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Original article

Shoulder kinematic features using arm elevation and rotation tests for classifying patients with frozen shoulder syndrome who respond to physical therapy☆

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Abstract

Physical therapy is an intervention commonly used in the treatment of subjects with frozen shoulder symptoms, with limited proven effect. The purpose of this study was to identify the kinematic features of patients with frozen shoulder who are more likely to respond to physical therapy. Thirty-four subjects presenting frozen shoulder syndrome were studied to determine altered shoulder kinematics and functional disability. Subjects received the same standardized treatment with passive mobilization/stretching techniques, physical modalities (i.e. ultrasound, shortwave diathermy and/or electrotherapy) and active exercises twice a week for 3 months. Initially, subjects were asked to perform full active motion in 3 tests: abduction in the scapular plane, hand-to-neck and hand-to-scapula. During the test, shoulder kinematics were measured using a 3-D electromagnetic motion-capturing system. In the initial and follow-up sessions, the self-reported Flexilevel Scale of Shoulder Function (FLEX-SF) was used to determine functional disability from symptoms. Improvement with treatment was determined using percent change in FLEX-SF scores over three months of treatment [(final score−initial score)/initial score × 100, >20% improvement and <=20% nonimprovement]. Shoulder kinematics were first analysed for univariate accuracy in predicting improvement and then combined into a multivariate prediction method. A prediction method with two variables (scapular tipping >8.4° during arm elevation, and external rotation >38.9° during hand to neck) were identified. The presence of these two variables (positive likelihood ratio = 15.71) increased the probability of improvement with treatment from 41% to 92%. It appears that shoulder kinematics may predict improvement in subjects with frozen shoulder syndrome. Prospective validation of the proposed prediction method is warranted.

Keywords: Frozen shoulder; Shoulder kinematics; Likelihood ratio; Prediction method

0. Introduction

Patients exhibiting frozen shoulder symptoms typically suffer pain, a limited range of motion and muscle weakness from disuse for periods ranging from several months to many years (Reeves, 1976; Shaffer et al., 1992). These symptoms usually respond to stretching/mobilization (Griggs et al., 2000; Vermeulen et al., 2006), but many patients with frozen shoulder syndrome still have some degree of pain and stiffness several years after onset of the disease (Reeves, 1976; Shaffer et al., 1992). Indeed, for patients with persistent symptoms, more aggressive interventions such as hydrodilatation, arthroscopic release or manipulation under anesthesia have been advocated (Dias et al., 2005). A prospective study of 41 patients with 5–10 years' follow-up indicated

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that 39% had full recovery, 54% had clinical limitation without functional disability and 7% had functional limitation (Reeves, 1976). Research regarding the efficacy of the early use of treatment strategies is warranted.

Although physical therapy is an intervention commonly used in the treatment of subjects with frozen shoulder symptoms, the effectiveness of physical therapy intervention has been limited (Griggs et al., 2000; Diercks and Stevens, 2004). One possible explanation for the lack of positive effects is the inability to define subgroups of patients who are most likely to respond to physical therapy. Developing an effective method for classifying patients with frozen shoulder symptoms could improve decision making by determining the patients who are most likely to benefit from physical therapy. Thus, determining methods for classifying patients with frozen shoulder symptoms is an important priority in the clinic and research.

Some investigators have suggested that frozen shoulder symptoms may be related to persistent synovitis, capsule contracture, contracted soft tissues and/or shoulder kinematic features (Loyd and Loyd, 1983; Neviaser, 1987; Parker et al., 1989; Mao et al., 1997; Griggs et al., 2000). Regardless of the potential factors related to frozen shoulder symptoms, altered shoulder kinematics is believed to exacerbate the condition and predispose patients to subacromial impingement, rotator cuff tendonitis, altered shoulder joint forces and possible degenerative changes (Ludewig and Cook, 2000; Lin et al., 2006). Thus, a more difficult and chronic course of frozen shoulder symptoms may develop. Additionally, previous research has indicated that the course of other types of shoulder dysfunction such as impingement (Ludewig and Cook, 2000; Lin et al., 2005) and shoulder tightness (Lin et al., 2006) may be associated with altered shoulder kinematics. It was the object of this study to identify the kinematic features of patients with frozen shoulder syndrome 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 determine whether impaired shoulder kinematics are associated with the degree of symptom-related functional disability in patients with frozen shoulder syndrome.

1. Methods

1.1. Subject recruitment

This was a predictive validity/diagnostic test study. It was conducted at the outpatient clinic of the Department of Physical Medicine and Rehabilitation at National Taiwan University Hospital. All subjects gave written informed consent. Subjects were recruited if they fulfilled the following inclusion criteria: 50% loss of passive movement of the shoulder joint relative to the nonaffected side, in 1 or more of 3 movement directions (i.e. forward flexion, abduction in the frontal plane, or external rotation in 0° of abduction) (Lundberg, 1969; Rizk et al., 1994; Diercks and Stevens, 2004); and duration of complaints of at least 3 months. Exclusion criteria were a history of stroke with residual upper-extremity involvement, diabetes mellitus, rheumatoid arthritis, rotator cuff tear, surgical stabilization of the shoulder, osteoporosis or malignancies in the shoulder region. Subjects who had pain or disorders of the cervical spine, elbow, wrist, or hand, or who had pain radiating from the shoulder to the arm were also excluded.

1.2. Subjects

A sample of 40 subjects was selected, based on availability for interview at the time of initial presentation to the clinic between August 2004 and May 2006 (Table 1). Three subjects did not return after the first session and were not included in the analysis. Two subjects left the study because of personal or work-related circumstances. In addition, 1 subject was excluded from further participation in the study during the follow-up interview because she revealed the existence of bilateral frozen shoulder syndrome with severe and progressive symptoms, precluding the possibility of resolving the symptom course of a unilateral frozen shoulder. The final data analysis was therefore conducted on 34 patients. Two of these patients had had previous steroid injections at least 2 months before and none of them had had previous physical therapy treatments.

1.3. Shoulder kinematics assessments

The FASTRAK 3-D electromagnetic motion-capturing system (Polhemus Inc., Colchester, VT, USA) was

Table 1
Baseline ($n = 40$) and follow up ($n = 34$) conditions of patients with frozen shoulder syndrome receiving 3-month treatment

	Affected shoulder		
	Unaffected shoulder	Baseline	Follow up
FLEX-SF[a] score	–	27.5±6.3	34.2±5.8
Duration (months)[b]	–	6.4±8.3	–
Flexion	172±15°	122±8°	145±10°
Abduction	165±18°	105±13°	123±18°
External rotation	85±16°	32±16°	43±22°
Internal rotation	74±19°	22±13°	34±24°
Pain[c]	–	4±3	2±3

[a] FLEX-SF = Flexilevel Scale of Shoulder Function.

[b] Duration of symptom (pain or limited range of motion).

[c] Pain intensity at the time of evaluation as determined with a visual analog scale (0–10).

used to detect shoulder complex movements. Three sensors for the system were attached to the bony landmarks with adhesive tape. Each sensor was 2.3 cm in length, 2.8 cm in width, 1.5 cm in height and weighed 17 g. One sensor was attached to the sternum, and one sensor was attached to the flat bony surface of the scapular acromion with adhesive tape. The third sensor was attached to the distal humerus with Velcro straps. Data collection was performed as outlined in previous investigations (Lin et al., 2005). In general, we followed the ISB guidelines for constructing a shoulder joint coordinate system (Wu et al., 2005). Recordings started with the subject in a sitting position, the arms relaxed at the sides. Kinematics was collected for 5 s in this resting seated posture. Subjects were then asked to perform full active ROM in 3 tests: abduction in the scapular plane, hand-to-neck and hand-to-scapula. The hand-to-neck and hand-to-scapula tests represented function-related tests (Yang and Lin, 2006). For abduction in the scapular plane, subjects were guided to maintain in the scapular plane oriented 40° anterior to the coronal plane (Ludewig and Cook, 2000). Three replicated movements were performed in each test to the maximum possible active motions of the arms. The order of tests was randomized. To quantitatively characterize shoulder and scapular kinematics, the peak humeral elevation angle, the scapulo-humeral rhythm (slope of scapular upward rotation to glenohumeral elevation) and the peak scapular tilt were used as dependent variables in the abduction in the scapular plane test (Fig. 1). For the hand-to-neck and hand-to-scapula tests, the peak external rotation ROM and peak internal rotation ROM were used as dependent variables (Fig. 1).

1.4. Reliability and accuracy of kinematic variables

For the system accuracy, within a 76-cm source-to-sensor separation, the RMS system accuracy is 0.15° for orientation and 0.3–0.8 mm for position (Ludewig and Cook, 2000). In our study, the within-session reliability ICC $(2, k)$ values ranged from .91 to .99 for subjects with frozen shoulder symptoms. These ICC values indicated good within-session reliability for the measured variables across the 3 tests. Furthermore, the standard error of our measurement was 0.2°, as calculated by the equation $\mathrm{SEM} = \mathrm{SD}\sqrt{(1-\mathrm{ICC})}$, where SD is the standard deviation. However, due to the progress of frozen shoulder symptoms in these patients, we did not test between-session reliability.

1.5. Functional evaluation

The self-reported Flexilevel Scale of Shoulder Function (FLEX-SF) was used to determine functional disability from symptoms (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. Each patient was asked to indicate functional disability at the baseline and at a 3-month follow up. The percentage change in FLEX-SF was calculated (final score−initial score)/initial score × 100). To develop a prediction method, we need to justify that the two subgroups show improvement and nonimprovement. If the change was $>20\%$, the patient was categorized in the improvement group. If change was $\leqslant 20\%$, the patient was categorized in the nonimprovement group. We chose 20% change in FLEX-SF as the improvement criterion because the patients generally felt satisfied with 20% improvement from our investigation in the clinic.

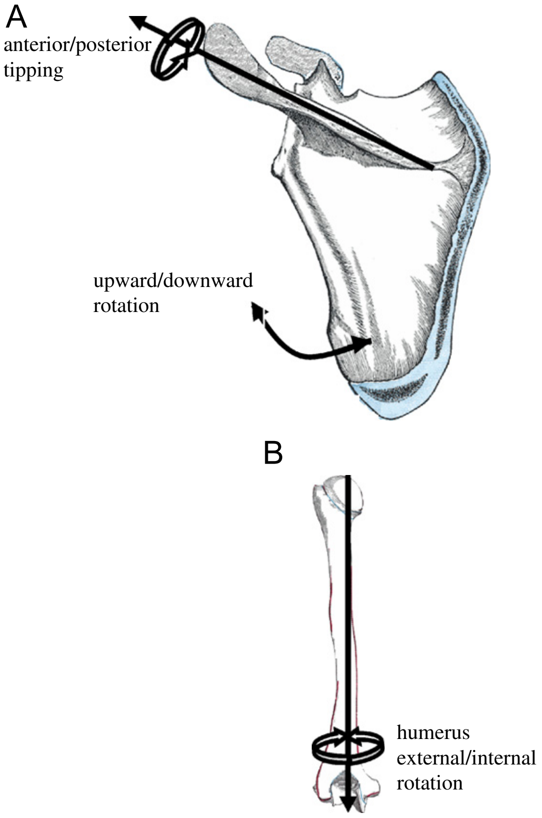

Fig. 1. Axes and rotations used to describe scapular and humeral orientation and position.

2. Treatments

Subjects received the same standardized treatment approach. The therapies included passive mobilization, stretching techniques, physical modalities (i.e. ultrasound, shortwave diathermy and/or electrotherapy) and active exercises. Each subject was treated by physical therapists with at least 3 years of clinical experience with the application of mobilization/stretching techniques for patients with frozen shoulder syndrome. Subjects were treated twice a week for 3 months. Subjects did not receive a home exercise programme but were advised to use the affected shoulder in daily activities whenever possible.

2.1. Statistical analysis

Improvement or nonimprovement 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 between the improvement and nonimprovement groups. Additionally, the planes of arm elevation between the two groups were also examined. Individual variables from the shoulder kinematics were tested for their relationship with the reference outcome using independent sample t tests. Variables with a significance level of $p<0.10$ were 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 (PLR) were calculated for all potential prediction variables (Sackett, 1992). The PLR is calculated as sensitivity/(1−specificity) and indicates the increase in the probability of improvement given a significant altered kinematic result. A PLR of 1 indicates that the kinematics does nothing to alter the probability of improvement, whereas PLR values >1 increase the probability of improvement given a significant altered kinematic result. PLR values between 2.0 and 5.0 generate small shifts in probability, values between 5.0 and 10.0 generate moderate shifts and values >10.0 generate large and often conclusive shifts in probability (Jaeschke et al., 1994). Potential prediction variables were entered into a stepwise logistic regression equation to determine the kinematics 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 multivariate prediction method for determining shoulder kinematics in the prediction of the progress of frozen shoulder syndrome.

3. Results

Of the 34 subjects completing the study, 26 (77%) were female. The mean age was 54.1±6.1 years (range 41–65 years). The involved shoulder distribution in the subjects with unilateral involvement was 18 right dominant (53%), 6 right nondominant (18%), and 10 left nondominant (29%). Overall, the mean improvement in FLEX-SF scores over the 3-month period was 4.8±3.4, with a mean percentage improvement of 15.2±5.3%. Fourteen subjects (41%) were classified as showing improvement and 20 (59%) as showing nonimprovement. The mean improvement in FLEX-SF scores in the improvement group over the 3-month period was 6.5±4.3, with a mean percentage improvement of 24.6±4.6%. In the nonimprovement group, the mean FLEX-SF score change was 2.4±1.8, with a mean percentage change of 8.8±6.5% (Fig. 2). There were no significant differences between the improvement and nonimprovement groups in duration of symptoms (5.9±7.1 versus 6.6±9.5 months), initial FLEX-SF scores (29.5±7.3 versus 26.5±5.6), or compliance with physical therapy treatment (20.6±0.9 versus 19.8±0.8 visits). Additionally, there was also no significant difference in received number of treatments regarding mobilization, stretching and/or physical modalities between the two groups. There was no difference between the two groups regarding the plane of arm elevation (40.6±0.5° versus 40.5±0.4°).

Representative kinematic data from a subject during arm elevation in the scapular plane are presented in Fig. 3. Although there was substantial variability among subjects, the general pattern was for the scapula to upwardly rotate and move posteriorly toward less anteriorly tipped positions as the arm elevated.

Four prediction variables were retained from shoulder kinematic variables (Table 2): scapular tipping, humeral elevation, scapulohumeral rhythm and external rotation (hand to neck). Cut-off values and diagnostic statistics for retained variables were obtained from ROC curve

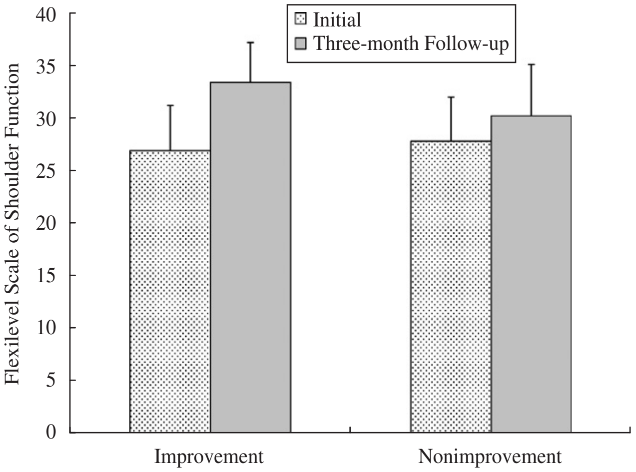

Fig. 2. Initial and 3-month follow-up Flexilevel scale of shoulder function for the improvement and nonimprovement groups. The mean percent change in the improvement group was 24.6±4.6%. For the nonimprovement group, the mean percent change was 8.8±6.5%.

analyses (Table 3). Among the kinematic variables, scapular tipping was the most predictive of improvement (PLR = 3.32).

The 4 potential prediction variables were entered into the logistic regression. Two were retained in the final model: scapular tipping and external rotation (hand to neck, model $\chi^2 = 14.03$, d$f = 2$, $P = 0.001$, Nagelkerke $R^2 = 0.46$); 11 of the 14 subjects were in the improvement group for two retained prediction variables at baseline. Three of the 14 subjects, with 1 of 2 variables present, were in the improvement group. Accuracy statistics were calculated for each level of the prediction method (Table 4). Based on the probability of improvement found in this study (41%) and the PLR values calculated, a subject with 2 variables present at baseline has an increased probability of improvement from 41% to 92%. If the criteria were changed to 1 variable present, the probability of improvement would increase to only 56%. Additionally, we did not find significant differences in the other kinematic variables.

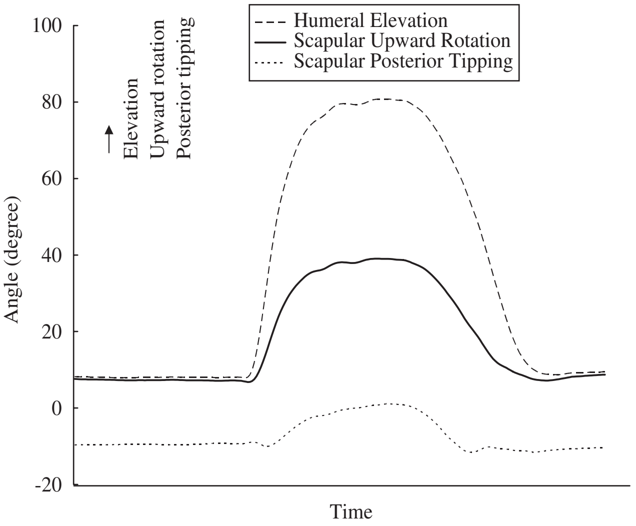

Fig. 3. Data for a representative subject with frozen shoulder. Scapular posterior tipping, scapular upward rotation and humeral elevation during arm elevation in the scapular plane.

4. Discussion

Although course of frozen shoulder syndrome is long term and the etiology is unclear, our results indicate that shoulder kinematics may be used as predictors of the clinical course of patients with frozen shoulder syndrome. Similar to other studies (Shaffer et al., 1992; Griggs et al., 2000; Diercks and Stevens, 2004), we were able to show only adequate effects of 3 months of treatment for some of our subjects' symptoms. Additionally, we found that symptoms worsened in some subjects despite treatment for 3 months. As noted by previous studies, symptoms of frozen shoulder may develop over 6 months and may be mainfested as long-lasting pain and restricted motion (Reeves, 1976; Shaffer et al., 1992; Dias et al., 2005). Nevertheless, by considering shoulder kinematics, especially scapula and humeral motions together, we were able to develop a prediction method that may be useful for assisting clinicians in identifying important shoulder kinematics that are likely to predict improvement with physiotherapy in patients with frozen shoulder syndrome.

The developed prediction method contains 2 variables: scapular tipping > 8.4° and external rotation (hand to neck) >38.9°. These findings are generally consistent with previous theories and research (Ludewig and Cook, 2000; Rundquist and Ludewig, 2004; Lin et al. 2006; Vermeulen et al., 2006). Adequate posterior tipping of the scapula elevates the anterior acromion and may be critical in obtaining adequate clearance of subacromial tissues, which may exclude impingement and further frozen shoulder syndrome (Ludewig and Cook, 2000; Lin et al., 2006). Our results support this hypothesis. Additionally, impaired external rotation has been reported in subjects with frozen shoulder syndrome (Rundquist and Ludewig, 2004; Vermeulen et al., 2006). Limited external rotation is related to tightened capsules and/or ligaments (Rundquist and Ludewig, 2004; Vermeulen et al., 2006). Cyriax proposed that tightness in a joint capsule would restrict motion in a predictable pattern, a capsular pattern (Cyriax, 1978). In the case of the frozen shoulder (adhesive capsulitis), a capsular

Table 2
Shoulder kinematic variables used in this study ($N = 34$)

	Improvement (>20% FLEX-SF scores, $N = 14/34$)	Nonimprovement (⩽20% FLEX-SF scores, $N = 20/34$)	p-value
Scapular posterior tipping	18.0±5.8°*	10.9±7.3°	0.004
Scapular upward rotation	31.8±12.6°	35.1±5.9°	0.304
Humeral elevation	102.5±19.9°*	89.3±18.0°	0.057
Scapulohumeral rhythm	0.70±0.13*	0.90±0.23	0.008
External rotation (Hand to neck)	52.3±26.6°*	39.9±16.2°	0.097
Internal rotation (Hand to back)	15.6±11.1°	11.0±5.5°	0.121

*Variables with a significance level of $p<0.10$ based on independent sample t tests.

Table 3
Sensitivity and specificity statistics (with 95% confidence intervals) for kinematic variables for predicting improvement

Kinematic variables associated with improvement	Sensitivity	Specificity	Positive likelihood ratio
Scapular posterior tipping > 8.4°	92.9 (66.1–98.8)	60.0 (36.1–80.8)	3.32
Humeral elevation >97.0°	71.4 (41.9–91.4)	70.0 (45.7–88.0)	2.08
Scapulohumeral Rhythm <0.88	100.0 (76.7–100.0)	50.0 (27.2–72.8)	2.10
External rotation (Hand to neck) > 38.9°	71.4 (41.9–91.4)	60.0 (36.1–80.8)	2.21

Table 4
A prediction method

No. of Predictor Variables Present	Sensitivity	Specificity	Positive likelihood ratio	Probability of improvement* (%)
2	78.6 (49.2–95.1)	95.0 (75.1–99.2)	15.71	92
1+	100.0 (76.7–100.0)	45.0 (23.1–68.4)	1.82	56

*The probability of improvement is calculated using the positive likelihood ratio and assumes a pretest probability of improvement of 41%.

pattern is one in which external rotation is more limited than abduction, which in turn is more limited than internal rotation. In our study, impaired external rotation is likely to predict improvement of frozen shoulder syndrome with physiotherapy. An interesting finding was that humeral elevation and scapulohumeral rhythm were not associated with chronic frozen shoulder disability. Although they appeared to be significant when analyzed at baseline between groups, the apparent significance was lost when it was entered into a prediction method with a multifactorial model. Theoretically, an adequate amount of humeral external rotation is required for humeral elevation (Rundquist and Ludewig, 2004). Therefore, our results suggest that subjects with adequate scapular tipping and humeral external motion are likely to show a treatment improvement effect.

The importance of a prediction method for determining shoulder kinematics in the prediction of the progress of frozen shoulder syndrome is best expressed using likelihood ratio statistics. When the subject meets the prediction rule's criteria, PLR expresses the change in odds favouring the improvement (Sackett, 1992). In our sample, treatment of subjects with frozen shoulder syndrome may result in about a 41% probability of the improvement without any attempt at prediction. Using 2 criteria variables present at baseline (PLR = 15.71), the probability of improvement is raised to 92%; therefore, these individuals respond to treatments. If only one variable is present, the probability of improvement increased only to 56%, which suggests that scapular tipping and external rotation of the shoulder, where they are judged to be less than the thresholds identified in this study, should be considered as important treatment goal/areas when considering mobilization/stretching treatments in these subjects.

Consideration in the assessment of the progress of frozen shoulder syndrome is important regarding the outcomes which are judged. Previous studies of assessment used impairment measures such as ROM and strength as primary means of evaluating the effectiveness of intervention (Reichmister and Friedman, 1999; Arslan and Celiker, 2001). In our opinion, traditional impairment measures may have insufficient reliability and validity. Therefore, we chose to reference functional FLEX-SF scores with good reliability and validity (Cook et al., 2003) that are representative of the desired outcome measures. The use of 20% improvement on the FLEX-SF scores as the reference standard was based on previous research involving intervention in subjects with frozen shoulder syndrome. Symptoms of frozen shoulder develop over 6 months, may last 2 years and may then gradually disappear ("self-limiting character," Lundberg, 1969; Reeves, 1976; Grey 1978). Sometimes, there may be long-lasting pain and restricted motion. Reeves (1976) described the natural history of frozen shoulder and found a mean duration of the symptoms of 30 months (range = 12–42). As our subjects' symptoms has been present for at least 3 months (range = 3–9), we therefore thought that 20% improvement in the FLEX-SF scores over a 3-month period would provide adequate distinction between subjects responding to the intervention and those simply benefiting from the natural history of adhesive capsulitis. Additionally, we found that patients generally felt satisfied with 20% improvement from our investigation in the clinic. On the other hand, different results may be expected from other criteria. This needs to be further validated.

Methodological standards for developing and validating a prediction method, modified from a clinical prediction rule, include three steps (McGinn et al., 2000). The initial step is the development of the method, the second step is validation of the method and the third step is an analysis of the impact of the method on clinical behaviour. The purpose of the current study was to develop a prediction method that would identify impaired shoulder kinematics associated with the degree of symptom-related functional disability in patients with frozen shoulder syndrome. Validation of the proposed prediction method is the purpose of an ongoing intervention trial to determine whether altered shoulder kinematics subjected to intervention meet the prediction criteria and demonstrate improvement in their follow-up. Eventually, the prediction method should be shown to improve decision making in clinical practice.

Limitations of the study should be noted. Interpretation of our results should be cautious because there was a lack of control over intervention in our study. We examined the treatments between improvement and nonimprovement groups and found that similar treatment protocols were applied to two groups. It is possible, however, that a specific modality tended to improve the condition over another. Although good within-session reliability was demonstrated in this study, the between-session reliability of these kinematic variables should be further investigated. In the present study, only shoulder kinematics and 3-month improvement were considered, and it is unknown whether other factors or long-term follow-up would provide similar results. Furthermore, the participant population was mainly subjects with idiopathic frozen shoulder. The generalizability of the study results to frozen shoulders with other pathologies is uncertain. The mean FLEX-SF score for the subjects with frozen shoulder was 27.5. Subjects with more severe impairments may be expected to show different alterations in kinematics. In addition, scapular kinematics were measured with sophisticated laboratory measures in our study: appropriate clinical measures of scapular motion/position corresponding to laboratory measures should be further investigated.

This investigation supports the assertion that shoulder kinematics are associated with the progress of disability in subjects with frozen shoulder syndrome. Based on the prediction method we found, a subject with frozen shoulder syndrome who meets 2 criteria (scapular tipping $>8.4^\circ$ and humeral external rotation (hand to neck) $>38.9^\circ$) at baseline has a probability of 92% of demonstrating improvement at 3-month follow-up. Although humeral external rotation is generally advocated as a treatment focus, our results further suggest that scapular tipping and humeral external rotation should be managed together. Additionally, specific least angles are recommended. However, before this prediction method can be considered ready for use in clinical practice, it should be validated in a prospective study.

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