Research Report

Shoulder Function and 3-Dimensional Kinematics in People With Shoulder Impingement Syndrome Before and After a 6-Week Exercise Program

Background and Purpose. Shoulder impingement syndrome is a common condition and is often managed with an exercise program. The purpose of this study was to examine an exercise program in patients with shoulder impingement syndrome. Specifically, the purpose was to identify changes that might occur in 3-dimensional scapular kinematics, physical impairments, and functional limitations. **Subjects.** Fifty-nine patients with impingement syndrome were recruited, and 39 patients successfully completed the 6-week rehabilitation program and follow-up testing. Impingement was defined as having at least 3 of 6 predefined clinical signs or symptoms. **Methods.** Subjects were assessed before and after a 6-week rehabilitation program and again at 6 months. Pain, satisfaction, and function were measured using the University of Pennsylvania Shoulder Scale. Range of motion, isometric muscle force, and 3-dimensional scapular kinematic data also were collected. Subjects were given a progressive exercise program that included resistive strengthening, stretching, and postural exercises that were done daily at home. Subjects also were given shoulder education related to anatomy, the basic mechanics of impingement, and strategies for reducing load on the shoulder. Each subject attended one physical therapy session per week for a 6-week period, primarily for monitoring and upgrading the exercise program. Pretest and posttest scores were compared using paired *t* tests and repeated-measures analysis of variance. **Results.** Passive range of motion increased for both external and internal rotation but not for elevation. Abduction external and internal rotation force all increased. There were no differences in scapular kinematics. Improvements were found for pain, satisfaction, and shoulder function and for Medical Outcomes Study 36-Item Short-Form Health Survey (SF-36) scores related to physical function. At 6-month follow-up, improvements made in pain, satisfaction, and function were maintained. **Discussion and Conclusion.** The use of this exercise protocol in the management of shoulder impingement syndrome may have a positive impact on patients' impairments and functional limitations. Our findings suggest a relatively simple exercise program combined with patient education may be effective and, therefore, merits study in a larger trial using a control group. Changes in scapular kinematics did not appear to be a primary mechanism underlying improvement in symptoms and function. [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.]

Key Words: *Biomechanics, Exercise, Shoulder impingement, Shoulder kinematics.*

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The term "shoulder impingement" was introduced by Neer[1] and refers to the 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. Most authors believe shoulder impingements are the most common cause of shoulder pain, and there is general consensus that impingement is the primary underlying problem or at least a mitigating factor in many rotator cuff disorders.[2–5] Neer[4] estimated that 95% of rotator cuff tears are due to impingement. In writing about impingement and rotator cuff disease, Cofield stated, "Certainly factors other than impingement alone can be involved, but this unifying concept has been most helpful in viewing various pathologic entities as being different stages of a common underlying process."[5(p975)] Because impingement is believed to contribute to the tearing of the rotator cuff,[5] early identification of impingement and intervention are desirable.

Multiple factors have been proposed to contribute to the development of impingement syndrome. These factors include abnormal acromial morphology,[6,7] aberrant kinematic patterns due to poor rotator cuff or scapular muscle function,[8–11] capsular abnormalities,[12–14] poor posture,[15–17] and overuse secondary to repetitive eccentric loading or sustained use of the arm above 90 degrees of elevation.[18–21] The variation in intervention approaches is directly related to various views on the mechanism leading to impingement.[22]

Researchers have investigated the effects of various rehabilitation protocols on people with impingement syn-

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Dr McClure, Dr Williams, and Dr Karduna provided concept/idea/research design and writing. Dr McClure and Mr Bialker provided data collection, and Dr McClure, Ms Neff, and Dr Karduna provided data analysis. Dr McClure provided project management and fund procurement. Mr Bialker and Dr Williams provided subjects and institutional liaisons. Dr McClure and Dr Williams provided facilities/equipment. Mr Bialker, Ms Neff, Dr Williams, and Dr Karduna provided consultation (including review of manuscript before submission). The authors acknowledge the assistance of Martin Kelley, PT, MSPT, OCS, and Brian Leggin, PT, MSPT, OCS, in developing the treatment protocol.

This study was approved by the institutional review boards of Arcadia University and the University of Pennsylvania.

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drome. Brox et al[23] compared a supervised exercise program with acromioplasty or placebo laser treatment in 125 patients with shoulder impingement. The exercise program was not standardized or described in detail but apparently consisted of low-resistance, repetitive rotation exercises done daily for 1 hour with twice-a-week supervision for between 3 and 6 months. The primary outcome measure was a Neer impingement test score (possible score of 100 points, with higher scores being better), which is based on pain (35 points), muscle force (30 points), active range of motion (ROM) (25 points), and radiographic assessment (10 points). They found that both the acromioplasty and exercise groups had improved Neer impingement test scores compared with the placebo group. In a follow-up of these patients 2.5 years later, both the exercise and acromioplasty groups had higher Neer impingement test scores than did the placebo group.[24]

Bang and Deyle[25] compared 52 subjects who were randomly assigned to 1 of 2 groups: a group that received supervised exercise with manual therapy and a group that received supervised exercise without manual therapy. Supervised exercise consisted of the following: 2 stretching exercises for the anterior and posterior shoulder performed 3 times for 30 seconds and 6 strengthening exercises performed in 3 sets of 10 repetitions (shoulder elevation, rowing, scapular-plane abduction with the arm medially rotated, horizontal abduction with lateral rotation, seated press-up off a chair, and elbow push-up with shoulder protraction) against elastic tubing of various grades based on a 10-repetition maximum. Manual therapy included individualized joint mobilization, which was not specified but could include passive physiological joint mobilization to the glenohumeral, cervical, or thoracic spine articulations, massage, or muscle stretching techniques. Both groups were treated 2 times per week for 3 weeks with resistive exercise and passive stretching aimed at the anterior and posterior shoulder musculature. The researchers measured pain, isometric force, and function using a shoulder scale that they had developed that had an intraclass correlation coefficient (ICC [3,1]) of .81 for test-retest reliability over a 24-hour period. Although both groups showed improvement, the subjects who received manual therapy showed greater gains than the subjects who did not receive manual therapy for all variables.

Some evidence exists that scapular dysfunction is associated with shoulder impingement. Warner et al,[26] using a moiré topography technique, demonstrated a pattern of increased scapular winging with glenohumeral elevation. This winging pattern appears to represent scapular internal rotation and anterior tilting. Recently, 3-dimensional kinematic analysis has demonstrated decreased scapular posterior tilt,[10,11] decreased upward rotation,[11] and decreased scapular external rotation[11] during glenohumeral elevation. Radiographic assessment at multiple joint angles revealed a decrease in scapular posterior tilt and upward rotation at 90 degrees of glenohumeral elevation and a decrease in posterior tilt at 45 degrees of glenohumeral elevation.[27] No study to date has assessed the effect of rehabilitation on scapular function in patients.

The primary purpose of our study was to identify changes that occur in physical impairments (3-dimensional kinematic patterns, thoracic posture, muscle force, and motion), functional outcome (as measured with the University of Pennsylvania Shoulder Scale), and general health status (as measured with the Medical Outcomes Study 36-Item Short-Form Health Survey [SF-36]) in patients with impingement syndrome following an intensive exercise program. A secondary purpose was to identify relationships between impairments and functional outcome that may help explain mechanisms involved with rehabilitation.

Method

A repeated-measures design was used, with all measurements being taken before and after a 6-week intervention period. Follow-up measurements of pain, satisfaction, and function also were collected at least 6 months after intervention.

Subjects

A total of 59 subjects were initially recruited and were judged to meet the criteria for the study. Subjects were recruited from the practices of Penn Therapy and Fitness and the Hospital of the University of Pennsylvania and also through general announcements in local printed media. Twenty subjects did not complete the 6-week exercise program and follow-up testing, leaving a total of 39 subjects. Data regarding the reasons for dropping out of the study were not collected systematically. A retrospective review of records revealed that subjects who did not complete the study cited either scheduling problems (n=4) or personal circumstances that prevented weekly visits (n=4), or they simply did not return and did not give an explanation (n=11). One subject elected to have an injection rather than participate in an exercise program. No subject reported an adverse response to the intervention, and subjects were not charged for intervention. This rate of attrition (33%) was similar to the overall rate of patient attrition (inability to complete a scheduled course of outpatient therapy) for the primary site used in the present study (38%). Descriptive characteristics of the subjects are given in Table 1.

The diagnosis of impingement was made initially by the referring physician and was confirmed by the physical

Table 1.
Descriptive Characteristics of Subjects

	Finishers (n=39)	Nonfinishers (n=20)
Age (y)		
$\overline{X}$	50.6	48.4
SD	13.1	12.1
Range	26–78	27–79
Sex		
Male	18 (46%)	14 (70%)
Female	21 (54%)	6 (30%)
Height (cm)		
$\overline{X}$	168	174
SD	9.6	11.3
Range	152–185	157–193
Weight (kg)		
$\overline{X}$	73.6	84.2
SD	14.6	16.0
Range	61–115	53–105
Duration of symptoms (data not available for 1 subject)		
<1 mo	3 (7.6%)	1 (5%)
1–3 mo	8 (20.5%)	5 (25%)
3–6 mo	7 (17.9%)	2 (10%)
>6 mo	20 (51.2%)	12 (60%)
Mechanism of injury (data not available for 3 subjects)		
No apparent reason	17 (43.5%)	8 (40%)
Trauma	8 (20.5%)	7 (35%)
Overuse	11 (28.2%)	5 (25%)

therapist who performed the initial examination. To be classified as having impingement, subjects had to demonstrate at least 3 of the following: (1) a positive Neer impingement test, (2) a positive Hawkins impingement test, (3) pain with active shoulder elevation, (4) pain with palpation of the rotator cuff tendons, (5) pain with isometric resisted abduction, and (6) pain in the C5 or C6 dermatome region.[10] Subjects were excluded if they demonstrated signs of a complete rotator cuff tear or acute inflammation. Signs of a complete tear were: (1) gross weakness in abduction or external rotation as evidenced by a 50% or greater deficit (relative to the uninvolved arm) in isometric force using a hand-held dynamometer and (2) positive magnetic resonance imaging findings for full-thickness rotator cuff tears from previous diagnostic evaluation. Signs of acute inflammation were severe resting pain or severe pain reported during either the Neer or Hawkins impingement test or during isometric resisted abduction. Additionally, subjects who were judged to have cervical spine-related symptoms, glenohumeral instability (as determined by a 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 (Arcadia University and University of Pennsylvania).

Instrumentation and Measurement Procedures

Three general types of measurements were collected: (1) 3-dimensional scapular kinematics, (2) impairment measurements of posture, motion, and muscle force, and (3) self-reported measurements of pain, satisfaction, and function.

Three-dimensional scapular kinematics. The Polhemus 3Space Fastrak* is an electromagnetic-based motion analysis system that we used for collecting 3-dimensional kinematic data of the shoulder complex and resting posture of both the shoulder and thorax. The details of the instrumentation and the error associated with these measurements have been previously described.[28–30] The average root-mean-square errors were below 5 degrees for all rotations when compared with sensors mounted directly to the scapula with bone pins.[28–30] The majority of the error with this method occurs above 120 degrees of humeral elevation. Subjects stood with their feet a comfortable width apart, their heels against a rigid support, and their elbows extended. The thoracic spine, scapula, and humerus were exposed. This position was maintained throughout the digitization and testing procedures. The following anatomic landmarks were palpated and marked with a dark pen by a physical therapist who was experienced with the test protocol: acromioclavicular (AC) joint line, posterior angle of the acromion, and spinous processes of first, third, and seventh thoracic vertebrae (T1, T3, and T7). These marks were used for subsequent receiver mounting and landmark digitization. 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 using double-sided tape. The humeral receiver was positioned on the distal humerus over a neoprene sleeve using elastic straps. The scapular receiver was positioned on the scapula via a custom-made, adjustable scapular-tracking jig machined from plastic, which was attached to the skin with Velcro adhesive fasteners.† We believe the jig remained well fixed to the scapula from these Velcro attachments during motion.

The arbitrary axis systems defined by the Polhemus 3Space Fastrak were converted to anatomically appropriate axis systems by using a series of standardized axes embedded in each segment.[31] These axis systems are derived from a series of points on each segment, which are palpated and individually digitized with a hand-held

* Polhemus Inc, 40 Hercules Dr, Colchester, VT 05446.
† Velcro USA Inc, 406 Brown Ave, Manchester, NH 03103.

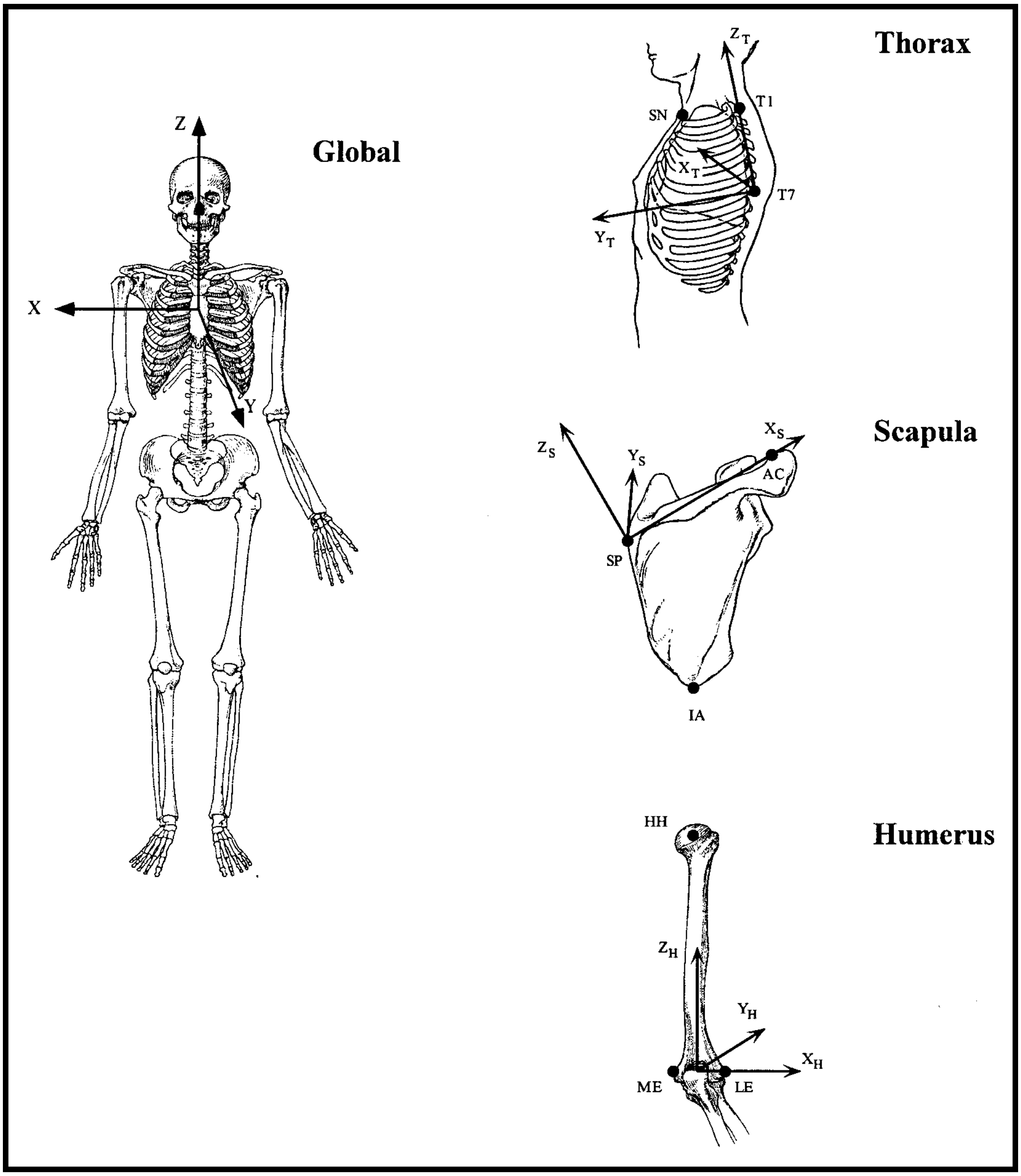

Figure 1.
Anatomical landmarks used for digitization and coordinate axes for each segment. Global: X=lateral, Y=anterior, Z=superior. Thorax: T1=first thoracic vertebrae, T7=seventh thoracic vertebrae, SN=sternal notch, Z_T=vector connecting T7 to T1, X_T=vector perpendicular to plane T1-T7-SN, Y_T=cross product of Z_T and X_T. Scapula: AC=acromioclavicular joint, SP=root of scapular spine, IA=inferior angle, X_S=vector connecting SP to AC, Y_S=vector perpendicular to plane AC-SP-IA, Z_S=cross product of X_S and Y_S. Humerus: HH=center of humeral head, LE=lateral epicondyle, ME=medial epicondyle, Z_H=vector connecting midpoint of ME and LE to HH, Y_H=vector perpendicular to plane ME-LE-HH, X_H=cross product of Y_H and Z_H. (Reprinted from: McClure PW, Karduna AR, Michener LA, Sennett BJ. Direct three-dimensional measurement of scapular kinematics during dynamic movement *in vivo*. *J Shoulder Elbow Surg*. 2001;10:269–277. Copyright 2001, with permission from Elsevier.)

probe as follows: thorax: T1, T7, and sternal notch; scapula: AC joint, root of the scapula spine, and inferior angle; and humerus: medial epicondyle, lateral epicondyle, and humeral head. All landmarks were palpated and located with a digitizer connected to the Polhemus system except for the center of the humeral head. This landmark was defined as the point on the humerus that moved the least according to a least-squares algorithm when the humerus was moved through short arcs of mid-range glenohumeral motion.[32] The location of these points and the resultant embedded axis systems are shown in Figure 1. With these frames established, the raw data from the Polhemus system were converted to anatomically defined rotations and displayed using a custom-made software program written in LabView data acquisition software.[‡]

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

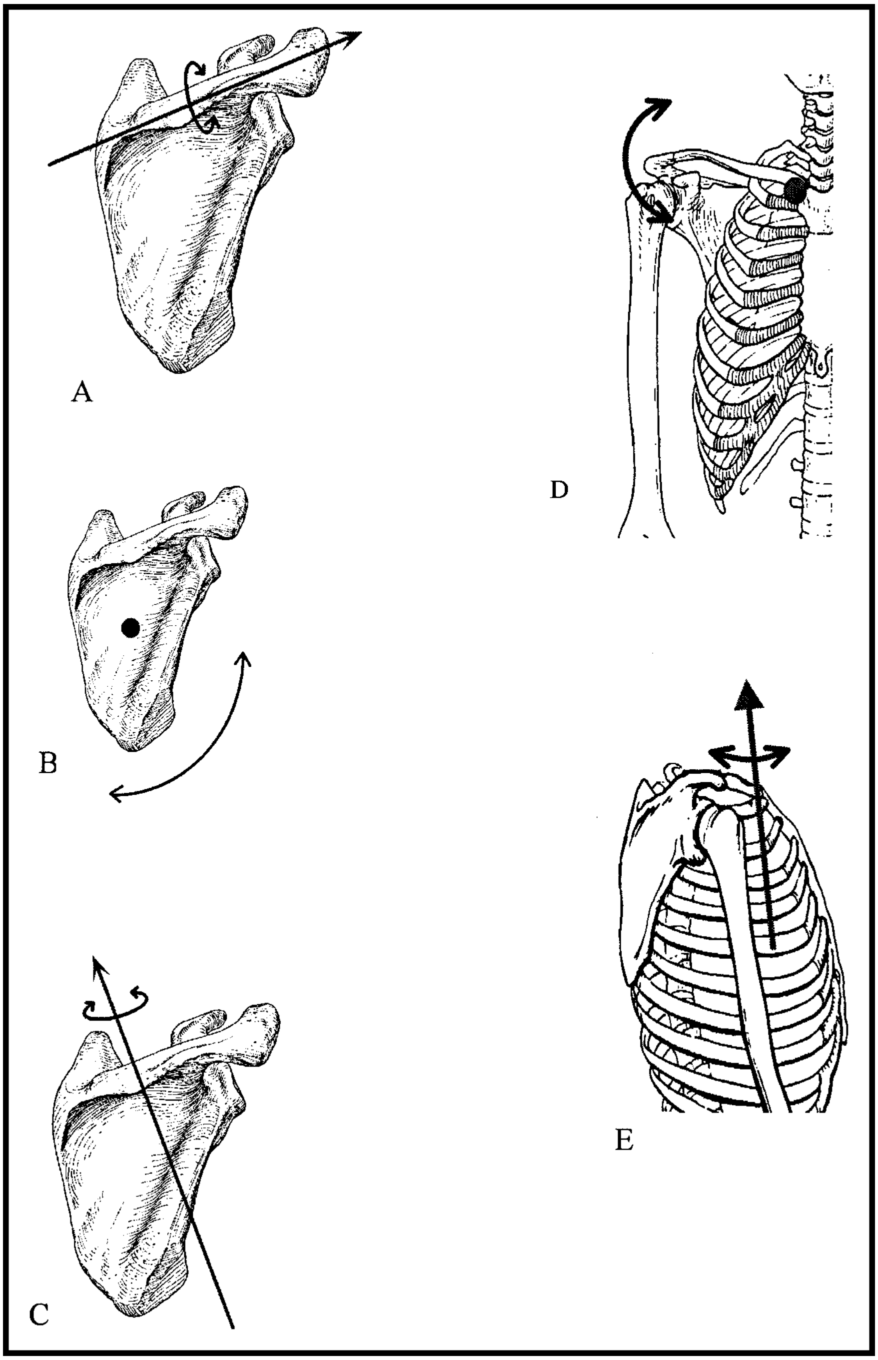

Figure 2.
Individual axes and rotations used to describe scapular orientation and position: (A) Scapular posterior tilting. Negative or decreasing values represent anterior tilting. (B) Scapular upward rotation. Negative or decreasing values represent downward rotation. (C) Scapular external rotation. 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.

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 using a Euler axis sequence (external rotation, upward rotation, and posterior tilting).[29] Each scapular rotation is depicted in Figure 2 (anterior and posterior tilting, internal and external rotation, and upward and downward rotation). Because the distance between the scapula and thorax is constrained by the clavicle (assuming no translation at the sternoclavicular or AC joint), the position of the scapula is restricted to only 2 degrees of freedom and we contend can be represented by the rotational motion of the clavicle: elevation and depression and retraction and protraction (Fig. 2). This is equivalent to describing the position of a point on the earth with the use of 2 angles: longitude and latitude. Clavicle motion was not monitored directly, but rather clavicular angles were derived from the location of the sternal notch and the AC joint, which were tracked with the thoracic and scapular receivers, respectively.

After mounting the receivers and digitization of appropriate landmarks, 3 primary test motions were actively performed: scapular-plane elevation, flexion in the sagittal plane, and internal and external rotation with the arm elevated to 90 degrees in the coronal plane. In an effort 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 done while data were collected continuously at a rate of 40 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 rotation was plotted versus humeral elevation and assessed individually. Only the symptomatic arm was tested, and the same tester took each subject's pretest and posttest measurements. To describe motion for the group, the interpolated data from all subjects were pooled and a single curve for each particular arm motion and scapular or clavicular rotation was plotted.

The manufacturer of the Polhemus system has reported an accuracy of 0.8 mm and 0.15 degrees for this device (measured statically), and we have verified this accuracy under controlled laboratory conditions. The error with our protocol using skin-mounted sensors has been tested previously by comparing measurements obtained from sensors mounted directly to the scapula via bone pins with measurements obtained with skin mounted sensors.[28] Mean errors associated with the skin-mounted sensors during scapular-plane elevation over the full range of elevation were found to be 1.2 degrees for clavicle protraction, 1.5 degrees for clavicle elevation, 4.7 degrees for scapular posterior tilting, 3.2 degrees for scapular external rotation, and 4.2 degrees for scapular upward rotation. The amount of error was dependent on the range of elevation, with much less error below 120 degrees of elevation and as much as 12.6 and 7.3 degrees of error for posterior tilting and external rotation, respectively, at 150 degrees. Interrater reliability was studied among 3 raters using this protocol on 9 subjects without symptoms of shoulder impingement. Sensors were removed and reattached between raters. Intraclass correlation coefficients (2,1) for scapular motions ranged from .69 to .95 depending on the specific scapular rotation and arc of motion assessed.

Impairments. Resting thoracic posture was measured using the thoracic sensor of the Polhemus system and was represented by the degree of flexion (anterior inclination from pure vertical) of a vector formed between T7 and T1. Shoulder passive ROM was measured using a standard goniometer. The following measurements were obtained: scapular-plane elevation, external rotation with arm at the side, and external rotation with the arm elevated to 90 degrees in the coronal plane. Composite internal rotation of the glenohumeral and scapulothoracic articulation was measured by noting the highest vertebral level reached with the thumb as the hand was moved behind the back and up the spine as high as possible. This method has been shown to yield measurements that we would consider to have satisfactory reliability (ICCs of .80 and .90).[33,34] Isometric shoulder muscle force was measured with the Microfet hand-held dynamometer[§] using a "make test" technique. Each subject was asked to exert maximal force against the dynamometer, which was held stationary by the tester. Measurements obtained with a hand-held dynamometer such as this instrument have been shown to be reliable (ICC=.84–.97) for shoulder medial rotation, lateral rotation, and abduction force on subjects without symptoms.[35] The following force measurements were obtained: (1) external rotation force with the arm by the side in neutral rotation, (2) internal rotation force with the arm by the side in neutral rotation, and (3) shoulder abduction force with the arm in the scapular plane at 45 degrees of elevation. Both force and ROM measurements were obtained such that subjects experienced mild or no pain during testing.

Self-report measures. We used the University of Pennsylvania Shoulder Scale, which has subscales for pain, satisfaction, and functional activities. The pain subscale asks subjects to rate their symptoms on a 10-point scale at rest, during light activities, and during strenuous activities. These ratings were combined for a possible score of 30, representing "no pain at all." Satisfaction was rated based on a single 10-point scale ranging from "completely unsatisfied" to "completely satisfied" in response to the question: "How satisfied are you with your current level of shoulder function?" Finally, function was assessed based on 20 questions related to functional activities, each rated on a 4-level ordinal scale with 3 representing "no difficulty" and 0 representing "cannot do at all." The highest functional score possible is 60 points. The combined total of the subscale scores may be used to determine a composite score based on 100 points, with higher scores being better. This scale has documented psychometric characteristics, including test-retest reliability (ICC=.94), responsiveness (standardized response mean=8.6, 90% confidence interval [CI]), and a minimal detectable change score of 12.1 (90% CI).[36] Subjects also completed the SF-36 questionnaire to describe their general health status.[37]

Intervention

A standardized intervention regimen was applied based on physical impairments associated with shoulder impingement. Interventions included exercises designed to: (1) strengthen the rotator cuff and scapular stabilizers, (2) enhance flexibility of the glenohumeral posterior capsule, pectoralis minor muscle, and upper thoracic spine, (3) improve upper-quarter postural awareness, and (4) enhance patient understanding of environmental and workplace factors that place high loads on the shoulder and are associated with overuse. Subjects were given color exercise instruction sheets depicting each exercise.

Strengthening exercises were performed using 0.9-m (3-ft) lengths of color-coded elastic bands (Thera-

[§] Hoggan Health Industries Inc, PO Box 957, Draper, UT 84020-0957.

Band[#]). All subjects began with 3 strengthening exercises using the lightest grade (yellow). These exercises were:

1. Shoulder external rotation starting in approximately 45 degrees of internal rotation, with the arm by the side and the elbow flexed to 90 degrees.

2. Shoulder internal rotation starting in approximately 45 degrees of external rotation, with the arm by the side and the elbow flexed to 90 degrees.

3. Shoulder extension starting with the arm forward flexed approximately 45 degrees.

The subjects were instructed to start with the band under very mild tension. When they were able to do 3 sets of 10 repetitions without feeling substantial pain or fatigue, the next strongest elastic band was used. Once they had progressed to using green (moderate resistance), new exercises were added, as follows:

1. Shoulder abduction (scapular plane) through a 0- to 60-degree arc with the elbow flexed 90 degrees and the shoulder in neutral rotation, holding the band in the hand with the band oriented horizontally across the body.

2. Shoulder flexion (sagittal plane) through a 0- to 60-degree arc starting with the elbow flexed 90 degrees and the shoulder in neutral rotation and punching forward, simultaneously extending the elbow and flexing the shoulder.

3. Scapular retraction starting with elbows flexed 90 degrees, the shoulder in neutral rotation, and the arms by the side, pinching the scapulae.

4. Shoulder external rotation starting with the arm abducted 45 degrees in the scapular plane with the elbows flexed 90 degrees, moving through an arc from 30 degrees of internal rotation to 30 degrees of external rotation.

The subjects were instructed to do 2 or 3 sets of 10 repetitions for each exercise, once per day.

Flexibility exercises were done throughout the 6-week period and consisted of the following:

1. Internal rotation towel stretch: Subjects were instructed to sit or stand while holding a towel with the affected arm behind the back and to use the other arm to pull the affected arm up the back.

2. Cross-body stretch: Subjects were instructed to sit or stand and hold the affected elbow with the opposite hand in front of the body and slowly pull the elbow across the body until they felt a comfortable stretch.

3. Upper thoracic extension stretch: Subjects were instructed to lie supine with a 5.1- or 7.6-cm (2- or 3-in) towel roll positioned between the shoulder blades and allow the shoulders to drop back to surface.

4. Doorway pectoral muscle stretch: Subjects were instructed to stand 0.3 to 0.6 m (1–2 ft) to the side of a doorframe and grasp the doorframe at shoulder height and then rotate the upper body away from the door.

5. Shoulder flexion stretch: Subjects were instructed to hold a stick or cane with both hands while lying supine and use the unaffected arm to raise both arms overhead until they felt a comfortable stretch.

6. Shoulder external rotation stretch: Subjects were instructed to lie supine and rest the affected arm on a pillow, 15.2 cm (6 in) from the side with the elbow bent. Then, holding a stick or cane with both hands, they were instructed to apply downward pressure to the affected arm by rotating it back.

All subjects were instructed to do the internal rotation towel stretch, the cross-body stretch, and the upper thoracic extension stretch. The remaining 3 flexibility exercises were shown based on the therapists' judgment, after taking goniometric measurements, as to whether a subject lacked normal flexibility for those motions. Subjects were instructed to hold an individual stretch for 30 seconds and to repeat each stretch 3 times. They were instructed to perform flexibility exercises at least once per day and twice if able.

To address upper-quarter posture, all subjects were instructed in a chin-tuck exercise, which was supposed to be performed at least 3 times every hour. Subjects were instructed to apply pressure to the chin with the fingers as the head was pulled back, holding it for 3 seconds. Emphasis was placed on keeping the motion horizontal and avoiding tilting the head back or looking at the ceiling.

Subjects were given an exercise adherence log and were required to make a least one visit per week to the treating physical therapist over the 6-week intervention period. Many subjects did not bring their adherence log on return appointments despite what we believed was apparent adherence to exercise. Therefore, adherence was monitored based on verbal reports, ability to dem-

[#] The Hygenic Corporation, 1245 Home Ave, Akron, OH 44310.

onstrate exercises, and weekly attendance where the exercise program was checked and modified appropriately. Subjects' muscle force and motion were tested weekly, primarily for motivational purposes. No subject who finished missed more than one weekly visit.

In addition to exercise, all subjects were given basic instruction regarding the anatomy and basic biomechanical issues related to shoulder impingement. This instruction included an explanation of arm and trunk positions that may promote impingement such as shoulder elevation with internal rotation or elevation with a flexed thoracic spine. Simple strategies to reduce loads on the shoulder were reviewed such as working with the arms below 60 degrees of elevation, keeping loads close to the body, use of armrests, and use of ergonomic aids or assistance from other people for heavy lifts. The concept of avoiding undue repetition and prolonged static work postures also was reviewed.

Data Analysis

Descriptive statistics were calculated for all dependent variables (kinematics, posture, muscle force, motion, shoulder function, and overall health status). For analysis of kinematic variables, plots based on group means before and after exercise were generated for each scapular and clavicular rotation (y-axis) versus humerothoracic motion (x-axis). To determine differences between pretest and posttest kinematics, a 2-way (time $\times$ humeral angle) analysis of variance was performed for each scapular and clavicular rotation. For the flexion and scapular-plane abduction tests, we included only the humeral angles of 60, 90, and 120 degrees during raising and lowering in the analysis because not all subjects were able to achieve 150 degrees and the arc between 60 and 120 degrees is believed to be the range where maximal impingement typically occurs.[38,39] For humeral rotation testing, we analyzed the data between 0 and 60 degrees of external rotation because this was the range all subjects were able to achieve. For posture, muscle force, and motion, paired t tests were used to determine differences before and after 6 weeks of intervention. Shoulder pain and function were compared before intervention and 6 weeks and 6 months after intervention using repeated-measures analysis of variance. Pearson product moment correlation coefficients were computed to determine the relationship between change in various impairments and change in overall shoulder function as measured by the University of Pennsylvania Shoulder Scale.

Results

Plots showing mean curves before and after intervention for each scapular and clavicular rotation during various arm motions are shown in Figures 3 through 5. During both shoulder flexion (Fig. 3) and scapular-plane abduction (also known as "scaption") (Fig. 4), a general pattern of scapular upward rotation, posterior tilting, and external rotation with clavicular elevation and retraction was observed. The pattern of motion found during raising of the arm was, in our view, very similar to that found during lowering of the arm. During both flexion and scapular-plane elevation, there were no increases in scapular posterior tilting, external rotation, or clavicular retraction after intervention. During humeral rotation with the arm abducted 90 degrees in the coronal plane, a general pattern of scapular posterior tilting, upward rotation, scapular external rotation, and clavicular retraction was found as the arm moved from internal to external rotation with very little change in clavicular elevation angle.

The data for thoracic posture, passive ROM, and muscle force are shown in Table 2. Thoracic posture did not change. Isometric force increased in all directions. Internal rotation (thumb up vertebral column) and external rotation with arm abducted to 90 degrees showed increases. The data from the University of Pennsylvania Shoulder Score are shown in Table 3. Subjects showed improvements in pain, satisfaction, and function 6 weeks after intervention. Thirty of the 39 subjects returned self-report forms 6 months after intervention, and the improvements were maintained. The SF-36 scores obtained before and after the rehabilitation period are shown in Figure 6. Increases ($P<.01$) were found for the physical function, role physical, bodily pain, vitality, and mental health subscales of the SF-36.

Correlation between the change in University of Pennsylvania Shoulder Scale score and changes in various impairment measurements were found for external rotation force ($r=.39$, $P=.01$) and internal rotation ROM ($r=-.54$, $P=.001$). These correlations indicate that a gain in external rotation force and a gain in internal rotation ROM (higher vertebral level) were associated with gains in functional scores. Correlations with change in internal rotation force, abduction force, and elevation ROM were not significant.

Discussion

Our data agree with those of other researchers[23–25,40,41] who have documented improvements in impairments and function following an exercise program in patients with impingement syndrome. We designed the intervention program to be simple and require a low number of visits. The program was essentially a home program with weekly coaching and minor modifications rather than one requiring extensive manual techniques from a physical therapist. Bang and Deyle[25] followed patients for 6 visits over 3 weeks and found that patients who received manual therapy and exercise demonstrated greater short-term improvements in muscle force and pain than those who received exercise only. A major limitation of

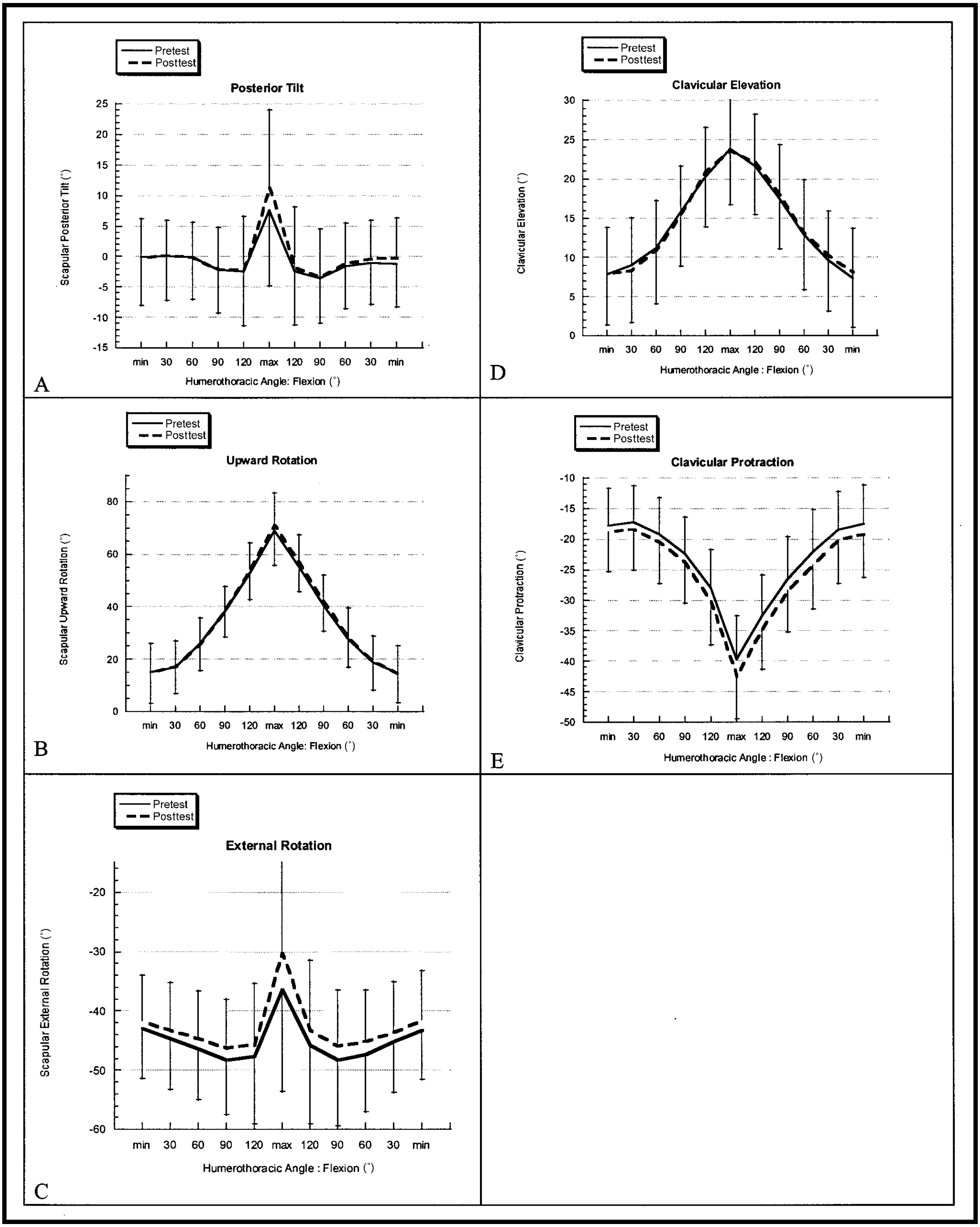

Figure 3.
Mean scapular and clavicular rotations during humerothoracic flexion during both raising (minimum to maximum) and lowering (maximum to minimum); error bars represent standard deviation. The solid line represents pretest values, and the dashed line represents posttest values. "Max" represents the mean peak flexion for all subjects, which was 148.1 degrees (SD=15.6) pretest and 152.0 degrees (SD=11.5) posttest, and these differences were not significant. (A) Posterior tilting. (B) Upward rotation. (C) Scapular external rotation. (D) Clavicular elevation. (E) Clavicular protraction (clavicular retraction is represented by decreasing values).

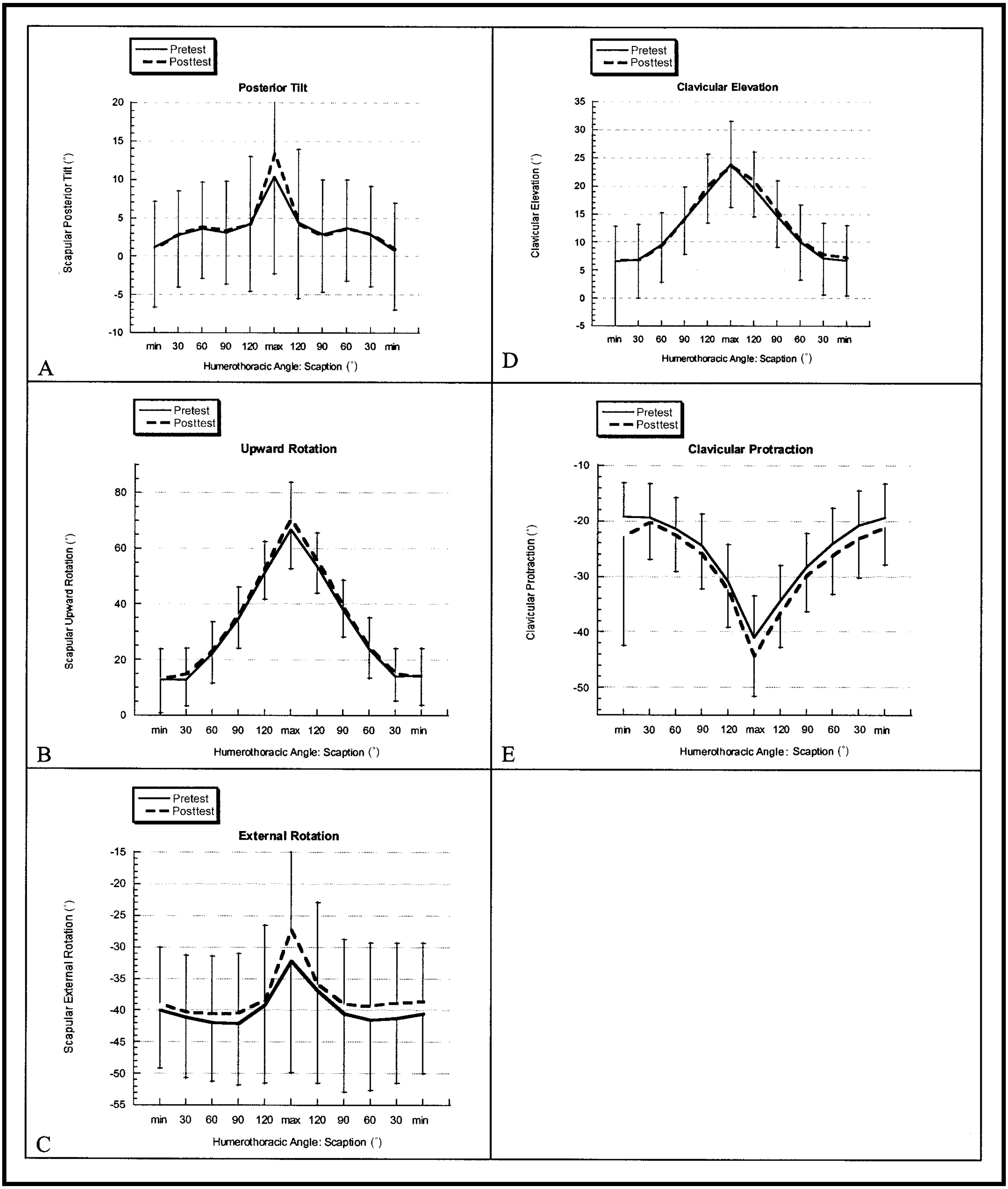

Figure 4.
Mean scapular and clavicular rotations during humerothoracic abduction in the scapular plane (scaption) during both raising (minimum to maximum) and lowering (maximum to minimum); error bars represent standard deviation. The solid line represents pretest values, and the dashed line represents posttest values. "Max" represents the mean peak scaption for all subjects, which was 144.6 degrees (SD=12.0) pretest and 148.0 degrees (SD=12.2) posttest, and these differences were not significant. (A) Posterior tilting. (B) Upward rotation. (C) Scapular external rotation. (D) Clavicular elevation. (E) Clavicular protraction (clavicular retraction is represented by decreasing values).

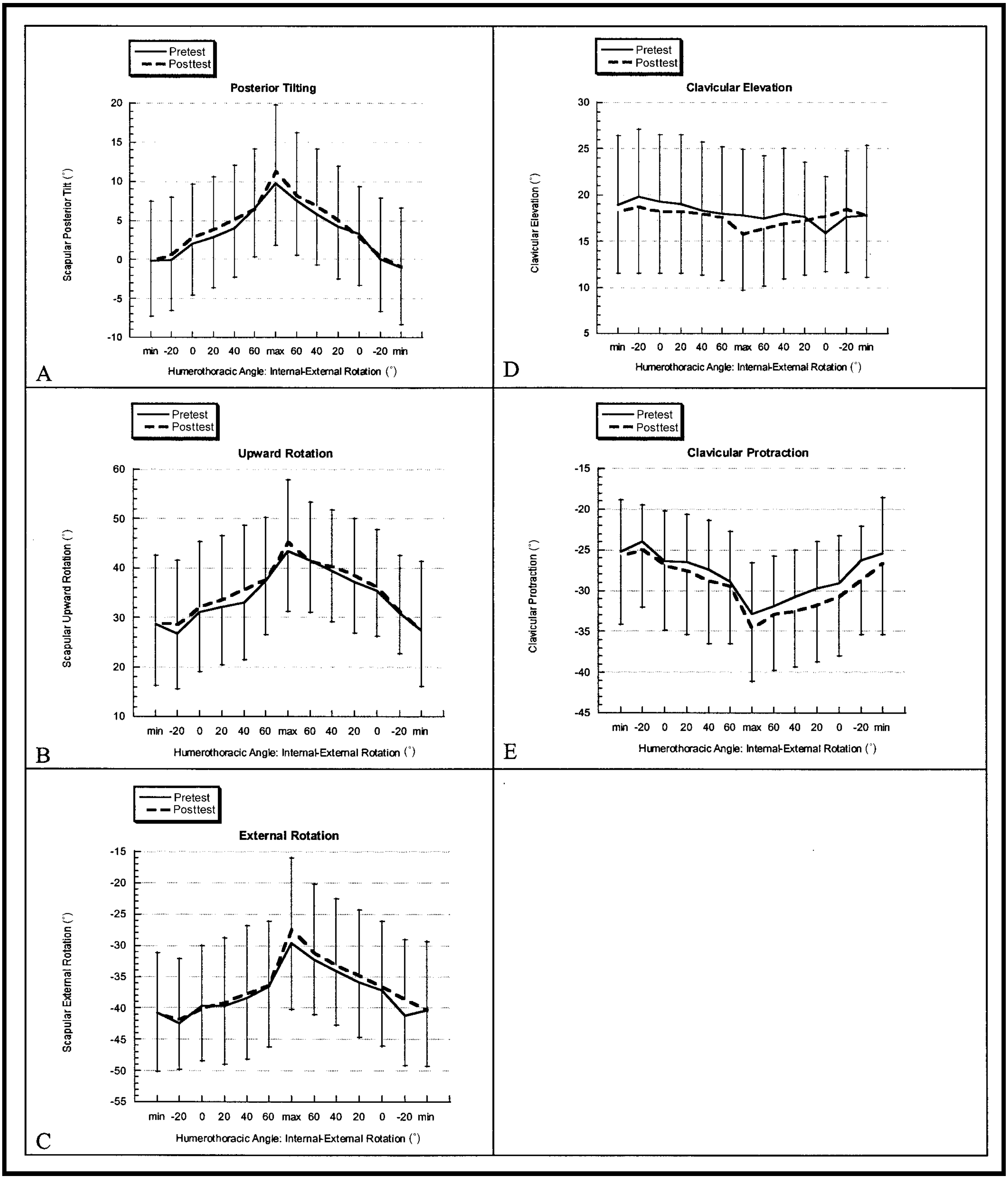

Figure 5.
Mean scapular and clavicular rotations during humerothoracic internal to external rotation (minimum to maximum) with the arm abducted to 90 degrees in the coronal plane; negative numbers represent internal rotation. The solid line represents pretest values, and the dashed line represents posttest values. "Max" represents the mean peak humerothoracic external rotation for all subjects, which was 79.3 degrees (SD=18.6) pretest and 83.0 degrees (SD=16.3) posttest, and these differences were not significant. "Min" represents the mean peak humerothoracic internal rotation for all subjects, which was −26.9 degrees (SD=25.3) pretest and −31.0 degrees (SD=15.1) posttest, and these differences were not significant. (A) Posterior tilting. (B) Upward rotation. (C) Scapular external rotation. (D) Clavicular elevation. (E) Clavicular protraction (clavicular retraction is represented by decreasing values).

Table 2.
Posture, Muscle Force, and Range of Motion Before and After the Exercise Program (Symptomatic Side)

	Before			After		
	X̄	SD	Range	X̄	SD	Range
Posture (thoracic) (°)	11.8	6.2	−1.5–28.9	11.1	6.2	0–27.2
Isometric force (N)						
Internal rotation	115.2	49.6	50.3–228.2	145.9[a]	63.2	68.1–274.5
External rotation	87.6	44.0	36.9–167.7	102.3[a]	11.2	44.5–207.8
Abduction	137.0	82.4	25.4–317.2	158.4[a]	74.4	41.4–324.8
Range of motion (°)						
Internal rotation (vertebral level)	8.8	3.7	3–16	7.0[a]	2.5	3–14
External rotation	64.9	13.0	45–90	69.7	4.3	40–95
External rotation at 90° of abduction	96.8	31.0	25–140	112.0[a]	22.3	80–148
Elevation	141.8	21.7	95–170	145.5	16.7	110–170

[a] Significantly improved after exercise ($P<.001$).

Table 3.
University of Pennsylvania Shoulder Scale Scores Before and 6 Weeks After Exercise and at 6-Month Follow-up

	Before Exercise (n=39)	6 Weeks After Exercise[a] (n=39)	6-Month Follow-up[a] (n=30)	Nonfinishers (Pretest) (n=20)
Pain subscale (out of 30, higher is better)				
X̄	16.9	25.2	25.2	17.3
SD	5.6	5.4	3.9	6.9
Range	4–26	2–30	15–30	8–28
Satisfaction subscale (out of 10, higher is better)				
X̄	3.7	6.9	7.9	3.1
SD	2.8	3.1	2.5	3.0
Range	0–9	1–10	2–10	0–9
Function subscale (out of 60, higher is better)				
X̄	42.7	51.2	52.9	39.6
SD	8.1	9.8	6.4	11.5
Range	24–58	9–60	38–60	18–57
Total score				
X̄	63.3	83.3	86.0	61.6
SD	13.6	16.9	14.5	21.1
Range	32–87	12–100	55–100	31–93

[a] All subscale scores and total score significantly improved 6 weeks after exercise and at 6-month follow-up versus before exercise ($P<.001$).

our work is that no control group was used. The positive changes we observed, therefore, cannot be distinguished from placebo effects or the natural history of shoulder impingement. Furthermore, the tester was not masked, and therefore bias may have been a factor. In addition, we did not examine the reliability of our measurements for the type of patients we were studying, and little is known about the reliability of data obtained from some of the measures that were used.

The natural history of shoulder impingement without intervention has not been well documented. Table 4 compares the results of our study with those of previous shoulder impingement studies where placebo or no intervention was compared with other interventions and pain and function were measured.[23,40,42] Although different measures of pain were used in each study, collectively they suggest that pain associated with impingement does not spontaneously resolve and may even worsen slightly with no intervention or placebo. Without active intervention, shoulder function showed a decline in 2 studies[23,40] and did not improve in another study.[42] In comparing our results with the results of these studies, we believe it is unlikely that natural history accounted for the positive changes in pain and function.

Ludewig and Cook[11] identified relatively lower serratus anterior muscle electromyographic activity in patients with impingement compared with controls during loaded elevation in the scapular plane. Several authors[10,11,26] have suggested that patients with impingement syndrome have altered scapular kinematics as compared with controls without symptoms of impingement syndrome. One explanation for a lack of change in

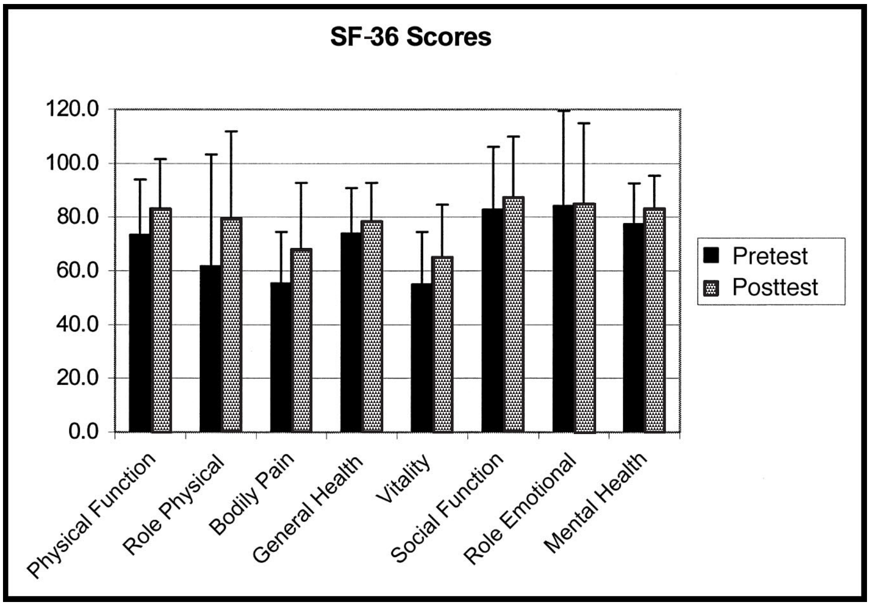

Figure 6.
Mean Medical Outcomes Study 36-Item Short-Form Health Survey (SF-36) scores; error bars represent standard error. Significant improvements ($P<.01$) were found for physical function, role physical, bodily pain, vitality, and mental health subscales.

scapular kinematics may be that the test movements we studied were not challenging enough to the musculature to show changes due to altered or improved muscle activation. Other studies[11,26,43] have suggested that patients with impingement show greater deficits under loaded conditions. It seems logical to us that testing with loads applied or under fatiguing conditions might amplify subtle deficits; however, we were hesitant to do this because of concerns about inducing pain or increasing symptoms.

We expected to find more substantial changes in kinematic patterns after exercise based on previous studies suggesting deficits in patients with impingement[10,11,26,43] as well as previous work suggesting that exercise in individuals with common postural deficits alters scapulohumeral rhythm.[44] Wang et al[44] found an increased relative contribution of the glenohumeral joint compared with the scapulothoracic joint during shoulder elevation after a 6-week exercise program that focused on the posterior scapular stabilizers and glenohumeral external rotators. They used a static technique that required digitization of multiple bony landmarks while the subjects held their arm in various positions statically, whereas our method tracked motion continuously. They also used planar projections to represent scapular motion, whereas we used a Euler angle system with axes embedded in each bony segment.

We believe another potential explanation for the lack of change in scapular kinematics is that not all patients with impingement have abnormal scapular motion. It may be that only a subset of patients with shoulder impingement may have scapular motion abnormalities. However, at present, there is no accepted or validated operational definition of "abnormal kinematics." Graichen et al[45] used 3-dimensional reconstruction of magnetic resonance images in subjects with and without impingement syndrome. They found that a subset of 5 out of 20 subjects with impingement syndrome showed a pattern that was abnormal, defined as greater than 2.5 standard deviations of the mean, yet these differences were obscured in the group data. The abnormality they identified was increased upward rotation of the scapula. 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 the subjects without impingement symptoms. In contrast to Graichen and colleagues' findings, Ludewig and Cook found subjects with impingement symptoms had less scapular upward rotation compared with subjects without impingement symptoms. Our subjects, as a group, anteriorly tilted their scapulae by about 1 degree between 60 and 90 degrees of elevation and then posteriorly tilted their scapulae about 1 degree between 90 and 120 degrees of scapular-plane elevation. These motions are small and within the range of measurement error. During flexion, our subjects anteriorly tilted their scapulae about 3 degrees between 60 and 120 degrees of humeral elevation. A defensible operational definition of "abnormal" kinematics remains to be determined.

There is also no standard method for determining which patients have abnormal scapular motion. Kibler[46] has described a simple test based on linear measures 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.[47,48] We believe a method of reliably identifying patients with scapular motion abnormalities that is suitable for routine clinical use would be of great value because it would allow intervention to be directed toward improving scapular muscle force and control in those patients. Shoulder impingement secondary to poor scapular control may require different intervention than impingement due to other causes.

Our intervention was focused primarily on changing physical impairments related to impingement in order

Table 4.
Comparison of Current Study Outcomes With Outcomes of Studies Using Placebo or No Intervention for Shoulder Impingement

Study	Description	Pain	Function
Brox et al,[23] 1993	Compared acromioplasty, supervised exercise (n=50), and detuned soft laser (placebo) (n=30) Measurements taken at 0, 3, and 6 mo Pain measured at rest and during activity on a 9-point scale (1=no pain, 9=worst pain) "Function" measured using Neer impingement test score, which combines muscle force, stability, and reaching ability (30=full function)	Placebo group: At rest: 5/9 pretest, 4/9 at 3 mo, 4.5/9 at 6 mo During activity: 7/9 pretest, 6/9 at 3 mo, 6/9 at 6 mo Exercise group: At rest: 5/9 pretest, 3/9 at 3 mo, 2/9 at 6 mo During activity; 7/9 pretest, 4/9 at 3 mo, 3/9 at 6 mo	Placebo group: 21/30 pretest, 20/30 at 3 mo, 15/30 at 6 mo Exercise group: 24/30 pretest, 24/30 at 3 mo, 25/30 at 6 mo
Blair et al,[42] 1996	Compared injection of corticosteroid (n=19) with injection of lidocaine only (placebo, n=21) Measurements taken at preinjection and average follow-up of 33 wk Pain measured on a 4-point scale (0=no pain, 1=mild pain, 2=moderate pain, 3=severe pain) Function measured for 5 tasks (0=unable, 1=able with difficulty, 2=no difficulty) (total score of 10=full function)	Placebo injection: Preinjection: $\overline{X}$=2.3 (n=9, severe pain; n=10, moderate pain; n=2, mild pain) Follow-up: $\overline{X}$=2.0 (n=5, severe pain; n=10, moderate pain; n=6, mild pain) Steroid injection: Preinjection: $\overline{X}$=2.4 (n=8, severe pain; n=10, moderate pain; n=1, mild pain) Follow-up: $\overline{X}$=1.2 (n=1, severe pain; n=2, moderate pain; n=16, mild pain)	Placebo injection: Preinjection: $\overline{X}$=6.4/10 Follow-up: $\overline{X}$=8.3/10 Steroid injection: Preinjection: $\overline{X}$=6.9/10 Follow-up: $\overline{X}$=9.1/10
Ginn et al,[40] 1997	Compared a 4-wk exercise program (n=33) with no intervention (n=33) Measurements taken before and after 4-wk intervention period Pain was measured on a 10-cm visual analog scale (10=worst pain) Self-rated improvement measured on a 5-point scale (1=completely recovered, 5=worsened)	Control group: Before: 1.4/10 After: 2.1/10 Exercise group: Before: 1.3/10 After: 1.0/10	Control group: Median=4/5 ("stayed the same") 50% reported "worse" Exercise group: Median=2/5 ("improved a lot") 11% reported "worse"
Current study	6-wk exercise program, no control group Measurements taken before exercise and at 6 wk and 6 mo after exercise Pain rated at rest and during light activity and heavy activity (30=no pain) Function measured on 20-item scale, with each item rated on scale of 3 (no difficulty) to 0 (unable to do) (total score of 60=full function)	Pre-exercise: 16.9/30 6 wk: 25.2/30 6 mo: 25.2/30	Pre-exercise: 42.7/60 6 wk: 51.2/60 6 mo: 52.9/60

to produce changes in pain and function. We found an association between shoulder function and 2 specific impairments, external rotation force and internal rotation ROM. In the absence of a control group, we could not determine whether improved motion and force caused an improvement in pain and function. It is possible that a decrease in pain allowed greater ROM and force generation.

Our exercise program emphasized rotator cuff strengthening and avoided elevation exercises until the glenohumeral rotators demonstrated enough force to use green Thera-Band. This approach was based on our belief that the glenohumeral rotators perform an important depressor function that keeps the humeral head centered on the glenoid fossa during elevation. Paletta et al[9] have documented that patients with rotator cuff tears demonstrate abnormal superior translation of the humeral head during elevation, which is abolished after rotator cuff repair. Therefore, our protocol was based on the belief that premature use of elevation exercises (flexion or abduction) with rotator cuff weakness may encourage the impingement process by allowing humeral head superior translation from the deltoid muscle and should not be used until adequate force and activation of the glenohumeral rotators has been achieved.

We found that the ability to move the thumb up the back, as a measure of internal rotation, improved by almost 2 vertebral levels. Internal rotation is believed to reflect the length of the glenohumeral joint posterior capsule, and tightness of this structure has been shown to promote anterior-superior translation of the humeral head consistent with subacromial impingement.[12] Measuring internal rotation by vertebral level has been criticized for poor intertester reliability by one group of researchers,[49] although they used ratings obtained for only 3 subjects, whereas other researchers[33,34] have found reasonable reliability (ICC>.80). Other researchers[50] also have pointed out that measuring medial rotation by vertebral level incorporates elbow motion and substantial scapulothoracic motion. We chose to use this measure primarily because patients with impingement are often unable to tolerate internal rotation with the arm elevated to 90 degrees. In addition, placing the hand behind the back appears to be important for several functional activities such as fastening a bra, tucking in a shirt, or toileting functions. Determining the optimal way to document tightness of the posterior capsular as well as the optimal way to improve it with stretching, we believe, are worthy of further study.

Despite exercises directed at encouraging upper thoracic extension, we did not find altered resting posture in the upper thoracic area, nor did we find increased thoracic extension during shoulder flexion. Upper thoracic extension is believed to be an essential component of arm elevation, and the exercise program may have facilitated subtle increases in upper thoracic motion that were not detected with our measurement system.

The relatively high attrition rate (33%) was disappointing and potentially biased the results. The subjects who dropped out, however, were very similar to those who completed the study in terms of age, size, duration of symptoms, pain intensity, and shoulder function. A greater percentage of male subjects than female subjects dropped out of the study. The majority of the subjects who dropped out (11/20) did not return after the first session, which consisted of initial testing and exercise training; 6 subject completed 2 visits, 1 subject completed 3 visits, and 3 subjects dropped out after 4 visits. We believe it is unlikely that an adverse response led to dropping out of the study, because no subject reported such a response and the exercise program was designed to avoid pain. We believe the urban location combined with stressful personal schedules prevented many subjects from completing the 6-week program, which may explain why our attrition rate was similar to that for all other patients seen at the same clinic (38%). The fact that patients were not paying for intervention may have been an incentive; however, the majority of patients in the primary clinic pay little or nothing out of pocket for intervention, and "free" intervention that emphasized a home exercise program may have been perceived as less valuable. Another possibility is that once patients realized the intervention consisted of a home exercise program, weekly clinic attendance may have been perceived as unimportant.

Conclusions

A simple 6-week exercise program aimed at strengthening the rotator cuff, increasing the flexibility of the posterior glenohumeral capsule, and encouraging upper thoracic extension and a retracted head position may have resulted in improved muscle force, motion, pain, and function in a group of patients with shoulder impingement. In the absence of a control group, we cannot say with certainty whether the intervention led to changes in the patients' status. The changes we observed, for example, cannot be distinguished from those that might occur due to the natural history of shoulder impingement syndrome. Alterations in 3-dimensional scapular kinematics were not observed after exercise, and this finding suggests the possibility that only a subset of patients with impingement syndrome may have problems with scapular motion.

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