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Scapular kinematics and impairment features for classifying patients with subacromial impingement syndrome☆

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ABSTRACT

Subacromial impingement syndrome (SAIS), which is associated with pain and a loss of function, has a high occurrence in the physically active population. Not all patients respond positively to treatment. Classifying patients can improve decision-making. The scapular kinematic and clinical impairments can aid in classifying the patients who are more likely to respond to physical therapy treatment. Thirty-three subjects (males, 20–33 years) presenting SAIS were studied to determine altered scapular kinematics and clinical impairments. Three measurements were collected: (1) three-dimensional scapular kinematics during performing functional tasks; (2) impairment outcomes of range of motion and muscle force; and (3) self-reported measurements of pain, satisfaction, and function. All patients received 6-week (2 times per week) physical therapy treatment. Improvement with treatment was determined using the Global Rating of Change Scale. Scapular kinematics and clinical impairments were first identified by *t*-test in predicting improvement and then combined into a multivariate prediction method. A prediction method with three variables (Flexilevel Scale of Shoulder Function score < 41, muscle power of serratus anterior $< 27.4\%$ body weight, degree of scapular internal rotation at 30° shoulder elevation during descending arm phase in unloaded condition $< 0.7°$) were identified. It appears that scapular kinematics and impairment features can be used to classify subjects with SAIS in addition to self-report. Prospective validation of the proposed prediction method requires further investigation.

Subacromial impingement syndrome (SAIS), which is associated with pain and a loss of function, has a high occurrence in the physically active population, accounting for 44–65% of all shoulder complaints during physician's office visits (van der Windt et al., 1995, 1996; Vecchio et al., 1995). Rehabilitation of SAIS performed by physical therapists may incorporate a variety of different physical intervention techniques, including therapeutic exercise, manual therapy, and physical modalities. However, not all patients respond positively to those treatments. Previous studies have shown that the success rates of physical therapy ranged from 20% to 79% (Winters et al., 1997; Hay et al., 2003). Given that a treatment strategy may be patient specific, identification of patients who are suitable for physical therapy programs and of the outcomes associated with reducing pain and functional improvement in patients with SAIS is warranted.

Classifying patients can improve decision-making. A review of the literature shows that the classification of SAIS varies. Based upon the degree of injury to the tissues of the subacromial space, Neer (1983) defined this disorder as a mechanical compression injury of the tissues of the subacromial space and proposed three progressive categories: the edema and hemorrhage stage, the deterioration of the tendon and bursa stage, and bone spurs and partial or full-thickness tendon rupture stage. Other classification systems have attempted to logically categorize the potential mechanistic factors of SAIS as direct/indirect, intrinsic/extrinsic, primary/secondary, or static/dynamic (Fu et al., 1991; Bigliani and Levine, 1997). Among those classifications, physical therapy-associated extrinsic factors are potential extrinsic mechanics that may lead to SAIS. These extrinsic factors include faulty posture, altered scapular/glenohumeral kinematics, and posterior capsular tightness (Michener et al., 2003). Some treatment principles are available, such as posture correction (Lewis et al., 2005), restoration of normal kinematics by strengthening rotator cuff and scapular

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muscles, and stretching posterior capsular tightness (McClure et al., 2004). The exact criteria for the classifications, however, are not provided. Thus, we cannot presently classify patients into definite categories suitable for physical therapy.

In clinical studies, many authors have reported positive treatment effects on SAIS (Brox et al., 1993; Bang and Deyle, 2000; McClure et al., 2004; Walther et al., 2004; Ginn and Cohen, 2005; Roy et al., 2009). However, applying those results in clinical practice is problematic. First, the diagnosis of SAIS in previous studies was based on a variety of clinical signs and symptoms (Michener et al., 2004). Subjects from different selection criteria may respond differently to treatment protocols. Second, those studies did not provide the specific characteristics of patients who responded to the treatments. Third, the mechanisms of treatment effects could not be generalized from results to support the hypotheses. For example, McClure et al. (2004) expected to find more substantial changes in kinematic patterns after exercise, based on previous studies suggesting kinematic differences between patients with SAIS and healthy individuals (Lukasiewicz et al., 1999; Ludewig and Cook, 2000). After 6 weeks of exercise training for impingement patients in their study, no significant kinematic changes were found. The insignificant findings in kinematics may be due to the high attrition rate (33%); insensitive assessment methods, such as testing shoulder kinematics of elevation without loading; or unspecific treatment protocols.

The specific purposes of the study were two-fold: (1) to identify the shoulder kinematic and impairment of the patients who are more likely to respond to physical therapy; specifically, this study used a prediction method modified from a clinical prediction rule (McGinn et al., 2000) to establish the method of outcome prediction after physical therapy in patients with SAIS; and (2) to determine which changes of impairments pre- and post-treatment are related to the successful outcome for SAIS. These may explain the mechanisms involved in physical therapy. To do so, all subjects received the same tests, measures, and treatments. The diagnostic value of each test or measure was judged to determine the characteristics of the subjects who responded best to the intervention.

1. Methods

1.1. Design and subjects

This was a repeated-measures design and a predictive validity/diagnostic test study, with outcome measurements being taken before and after a 6-week physical therapy treatment. No control group was incorporated into this study. This study recruited 58 patients with SAIS from the orthopedics clinic in National Taiwan University Hospital and also through general announcements in local Internet media. After screening of the patients with the tests (criteria), 33 subjects met the criteria for the study. All signed an informed consent form approved by the Ethics Committee of the University Hospital. Prior to initiation of the study, based on our pilot study, a sample size of 33 subjects was calculated to provide 80% power to detect differences of 6° of scapular kinematic variables with 6° standard deviation between the improvement and non-improvement groups. Subjects had to demonstrate at least 3 of the following: (1) a positive Neer impingement test, (2) a positive Hawkins impingement test, (3) a painful arc, (4) pain with isometric resisted abduction, (5) pain with palpation of the rotator cuff tendons, and (6) pain with active shoulder elevation. Subjects were excluded if they demonstrated signs of a complete rotator cuff tear or acute inflammation.

1.2. Outcomes and treatments

The FASTRAK motion analysis system (Polhemus Inc., Colchester, Vermont, USA) was used to detect shoulder complex movements. We followed the International Society of Biomechanics guidelines for constructing a shoulder joint coordinate system (Wu et al., 2005). The sensors for the motion-capturing system were attached to the bony landmarks (the sternum, the scapular acromial process, and the distal humerus between the lateral and medial epicondyles) with adhesive tape. A fourth sensor attached to a stylus was used to digitize palpated anatomical coordinates. Recordings started with the subject in a sitting position, the arms relaxed at the sides. Subjects were then asked to elevate their arms in the scapular plane (40° anterior to the coronal plane) with and without holding a 2-kg weight (Fig. 1). Three replicated movements were performed. To quantitatively characterize shoulder and scapular kinematics; the upward rotation, internal rotation, and scapular tilt at 30°, 60°, 90°, and 120° of humeral elevation were used as dependent variables.

The passive ROM (Range of motion) was assessed with the subject in a supine position. The subject's arm was moved passively to the end of rotation with the arm held in 90° abduction by the tester. The recorder placed a hand-held goniometer (Ever Prosperous Instrument, Inc., Taiwan) with the two arms parallel to the forearm and trunk, respectively, and documented the rotation ROM. Goniometry measurement of shoulder ROM has been demonstrated to be highly reliable in previous studies (intratester intraclass correlation coefficients ICC range: 0.80–0.93 from MacDermid et al. (1999) and Riddle et al. (1987) as well as in our pilot study (ICC = 0.96)). Isometric shoulder muscle forces (shoulder external rotation force, shoulder internal rotation force, shoulder abduction force, scapular retraction force) were measured with the FET-micro Hand-Held Dynamometer using a "make test" technique (Michener et al., 2005; Laudner et al., 2008). The average of 3 consecutive measurements was used for data analysis. The high intrarater reliability of force measurements has been reported (0.81–0.94) (McClure et al., 2006). The posture of the thoracic spine in the sagittal plane was measured in a relaxed sitting position. Sensors were adhered to the tragus of the ear, C7, and lateral tip of the acromion during the measurement. The forward head posture was the angle between the vertical axis and vector from C7 to the tragus

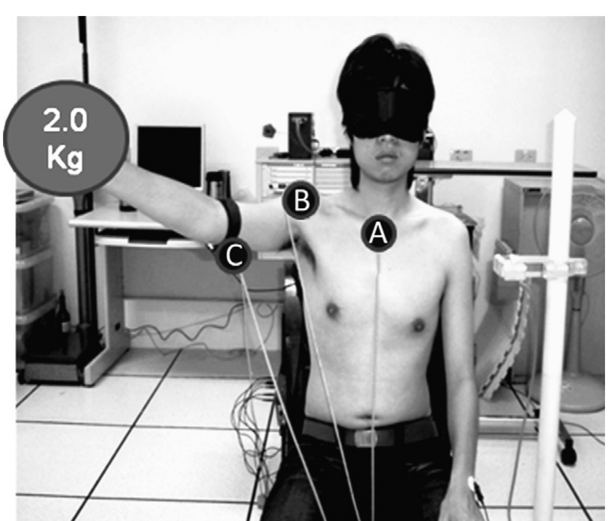

Fig. 1. Abduction in the scapular plane test. Abduction in the scapular plane while holding a 2-kg weight. (A) Sternum; (B) flat bony surface of the scapular acromion; and (C) distal humerus.

of the ear. The forward shoulder posture was determined by the angle between the vertical axis and the vector from C7 to the lateral tip of the acromion (Lewis et al., 2005). The humerus was passively moved into the starting position of 90° of flexion and 0° of adduction with neutral rotation for assessment of posterior shoulder tightness. This was measured by the inclinometer (Lin and Yang, 2006).

The self-reported Flexilevel Scale of Shoulder Function (FLEX-SF) was used to determine functional disability at the baseline and at post-treatment (Cook et al., 2003). In this scale, respondents answer a single question that grossly classifies their level of function as low, medium or high. They then respond to only the items that target their level of function. Scores were recorded from 1, representing the most limited function, to 50, representing full function. Change in the perception of outcome after the treatment was measured by a Global Rating of Change Scale (GRCS) (Jaeschke et al., 1989). The GRCS is a 15-point global rating scale ranging from −7 ("a very great deal worse") to 0 ("about the same") to +7 ("a very great deal better") (Jaeschke et al., 1989; Fritz and Irrgang, 2001). To develop a prediction method in our study, we justify the criteria of 4 GRCS scores as improvement and non-improvement groups. We chose 4 GRCS scores as the improvement criteria because the patients generally felt satisfied with their improvement, as indicated by our investigation in the clinic. A standardized intervention regimen (Table 1), modified from the evidence demonstrating a beneficial effect for exercise in the treatment of SAIS, was applied (Kuhn, 2008). These included manual therapy (joint and soft tissue mobilization techniques), ROM exercises (shoulder shrugs and shoulder retraction), stretching exercises (corner anterior shoulder stretching and arm cross-body posterior shoulder stretching), and strengthening exercises (rotator cuff and scapula stabilizing muscles strengthening exercises: internal/external rotation, scaption, chair press, push-up plus, press-up, rows, upright row, and lower row). An independent trained measurer blinded to treatment assessed the outcomes.

1.3. Data analysis

Improvement or non-improvement was then used as the reference outcome. To address potential confounding variables, we compared the duration of symptoms, initial FLEX-SF scores, and compliance with physical therapy treatment (number of actual physical therapy treatment sessions divided by number of proposed physical therapy treatment sessions) between the improvement and non-improvement groups. Variables from the shoulder kinematics and clinical impairments were tested for their relationship with the reference outcome using independent sample *t*-tests. Variables with a significance level of $p < 0.10$ may be retained as potential prediction variables; a more liberal significance level was chosen at this stage to avoid excluding potential predictive variables. For a significant relationship, sensitivity and specificity values were calculated for all possible cut-off points and then plotted as a receiver operator characteristic (ROC) curve (Hagen, 1995). The point on the curve nearest the upper left-hand corner represents the value with the best diagnostic accuracy, and this point was selected as the cut-off defining a positive test (Deyo and Centor, 1986). Sensitivity, specificity, and positive likelihood ratios (PLRs) were calculated for all potential prediction variables (Sackett, 1992). The PLR was calculated as sensitivity/(1 − specificity) and indicates the increase in the probability of improvement given a significant altered shoulder kinematics and impairment result (Jaeschke et al., 1994). Potential prediction variables were entered into a stepwise logistic regression equation to determine the predictors for improvement using a multivariate model. A significance of 0.05 was required to enter a variable into the model, and a significance of 0.10 was required to remove it. Variables retained in the regression model were used to develop a multivariable prediction method for determining shoulder kinematics and outcomes in the prediction of the progress of SAIS. Receiver Operating Characteristic (ROC) curves were used to assess each kinematic and impairment efficiency in differentiating who did and who did not experience clinically important change (a GRCS larger than 4 or equal to 4).

Table 1
Description of standardized intervention regimen.

Protocol	Description
Manual therapy	Joint and soft tissue mobilization
ROM exercise	Shoulder shrugs, shoulder retraction
Stretching exercise	Anterior shoulder stretching, posterior shoulder stretching
Strengthening exercise	Rotator cuff and scapula stabilizing exercises: scaption, chair press, push-up plus, press-up, rows

Evidence-based medicine exercise protocol for impingement syndrome (modified from Kuhn (2008)). Each stretch should be held for 30 s and repeated 5 times, with a 10-s rest between each stretch. ROM and stretching exercises were performed daily. Manual therapy and strengthening exercises were performed 2 times weekly.

2. Results

Of the 33 subjects recruited in this study, 32 patients completed the 6-week treatment. Subjects reported compliance rates of over 80% (sessions of actual treatment/sessions of proposed treatment). The final data were based on 33 subjects. In the case of the dropout, the sequence of variables was regarded as constant. After treatment, 23 subjects (69.7%) were classified as showing improvement and 10 (30.3%) as showing non-improvement (Table 2). The mean improvement in FLEX-SF scores in the improvement group was 10.0 ± 3.1, with a mean percentage improvement of $32.0 \pm 9.5\%$. In the non-improvement group, the mean FLEX-SF score change was 1.6 ± 3.9, with a mean percentage change of $5.1 \pm 9.7\%$. The age, height, weight, and duration of symptoms and ROM in the two groups were similar ($p > 0.05$). Table 3 shows all the initial outcome variables between the 2 groups. Significant differences between groups were observed in external rotator, serratus anterior force, FLEX-SF score, and two scapular kinematic variables: upward rotation at 30° shoulder elevation during the ascending phase and scapular internal rotation at 30° shoulder elevation during the descending phase in the unloaded condition.

These variables were entered into the logistic regression. Three were retained in the final model: FLEX-SF score, scapular internal rotation at 30° shoulder elevation during the descending phase in the unloaded condition, and serratus anterior force (model $\chi^2 = 23.71$, $df = 3$, $P < 0.0001$, Nagelkerke $R^2 = 0.725$). Of those variables retained in the final model, cut-off values and diagnostic statistics from ROC curve analyses were a FLEX-SF score of 41, 27.4% of body weight serratus anterior force, and 0.7° of scapular internal rotation at 30° shoulder elevation during the descending phase in the unloaded condition (Table 4). Thirteen of the 23 subjects were in the improvement group for 1 retained prediction variable at

Table 2
Demographic data of subjects.

	Improvement (GRCS ≥ 4, $N = 23/33$)	Non-improvement (GRCS < 3, $N = 10/33$)	*p*-value
Age (year)	23.6 ± 3.4	22.9 ± 3.2	0.606
Height (cm)	170.3 ± 7.8	170.7 ± 6.1	0.722
Weight (kg)	68.0 ± 6.8	66.2 ± 5.9	0.472
Symptom duration (months)	22.6 ± 18.1	29.4 ± 15.2	0.325
Flexion (°)	170.3 ± 7.8	170.7 ± 6.1	0.888
Abduction (°)	168.3 ± 13.5	170.3 ± 9.6	0.683
External rotation (°)	102.7 ± 19.1	107.6 ± 9.7	0.450

Table 3
The initial ROM, muscle force, posture, shoulder posterior tightness, and self-report outcomes in improvement and non-improvement groups.

	Improvement (23/33)	Non-improvement (10/33)	p-value
Internal rotation (°)	56.3 ± 7.2	57.7 ± 11.1	0.668
External rotation (°)	102.7 ± 19.1	107.6 ± 9.7	0.450
External rotator (% weight)	14.9 ± 3.0[a]	17.0 ± 3.1	0.076
Internal rotator (% weight)	23.4 ± 5.5	25.9 ± 6.5	0.246
Abductor (% weight)	22.2 ± 5.5	24.8 ± 5.0	0.208
Serratus anterior (% weight)	22.9 ± 3.9[a]	26.4 ± 5.2	0.040
Lower trapezius (% weight)	11.5 ± 2.7	12.1 ± 1.8	0.563
Posture (°)	33.3 ± 8.0	30.1 ± 5.2	0.249
Forward head (°)	43.6 ± 4.6	45.9 ± 4.9	0.209
Forward shoulder (°)	74.0 ± 3.2	75.3 ± 4.8	0.380
Posterior shoulder tightness (°)	43.4 ± 13.3	44.9 ± 8.8	0.753
FLEX-SF[b] score	34 ± 4	41 ± 6	<0.0005

[a] Variables with a significance level of $p < 0.10$ based on independent sample t-tests.
[b] Flexilevel Scale of Shoulder Function.

baseline. Ten of the 23 subjects, with 2 of 3 variables present, were in the improvement group. Accuracy statistics were calculated for each level of the prediction method (Table 5). Based on the probability of improvement found in this study (69%) and the PLR values calculated, a subject with 3 variables present at baseline has an increased probability of improvement, from 69% to 100%. If the criteria were changed to 2 variables present, the probability of improvement would increase to 88%.

3. Discussion

In this study, we were primarily interested in classifying patients for improving clinical decision-making. Similar to previous studies (McClure et al., 2004; Walther et al., 2004), we were able to show adequate effects of 6 weeks of treatment in some of our patients. Additionally, our results support the classification in patients with SAIS. Less internal rotation of the scapula (0.7°), inadequate serratus anterior muscle force (27.4% body weight), and functional disability (FLEX-SF score < 41) are potential classification factors, as they could predict the clinical course in patients with SAIS in our study. We believe that these factors may contribute to impingement and can be used for classification in patients with SAIS.

With regard to internal rotation of the scapula, greater internal rotation of the scapula (a protraction or winging scapula) is believed to narrow the anterior opening of the subacromial space as the shoulder moves from a retracted to a protracted position (Solem-Bertoft et al., 1993). Our results support this hypothesis. We found that less internal rotation at 30° of shoulder elevation is an important factor for clinical course prediction. Practically, our finding was noted during the arm descending phase. In investigating arm elevations, Borstad and Ludewig (2002) found increased internal rotation of the scapula during the arm descending phase as compared to the arm ascending phase. Thus, in our investigation, the less internal rotation during the arm descending phase can avoid impingement. Although no quantification of the internal rotation during arm descending phase relative to patient characteristics has been presented in the literature, we did visually observe some patients with more internal rotation of the scapula (a protracted or winging scapula) during the arm descending phase. We suggest that this phenomenon should be included in a clinical examination to classify patients. For a clinically meaningful assessment, the subject should display virtually no scapular internal rotation on arm decent at 30°. Development and the diagnostic accuracy of the test should be further investigated.

We found that self-reported shoulder function (FLEX-SF) could identify subgroups that were more likely to respond to our treatment, with the criteria being a FLEX-SF score of 41. Similar results have been found previously in one cohort study (Nitz et al., 2009). In that study, patients with shoulder impingement who improved were differentiated from those who did not improve from physical therapy intervention. Improved patients had initial QuickDASH scores of 50 ± 16, as compared to not-improved patients, who scored 29 ± 19 (a higher score indicates greater disability). Our study indicated that improved patients had initial FLEX-SF scores of 34 ± 4, as compared to not-improved patients, who had initial scores of 41 ± 6. Patients with perception of more shoulder dysfunction appeared to benefit more from physical therapy. Classification of patients with their perception of function is recommended.

Because the insertion of the serratus anterior is the medial border and inferior angle of the scapula, the decreased muscular activity is believed to be related to the inadequate upward rotation of the scapula to elevate the anterior acromion in patients with SAIS (Ludewig and Cook, 2000). Our data also support this assumption. In our investigation, the upward rotation of the scapula and the serratus anterior muscle force are 2 of the potential prediction variables in the logistic regression. Thus, serratus anterior muscle force can be used to classify patients with SAIS. Specifically, we found that the muscle force of the serratus anterior can be increased through our strengthening protocol and result in better functional outcomes. Given that the function of the serratus anterior is also related to a winging scapula, one of the prediction factors in our investigation, examination of serratus anterior function is necessary in subjects with SAIS.

The importance of a prediction method in the prediction of the treatment outcome in patients with SAIS is best expressed using likelihood ratio statistics. When the subject meets the prediction rule criteria, PLR expresses the change in odds favoring the improvement (Sackett, 1992). In our sample, treatment of subjects with SAIS may result in about a 69% probability of improvement without any attempt at prediction. Using 2 criteria variables present at baseline (PLR = 3.33), the probability of improvement is raised to 88%; if all three variables are present, the probability of improvement increases to 100%. Therefore, all individuals with 3 positive variables respond to treatments. This suggests that scapular internal rotation, serratus anterior muscle force, and the patient's perception of function, where they are judged to be less than the thresholds identified in this study, should be considered as important treatment targets.

Limitations of the study should be noted. Our results should be interpreted with caution because of a lack of control over intervention in our study. In the absence of a control group, we could not determine whether improved shoulder function and force resulted

Table 4
Sensitivity and specificity statistics (with 95% confidence intervals) of predicting variables.

Predicting variables	Sensitivity	Specificity	Positive likelihood ratio
FLEX-SF[a] (<41)	100.00 (85.0–100.0)	50.00 (18.9–81.1)	2.00
Serratus anterior (<27.4% weight)	91.30 (71.9–98.7)	50.00 (18.9–81.1)	1.83
IR (<0.7°)	73.9 (151.6–89.7)	70.00 (34.8–93.0)	2.46

[a] Flexilevel Scale of Shoulder Function.

Table 5
A prediction method.

No. of predictor variables present	Sensitivity	Specificity	Positive likelihood ratio	Probability of improvement (%)
1+	100.00 (85.0–100.0)	0.00 (0.0–31.0)	1	69
2+	100.00 (85.0–100.0)	70.00 (34.8–93.0)	3.33	88
3	56.52 (34.51–76.78)	100.00 (68.97–100.00)		100

in a self-report improvement. In the present study, only scapular kinematics, shoulder-related outcomes, and post-treatment improvement were considered, and it is unknown whether other factors or long-term follow-up would provide similar results. Furthermore, the participant population was all male and aged between 20 and 32. The generalizability of the study results to females or other age groups is uncertain. Because 33 subjects is a small number on which to perform regression analysis, our results indicate that further research with a large sample size is needed.

4. Conclusion

This investigation supports the assertion that classifying patients for improved clinical decision-making is possible. Based on the prediction method we found a subject with SAIS who meets 3 criteria (FLEX-SF score < 41, muscle force of serratus anterior $< 27.4\%$ body weight, degree of scapular internal rotation at 30° shoulder elevation < 0.7 degree) at baseline has a probability of 100% of demonstrating improvement at 6-week follow-up. Self-reported functional status and muscle force of the serratus anterior should be examined in patients with SAIS. Tests to identify internal rotation of the scapula should be further investigated. Further study is required to transform these findings into a practical tool. For the multivariable regression model, validation with a large sample size is also needed.

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