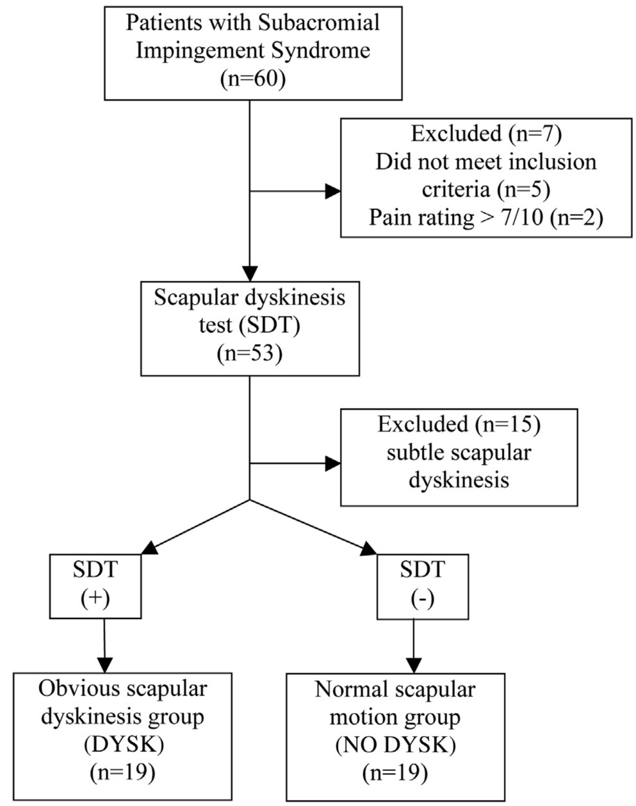

Fig 1 Flowchart demonstrating subject screening and group assignment. Abbreviations: DYSK, obvious scapular dyskinesis group; NO DYSK, normal scapular motion group; SDT, scapular dyskinesis test.

flexion, initially scapular internal rotation occurs,[9] then the scapula externally rotates toward the end range of flexion.[8] Patients with SAIS generally have a pattern of less upward rotation and external rotation, along with greater clavicle elevation and retraction compared with healthy controls.[5] Scapular motion is controlled in part by the force couple between the trapezius and serratus anterior muscles.[10] Increased upper trapezius muscle activity along with decreased lower trapezius and serratus anterior muscle activity[7,11-13] have been reported in patients with SAIS. Altered muscle activations associated with abnormal scapular motion are theorized to contribute to SAIS.[7]

Visual alterations in scapular movement have been termed scapular dyskinesis.[14] The scapular dyskinesis test was developed to visually identify dyskinesis during active shoulder elevation.[15] Collegiate overhead athletes with dyskinesis identified by the scapular dyskinesis test have reduced scapular upward rotation, reduced clavicular elevation, and greater clavicular protraction compared with those with no dyskinesis.[16] It is unclear if these results generalize to patients with shoulder pain.

Defining the kinematic and muscle activity impairments related to scapular dyskinesis in patients with shoulder pain can provide foundational knowledge for treatment and understanding of scapular dyskinesis. The purpose of this study was to characterize scapular kinematics and muscle activity in patients with SAIS with visually identified scapular dyskinesis compared with those without dyskinesis.

List of abbreviations:

MDC **minimal detectable change**
Penn **Pennsylvania Shoulder Score**
SAIS **subacromial impingement syndrome**

Methods

Participants

A convenience sample of 60 adults (18–70y) was recruited consecutively from rehabilitation and physician offices to screen for participation. SAIS was confirmed with inclusion criteria of 3 of 5 positive tests[17]: painful arc,[18] pain or weakness with resisted external rotation,[19] Neer test,[20] Hawkins-Kennedy test,[21] and Jobe test.[22] Exclusion criteria included adhesive capsulitis (25% limitation of passive shoulder motion in ≥2 motions),[17] pain ≥7 (out of 10), history of upper arm fracture, systemic musculoskeletal disease, shoulder surgery, active/passive cervical motion reproducing shoulder pain,[23] or positive for a full thickness rotator cuff tear (drop arm,[24] lag sign,[25] lift-off[26] tests). Participants were then tested for scapular dyskinesis with the scapular dyskinesis test. Those with obvious dyskinesis (n=19) and no dyskinesis (n=19) were retained for kinematic and muscle activity testing. Participants signed an informed consent approved by the local institutional review board. Table 1 describes participant demographics and characteristics. Figure 1 depicts subject screening and group assignment.[27]

An a priori power analysis indicated that 32 participants (assigned in a 1:1 group ratio) were needed. Sample size estimation was based on a pilot test of 11 participants and on the assumption that a 10% difference in muscle activity[7] and a 4° difference in scapular upward rotation[7,28] and a 2° difference in all other kinematic variables[5,29] between groups would constitute clinically meaningful differences.

Table 2 Kinematics sensor and electromyography electrode placement

Kinematics		
Segment	Sensor Placement	Bony Landmarks Used to Define the Rigid Segment
Thorax	Spinous process of T3	• Spinous process of the C7 • Sternal notch • Spinous process of the T7 • Xiphoid process
Scapula	Posterior lateral acromion	• Root of the spine • Inferior angle of the scapula • Posterolateral acromion process
Humerus	Posterior distal humerus	• Medial humeral epicondyle • Lateral humeral epicondyle • Humeral head center, not directly digitized*

Electromyography	
Muscle	Electrode Placement
Upper trapezius	• Immediately lateral to a point midway between the spinous process of T1 and the acromion process
Middle trapezius	• Immediately lateral to a point midway between the spinous process of T3 and the root of spine of the scapula
Lower trapezius	• Immediately lateral to a point midway between the spinous process of T7 and the inferior angle of the scapula
Serratus anterior	• Along the midaxillary line over the 6th rib
Infraspinatus	• 2.54cm inferior to the spine of the scapula at a point midway between the root of the spine of the scapula and the posterior acromion process

* The humeral head center is estimated by moving the arm through various small arcs of motion to define the center by the least-squares method.

Instrumentation and procedures

Participants completed a history and demographics form and the Pennsylvania Shoulder Score (Penn).[30] The Penn has demonstrated acceptable reliability and validity, with a standard error of measurement of 8.5 scale points and a minimal detectable change (MDC) of 12.1 scale points.[30]

Scapular dyskinesis test

The scapular dyskinesis test[16] was used to assign participants to the dyskinesis group or no dyskinesis group. Scapular motion was observed during weighted shoulder flexion[15,16] because scapular dyskinesis is more prevalent during flexion.[16,31] Participants performed 5 consecutive repetitions of bilateral, active, and weighted shoulder flexion using dumbbells according to their body weight: 1.4kg (3lb) for those weighing <68.1kg (150lb) and 2.3kg (5lb) for those >68.1kg (150lb).[15,16]

Two examiners with standardized training to perform the scapular dyskinesis test[15] independently and simultaneously categorized patients with visually obvious dyskinesis, subtle dyskinesis, or normal scapular motion. Examiners were blinded to each other's assessment but were not blinded to which shoulder was painful. Lack of evidence of scapular motion abnormality was classified as normal motion. Subtle dyskinesis was classified when only mild or questionable evidence of scapular motion abnormality occurred not consistently present. Participants with subtle dyskinesis ($n=15$) were excluded to maximize the potential for detecting between-group differences. Obvious scapular dyskinesis was present if there was striking, clearly apparent abnormality evident on at least 3 out of 5 trials.[15,16] Interrater reliability of the scapular dyskinesis test between the 2 examiners was good (74.2% agreement; $\kappa=.58$), which is comparable with previous research.[15] For the purpose of group assignment, subjects were classified according to the first examiner's rating.

Kinematics and muscle activity

Participants were outfitted with electromagnetic motion sensors for capture of 3-dimensional motion and surface electromyography electrodes to measure shoulder muscle activity. Kinematics and surface electromyography were collected during 5 consecutive repetitions of bilateral weighted shoulder flexion (separate from the scapular dyskinesis test), using the same weights as used for the scapular dyskinesis testing. Each repetition of arm elevation was performed to a count of 6 seconds: 3 seconds each to elevate and lower. MotionMonitor software[a] was used for data acquisition to synchronize and store the data for future processing. Data were exported and reduced with MATLAB.[b]

Scapular kinematics

The 3-dimensional kinematics of the thorax, scapula, and humerus were tracked using the Polhemus 3 Space FASTRAK electromagnetic motion capture system.[c] With participants in a quiet standing position, sensors were attached to each bony segment with adhesive tape or rubber straps. The local coordinate systems for each bony segment were created by digitizing bony landmarks[8,32,33] as described in table 2. Absolute sensor orientation data were transformed to describe the relative positions of the local coordinate system of each bony segment. Standard Euler angle sequences were used to describe the orientation of the segments.[34] Scapular orientation relative to the thorax was described as external/internal rotation, upward/downward rotation, and posterior/anterior tilting. Two clavicular rotations were used to describe the scapular position and were represented by the angular motion of the clavicle: elevation/depression and protraction/retraction, which were derived from the location of the sternal notch and the acromioclavicular joint and tracked with the thoracic and scapular sensors, respectively. Scapular kinematics was calculated at 4 arm angles (30°, 60°, 90°, 120°) during the ascending and descending phases of shoulder flexion. The middle 3 of the 5 consecutive repetitions were used for data analyses. The Polhemus system has reported an accuracy of 0.8mm and 0.15°.[8]

A subsample (n=12) of the participants was retested within 1 week of their initial data collection to assess test-retest intrarater reliability of the kinematic variables, and it was found to be fair to excellent (table 3).

Muscle activity

Muscle activity was measured using dual 10-mm silver bar preamplified surface electromyography electrodes,[d] with an amplification factor of 10k and a common mode rejection ratio >92dB at 60Hz. Surface electromyography signals were collected from the upper trapezius muscle, middle trapezius muscle, lower trapezius muscle, serratus anterior muscle, and infraspinatus muscle of the involved arm of each participant. Electrode placement sites were first vigorously cleaned with alcohol. Then the electrodes were placed as described in table 2 and held with adhesive tape.[35] A reference electrode was adhered with adhesive over the contralateral olecranon process.

For normalization, surface electromyography data were collected during 2 trials while participants performed a reference contraction against resistance for 5 seconds at the midpoint of the testing motion at −90° of flexion in the sagittal plane. A rest period of 60 seconds was given between trials to avoid fatigue. This reference contraction protocol was used because it was in the same plane and at the midpoint of the dynamic testing and was less demanding and painful for the participants compared with a maximal voluntary isometric contraction normalization test for each muscle.[36] Raw surface electromyography data were sampled at 960Hz, band-pass filtered (20−400Hz), and exported to MATLAB, where a notch filter (59−61Hz) was applied. Custom-written MATLAB code performed full wave rectification and calculated the average rectified values from the middle 3 of 5 consecutive arm elevation repetitions. The average rectified value was calculated for 3 arm elevation intervals (30°−60°, 60°−90°, 90°−120°). For the reference contraction, a 3-second analysis window was used to calculate the normalization value. Then, the average rectified values from the 2 trials were calculated for each muscle. The average rectified values during the 3 arm elevation intervals throughout the ascending and descending phases of shoulder flexion were normalized to the average rectified values of the reference contraction and were expressed as a percentage of the reference contraction. A subsample of the participants (n=12) was retested within 1 week of their initial data collection session to assess test-retest intrarater reliability of surface electromyography; it was found to be fair to excellent (see table 3). Absolute mean and mean between-day differences of the surface electromyography muscle activity (mV) during the reference contraction are reported in table 4.

Data analysis

Demographic differences between groups were tested using *t* tests (continuous data) and chi-square tests (nominal data). Comparisons of scapular kinematics and surface electromyography muscle activity were performed using separate mixed-model analyses of variance for the ascending and descending phase of each dependent variable, with group (dyskinesis group, normal scapular motion group) as the between-subjects factor, the 4 arm elevation angles (30°, 60°, 90°, 120°) as the repeated factor for scapular kinematics, and the 3 arm elevation intervals (30°−60°, 60°−90°, 90°−120°) as the repeated factor for surface electromyography muscle activity. Statistical significance was set at $\alpha=.05$. In the case of interactions, effects of group at each repeated factor were compared, and Bonferroni correction was used to adjust for multiple comparisons. All statistical tests were performed with SPSS version 21.[e]

Results

Descriptives are reported in table 1. There were no statistically significant differences between the groups except the dyskinesis group reported 9.1 points lower on the Penn total score and 6.0 points lower on the function subscale compared with the normative scapular motion group.

Scapular kinematics

Figure 2 depicts plots of scapular kinematics during arm elevation. Significant group × arm elevation angle interactions were demonstrated during the descending phase for upward rotation ($F_{3,36}=2.89$; $P=.039$) and clavicular elevation ($F_{3,36}=4.19$; $P=.012$); however, there were no post hoc differences between groups at any specific arm elevation angle. During the descent, there were no significant group main effects for upward rotation ($F_{1,35}=0.56$; $P=.457$) and clavicular elevation ($F_{1,36}=0.25$; $P=.618$). During the ascending phase, there were no significant interactions or group main effects, respectively, for scapular upward rotation ($F_{3,35}=1.01$; $P=.398$; $F_{1,35}=0.05$; $P=.833$) and clavicle elevation ($F_{3,36}=2.28$; $P=.096$; $F_{1,36}=0.19$; $P=.663$). Scapular external rotation demonstrated a significant main effect for group during the ascending ($F_{1,36}=4.56$; $P=.035$) and descending phases ($F_{1,36}=5.41$; $P=.022$); the dyskinesis group had less external rotation in the ascending phase (mean difference, 2.1°; 95% confidence interval, 0.2°−4.1°) and descending phase (mean difference, 2.5°; 95% confidence interval, 0.4°−4.6°) compared with the normal scapular motion group. This difference in scapular external rotation was not influenced by arm elevation angle (no interaction) during the ascending ($F_{3,35}=0.25$; $P=.862$) or descending phases ($F_{3,34}=0.42$; $P=.740$). There were no significant interactions or group main effects, respectively, for scapular posterior tilt during the ascending ($F_{3,32}=0.57$; $P=.640$; $F_{1,34}=0.01$; $P=.956$) or descending ($F_{3,33}=0.09$; $P=.963$; $F_{1,34}=0.26$; $P=.615$) phases and for clavicular protraction during the ascending ($F_{3,35}=0.58$; $P=.633$; $F_{1,36}=0.57$; $P=.454$) or descending ($F_{3,35}=1.57$; $P=.201$; $F_{1,37}=0.72$; $P=.402$) phases.

Surface electromyography

Table 5 provides means ± SEs for surface electromyography expressed as percentage of the reference contraction. A significant group × arm elevation interval interaction was found for the upper trapezius surface electromyography muscle activity during the ascending phase ($F_{2,35}=3.91$; $P=.029$). Post hoc differences between groups demonstrated that the dyskinesis group had higher upper trapezius surface electromyography muscle activity during the 30°−60° interval ($t=2.76$; $P=.009$), with a 12.0% difference between groups. There was no significant difference for upper trapezius surface electromyography muscle activity between groups during the other arm elevation intervals and no significant group main effect ($F_{1,32}=2.80$; $P=.104$). During the ascending phase, no significant group × arm elevation interactions or group main effects, respectively, were found for the middle trapezius ($F_{2,35}=1.24$; $P=.302$; $F_{1,35}=1.25$; $P=.271$), lower trapezius ($F_{2,35}=1.01$; $P=.370$; $F_{1,34}=.09$; $P=.762$), serratus anterior ($F_{2,36}=2.21$; $P=.116$; $F_{1,36}=.29$; $P=.589$), and infraspinatus

Table 3 Intratest reliability for scapular kinematics and normalized sEMG muscle activity

Variables	ICC	SEM	MDC	ICC	SEM	MDC
			Scapular Kinematics			
Arm Elevation Angle		Ascending Phase			Descending Phase	
External rotation						
30°	0.22	3.87	5.47	0.39	4.94	6.98
60°	0.41	4.00	5.65	0.63	3.87	5.47
90°	0.68	3.42	4.84	0.77	3.49	4.93
120°	0.89	2.88	4.08	0.92	2.96	4.18
30°–120	0.55	3.84	5.43	0.68	3.79	5.36
Upward rotation						
30°	0.90	3.87	5.47	0.89	4.79	6.77
60°	0.92	4.11	5.81	0.91	4.60	6.51
90°	0.90	4.35	6.15	0.91	4.25	6.01
120°	0.89	3.98	5.62	0.90	3.46	4.89
30°–120°	0.90	3.89	5.51	0.90	3.76	5.32
Posterior tilt						
30°	0.83	1.55	2.20	0.93	1.09	1.54
60°	0.84	1.81	2.56	0.92	1.24	1.76
90°	0.93	1.82	2.57	0.83	2.71	3.83
120°	0.95	2.29	3.23	0.78	4.74	6.71
30°–120°	0.89	2.32	3.28	0.86	2.38	3.37
Clavicular elevation						
30°	0.84	2.23	3.15	0.93	1.46	2.06
60°	0.85	2.46	3.47	0.89	2.13	3.01
90°	0.91	1.90	2.69	0.82	2.45	3.47
120°	0.93	1.43	2.02	0.71	2.84	4.02
30°–120°	0.88	2.06	2.91	0.86	2.22	3.14
Clavicular protraction						
30°	0.83	2.45	3.46	0.79	3.39	4.79
60°	0.79	3.08	4.35	0.83	3.35	4.74
90°	0.76	3.30	4.66	0.78	3.35	4.74
120°	0.75	2.75	3.89	0.72	2.79	3.94
30°–120°	0.78	2.93	4.15	0.80	3.12	4.41
			sEMG Muscle Activity			
Upper trapezius						
30°–60°	0.70	9.91	14.01	0.81	7.35	10.40
60°–90°	0.42	7.59	10.73	0.56	6.66	9.41
90°–120°	0.76	8.78	12.42	0.40	8.50	12.02
Middle trapezius						
30°–60°	0.58	8.43	11.93	0.53	2.05	2.90
60°–90°	0.74	3.59	5.08	0.83	1.22	1.73
90°–120°	0.61	7.50	10.61	0.72	2.64	3.73
Lower trapezius						
30°–60°	0.67	6.86	9.70	0.66	5.82	8.23
60°–90°	0.71	8.63	12.21	0.55	4.72	6.68
90°–120°	0.70	10.41	14.72	0.86	5.92	8.38
Serratus anterior						
30°–60°	0.67	10.91	15.44	0.30	11.70	16.54
60°–90°	0.85	8.27	11.69	0.85	6.54	9.25
90°–120°	0.74	17.27	24.42	0.43	15.07	21.32
Infraspinatus						
30°–60°	0.23	9.64	13.63	0.77	3.38	4.78
60°–90°	0.70	4.41	6.24	0.30	5.02	7.09
90°–120°	0.58	6.46	9.13	0.66	4.11	5.81

NOTE. Scapular kinematics is expressed as degrees, and normalized sEMG muscle activity is expressed as percentage of the reference contraction.
Abbreviations: ICC, intraclass correlation coefficient; SEM, standard error of measurement; sEMG, surface electromyography.

Table 4 Absolute mean and mean between-day differences in surface electromyography muscle activity during the reference contraction used for intrarater test-retest reliability

Muscle Activity (mV)	Test	Retest	Mean Difference
Upper trapezius	96±62	132±102	36
Middle trapezius	83±57	95±76	12
Lower trapezius	70±60	71±93	1
Serratus anterior	68±164	47±67	21
Infraspinatus	46±19	52±27	6

NOTE. Values are mean ± SD.

($F_{2,31}=1.35$; $P=.275$; $F_{1,34}=.40$; $P=.533$) surface electromyography muscle activity. During the descending phase, a significant group × arm elevation interval interaction was found for the upper trapezius ($F_{2,35}=3.57$; $P=.034$), middle trapezius ($F_{2,35}=3.47$; $P=.037$), and infraspinatus ($F_{2,36}=3.42$; $P=.044$) surface electromyography muscle activity. However, no post hoc differences between groups were found at any specific arm elevation interval. During descent, there were no significant group main effects for the upper trapezius ($F_{1,35}=.09$; $P=.766$), middle trapezius ($F_{1,34}=2.34$; $P=.135$), and infraspinatus muscles ($F_{1,36}=2.40$; $P=.130$). There were no significant interactions or group main effects, respectively, for the lower trapezius ($F_{2,36}=1.59$; $P=.212$; $F_{1,35}=.01$; $P=.957$) or serratus anterior

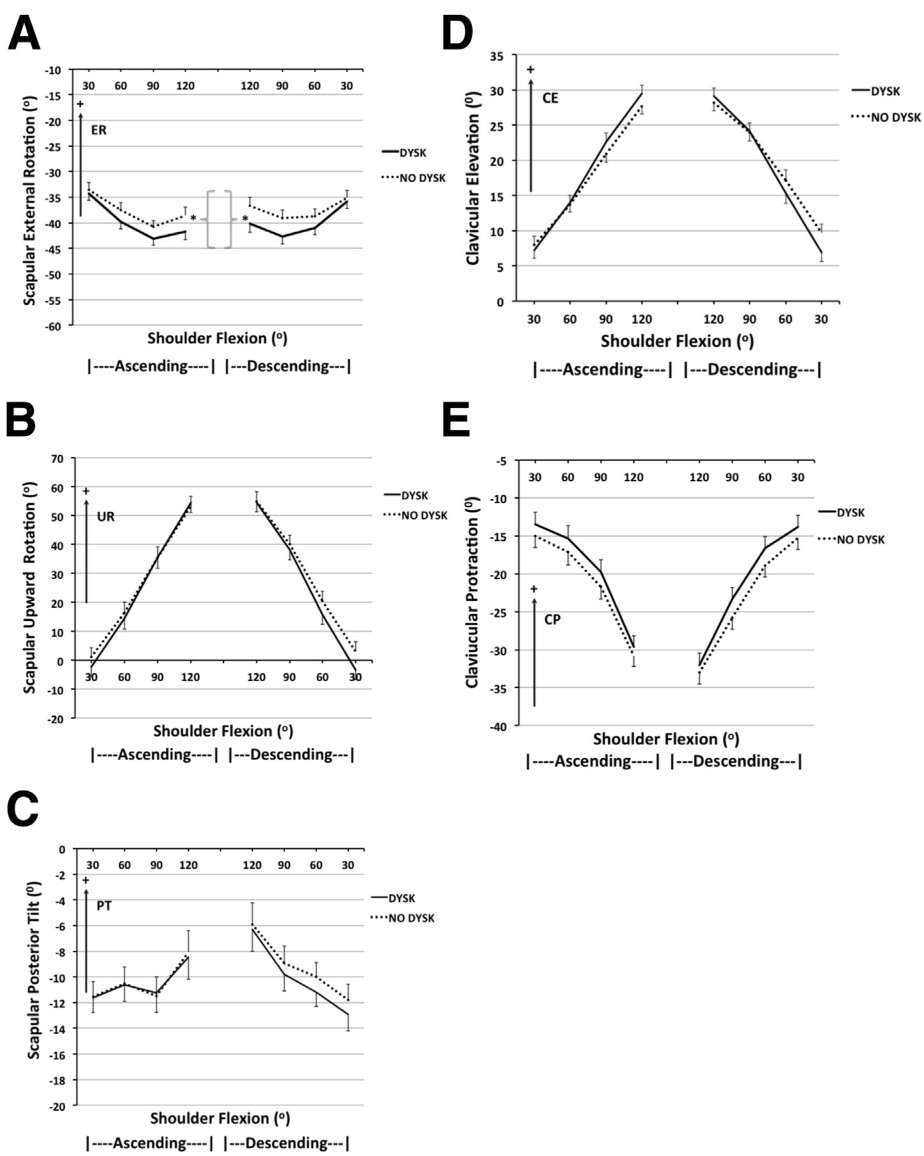

Fig 2 Mean scapular kinematics expressed as degrees at 4 arm elevation angles of weighted shoulder flexion during the ascending and descending phases in those with DYSK and NO DYSK. (A) Scapular external rotation (ER); (B) scapular upward rotation (UR); (C) scapular posterior tilt (PT); (D) clavicular elevation (CE); (E) clavicular protraction (CP). The solid line indicates the mean values for the DYSK group; dashed line, mean values for the NO DYSK group. Error bars indicate the SE. Positive directions are defined as scapular external rotation, upward rotation, and posterior tilt and clavicular elevation and protraction. *$P<.05$, main effect of group. Abbreviations: DYSK, obvious scapular dyskinesis group; NO DYSK, normal scapular motion group.

Table 5 Normalized surface electromyography muscle activity during 3 arm elevation intervals of weighted shoulder flexion

	DYSK (n=19)	NO DYSK (n=19)	DYSK (n=19)	NO DYSK (n=19)
Arm Elevation Interval	Ascending Phase		Descending Phase	
Upper trapezius				
30°–60°	29.6±3.1	17.6±3.1*	16.5±2.9	13.0±2.9
60°–90°	23.4±3.7	16.5±3.6	12.1±2.9	10.6±2.9
90°–120°	25.1±4.0	26.7±4.0	12.2±2.9	20.1±2.9
Middle trapezius				
30°–60°	9.1±2.3	13.1±2.3	5.0±1.6	6.1±1.6
60°–90°	11.9±3.2	11.4±3.2	5.5±1.6	5.1±1.6
90°–120°	11.4±3.3	18.8±3.3	6.6±1.6	13.0±1.6
Lower trapezius				
30°–60°	15.9±3.6	20.7±3.7	11.5±2.3	10.0±2.4
60°–90°	15.6±3.6	18.4±3.7	9.7±2.3	7.4±2.3
90°–120°	20.2±3.6	16.0±3.7	9.7±2.3	13.9±2.3
Serratus anterior				
30°–60°	32.2±5.4	22.5±5.5	12.5±2.8	16.5±2.9
60°–90°	34.0±5.5	37.6±5.5	19.5±4.1	19.7±4.1
90°–120°	33.7±5.4	46.0±5.5	21.9±5.4	35.9±5.5
Infraspinatus				
30°–60°	10.7±2.3	15.8±2.3	7.5±1.5	8.4±1.5
60°–90°	12.8±2.9	10.8±2.9	6.0±1.2	4.5±1.2
90°–120°	16.3±2.7	18.7±2.7	7.2±1.7	13.1±1.7

NOTE. Values are mean ± SE. Values are expressed as percentage of the reference contraction.
Abbreviations: DYSK, obvious scapular dsykinesis group; NO DYSK, normal scapular motion group.
* $P<.0125$, post hoc difference between groups in the arm elevation interval.

($F_{2,36}=1.59$; $P=.218$; $F_{1,36}=2.33$; $P=.135$) muscles in the descending phase.

Discussion

Patients with SAIS-related shoulder pain and scapular dyskinesis have reduced scapular external rotation and increased upper trapezius muscle activity during arm elevation compared with those with normal scapular motion. These differences may be compensatory strategies or causative factors. We studied 5 muscles and 5 kinematic variables but found only 2 deficits, which may be explained by the variable patterns of dyskinesis and the transient nature of the dyskinesis during arm elevation. Obvious dyskinesis does appear to adversely affect shoulder function; however, the 6.0-point lower score on the Penn function subscale was less than the MDC of 8.6 points for the subscale.[30] Because the groups differed on their Penn scores for functional loss, we performed a secondary group comparison in which the Penn scores were entered as a covariate. The results did not differ from those in which we did not control for the Penn scores, indicating that the differences in scapular external rotation and upper trapezius muscle activity were likely not caused by the differences in self-report shoulder functional loss. Clinical studies are needed to determine if correction of identified muscle and movement deficits will abolish scapular dyskinesis and improve patient-rated outcomes.

There was less scapular external rotation during arm elevation and descent in patients with obvious dyskinesis. Reduced external rotation could contribute to the development and progression of subacromial impingement or pain or result from the altered muscle activity. The motion of scapula external rotation shows more variability across subjects, planes of elevation, and degrees of arm elevation.[5,8,9] Studies[7,29] have found an increase in scapula internal rotation in patients with SAIS, whereas other studies[6,37,38] have found no differences in scapular external/internal rotation between patients with SAIS and asymptomatic individuals. The original study[16] reported that the scapular dyskinesis test did not find scapular external rotation alterations between those with and without visual dyskinesis. The mean of 2.1° to 2.5° less external rotation did surpass our threshold of 2° of clinically meaningful differences,[5,29] but it was lower than our measurement error for the external rotation variable during the 30° to 120° interval in both the ascending and descending phases (standard error of measurement=3.8°, MDC=5.4°), indicating caution. Prior studies have reported scapular internal/external rotation deficits ranging from 2.0° to 5.2°[7,29] in patients with SAIS compared with healthy controls. Our smaller differences may be clinically meaningful and may contribute to reduced self-report shoulder function found in those with obvious dyskinesis. This reduction of scapular external rotation during arm elevation may be enough to impact the available subacromial space and contribute to the symptoms of SAIS in these patients.

The middle and lower trapezius muscles control and produce scapular external rotation. Altered middle and lower trapezius muscle activity would be expected to accompany the decreased scapular external rotation if the changes in external rotation were primarily caused by altered muscular control. We found no differences in the middle and lower trapezius muscle activity. However, there was greater upper trapezius muscle activity in the obvious dyskinesis group during the 30° to 60° arm interval, which may have reduced the magnitude of the scapular external rotation in the obvious dyskinesis group.

Patients with obvious dyskinesis had 12% greater upper trapezius muscle activity. This increased upper trapezius muscle activity may be an attempt to control the dyskinesis or assist with arm elevation. Increased upper trapezius muscle activity has commonly been reported in patients with SAIS[7,11,12] who were not evaluated for dyskinesis. Greater upper trapezius muscle activity may alter the force couples among the scapula muscles necessary during arm elevation and may contribute to muscle imbalance in patients with SAIS and obvious dyskinesis. Restoration of scapular muscle balance should be emphasized in the rehabilitation of these patients. With increased upper trapezius muscle activity, kinematic changes of greater scapular upward rotation and clavicular elevation were expected, but we not find any differences. Treatment interventions of motor control and performance techniques to reduce the activity of the upper trapezius muscle during arm elevation may serve to reduce visual dyskinesis and improve function; however, clinical trials are needed to verify this hypothesis. Differences in upper trapezius muscle activity did surpass the threshold of 10% for determining clinically meaningful differences,[7] but they were lower than the MDC (14%) and should be interpreted with caution. We found no differences for the other muscles studied. Given the complex synergy that exists among the muscles of the shoulder, future studies should consider other variables (eg, muscle onset latency, muscle activation and deactivation times).

No differences between groups for the other 4 kinematic variables were found. This differs from the original validation study of the scapular dyskinesis test,[16] which found that the obvious dyskinesis group had less upward rotation and clavicular elevation and greater clavicular protraction during the ascending phase of shoulder flexion. In the original scapular dyskinesis test study,[16] participants were overhead athletes with subclinical levels of pain. The difference in participant samples is likely a main reason for the discordant findings between studies. We did not find differences between groups for scapular upward rotation, which may be because of the high variability of this measure. We expected greater clavicle elevation during the ascending phase because of our findings of higher upper trapezius muscle activity in the obvious dyskinesis group. The magnitude of clavicle elevation was higher (approximately 20°) than those reported in previous studies (approximately 10°),[6,16] which could be associated with shoulder hiking, commonly observed in patients to assist in elevating the arm to reduce shoulder pain.[11] Finally, no differences between groups were found for scapular posterior tilt, which is consistent with prior studies.[16,39]

Study limitations

The variability in pathologies that compromise the diagnostic label of SAIS may have confounded our ability to detect between-group differences. It is unclear if impingement is the sole mechanism. Rather, it is likely a complex of conditions involving a combination of intrinsic and extrinsic factors. A more descriptive label (eg, subacromial pain syndrome, anterior shoulder pain) may be more appropriate.[40] It is possible that there are subsets of scapular dyskinesis with unique kinematic patterns and muscle activity. Patients were not subgrouped for winging or dysrhythmia[15,31] because those classifications are unreliable.[31] Kinematics was assessed at only 4 arm elevation angles, which may have failed to capture the transient nature of dyskinesis that occurred at other elevation angles. Finally, the single reference contraction used to normalize the surface electromyography muscle activity may not represent the maximum level of muscle activation for all muscles tested and may have increased variability in the surface electromyography. Using a reference contraction that does not yield a maximal contraction may also restrict the ability to compare between groups and individuals or between percentage muscle activities within individuals. The use of separate maximal contractions for each muscle is a common normalization method, but it may be impractical[12] because of increased pain and fatigue associated with maximal repetitive testing. Specific positions for electing maximal contractions for the trapezius and serratus anterior muscles have been previously established.[41] However, these prior studies using muscle tests designated for maximum activation[41,42] have also found considerable variability in trapezius and serratus anterior muscle activity.

Conclusions

Modest differences in scapular kinematics and muscle activation were found in patients with SAIS and obvious scapular dyskinesis compared with those with normal scapular motion. Specifically, patients with obvious dyskinesis had less scapular external rotation and higher upper trapezius muscle activity, along with greater self-report shoulder functional loss. Further clinical studies are needed to determine if correction of the identified deficits will eliminate scapular dyskinesis and improve patient-rated outcomes.

Suppliers

a. Innovative Sports Training, Inc. 3711 N Ravenswood Ave, Chicago, IL 60613.
b. MathWorks, 3 Apple Hill Dr, Natick, MA 01760.
c. Polhemus Inc, 40 Hercules Dr, Colchester, VT 05446.
d. Bagnoli-8; Delsys Inc, 650 Beacon St, Boston, MA 02215.
e. IBM Corp, 1 New Orchard Rd, Armonk, NY 10504.

Keywords

Electromyography; Rehabilitation; Scapula; Shoulder impingement syndrome

Corresponding author

Andrea Diniz Lopes, DSc, Research Support, Center for Clinical Outcomes Studies, A.T. Still University, 5850 E Still Circle, Mesa, AZ 85206. *E-mail address:* alopes@atsu.edu.

Lori A. Michener, PhD, PT, ATC, Division of Biokinesiology and Physical Therapy, University of Southern California, 1540 E Alcazar St, CHP 155, Los Angeles, CA 90089. *E-mail address:* lmichene@usc.edu.

Acknowledgment

We thank R. Curtis Bay, PhD, Biostatistician, for his assistance with the data analysis.

References

1. van der Windt DA, Koes BW, de Jong BA, Bouter LM. Shoulder disorders in general practice: incidence, patient characteristics, and management. Ann Rheum Dis 1995;54:959-64.

2. Chard MD, Hazleman R, Hazleman BL, King RH, Reiss BB. Shoulder disorders in the elderly: a community survey. Arthritis Rheum 1991; 34:766-9.
3. Vecchio P, Kavanagh R, Hazleman BL, King RH. Shoulder pain in a community-based rheumatology clinic. Br J Rheumatol 1995;34:440-2.
4. Michener LA, McClure PW, Karduna AR. Anatomical and biomechanical mechanisms of subacromial impingement syndrome. Clin Biomech (Bristol, Avon) 2003;18:369-79.
5. Timmons MK, Thigpen CA, Seitz AL, Karduna AR, Arnold BL, Michener LA. Scapular kinematics and subacromial-impingement syndrome: a meta-analysis. J Sport Rehabil 2012;21:354-70.
6. McClure PW, Michener LA, Karduna AR. Shoulder function and 3-dimensional scapular kinematics in people with and without shoulder impingement syndrome. Phys Ther 2006;86:1075-90.
7. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys Ther 2000;80:276-91.
8. McClure PW, Michener LA, Sennett BJ, Karduna AR. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. J Shoulder Elbow Surg 2001;10:269-77.
9. Ludewig PM, Phadke V, Braman JP, Hassett DR, Cieminski CJ, LaPrade RF. Motion of the shoulder complex during multiplanar humeral elevation. J Hand Surg [Am] 2009;91:378-89.
10. Ludewig PM, Cook TM, Nawoczenski DA. Three-dimensional scapular orientation and muscle activity at selected positions of humeral elevation. J Orthop Sports Phys Ther 1996;24:57-65.
11. Cools AM, Declercq GA, Cambier DC, Mahieu NN, Witvrouw EE. Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. Scand J Med Sci Sports 2007;17:25-33.
12. Chester R, Smith TO, Hooper L, Dixon J. The impact of subacromial impingement syndrome on muscle activity patterns of the shoulder complex: a systematic review of electromyographic studies. BMC Musculoskelet Disord 2010;11:45.
13. Diederichsen LP, Norregaard J, Dyhre-Poulsen P, et al. The activity pattern of shoulder muscles in subjects with and without subacromial impingement. J Electromyogr Kinesiol 2009;19:789-99.
14. Kibler WB, Ludewig PM, McClure PW, Michener LA, Bak K, Sciascia AD. Clinical implications of scapular dyskinesis in shoulder injury: the 2013 consensus statement from the 'Scapular Summit'. Br J Sports Med 2013;47:877-85.
15. McClure P, Tate AR, Kareha S, Irwin D, Zlupko E. A clinical method for identifying scapular dyskinesis, part 1: reliability. J Athl Train 2009;44:160-4.
16. Tate AR, McClure P, Kareha S, Irwin D, Barbe MF. A clinical method for identifying scapular dyskinesis, part 2: validity. J Athl Train 2009; 44:165-73.
17. Michener LA, Walsworth MK, Doukas WC, Murphy KP. Reliability and diagnostic accuracy of 5 physical examination tests and combination of tests for subacromial impingement. Arch Phys Med Rehabil 2009;90:1898-903.
18. Kessel L, Watson M. The painful arc syndrome. Clinical classification as a guide to management. J Hand Surg [Br] 1977;59:166-72.
19. Leroux JL, Thomas E, Bonnel F, Blotman F. Diagnostic value of clinical tests for shoulder impingement syndrome. Rev Rhum Engl Ed 1995;62:423-8.
20. Neer CS 2nd. Impingement lesions. Clin Orthop 1983;173:70-7.
21. Hawkins RJ, Kennedy JC. Impingement syndrome in athletes. Am J Sports Med 1980;8:151-8.
22. Jobe FW, Moynes DR. Delineation of diagnostic criteria and a rehabilitation program for rotator cuff injuries. Am J Sports Med 1982;10: 336-9.
23. Maitland GD. Vertebral manipulation. London: Butterworth Heinemann; 1986.
24. Calis M, Akgun K, Birtane M, Karacan I, Calis H, Tuzun F. Diagnostic values of clinical diagnostic tests in subacromial impingement syndrome. Ann Rheum Dis 2000;59:44-7.
25. Hertel R, Ballmer FT, Lombert SM, Gerber C. Lag signs in the diagnosis of rotator cuff rupture. J Shoulder Elbow Surg 1996;5:307-13.
26. Gerber C, Krushell RJ. Isolated rupture of the tendon of the subscapularis muscle. Clinical features in 16 cases. J Hand Surg [Br] 1991;73:389-94.
27. Vandenbroucke JP, von Elm E, Altman DG, et al. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): explanation and elaboration. PLoS Med 2007;4:e297.
28. Ebaugh DD, McClure PW, Karduna AR. Effects of shoulder muscle fatigue caused by repetitive overhead activities on scapulothoracic and glenohumeral kinematics. J Electromyogr Kinesiol 2006;16:224-35.
29. Hebert LJ, Moffet H, McFadyen BJ, Dionne CE. Scapular behavior in shoulder impingement syndrome. Arch Phys Med Rehabil 2002;83:60-9.
30. Leggin BG, Michener LA, Shaffer MA, Brenneman SK, Iannotti JP, Williams GR Jr. The Penn shoulder score: reliability and validity. J Orthop Sports Phys Ther 2006;36:138-51.
31. Uhl TL, Kibler WB, Gecewich B, Tripp BL. Evaluation of clinical assessment methods for scapular dyskinesis. Arthroscopy 2009;25: 1240-8.
32. Karduna AR, McClure PW, Michener LA, Sennett B. Dynamic measurements of three-dimensional scapular kinematics: a validation study. J Biomech Eng 2001;123:184-90.
33. McClure PW, Bialker J, Neff N, Williams G, Karduna A. Shoulder function and 3-dimensional kinematics in people with shoulder impingement syndrome before and after a 6-week exercise program. Phys Ther 2004;84:832-48.
34. Wu G, van der Helm FC, Veeger HE, et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand. J Biomech 2005;38:981-92.
35. Cram JR, Kasman GS. Introduction to surface electromyography. Gaithersburg: Aspen Publishers; 1998.
36. Criswell E. Instrumentation. In: Criswell E, Cram JR, editors. Cram's introduction to surface electromyography. Sudbury: Jones and Bartlett; 2011. p 49-51.
37. Lukasiewicz AC, McClure P, Michener L, Pratt N, Sennett B. Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement. J Orthop Sports Phys Ther 1999;29:574-83; discussion 84-6.
38. Endo K, Ikata T, Katoh S, Takeda Y. Radiographic assessment of scapular rotational tilt in chronic shoulder impingement syndrome. J Orthop Sci 2001;6:3-10.
39. Seitz AL, McClure PW, Lynch SS, Ketchum JM, Michener LA. Effects of scapular dyskinesis and scapular assistance test on subacromial space during static arm elevation. J Shoulder Elbow Surg 2012;21:631-40.
40. Braman JP, Zhao KD, Lawrence RL, Harrison AK, Ludewig PM. Shoulder impingement revisited: evolution of diagnostic understanding in orthopedic surgery and physical therapy. Med Biol Eng Comput 2014;52:211-9.
41. Ekstrom RA, Soderberg GL, Donatelli RA. Normalization procedures using maximum voluntary isometric contractions for the serratus anterior and trapezius muscles during surface EMG analysis. J Electromyogr Kinesiol 2005;15:418-28.
42. Michener LA, Boardman ND, Pidcoe PE, Frith AM. Scapular muscle tests in subjects with shoulder pain and functional loss: reliability and construct validity. Phys Ther 2005;85:1128-38.