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Radiographic assessment of scapular rotational tilt in chronic shoulder impingement syndrome

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Abstract This study presents an objective evaluation of both scapular upward and axial rotational tilts in shoulder impingement syndrome, using a scapular spine line defined on antero-posterior (AP) radiographs of the shoulder as the referential line. Twenty-seven patients with unilateral shoulder motion pain, who were diagnosed as having chronic shoulder impingement syndrome, were enrolled in the study. Scapular upward and axial rotational tilts were compared between the affected and contralateral shoulders. AP radiographs were obtained at shoulder abduction angles of 0°, 45°, and 90°, and the X-ray films were digitized by computer. The upward and axial rotational tilts of the scapula were then evaluated on the digital images. In shoulder impingement syndrome, both upward and axial external rotations of the scapula were impaired at the painful arc angle of abduction. This tended to be more apparent for the axial rotation of the scapula than for the upward rotation. These reductions in scapular rotations reduce available clearance for the rotator cuff and humeral greater tuberosity as the shoulder is abducted.

Key words Shoulder impingement syndrome · Scapula · Rotation · Tilt · Radiography

Introduction

Shoulder impingement syndrome is the result of impingement of the acromion, coracoacromial ligament, coracoid process, and/or acromioclavicular joint on the rotator cuff mechanism that passes beneath them as the glenohumeral joint is moved, particularly during flexion and rotation.[3,14,18,29] Many factors, including acromial spur, rotator cuff insufficiency, posterior capsular tightness, glenohumeral instability, and scapular motion disorders,[1,5,7,8,10,13,18,20,22,25,28] are thought to contribute to impingement. With regard to scapular motion factors, which involve three-dimensional rotation and displacement, difficulties have been noted in analyzing these abnormalities. Some authors have examined abnormal scapular motions in shoulder impingement syndrome using various procedures such as moiré topography,[27] or physical measurement, by palpating the lateral scapular slide.[11] These methods, however, cannot assess scapular rotation. Lukasiewicz et al.[13] studied three-dimensional scapular rotation and orientation in shoulder impingement syndrome using a three-dimensional electromechanical digitizer, and identified reduced posterior tilting and excessive superior translation in the subjects with impingement. The method adopted in their report was regarded as highly reliable, but it is not thought to be always accurate in determining the same points on the scapula while the arm is being raised, particularly in obese patients.

Some authors have used radiographic techniques to examine scapular motion disorders, focussing on scapular rotation in shoulder impingement syndrome.[23,26] They have usually examined the glenoid inclination angle in the coronal or scapular plane and found that, during shoulder elevation, the scapula rotates both upward and axially, but that the axial rotation of the scapula makes reproducible two-point selection on the glenoid difficult.

We have designed a simple and accurate method of evaluating both scapular upward and axial rotational tilts by using plain antero-posterior (AP) radiography. The purpose of this study was to identify the types of scapular rotational tilt disorders that affect shoulder impingement.

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Subjects and methods

Subjects and their classification

Of the patients who visited our outpatient clinic with complaints of shoulder pain, 27 patients with unilateral shoulder pain were diagnosed as having chronic shoulder impingement syndrome, and were enrolled in this study. Criteria for selection were: positivity for Neer's impingement sign [19]and painful arc sign,[29] and an absence of cervical radiculopathy symptoms. Patients with positive drop arm signs or frozen shoulders were excluded. All patients reported pain during resisted isometric abduction. Fourteen subjects were men and 13, women; the subjects ages ranged from 41 to 73 years, with a mean age of 57.5 years. We compared the scapular upward and axial rotations in four groups of shoulders: on the affected and contralateral sides of the patients, and on the dominant and non-dominant sides in a group of normal controls. In this study, group 1 shoulders were the 27 affected shoulders and group 2 were the 27 contralateral shoulders of the same patients. In group 1, dominant shoulders accounted for 78% (21 patients).

For the evaluation of the reliability of radiographic re-examination and laterality of normal shoulders, 7 normal volunteers (14 shoulders) were examined twice with the same modality. The normal volunteer group consisted of 8 men and 6 women, aged from 52 to 64, with a mean age of 57.1 years.

Selection of scapular rotation

The perpendicular distance between the acromion and the humeral greater tuberosity is critical for shoulder impingement. All motions of the scapula can be described as surface motion in three planes, coronal, sagittal, and transverse.[23,30] Rotation in the coronal plane accounts for upward and downward rotation, in the sagittal plane for external and internal axial rotation, and in the transverse plane for protraction and retraction. Among these rotations, rotation in the transverse plane does not have an effect on the perpendicular distance between the acromion and the humeral greater tuberosity. For the precise evaluation of scapular rotations in the coronal and sagittal planes, the scapular rotation tilt in the transverse plane needs to have a constant value. It has been reported that protraction and retraction rotation shows a small arc range in coronal plane abduction.[16] Consequently, to minimize the influence of protraction and retraction rotation of the scapula, in the coronal plane abduction motion, the upward and the axial rotation tilts of the scapula of the four groups of shoulders were evaluated radiographically.

Radiographic technique

The patient was seated, facing backwards, in a sturdy chair. The tip of the coracoid process was selected as the radiographic center. The patient was instructed to abduct the shoulder in the coronal plane with the shoulder in the neutral position for internal — external rotation, the forearm in the neutral position for pronation — supination, and the elbow in the fully extended position. An AP radiograph of the shoulder was taken perpendicular to the frontal axis of the thorax at shoulder abductions of 0°, 45°, and 90°. Accurate measurement of the abduction angles was obtained with a right-angle isosceles-triangle device. The distance between the film and the X-ray tube was set at 1.2 m. Radiographs of the shoulder on one side and the other were taken consecutively.

Digital imaging

Digital imaging of X-ray films was done with a computer (Macintosh Centris 650; Apple Computers, Cupertino, CA, USA), and an image scanner (JX-250; Sharp, Osaka, Japan). The image processing software consisted of Adobe Photoshop 3.0 (Adobe Systems, San Jose, CA, USA) and NIH Image 1.59 (National Institutes of Health, Bethesda, MD, USA). Images were taken up at a scanner resolution of 400 dpi, using a gray scale. Digital images were magnified four times in order to reduce methodological bias.

Parameter of the upward rotation tilt of the scapula

The scapular spine has been noted as the functional axis of the shoulder joint.

In this study, a new referential line for assessing scapular rotation was introduced. The point of intersection of the upper border of the scapular spine and the acromio-clavicular joint was defined as the outside point, and the medial end of the upper border of the scapular spine the inside point. The line passing through these inside and outside points of the scapular spine was defined as the scapular spine line (Fig. 1). The scapular upward rotation angle (SURA), that is, the angle of tilt between the scapular spine line and the horizontal, was adopted as the parameter of the upward rotational tilt (Fig. 2).

Parameter of the axial rotation tilt of the scapula

The upward motion of the coracoid process during shoulder abduction (Fig. 3) is characteristic of axial rotation of the scapula.[23] The positional relationship of the coracoid process in the scapula can represent the axial rotation tilt of the scapula at a one-to-one ratio. In

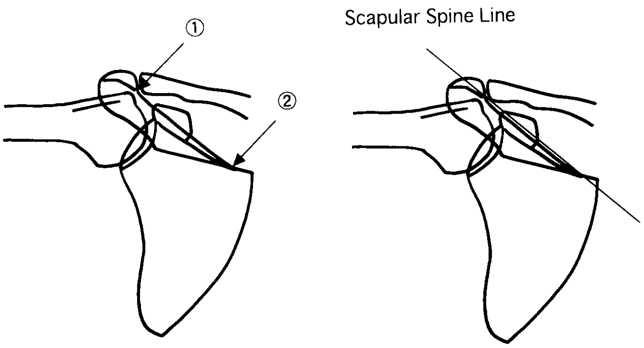

Fig. 1. The point of intersection of the upper border of the scapular spine and the acromio-clavicular joint was defined as the outside point (point *1*), and the medial end of the scapular spine as the inside point (point *2*). The line passing through these two points was defined as the scapular spine line

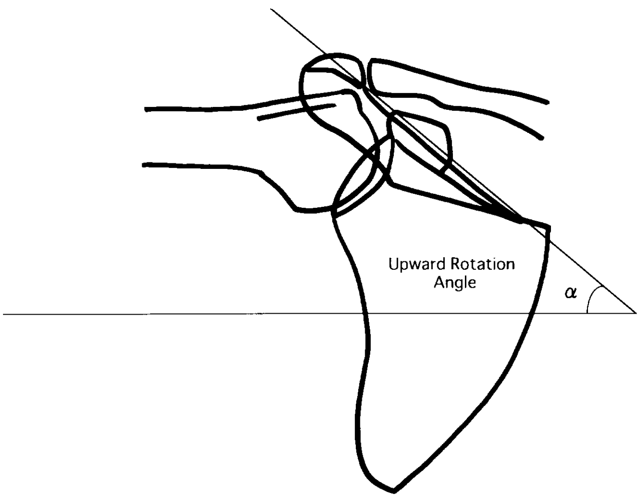

Fig. 2. The scapular upward rotation angle is shown as α

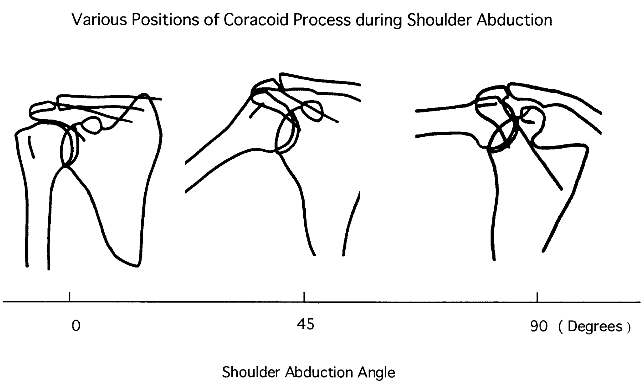

Fig. 3. This typical drawing of various positions of the coracoid process during shoulder abduction was obtained by tracing anterior-posterior X-ray films of normal shoulder abduction at 0°, 45°, and 90°. The upward motion of the coracoid process, which is the characteristic motion of axial rotation of the scapula, is shown

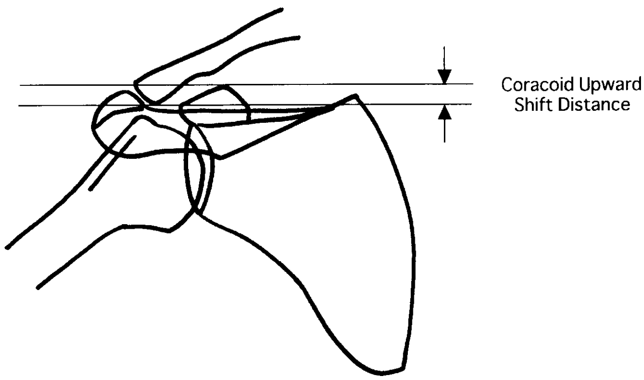

Fig. 4. Rotated image. One of the horizontal lines is the scapular spine line, and the other is a line passing along the top of the coracoid process, parallel to the rotated scapular spine line. The distance between the rotated scapular spine line and the upper border of the coracoid process is the coracoid upward shift distance (CUSD). If the upper border of the coracoid process is above the rotated scapular spine line, a plus sign is attached to the distance value, whereas if it is under the rotated scapular spine line, a minus sign is attached

order to evaluate the axial rotation tilt of the scapula, the distance between the scapular spine line and the upper border of the coracoid process was defined as the coracoid upward shift distance (CUSD), and was measured on digital images. With the aid of the Adobe Photoshop software, the digital image was rotated so that the scapular spine line became horizontal, and another horizontal line was then drawn along the top of the coracoid process. The distance between the two horizontal lines, i.e., the scapular spine line and the line along the top of the coracoid process, was measured with the NIH Image 1.59 (Fig. 4). In order to standardize the CUSD, the following formula was applied, where HHR is the humeral head radius:

$$\text{Standardized CUSD} = \text{CUSD} \times \text{mean HHR/individual HHR}$$

The standardized CUSD was then adopted as the parameter of the axial rotation tilt of the scapula.

Parameter of the protraction and retraction rotation tilt of the scapula

The length between the inside and outside points of the scapular spine described above was termed the length of the scapular spine (LSS). By protraction and retraction rotation, that is, the rotation in the transverse plane, the LSS changes its projected size on the radiograph. So the LSS corresponds to the parameter of the protraction-retraction tilt of the scapula. In order to standardize the LSS, the following formula was applied:

$$\text{Standardized LSS} = \text{LSS} \times \text{mean HHR /individual HHR}$$

Table 1. Mean (±SD) scapular upward rotation angles in groups 1 and 2

Shoulder abduction	Group	SURA (°)	*P* value[a]
0°	1	9.1 ± 5.6	0.24
	2	11.2 ± 6.5	
45°	1	20.1 ± 8.7	0.13
	2	24.0 ± 8.4	
90°	1	40.7 ± 8.7	0.04
	2	44.3 ± 7.2	

SURA, Scapular upward rotation angle
[a] Mann-Whitney *U*-test

Statistical analysis

All data values were expressed as means ± SD. The Mann-Whitney *U* — test was used for statistical analysis of differences between the two shoulder groups in the patients. Differences between the healthy sides of patients and the non-dominant sides of normal volunteers were also evaluated. A *P* value less than 0.05 was taken as significant. For the evaluation of reproducibility, a single regression analysis was performed in the normal volunteer group. The laterality in the normal volunteer group was also evaluated.

Results

Parameter of the upward rotation tilt of the scapula (Table 1)

The SURA at 0° shoulder abduction was 9.1 ± 5.6° for group 1 and 11.2 ± 6.5° for group 2 ($P = 0.24$), and at 45° shoulder abduction it was 20.1 ± 8.7° for group 1 and 24.0 ± 8.4° in group 2 ($P = 0.13$). At both these angles, the SURA in the two groups was not significantly different. At 90°, however, the SURA was 40.7 ± 8.7° for group 1 and 44.3 ± 7.2° for group 2, showing a significant difference ($P < 0.05$). Significant differences between the two groups thus depended on the degree of shoulder abduction.

Parameter of the axial rotation tilt of the scapula (Table 2)

The mean humeral head radius was 24.0 mm (25.6 mm for men, 22.5 mm for women). The standardized CUSD at 0° shoulder abduction was −4.5 ± 9.2 mm for group 1 and −4.6 ± 6.9 mm for group 2, with no significant difference ($P = 0.68$). For 45° shoulder abduction, the corresponding values were 0.5 ± 5.9 mm for group 1 and 3.8 ± 6.2 mm for group 2, showing a significant difference ($P < 0.05$). At 90° shoulder abduction, the CUSD was 6.7 ± 6.0 mm for group 1 and 11.6 ± 6.5 mm for group 2, for an even more significant difference ($P < 0.01$). The significant differences between the two groups thus increased according to the degree of shoulder abduction. This tendency was more apparent for the axial than for the upward rotation tilt of the scapula.

Table 2. Mean (±SD) standardized coracoid upward shift distances in groups 1 and 2

Shoulder abduction	Group	Standardized CUSD (mm)	*P* value[a]
0°	1	−4.5 ± 9.2	0.68
	2	−4.6 ± 6.9	
45°	1	0.5 ± 5.9	0.04
	2	3.8 ± 6.2	
90°	1	6.7 ± 6.0	0.01
	2	11.6 ± 6.5	

CUSD, Coracoid upward shift distance
[a] Mann-Whitney *U*-test

Table 3. Mean (±SD) standardized lengths of the scapular spine lines in groups 1 and 2

Shoulder abduction	Group	Standardized LSS (mm)	*P* value[a]
0°	1	69.7 ± 9.8	0.96
	2	69.8 ± 8.8	
45°	1	68.5 ± 10.7	0.59
	2	68.3 ± 6.0	
90°	1	73.8 ± 8.5	0.44
	2	72.0 ± 5.9	

LSS, Length of the scapular spine line
[a] Mann-Whitney *U*-test

Parameter of the protraction and retraction rotation tilt of the scapula (Table 3)

The standardized LSS at 0° shoulder abduction was 69.7 ± 9.8 mm for group 1 and 69.8 ± 8.8 mm for group 2, with no significant difference ($P = 0.96$). For 45° shoulder abduction, the corresponding values were 68.5 ± 10.7 mm for group 1 and 68.3 ± 6.0 mm for group 2, with no significant difference ($P = 0.59$). At 90° shoulder abduction, the corresponding values were 73.8 ± 8.5 mm for group 1 and 72.0 ± 5.9 mm for group 2, with no significant difference ($P = 0.44$). No significant differences were observed between the standardized LSS at each of the abduction angles in the two groups.

Reliability of radiographic re-examination (Tables 4-1 to 4-3)

The 14 normal shoulders from 7 normal volunteers were included for the evaluation of the reliability of radiographic re-examination. Good reproducibility

Table 4-1. Reliability of radiographic re-examination of the SURA in normal volunteers

Variable	Group	Measurement	Coefficient	*P* value[a]
SURA 0°	1st	13.4 ± 5.7	0.93	<0.0001
	2nd	11.6 ± 5.3		
SURA 45°	1st	24.7 ± 7.6	1.09	<0.0001
	2nd	25.4 ± 7.0		
SURA 90°	1st	43.9 ± 8.7	0.98	<0.0001
	2nd	45.6 ± 9.1		

1st, First radiographic examination; 2nd, second radiographic examination
0°, 45°, and 90° indicate degree of shoulder abduction
[a] Simple regression test

Table 4-2. Reliability of radiographic re-examination of the standardized CUSD in normal volunteers

Variable	Group	Measurement	Coefficient	*P* value[a]
Standardized	1st	−1.7 ± 4.7	0.96	<0.0001
CUSD 0	2nd	−1.8 ± 4.2		
Standardized	1st	5.3 ± 4.6	0.95	<0.0001
CUSD 45	2nd	5.0 ± 4.5		
Standardized	1st	10.7 ± 5.1	1.20	<0.0001
CUSD 90	2nd	11.6 ± 4.4		

[a] Simple regression test

Table 4-3. Reliability of radiographic re-examination of the standardized LSS in normal volunteers

Variable	Group	Measurement	Coefficient	*P* value[a]
Standardized	1st	81.0 ± 9.5	1.06	<0.0001
LSS 0	2nd	79.8 ± 8.8		
Standardized	1st	80.5 ± 10.2	1.24	<0.0001
LSS 45	2nd	78.2 ± 7.9		
Standardized	1st	80.8 ± 7.8	0.93	<0.0001
LSS 90	2nd	80.2 ± 8.3		

[a] Simple regression test

was shown with all variables by simple regression analysis.

Laterality of the normal volunteers (Tables 5-1 to 5-3)

All variables of scapular rotational tilts showed no significant differences between the dominant and non-dominant shoulders in the normal volunteers.

Differences between the non-dominant sides of normal volunteers and the healthy sides of patients (Tables 6-1 to 6-3)

Comparisons between the non-dominant shoulders of volunteers and the healthy sides of patients showed no significant differences for the SURA and the standardized CUSD. On the other hand, standardized LSS showed significant differences.

Discussion

Factors exacerbating shoulder impingement syndrome have been discussed from both structural and functional standpoints.[2,5,9,14,18] Research indicates that shoulder impingement is the most common cause of shoulder pain, and it is often treated conservatively with exercises to improve the function of the rotator cuff muscles and the function of the muscles controlling the scapula.[9,17,21] The mechanism of shoulder impingement, however, cannot be explained entirely by structural factors such as acromial and acromioclavicular spurs, or by abnormal acromial shape and slope.[1,6,18,24] Several functional factors, including loss of the humeral head depression mechanism,[20] tightness of the posterior shoulder capsule,[7] capsular laxity,[8] and functional scapular abnormalities[11,13,15,22,28] have also been shown to be associated with shoulder impingement.

Table 5-1. Laterality of the SURA in normal volunteers

Variable	Group	Measurement	*P* value[a]
SURA 0	Dominant	11.9 ± 5.3	0.61
	Non-dominant	13.4 ± 6.0	
SURA 45	Dominant	25.4 ± 8.7	0.96
	Non-dominant	24.5 ± 6.6	
SURA 90	Dominant	43.7 ± 9.3	0.58
	Non-dominant	45.4 ± 8.8	

[a] Mann-Whitney *U*-test

Table 5-2. Laterality of the standardized CUSD in normal volunteers

Variable	Group	Measurement	*P* value[a]
Standardized	Dominant	−1.9 ± 4.8	0.55
CUSD 0	Non-dominant	−1.2 ± 3.5	
Standardized	Dominant	4.6 ± 4.7	0.65
CUSD 45	Non-dominant	5.6 ± 4.8	
Standardized	Dominant	10.2 ± 4.0	0.24
CUSD 90	Non-dominant	11.4 ± 5.8	

[a] Mann-Whitney *U*-test

Table 5-3. Laterality of the standardized LSS in normal volunteers

Variable	Group	Measurement	*P* value[a]
Standardized	Dominant	11.9 ± 5.3	0.82
LSS 0	Non-dominant	13.4 ± 6.0	
Standardized	Dominant	25.4 ± 8.7	0.71
LSS 45	Non-dominant	24.5 ± 6.6	
Standardized	Dominant	43.7 ± 9.3	0.82
LSS 90	Non-dominant	45.4 ± 8.8	

[a] Mann-Whitney *U*-test

Table 6-1. Differences between the SURAs of the non-dominant side in normal volunteers (group V) and the healthy side in patients (group H)

Variable	Group	Measurement	*P* value[a]
SURA 0	V	13.4 ± 6.0	0.32
	H	11.2 ± 6.5	
SURA 45	V	24.5 ± 6.6	0.60
	H	24.0 ± 8.4	
SURA 90	V	45.4 ± 8.8	0.70
	H	44.3 ± 7.2	

[a] Mann-Whitney *U*-test

Table 6-2. Differences between standardized CUSDs of the non-dominant side in normal volunteers (group V) and the healthy side in patients (group H)

Variable	Group	Measurement	*P* value[a]
CUSD 0	V	−1.2 ± 3.5	0.07
	H	−4.6 ± 6.9	
CUSD 45	V	5.6 ± 4.8	0.39
	H	3.8 ± 6.2	
CUSD 90	V	11.4 ± 5.8	0.96
	H	11.6 ± 6.5	

[a] Mann-Whitney *U*-test

Table 6-3. Differences between standardized LSS of the non-dominant side in normal volunteers (group V) and the healthy side in patients (group H)

Variable	Group	Measurement	*P* value[a]
Standardized	V	76.3 ± 5.0	0.01
LSS 0	H	69.8 ± 8.8	
Standardized	V	75.8 ± 7.5	<0.01
LSS 45	H	68.3 ± 6.0	
Standardized	V	76.6 ± 4.9	0.02
LSS 90	H	72.0 ± 5.9	

[a] Mann-Whitney *U*-test

Recently, functional scapular abnormalities have been emphasized as a cause of shoulder impingement. Kibler[11] evaluated abnormal scapular motion in shoulder impingement syndrome, using a physical measurement by palpating the lateral scapular slide, and found that the slide in the coronal plane was different between symptomatic and asymptomatic athletes. By radiographic techniques, Poppen and Walker[23] examined the ratio of glenohumeral to scapulothoracic movement, the center of rotation of the glenohumeral joint, and the average excursion of the humeral ball on the face of the glenoid. They demonstrated that abnormal shoulders had an altered glenohumeral-to-scapulothoracic ratio, which was associated with significant pain. Suzuki et al.[26] measured the scapular upward rotation angle, in subjects with rotator-cuff lesion, in the scapular plane but not in the sagittal plane. In measuring the upward scapular rotation by their method, it is difficult to reproducibly identify the two glenoid points required to define the reference line, because the glenoid face tilts and rotates concomitantly with the axial rotational motion of the scapula.

For the present study, a new reference line, which was defined as the scapular spine line, was introduced to evaluate scapular rotation. This scapular spine line on AP radiographs taken at each position of arm abduction allows measurements of the proper scapular upward rotation angle and also of the coracoid upward shift distance, which represents the scapular axial rotation tilt angle. Both the rotations in the coronal and in the sagittal planes proved to be accurately evaluated. An additional advantage of the method was that other exacerbating factors in shoulder impingement syndrome, such as thoracic kyphosis or capsular laxity,[4,5,14] could be ruled out by comparing the scapular rotations of the affected side with those of the healthy side. At 0° shoulder abduction, no significant difference was observed in either scapular upward or external axial rotation tilt between the affected and contralateral sides. At 45°, the scapular axial rotation tilt of the affected shoulders was significantly less than that of the contralateral side ($P < 0.05$). At 90°, the scapular upward rotation and the scapular external axial tilts of the affected shoulders were significantly less, ($P < 0.05$) and ($P < 0.01$) respectively, than those of the contralateral side.

Our results concerning the reduced axial rotation of the scapula are consistent with the findings of Lukasiewicz and co-workers,[13] who used a three-dimensional electromechanical digitizer. Furthermore, we have, for the first time, shown reduced scapular upward rotation tilt, by objective data, in shoulder impingement syndrome.

In shoulder impingement syndrome, the coupling disorders of both external axial and upward rotations of the scapula have been presented for the first time in our study. This condition may produce a collision between the humeral greater tuberosity and the antero-lateral edge of the acromion during shoulder abduction.

Some authors have suggested that reduced scapular rotation may be caused by dysfunction of the shoulder girdle muscles, especially the trapezius and serratus anterior, and that dysfunction of these muscles causes shoulder impingement.[13,15,21,22,27,28] Our data are consistent with this hypothesis.

In the clinical assessment of shoulder impingement syndrome, reduced movement of the inferior angle of the scapula, compared with that on the healthy side, is frequently palpable on the affected side during shoulder elevation before the painful arc angle is reached. This corresponds to reduced scapular axial rotation. However, a limitation of this study is that actual three-dimensional rotations of the scapula cannot be measured with the present method, and only abduction motion can be evaluated by our method. For planning the measurement of scapular rotations in shoulder flexion, other complicated methods will be needed. Our methods are simple and reproducible, and are suitable for the diagnosis and follow-up of shoulder girdle pain.

Our study confirms that a wide supraspinatus outlet is created by scapular external and upward rotations so that subacromial impingement can be avoided in normal shoulder elevation. For the assessment of shoulder impingement syndrome, early evaluation of scapular functional tilt is indispensable. Regardless of whether there is a surgical indication for rotator cuff tear, specific rehabilitation, such as stretching of the scapulo-thoracic articulation and gleno-humeral joint, or strengthening exercises for the shoulder girdle muscles, should be encouraged so that normal scapular motion can be restored as soon as possible.

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