Research Report

Shoulder Function and 3-Dimensional Scapular Kinematics in People With and Without Shoulder Impingement Syndrome

Background and Purpose. Several factors such as posture, muscle force, range of motion, and scapular dysfunction are commonly believed to contribute to shoulder impingement. The purpose of this study was to compare 3-dimensional scapular kinematics, shoulder range of motion, shoulder muscle force, and posture in subjects with and without primary shoulder impingement syndrome. **Subjects.** Forty-five subjects with impingement syndrome were recruited and compared with 45 subjects without known pathology or impairments matched by age, sex, and hand dominance. **Methods.** Shoulder motion and thoracic spine posture were measured goniometrically, and force was measured with a dynamometer. An electromagnetic motion analysis system was used to capture shoulder kinematics during active elevation in both the sagittal and scapular planes as well as during external rotation with the arm at 90 degrees of elevation in the frontal plane. **Results.** The impingement group demonstrated slightly greater scapular upward rotation and clavicular elevation during flexion and slightly greater scapular posterior tilt and clavicular retraction during scapular-plane elevation compared with the control group. The impingement group demonstrated less range of motion and force in all directions compared with the control group. There were no differences in resting posture between the groups. **Discussion and Conclusion.** The kinematic differences found in subjects with impingement may represent scapulothoracic compensatory strategies for glenohumeral weakness or motion loss. The decreased range of motion and force found in subjects with impingement support rehabilitation approaches that focus on strengthening and restoring flexibility. [McClure PW, Michener LA, Karduna AR. Shoulder function and 3-dimensional scapular kinematics in people with and without shoulder impingement syndrome. *Phys Ther.* 2006;86:1075–1090.]

Key Words: *Exercise, Force production, Impingement, Kinematics, Scapula, Shoulder.*

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What problems did the researchers set out to study, and why?
Various factors have been proposed to contribute to subacromial impingement syndrome (SAIS) of the shoulder, many of which (eg, abnormal acromial morphology) cannot be modified through physical therapy intervention. In this study, researchers sought to compare several factors thought to be modifiable with rehabilitation in people with and without SAIS. These factors included kinematics of the scapula, shoulder range of motion, shoulder muscle force, and both upper thoracic spine and shoulder resting posture.

Who participated in the study?
Forty-five subjects with impingement syndrome (SAIS group) and 45 matched subjects without known shoulder pathology or impairment (control group). Subjects were matched by age, sex, and hand dominance.

What new information does this study offer?
Many researchers have studied the scapular kinematics in patients with SAIS, but results of these studies to date have been largely variable. The results of previous studies may be limited, however, because often control subjects were included who were not matched to the subjects with SAIS, or because the studies compared shoulder motion of the affected shoulder to the asymptomatic side only. In addition, prior studies of scapular kinematics typically have not examined the shoulder for other potential concomitant impairments, such as abnormal isometric force production, range of motion, or spinal or scapular posture. The current study included a matched control group as well as measurements of several physical characteristics of patients with SAIS.

How did the researchers go about the study?
All subjects were examined with the following tests and measures: (1) goniometric measurement of shoulder range of motion, (2) assessment of upper thoracic spine and scapular resting posture, (3) measurement of shoulder isometric muscle force with a handheld dynamometer, and (4) assessment of shoulder kinematics with an electromagnetic motion analysis system during 3 active shoulder motions (shoulder flexion, scapular plane elevation, and external rotation at 90 degrees of abduction).

What did the researchers find?
There were no differences in resting posture between the subjects with and without SAIS. The SAIS group demonstrated less range of motion of the shoulder in all directions assessed, and less isometric muscle force for shoulder external rotation and scapular plane elevation. Finally, subjects with SAIS demonstrated slightly greater upward rotation of the scapula and elevation of the clavicle with shoulder flexion and slightly more posterior tilt and retraction of the clavicle with scapular plane elevation compared with those who did not have SAIS.

How might the results of this study apply to patients who are treated by physical therapists from this point forward?
As the authors theorize, the limited mobility and decreased shoulder muscle force identified in the SAIS group may support the use of interventions designed to improve shoulder strength and mobility. In addition, the authors propose that the kinematic differences identified between the two groups of subjects may represent compensatory scapulothoracic movement strategies, possibly as a result of weakness of the shoulder musculature or loss of mobility of the shoulder. Although the potential clinical implications of these small kinematic differences between groups are yet to be determined, identification of these findings could possibly lead clinicians to address impairments in strength, range of motion, or motor control that are hypothesized to contribute to the altered kinematics of the shoulder girdle.

What are the limitations of the study, and what further research is needed?
Several limitations can be identified in this study. First, all measurements of range of motion, muscle force, and kinematics were performed by a single examiner who was not blind to group assignment, which could lead to examiner bias. Second, the average differences between groups for the kinematic measures were small, ranging from 2.9 to 3.8 degrees. These small differences might not be detectable in a standard clinical environment—and might not be clinically relevant. Further research is needed to determine whether a management strategy that specifically addresses the identified impairments of reduced muscle force, range of motion, and altered kinematics results in greater improvements in pain, activity, and participation than competing noninvasive management strategies.

[McClure PW, Michener LA, Karduna AR. Shoulder function and 3-dimensional scapular kinematics in people with and without shoulder impingement syndrome. *Phys Ther.* 2006;86:1075–1090.]

Summarized by Julie M Whitman, PT, DSc, OCS, FAAOMPT, Assistant Professor, Department of Physical Therapy, Regis University, Denver, Colo.

The concept of shoulder subacromial impingement syndrome (SAIS) was introduced by Neer[1] in 1972 and represents mechanical compression of the rotator cuff, subacromial bursa, and biceps tendon against the anterior undersurface of the acromion and coracoacromial ligament, especially during elevation of the arm. Neer stated that as many as 95% of all rotator cuff tears could be attributed to mechanical impingement. More recently, the impingement concept has been challenged. Budoff et al[2] estimated that 90% to 95% of rotator cuff abnormalities could be attributed to intrinsic breakdown of the rotator cuff tendons because of tension overload, overuse, and traumatic injury rather than direct mechanical compression. Although some researchers currently question whether mechanical impingement is the primary mechanism producing injury to the subacromial tissues,[2] most authors acknowledge that it is at least a factor associated with rotator cuff pathology.[3,4] Despite the controversy over etiology, "shoulder subacromial impingement syndrome" is a broad term that likely encompasses a spectrum of pathology involving the rotator cuff, biceps tendon, and subacromial bursa. Shoulder subacromial impingement syndrome is believed to be the most common cause of shoulder pain, accounting for 44% to 65% of all complaints of shoulder pain during a physician's office visit.[5–7]

Impingement is believed to be part of the process involved in degeneration of the rotator cuff; therefore, early identification of modifiable physical factors associated with impingement would be highly desirable. Multiple factors have been proposed to contribute to the development of SAIS, and we previously reviewed these factors in detail.[3] These factors include abnormal acromial morphology,[4,8] aberrant kinematic patterns associated with altered rotator cuff or scapular muscle function,[9–12] capsular abnormalities (including posterior capsular tightness as well as capsular laxity),[13–16] poor posture,[17–19] and overuse secondary to repetitive eccentric loading or sustained use of the arm above 90 degrees of elevation.[2,20–22]

Several investigators[10,11,23–25] have studied scapular kinematics during arm elevation in patients with SAIS. These studies have included several methods of capturing scapular motion, including moiré topography, electromechanical digitization, radiographic methods, magnetic resonance imaging, and electromagnetic tracking devices. The findings from these studies related to patients with SAIS have been mixed, with some studies demonstrating less posterior tilt[10,11,25] and less upward rotation of the scapula[10,11] and others reporting no differences[24] or greater external rotation of the scapula.[23] One limitation for most of these studies is that control subjects were not specifically matched to subjects with impingement, and one study[25] compared shoulder motion for the symptomatic side only to the asymptomatic side of the same subjects. In addition, few of the previous studies of scapular kinematics provided a strong link between kinematic differences and physical impairments that might help explain differences such as deficient muscle force or shoulder range of motion (ROM). Given the variability of findings and the limited scope of previous studies, we chose to investigate the physical characteristics of patients with shoulder impingement further.

For this study, we chose to focus on factors that are believed to be directly modifiable with physical rehabil-

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This study was approved by the institutional review boards of Arcadia University and Drexel University (formerly Allegheny University of Health Sciences).

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Foundation for Physical Therapy

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Table 1.
Subject Characteristics

Variable	Control Subjects (n=45) $\overline{X}$ (SD)[a]	Range	Subjects With Impingement (n=45) $\overline{X}$ (SD)[a]	Range
Age (y)	43.6 (12.4)	26–74	45.2 (12.8)	24–74
Height (cm)	172.0 (10.2)	155–196	171.7 (9.4)	155–194
Weight (kg)	75.3 (17.5)	45–113	79.9 (17.2)	51–136
Sex	21 F, 24 M		21 F, 24 M	
Dominant side	38 R, 7 L		38 R, 7L	
Pain (0–10; 0=no pain)			3.7 (2.3)	0–9.3
Function (50 points possible; 50=no functional loss)			29.8 (9.1)	6.7–43.3

[a] Sex is reported as number of females (F) or males (M), and dominant side is reported as number of subjects with right-side dominance (R) or left-side dominance (L).

itation. The specific purpose of this study was to compare several physical factors between a group of symptomatic subjects with clinical signs of primary SAIS and an age- and sex-matched control group of subjects without shoulder pain. The specific factors that we chose to compare were: 3-dimensional scapular kinematics during arm elevation, shoulder ROM, shoulder muscle force, and thoracic spine and shoulder resting posture. We hypothesized that, compared with subjects without SAIS, subjects with SAIS would show altered scapular kinematics, decreased shoulder ROM and shoulder muscle force, and increased forward shoulder and thoracic spine flexion.

Method

Subjects

Forty-five subjects seeking care for shoulder pain and diagnosed with SAIS were recruited from a university-based orthopedic practice. Additionally, 45 control subjects without known pathology or impairments were recruited and matched with regard to sex, age (within 5 years), and hand dominance from the university and surrounding community as well as through personal contacts of the investigators. The basic descriptive characteristics of the subjects are given in Table 1. Additionally, to further characterize the subjects with impingement, pain and function, as measured with the self-report section of the American Shoulder and Elbow Surgeons Self-Report Form,[26] were reported. Pain was measured with a 10-cm visual analog scale anchored by "no pain" and "pain as bad as it can be." Function was derived from 10 function-related questions scored on a 4-point Likert scale and converted to a score out of a maximum of 50 points representing full function. Two subjects had had symptoms for less than 1 month, 14 had had symptoms for between 1 and 3 months, 12 had had symptoms for between 3 and 6 months, and 17 had had symptoms for greater than 6 months.

The diagnosis of SAIS was made initially by the referring physician and was confirmed by the physical therapist who performed the initial examination (LAM). To be classified as having SAIS, subjects had to demonstrate at least 3 of the following: positive Neer impingement test, positive Hawkins impingement test, pain with active shoulder elevation, pain with palpation of the rotator cuff tendons, pain with isometric resisted abduction, and pain in the C5 or C6 dermatome region. Subjects were excluded if they demonstrated signs of a complete rotator cuff tear or acute inflammation. Signs of a complete tear were gross weakness in abduction or lateral rotation, as evidenced by a 50% or greater deficit (relative to the uninvolved arm) in isometric force measured with a handheld dynamometer, or positive magnetic resonance imaging findings for a full-thickness rotator cuff tear from a previous diagnostic evaluation. Signs of acute inflammation were severe resting pain or severe pain reported during either the Neer or the Hawkins impingement test or during isometric resisted abduction. Additionally, subjects who were judged to have cervical spine–related symptoms, glenohumeral instability (positive apprehension, anterior drawer, or sulcus test), or previous shoulder surgery were excluded. The study was explained to all subjects who met the criteria, and they were asked to read and sign the informed consent agreement approved by the university institutional review boards.

Instrumentation and Measurement Procedures

Four basic types of measurements were collected: 3-dimensional scapular kinematics, shoulder ROM, shoulder muscle force, and resting posture.

Three-dimensional scapular kinematics. The Polhemus 3SPACE FASTRAK* is an electromagnetic motion analysis system that was used for collecting 3-dimensional kinematic data on the shoulder complex. A transmitter mounted on a fixed base emits a signal that is detected by receivers attached to bony segments of interest. The receivers serve as sensors to capture the position and orientation of each segment. The details of the instrumentation and sensor attachments and the error associ-

* Polhemus Inc, 40 Hercules Dr, Colchester, VT 05446.

ated with these measurements have been described elsewhere.[27–29]

Subjects stood with their feet a comfortable width apart, their heels aligned with a piece of tape on the floor, and their elbows extended. This position was maintained throughout the digitization and testing procedures. The transmitter served as a global reference frame and was fixed to a rigid plastic base and oriented such that it was level and its coordinate axes were aligned with the cardinal planes of the human body. The thoracic sensor was placed on the thorax at T3 with double-sided tape. The humeral receiver was positioned on the distal humerus with an appropriately sized, molded thermoplastic cuff secured with elastic straps. The scapular receiver was positioned on the scapula with a custom-made, adjustable scapular tracking jig machined from plastic and attached to the skin with Velcro adhesive fasteners.[†,28]

The arbitrary axis systems defined by the Polhemus 3SPACE FASTRAK were converted to anatomically appropriate axis systems by use of a series of standardized axes embedded in each segment.[30] These axis systems were derived from a series of points on each segment that were palpated and individually digitized with a handheld probe and that have been described in detail elsewhere.[27,28] With these frames established, the raw data from the Polhemus system were converted to anatomically defined rotations and displayed with a custom-made software program written in LabView data acquisition software.[‡]

Three scapular rotations were used to describe scapular orientation, and 2 clavicular rotations were used to describe scapular position. The 3 scapular rotations were defined with a Euler axis sequence (external rotation, upward rotation, and posterior tilting).[31] The scapular rotations are depicted in Figures 1A to 1C (anterior and posterior tilting, upward and downward rotation, and internal and external rotation). Because the distance between the scapula and the thorax is constrained by the clavicle (assuming no translation at the sternoclavicular or acromioclavicular joint), the position of the scapula is restricted to only 2 degrees of freedom and can be represented by the rotational motion of the clavicle: elevation and depression and retraction and protraction (Figs. 1D and 1E). This method is equivalent to describing the position of a point on the earth with the use of 2 angles: longitude and latitude. Clavicular motion was not monitored directly; rather, clavicular angles were derived from the location of the sternal notch and the acromioclavicular joint, which were tracked with the thoracic and the scapular receivers, respectively. The average root-mean-square errors were below 5 degrees for all rotations when compared with data from sensors mounted directly on the scapula with bone pins.[28] The majority of the error with this method occurs above 120 degrees of humeral elevation.

After mounting of the receivers and digitization of the appropriate landmarks, 3 primary test motions were actively performed: scapular plane elevation (scaption), flexion in the sagittal plane, and humeral external rotation starting with the arm internally rotated and elevated to 90 degrees in the coronal plane. To ensure the proper plane of elevation during active movements, the tester monitored online data from the Polhemus system. During elevation, subjects were instructed to keep their thumbs pointing toward the ceiling and to elevate their arms at a rate such that full elevation was accomplished over approximately 3 seconds. Lowering was performed at the same rate. For each test motion, 3 complete cycles of movement were carried out while data were collected continuously at a rate of approximately 16 Hz. Subsequent to data collection, data were averaged from the 3 cycles, and a linear interpolation scheme was used to obtain data at 5-degree increments of humeral motion. Each scapular or clavicular rotation was plotted against the corresponding humerothoracic motion (elevation or rotation). Only the symptomatic arm was tested in subjects with SAIS, and the corresponding arm was tested in control subjects. In each group, 38 subjects were right hand dominant, and 7 subjects were left hand dominant. In each group, the dominant side was tested in 24 subjects, and the non-dominant side was tested in 21 subjects. The same tester performed all measurements (LAM). The tester was not unaware of group assignment, but bias was minimized by the fact that a different researcher (PWM) completed kinematic data reduction and processing after the actual test session. To describe motion for the group, the interpolated data from all subjects were pooled, and a single curve for each test motion and each scapular or clavicular rotation was plotted.

Shoulder ROM, shoulder muscle force, and resting posture. Active ROM of glenohumeral joint flexion, abduction, and external and internal rotations with the glenohumeral joint at 90 degrees of abduction were measured with a standard plastic goniometer. The average of 2 measurements was used for data analysis. To specifically assess for posterior capsular tightness, passive internal rotation was measured with the subject's shoulder in 90 degrees of forward flexion and the elbow flexed to 90 degrees. The scapula was stabilized by the examiner applying an inferiorly directed force to the acromion and lateral aspect of the scapular spine. Next, the

† Velcro USA Inc, 406 Brown Ave, Manchester, NH 03103.

‡ National Instruments Corp, 11500 N Mopac Expressway, Austin, TX 78759-3504.

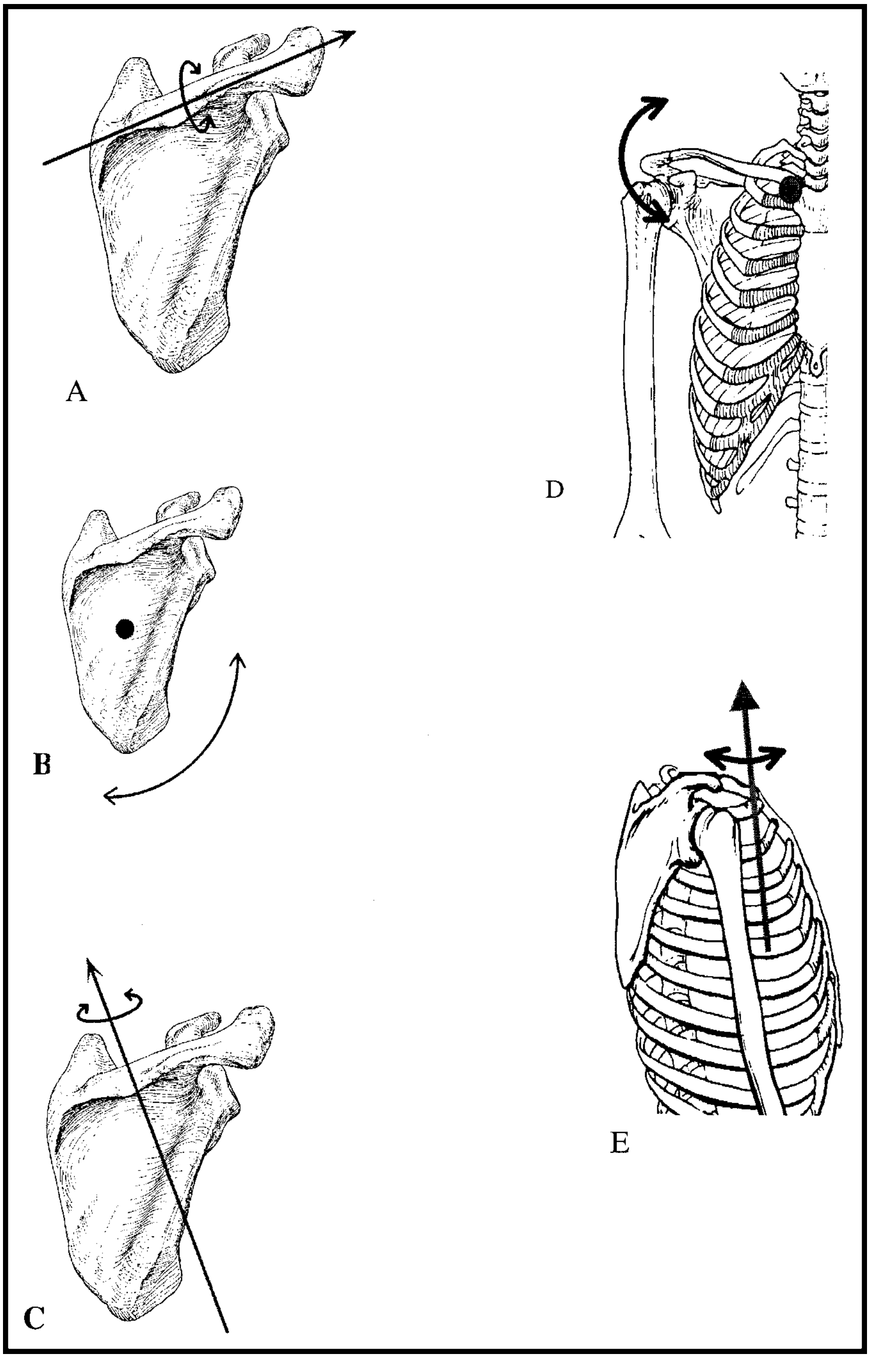

Figure 1.
Individual axes and rotations used to describe scapular orientation and position. (A) Scapular posterior tilting. Negative or decreasing values represent anterior tilting. (B) Scapular upward rotation. Negative or decreasing values represent downward rotation. (C) Scapular external rotation. Decreasing values represent scapular internal rotation. Because the scapula remains internally rotated relative to the frontal plane of the thorax, these values remain negative. (D) Clavicular elevation. Negative or decreasing values represent clavicular depression. (E) Clavicular protraction. Decreasing values represent retraction. Because the clavicle tends to remain retracted relative to the frontal plane of the thorax, these values typically remain negative. Reprinted with permission of the American Physical Therapy Association from: McClure PW, Bialker J, Neff N, et al. Shoulder function and 3-dimensional kinematics in people with shoulder impingement syndrome before and after a 6-week exercise program. *Phys Ther.* 2004;84:832–848.

humerus was internally rotated passively until the examiner detected resistance to further movement, and humeral internal rotation was measured in degrees with a gravity inclinometer placed on the posterior aspect of the forearm, just proximal to the ulnar styloid process. The average of 3 consecutive measures was used for data analysis. The between-day intrarater reliability of ROM measurements was established with 12 control subjects and was found to be satisfactory, with intraclass correlation coefficients (ICC[3,k]) ranging from .84 to .93.

Force was assessed with the "break test method," in which the subject resisted the prescribed motion until the examiner overcame the subject's isometric contraction.[32] A Nicolas handheld dynamometer[§] was used to measure the resistance (in kilograms) by placing the dynamometer and the examiner's forearm perpendicular to the subject's arm, just proximal to the ulnar styloid process. Three tests that have been demonstrated to reflect the performance of the rotator cuff muscles were performed with the subject seated and the trunk stabilized: shoulder external rotation in neutral at 0 degrees of elevation, shoulder internal rotation in neutral at 0 degrees of elevation, and shoulder abduction at 90 degrees of elevation and 40 degrees anterior to the frontal plane and neutral shoulder rotation.[33] The average of 3 consecutive measurements was used for data analysis. The between-day intrarater reliability of force measurements was established with 12 control subjects and was found to be satisfactory, with ICC(3,k) values ranging from .81 to .94.

The posture of the thoracic spine in the sagittal plane was measured in a relaxed standing position. A gravity inclinometer was centered at the level of the spinous process of the third thoracic vertebra (T3), with contact of the inclinometer maintained over T3 and superior to T3 during the measure-

[§] Lafayette Instruments, Sagamore Pkwy North, PO Box 57293700, Lafayette, IN 47903.

ment. The average of 3 measurements was used for data analysis. The between-day intrarater reliability of data obtained with this method was established with 12 control subjects and was found to be satisfactory, with an ICC(3,k) of .95. Forward shoulder posture was measured in a relaxed standing position. In order to standardize the test position, each subject was asked to place the heels and back against the wall and then lean the head back against the wall by extending the cervical spine until the head touched the wall. Forward shoulder posture was measured in this position by placing a carpenter square against the wall to measure the perpendicular distance from the wall to the posterior angle of the acromion.[34] The average of 3 consecutive measurements was used for data analysis. The between-day intrarater reliability of data obtained with this method was established with 12 control subjects and was found to be excellent, with an ICC(3,k) of .90. All measurements of kinematics, force, ROM, and posture were taken by one examiner (LAM), who was aware of group assignments.

Data Analysis

Descriptive statistics were computed for all variables. For scapular kinematic data, plots of group data were generated for each scapular or clavicular rotation with humerothoracic motion as the independent variable plotted on the horizontal axis. To compare motions between groups, we used a 2-way analysis of variance (group × angle) with group as the between-subjects factor and angle as the repeated factor. When significant group × angle interactions were found, follow-up *post hoc t* tests were conducted to compare groups at specific angles of humerothoracic motion. For flexion and scaption, humerothoracic angles of 60, 90, and 120 degrees were assessed, and for humeral external rotation, angles of 0, 25, and 50 degrees were assessed. For ROM, force, and posture measures, independent *t* tests were used to compare groups. A type I error value was set at .05 for all statistical tests.

Results

Plots describing the scapular and clavicular rotations are shown in Figures 2 and 3 for humerothoracic flexion and scaption, respectively. Both groups demonstrated the same general pattern of motion during humerothoracic elevation that was found previously.[11,29] Specifically, with increasing angles of humerothoracic elevation, subjects demonstrated scapular posterior tilting, upward rotation, and external rotation with clavicular elevation and retraction.

A summary of the analyses of variance and follow-up *t* tests for flexion, scaption, and humeral external rotation are shown in Table 2. During flexion, no group × angle interaction or main effect for group was found for scapular posterior tilting, external rotation, or clavicular protraction; this result indicated similar patterns between groups for these motions. There was an interaction effect for upward rotation and clavicular elevation; this result indicated greater upward rotation and clavicular elevation in the impingement group. *Post hoc* analysis revealed that statistically significant group differences were found at 90 and 120 degrees of flexion for both motions. The average differences between groups at these 2 angles were 4.9 degrees for upward rotation and 2.9 degrees for clavicular elevation.

During scaption, no group × angle interaction or main effect for group was found for scapular external rotation or clavicular elevation; this result indicated similar patterns between groups for these motions. There was a significant interaction effect for posterior tilting, upward rotation, and clavicle protraction; this result indicated greater posterior tilt, upward rotation, and clavicular retraction (negative protraction) in the impingement group. *Post hoc* analysis revealed that group differences for posterior tilt and clavicular retraction were statistically significant at 120 degrees, whereas group differences for upward rotation were significant at 90 degrees. The actual differences between groups at 120 degrees of scaption were 3.3 degrees for posterior tilting, 3.1 degrees for clavicular retraction, and 3.8 degrees for upward rotation.

Figure 4 shows scapular and clavicular rotations while the humerus moved from internal to external rotation with the arm abducted to horizontal. During humeral external rotation, the scapula demonstrated posterior tilting, upward rotation, and external rotation with some clavicular retraction and no clavicular elevation. There were no significant group × angle interactions or main effects for group for any of these motions; these results indicated that the 2 groups showed similar scapular and clavicular motions.

Group comparisons for ROM, force, and thoracic spine and forward shoulder resting posture are shown in Table 3. The impingement group showed significantly less ROM and less force for all measures compared with the control group. No significant differences were found between the groups for either upper thoracic spine or forward shoulder resting posture.

Discussion

This observational, cross-sectional comparison group study provides information describing impairments, scapular kinematics, and functional loss in subjects with SAIS compared with age- and sex-matched subjects without SAIS. We found only modest differences between the groups in scapular and clavicular kinematics, clear differences between the groups in shoulder ROM and

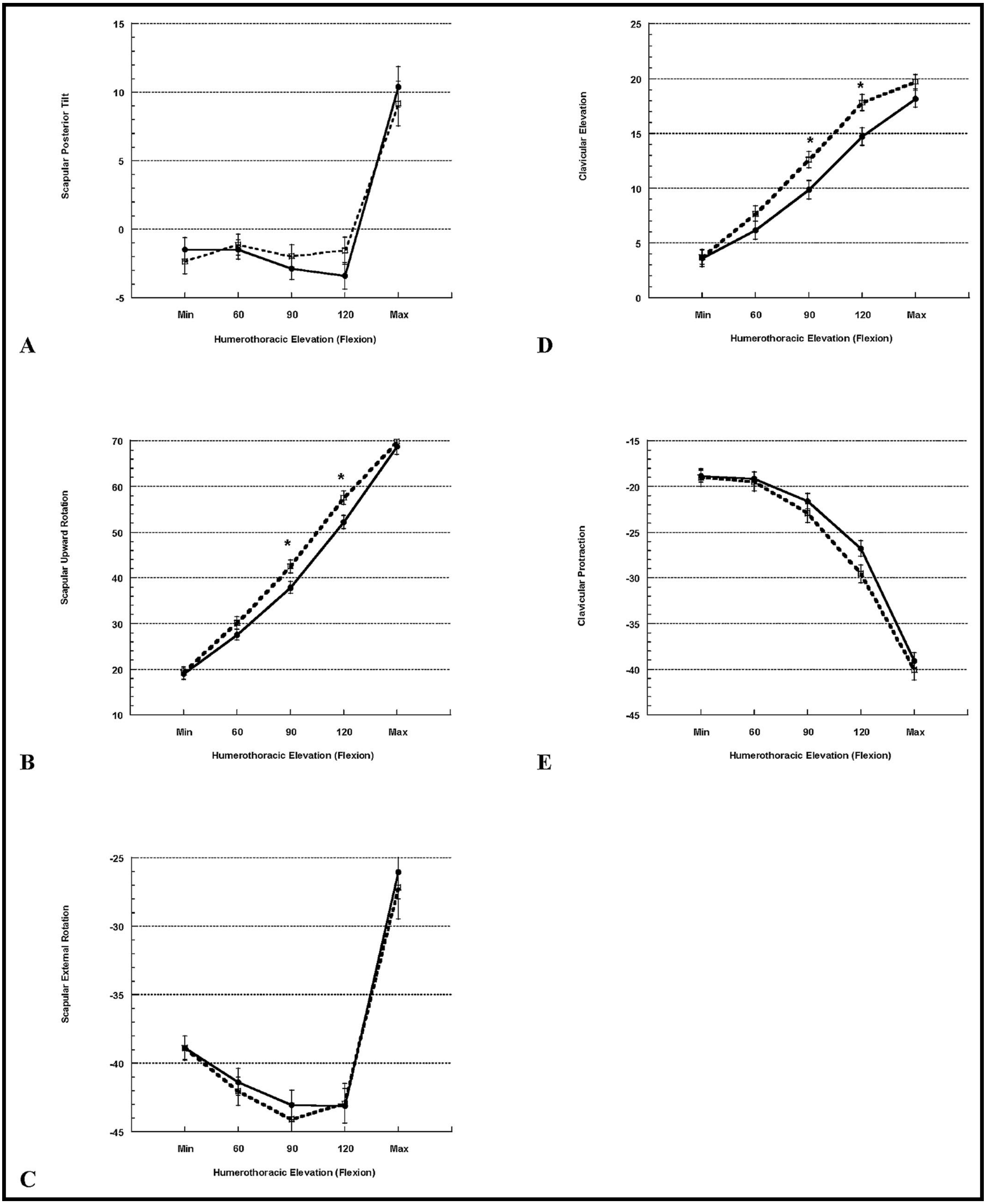

Figure 2.
Mean scapular and clavicular rotations during humerothoracic flexion. Error bars represent SEs. The solid line represents control subjects, and the dashed line represents subjects with impingement. Max=mean peak flexion for each group: 155.5 degrees (SD=9.2) for control subjects and 148.1 degrees (SD=15.4) for subjects with impingement. Three subjects with impingement did not reach 120 degrees for flexion; therefore, the values at 120 degrees and Max are based on 42 subjects from each group. (A) Posterior tilting. (B) Upward rotation. (C) External rotation. (D) Clavicular elevation. (E) Clavicular protraction (clavicular retraction is represented by decreasing values). An asterisk indicates a *P* value of $<.05$.

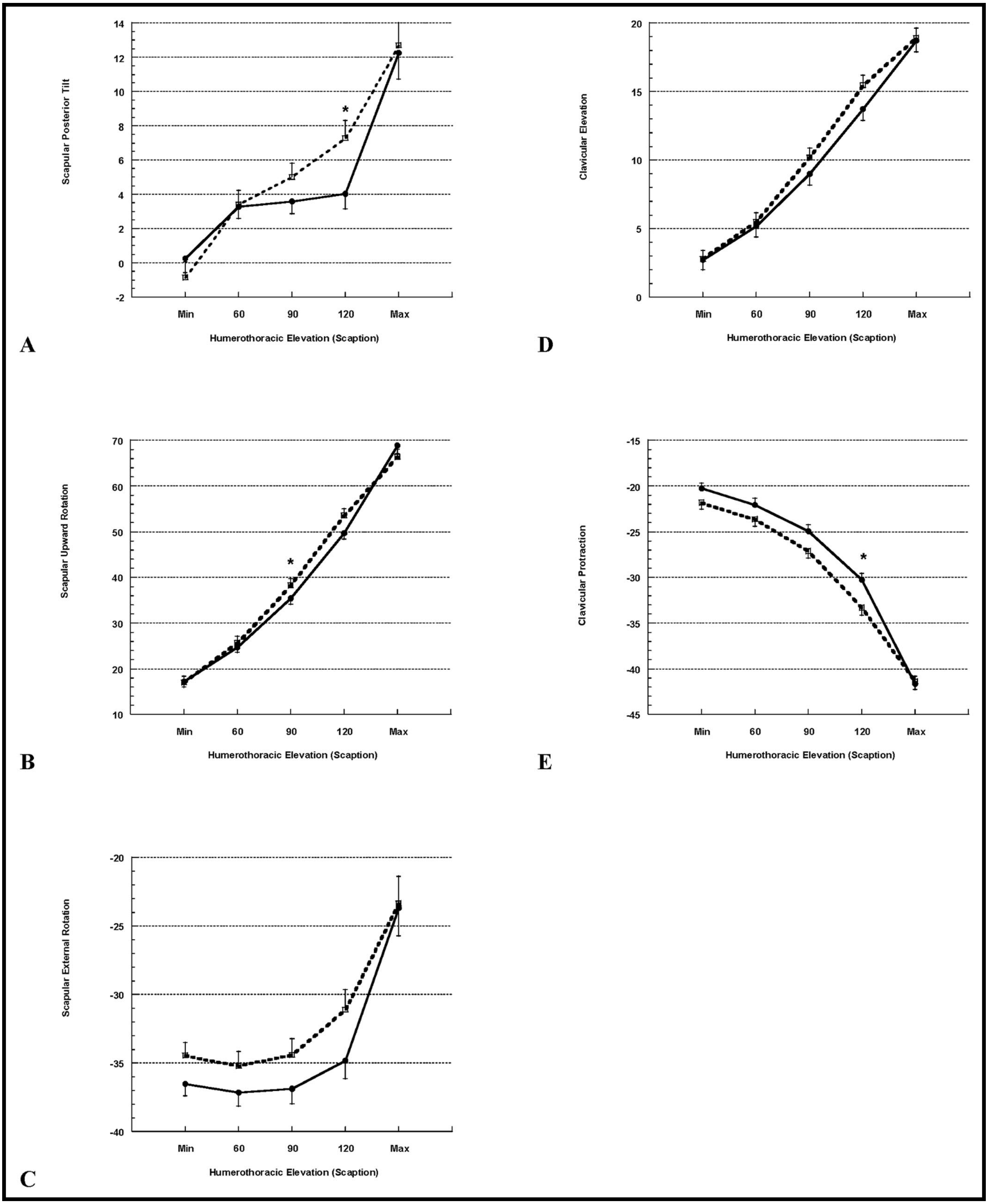

Figure 3.
Mean scapular and clavicular rotations during humerothoracic scapular plane elevation (scaption). Error bars represent SEs. The solid line represents control subjects, and the dashed line represents subjects with impingement. Max=mean peak flexion for each group: 153.9 degrees (SD=8.8) for control subjects and 142.8 degrees (SD=13.2) for subjects with impingement. Four subjects did not reach 120 degrees for scaption; therefore, the values at 120 degrees and Max are based on 41 subjects from each group. (A) Posterior tilting. (B) Upward rotation. (C) External rotation. (D) Clavicular elevation. (E) Clavicular protraction (clavicular retraction is represented by decreasing values). An asterisk indicates a *P* value of $<.05$.

Table 2.
Summary of Two-Way Analysis of Variance of Kinematic Data During Each Motion

	Flexion		Scaption		Humeral External Rotation	
Variable	***P***	**Follow-up *t* Test (*P*)**	***P***	**Follow-up *t* Test (*P*)**	***P***	**Follow-up *t* Test (*P*)**
Scapular posterior tilt		NA[a]		120° (.011)		NA
Group	.413		.246		.174	
Humeral angle	.000		.000		.000	
Group × angle	.142		.040		.490	
Scapular upward rotation		90° (.010); 120° (.020)		90° (.049)		NA
Group	.151		.604		.981	
Humeral angle	.000		.000		.000	
Group × angle	.018		.002		.405	
Scapular external rotation		NA		NA		NA
Group	.743		.252		.397	
Humeral angle	.000		.000		.000	
Group × angle	.684		.290		.642	
Clavicular elevation		90° (.008); 120° (.007)		NA		NA
Group	.047		.217		.153	
Humeral angle	.000		.000		.007	
Group × angle	.002		.067		.541	
Clavicular protraction		NA		120° (.025)		NA
Group	.340		.111		.513	
Humeral angle	.000		.000		.000	
Group × angle	.058		.025		.366	

[a] NA=not appropriate.

shoulder muscle force, and no differences in resting posture of the shoulder or upper thoracic spine.

Scapular Kinematics

We found only modest differences, all less than 5 degrees, in scapular kinematics between the groups. Table 4 compares our results with those of previous studies. During flexion, subjects with SAIS showed slightly greater upward rotation and clavicular elevation than did control subjects; in contrast, other studies[11,25] demonstrated less upward rotation in subjects with SAIS. However, the greater clavicular elevation found in the present study is similar to a previous finding of greater scapular elevation.[10] The clinical importance of these small differences is difficult to assess. Greater scapular upward rotation and clavicular elevation may represent compensatory responses for glenohumeral weakness or glenohumeral joint stiffness or an attempt to reduce direct subacromial impingement.

During scapular plane elevation, we found greater posterior tilt, upward rotation, and clavicular retraction in subjects with SAIS than in the control subjects. The greater posterior tilt and clavicular retraction in our subjects with SAIS could be interpreted as favorable compensatory responses to increase subacromial space.[35] These findings contrast with previously reported less posterior tilt and upward rotation in subjects with SAIS.[10,11,23,25] In earlier work, [10] we found less posterior tilt and greater superior elevation of the scapula in subjects with SAIS. However, the methods and subjects in that study differed in several important ways from those in the present study. Because an electromechanical digitizer was used rather than electromagnetic tracking, subjects had to hold their arms in a given static position while multiple points were palpated and digitized. In addition, planar projections were used to calculate angles rather than a Euler angle sequence, and subjects were not specifically screened or excluded for rotator cuff tears. Ludewig and Cook[11] found that subjects with impingement symptoms anteriorly tilted their scapulae about 2 degrees during humeral elevation (60°–120°) in the scapular plane, in contrast to the posteriorly titled scapulae seen in subjects without impingement symptoms. The different results obtained in the present study (greater posterior tilt with SAIS) may be attributable to differences in measurement methods, in that Ludewig and Cook used a scapular sensor mounted directly over the acromion, whereas we used a scapular tracking jig to attach the sensor. They also studied only male construction workers having work-related symptoms, whereas our sample included men and women drawn primarily from an orthopedic surgeon's university-based office practice. Alternative explanations for the differences between our findings and those of other studies are that scapular motion among patients with SAIS simply is highly variable because of both patient and measurement factors and that the

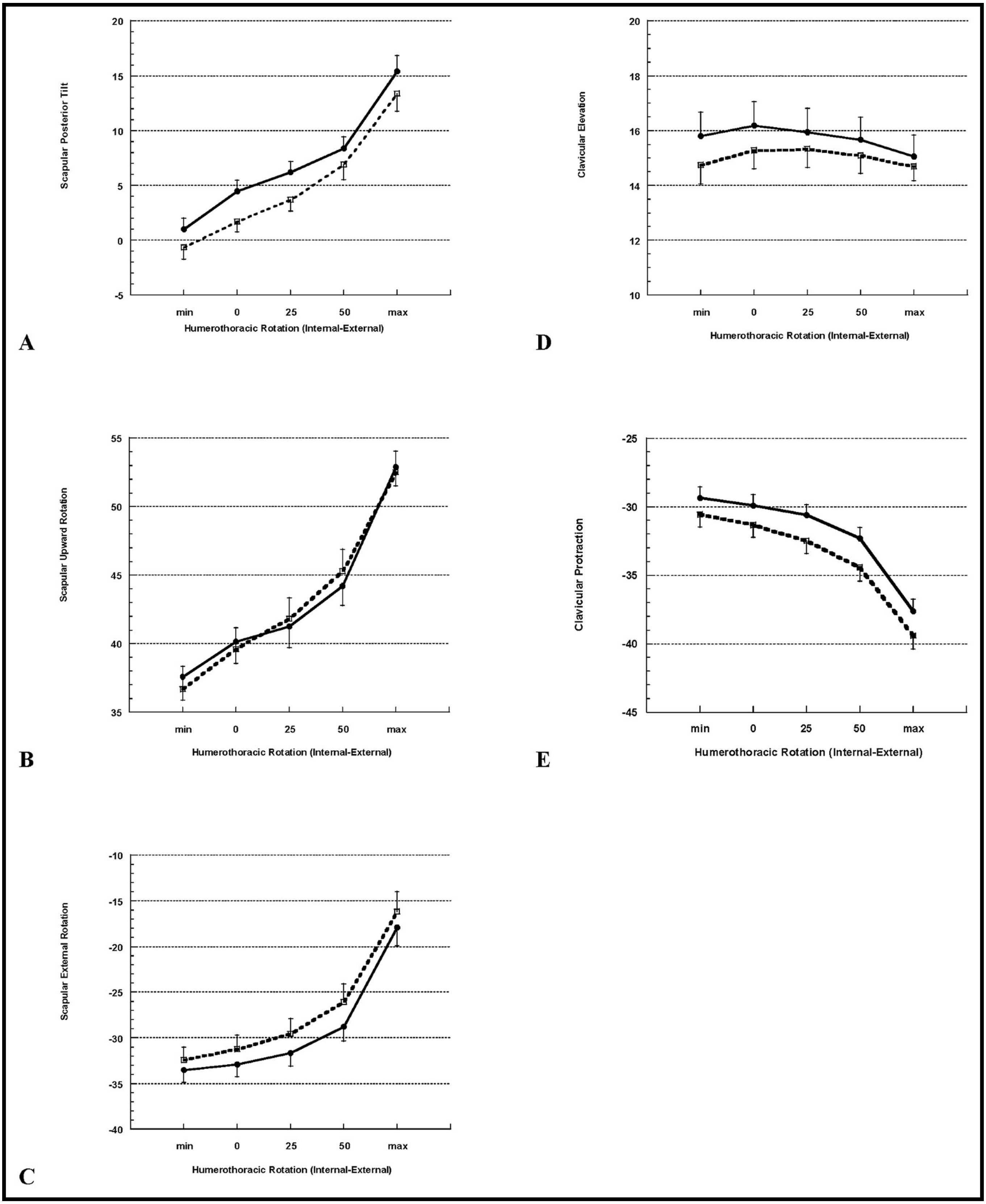

Figure 4.
Mean scapular and clavicular rotations during humerothoracic external rotation with the arm abducted 90 degrees. Error bars represent SEs. The solid line represents control subjects, and the dashed line represents subjects with impingement. Max=mean peak external rotation for each group: 79.8 degrees (SD=9.6) for control subjects and 77.7 degrees (SD=15.6) for subjects with impingement. (A) Posterior tilting. (B) Upward rotation. (C) External rotation. (D) Clavicular elevation. (E) Clavicular protraction (clavicular retraction is represented by decreasing values).

Table 3.
Group Comparisons for Shoulder Range of Motion (ROM), Force, and Resting Posture

Variable[a]	$\overline{X}$ (SD) for the Following Subjects: Control	Impingement	P
Shoulder ROM (°)			
Passive IR 90° flexion	38.9 (5.8)	28.4 (12.5)	<.001
Active IR 90° abduction	70.0 (12.6)	50.1 (19.5)	<.001
Active ER 90° abduction	111.9 (10.0)	90.9 (17.0)	<.001
Active flexion	163.5 (6.0)	144.6 (17.4)	<.001
Shoulder muscle force (kg)			
IR	14.0 (3.9)	11.6 (4.2)	.011
ER	12.4 (2.6)	9.6 (3.0)	<.001
Scapular plane elevation	8.6 (2.7)	5.6 (3.0)	<.001
Posture			
Thoracic spine inclination (°)	70.5 (6.0)	69.4 (6.4)	.415
Forward shoulder (cm)	8.6 (1.9)	9.0 (1.8)	.364

[a] IR=internal rotation, ER=external rotation.

modest differences found in all studies simply reflect chance variations among relatively small samples.

We found no kinematic differences between groups during humeral external rotation with the arm abducted 90 degrees in the frontal plane. The primary motions occurring with this test movement were scapular posterior tilting, upward rotation, and external rotation.

One explanation for a lack of larger differences in scapular kinematics may be that the test movements that we studied were not challenging enough to reveal changes because of altered muscle activation. Other studies[11,36,37] have suggested that subjects with SAIS show greater deficits under loaded conditions at relatively low loads (1.35–2.25 kg [3–5 lb]) held in the subject's hand during testing. Testing with loads applied or under fatiguing conditions may amplify subtle deficits; however, we were hesitant to do such testing because of concerns about inducing pain or increasing symptoms. We also tried to exclude subjects with obvious or symptomatic rotator cuff tears, in contrast to an earlier study in which subjects showing signs of rotator cuff tears were not specifically excluded.[10]

Another potential explanation for the lack of more dramatic differences between groups is that perhaps only a small subset of people with SAIS truly have abnormal scapular motion. Because shoulder impingement is a "syndrome," it likely has several subvarieties, one of which may involve abnormal scapular kinematics. However, at present, there is no accepted or validated operational definition of "abnormal scapular kinematics." Graichen et al[24] used 3-dimensional reconstruction of magnetic resonance images in subjects with and subjects without SAIS. They found that a subset of 5 of 20 subjects with SAIS showed a pattern that was abnormal, defined as greater than 2.5 standard deviations from the mean, yet these differences were obscured in the group data. The abnormality that they identified was increased upward rotation of the scapula, a result that agrees with our findings. A defensible and standard operational definition of abnormal scapular kinematics remains to be determined.

There is also no standard clinical method for identifying people who may have abnormal scapular motion or so-called scapular dyskinesia. Kibler[38] described a simple test based on linear measurements of the distance between the scapula and the vertebral column with the arm in defined positions. The reliability and validity of data obtained with this method, however, have been challenged.[39,40] Kibler and colleagues[41] also described a rating system for scapular dyskinesia that is based on visual judgments, that is simple enough for routine clinical use, and that appears to have promise, although the initial reliability was questionable. We also have preliminary evidence of satisfactory reliability and validity of a visually based system for identifying scapular dyskinesia.[42,43] A method that can reliably identify people with scapular motion abnormalities and that is suitable for routine clinical use would be of great value because it would allow interventions to be directed specifically toward improving scapular muscle force and control in those people.

As with other musculoskeletal syndromes, such as low back pain,[44] it may be helpful to identify subcategories of SAIS to guide interventions. Our findings of modest kinematic differences as well as previous work demonstrating symptomatic improvement without an alteration of scapular kinematics[27] could be interpreted as supporting the concept of tension overload as a primary culprit rather than mechanical compression associated with altered scapular kinematics. Our belief is that SAIS likely includes several etiologic subvarieties, such as tension overload, scapular dyskinesia, rotator cuff weakness, posterior shoulder tightness, and primary compression from subacromial spurs or degenerative changes. Accurately identifying each of these varieties and impairments may lead to a different primary emphasis in interventions as well as help focus future research.

Table 4.
Summary of Studies Related to Scapular Kinematics in Shoulder Impingement

Article	Subjects	Methods	Findings for Impingement
Warner et al[36]	22 asymptomatic 22 instability 7 impingement	Moiré topography to assess asymmetry Increased topography would reflect winging, which could be produced by scapular internal rotation or anterior tilting Static and dynamic elevation with load and without load	Static test: 14% of control subjects had scapulothoracic asymmetry compared with 32% of subjects with instability and 57% of subjects with impingement Dynamic test: 18% of control subjects had asymmetry compared with 64% of subjects with instability and 100% of subjects with impingement
Lukasiewicz et al[10]	17 impingement 20 asymptomatic	Electromechanical digitizer Scapular-plane elevation Static measures of 30° increments of humeral elevation	Less posterior tilt Greater superior elevation of scapula
Ludewig and Cook[11]	26 impingement 26 asymptomatic	Electromagnetic tracking Scapular plane elevation Dynamic motion in both unloaded and loaded conditions	Slight anterior tilt instead of posterior tilt Less upward rotation Greater internal rotation in loaded condition
Endo et al[25]	27 unilateral impingement, 54 shoulders	Anteroposterior radiographs at 0°, 45°, and 90° Indirect, linear measures used to reflect scapular tilt and internal rotation Static measures, coronal-plane elevation	Less posterior tilt Less upward rotation
Graichen et al[24]	20 impingement (14 with stage 1 and stage 2 impingements, 6 with stage 3 impingement) 14 asymptomatic, also uninvolved shoulder of the patient group	Magnetic resonance imaging 3-dimensional reconstruction	No significant difference between groups Subset of 5 subjects showed clear greater upward rotation
Hebert et al[23]	41 with at least one sign of shoulder impingement (29 of which had confirmed shoulder impingement syndrome) 10 asymptomatic	Electromagnetic tracking Sagittal-plane and frontal-plane elevation Static measures at rest and at 70°, 90°, and 110°	No differences between symptomatic and asymptomatic sides in subjects with impingement Greater external rotation ("anterior transverse rotation") than in control subjects
Present study	45 impingement 45 asymptomatic	Electromagnetic tracking Sagittal- and scapular-plane elevation Humeral external rotation at 90° Dynamic motion, no loads	Sagittal plane: greater upward rotation and greater clavicular elevation Scapular plane: greater posterior tilt and greater clavicular retraction

Shoulder Muscle Force and Shoulder ROM

We also found deficits in isometric force production and ROM in subjects with SAIS. Deficits in rotator cuff force production are associated with unwanted superior translation of the humeral head,[12,45] which would perpetuate the process of impingement. Likewise, excessive tightness of capsular structures may lead to obligate translation producing superior translation of the humeral head.[13] We could not determine how much of the decreased strength and ROM was attributable directly to pain or whether these differences could be attributable to actual changes in neuromuscular tissues (atrophy or altered motor recruitment) and adaptive shortening of the periarticular connective tissues. It is common to observe improvement in ROM and force production after subacromial injection of anesthetic; this observation suggests that these impairments are often attributable to pain and inhibition rather than true changes in muscle or connective tissues. Distinguishing people whose impairments are primarily attributable to pain from those with structural changes causing weakness and loss of motion may help to direct rehabilitation programs. Because of the age ($\overline{X}$=45 years) and duration of symptoms (64% had had symptoms for more than 3 months) of the subjects in our sample, we believe that at least some of the differences between groups likely represent true changes in the neuromuscular system (ie, muscle atrophy or poor motor recruitment) as well as adaptive shortening of the periarticular connective tissues. The presence of true structural changes would help explain the generally positive response to rehabilitation programs emphasizing stretching and strengthening.[27,46–50]

Several authors[13–15] have suggested that posterior capsular tightness is related to SAIS. Posterior capsular tightness has been inferred by a lack of internal rotation[15] and by a cross-body adduction measurement with the scapula stabilized.[14] Gerber et al[51] showed that plication of the posterior capsule leads to decreased flexion and internal rotation. Harryman et al[13] showed that selective tightening of the posterior portion of the shoulder capsule causes obligate anterior and superior translation of the humeral head with passive shoulder flexion in a cadaver model. Abnormal humeral motion can result in a decrease in the subacromial space during overhead activities. In our sample, subjects with SAIS did not seem to have selective tightness of the posterior capsule but did have more generalized limited motion, as evidenced by decreased external rotation. It is possible that selective tightness of the posterior capsule is more common in a younger, athletic population involved in athletics requiring overhead use of the arm.[16,52,53] Data from Tyler et al[14] suggested that selective posterior capsular tightness was most obvious when the impingement was on the dominant side. When we reevaluated our data, analyzing only subjects with impingement on the dominant side and the corresponding control subjects (21 subjects in each group), the ROM differences between the groups were virtually the same, with limitations in both external rotation and internal rotation similar to those seen in the entire group and in subjects whose impingement was on the nondominant side.

Posture

There were no differences between groups in upper thoracic spine sagittal-plane posture. Many authors[17,54,55] have postulated that a flexed thoracic spine may place the shoulder at a mechanical disadvantage and that rehabilitation generally should encourage upper thoracic spine extension. However, static thoracic spine posture may not be the culprit; rather, a lack of thoracic mobility may be. One recent study[56] showed that although subjects with SAIS had thoracic spine resting postures similar to those of subjects without SAIS, they had significantly less sagittal-plane mobility than did subjects without SAIS. Other work[57] has shown that upper thoracic spine extension, ipsilateral rotation, and lateral flexion occur during arm elevation in both scaption and flexion. Therefore, thoracic mobility may be more important than resting posture.

There were no differences between groups in forward shoulder posture. The forward shoulder measurement is believed to capture potential tightness of the pectoralis minor muscle or weakness of the posterior scapular musculature, allowing for the shoulders to rest in a forward position. Differences between subjects with SAIS and age-matched control subjects may be more evident in a younger, athletic population, in which tightness and overuse of the pectoral muscles or posterior scapular muscle weakness may be more common.

Conclusion

Subjects with signs and symptoms of primary SAIS had clear deficits in shoulder ROM and shoulder muscle force production in multiple directions. These deficits support the need for exercise rehabilitation and may be related to pain and to true changes in neuromuscular and periarticular connective tissues. Subjects with SAIS failed to show differences from matched control subjects with regard to upper thoracic spine or forward shoulder posture. Modest differences between subjects with and subjects without SAIS were found for scapular kinematics, and these differences were most discernible at the midrange of humerothoracic elevation. Subjects with SAIS showed slightly greater scapular upward rotation and clavicular elevation during flexion and slightly greater posterior tilt and clavicular retraction during scaption. These differences are of questionable clinical importance but may represent minor compensatory motions. More work is necessary to accurately distinguish subjects with clinically important scapular motion abnormalities.

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