Humeral Head Morphometry Can Predict the Presence of Subacromial Spurs: Measurements of Dried Bones from Human Shoulder Girdles

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Objective: To clarify the relationship between the morphological characteristics of the bones of the shoulder girdle and the presence of subacromial spurs (SS).
Methods: The bones of 36 cadaveric shoulder girdles were measured. After dividing the bone specimens into SS present and absent groups, various bone parameters between the two groups were statistically compared. Logistic regression analysis was conducted to assess the significance of each parameter as a predictor of SS formation. A receiver operating characteristic curve analysis was used to determine the cut-off point and to assess the sensitivity and specificity of the parameters showing significant differences.
Results: SS were found in 16 scapulae. The values for five parameters of the examined shoulder girdles were significantly different between the two groups. The presence of SS depended on the humeral head ratio, which was calculated by dividing the length of the greater tubercle of the humerus by the length of the lesser tubercle. A cut-off value of 1.97 was suitable for discriminating between the presence and absence of SS (sensitivity, 75%; specificity, 80%).
Conclusion: The presence of SS is related to several morphological characteristics of the shoulder girdle and, the presence of SS can be predicted using humeral head morphometry.

Key words: Bone spur; Clavicle; Humeral head; Scapula; Shoulder impingement syndrome

INTRODUCTION

A subacromial spur (SS) is a bony deformation occurring on the under-surface or front end of the acromion (Fig. 1). Many reports have suggested that SS develops after repetitive subacromial impingement or by ossification of the coracoacromial ligamentous insertion on the under-surface of the acromion due to traction on the ligament [1-4]. In addition, SS are thought to contribute to the occurrence and progression of rotator cuff tears, which eventually cause severe pain or functional disturbances [5-8]. Although the clinical significance of arthroscopic subacromial decompression (decompressing the subacromial space by removing bone spurs and soft tissue arthroscopically) is uncertain [9], the usefulness of the arthroscopic subacromial decompression [10] and the relationship between SS and rotator cuff tears [11, 12] have been reported.

Although radiography is generally used for the

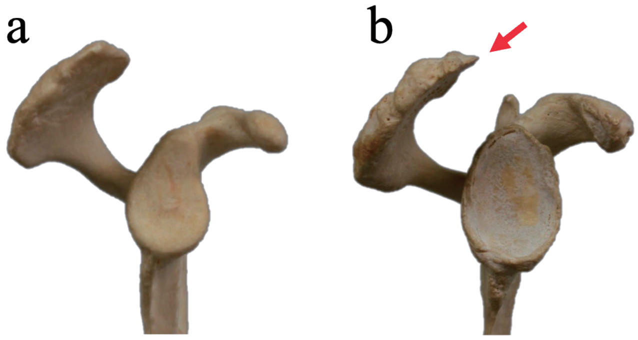

Fig. 1 The acromion, showing the absence (a) and presence (b) of a subacromial spur (SS) (arrow).

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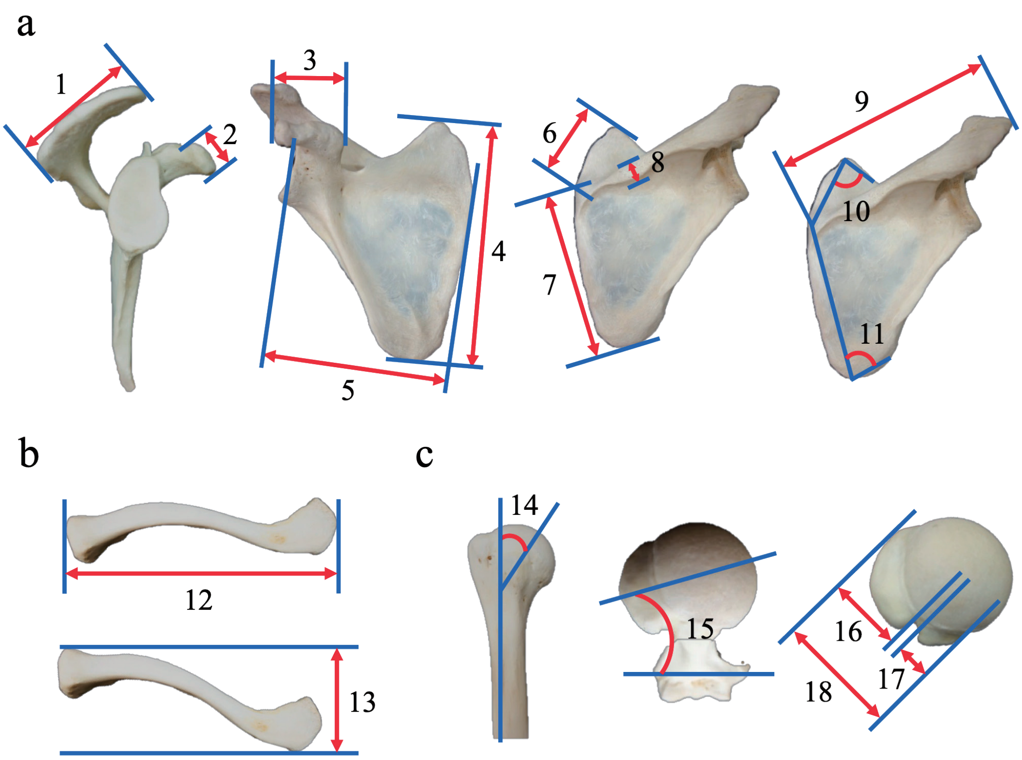

Fig. 2 (a) Parameters affecting scapular morphology: 1. acromion width, 2. short axis of the coracoid process, 3. long axis of the coracoid process, 4. long axis of the scapular body, 5. short axis of the scapular body, 6. length of the superior scapula, 7. length of the inferior scapula, 8. short axis of the scapular spine, 9. long axis of the scapular spine, 10. superior angle, and 11. inferior angle. (b) Parameters affecting clavicular morphology: 12. long axis of the clavicle and 13. anteroposterior diameter of the clavicle. (c) Parameters affecting humeral morphology: 14. neck shaft angle, 15. humeral head retroversion, 16. length of the greater tubercle of the humerus, 17. length of the lesser tubercle of the humerus, and 18. humeral head length.

initial diagnoses of various shoulder diseases, such as subacromial impingement syndrome and rotator cuff tears, the accuracy of such measurements may be questioned, especially when investigating whether SS exists [13, 14]. Therefore, an accurate and convenient method for diagnosing the presence of an SS is desirable.

Possible contributors to subacromial impingement syndrome have been demonstrated to cause dysfunction within individual components of the shoulder complex, such as abnormal axial rotation of the humerus [15], abnormal scapular position [16, 17], degeneration of the rotator cuff [11, 18], and the actual shape of the acromion [19, 20]. In 1986, Aoki *et al.* [19] examined bleached skeletons and found that the slopes of acromions with SS were flatter than those of acromions without SS. Subsequently, many studies describing the relationship between acromial morphology and SS formation have been published [7, 21–23]. However, there is no published evidence demonstrating the correlation between shoulder girdle morphological characteristics and SS formation. This study sought to clarify the relationship between the morphological characteristics of the shoulder girdle and SS formation.

MATERIALS AND METHODS

A total of 36 dry, cadaveric shoulder girdle bones (scapula, clavicle, and humerus; 18 right-sided and 18 left-sided from 28 men and 8 women) were selected from the anatomy laboratory in our department. The bones belonged to mature adults, but the exact ages of the individuals were unknown. The acromial type was classified according to Bigliani *et al.* [24]. Several dimensions and angles of the bones were measured (Fig. 2).

In the scapula, 11 parameters were measured (Fig. 2a). Acromion width (1) was defined as the distance between its anterior and posterior ends. The short axis of the coracoid process (2) was defined as the length between the superior and inferior ends of the coracoid process, whereas its long axis (3) was defined as the length between its medial and lateral ends. The long axis of the scapular body (4) was defined as the length between its top and bottom, whereas the short axis (5) was defined as the length between the glenoid and the spinal triangle. The superior scapula length (6) was defined as the distance between the spinal triangle and the top of the scapular body. The inferior scapula length (7) was defined as the distance between the spinal triangle and the bottom of the scapular body. The short axis of the scapular spine (8) was defined as the maximum distance along the short axis of the scapular spine, whereas the long axis (9) was defined as the distance between the lateral edge of the acromion and the spinal triangle. The superior angle (10) was defined as the angle between a vector passing through the spinal triangle and the top of the scapular body and the superior border. The inferior angle (11) was defined as the angle between a vector passing from the spinal triangle to the bottom of the scapular body and a vector passing from the bottom of the scapular body to the protrusion on the lateral border of the scapula. The size of SS, which was defined as the distance from the point where the inclination of the anterior edge of the acromion abruptly increased to the tip of the spur

Table 1 Comparison between the subacromial spur (SS) absent and SS present groups

	SS absence (N = 20)	SS presence (N = 16)	P
Acromion width	3.11 ± 0.27	3.25 ± 0.33	0.195
Short axis of the coracoid process*	**0.98 ± 0.12**	**1.05 ± 0.08**	**0.026**
Long axis of the coracoid process	2.99 ± 0.21	3.10 ± 0.14	0.079
Long axis of the scapular body	10.03 ± 0.78	10.40 ± 0.47	0.713
Short axis of the scapular body*	**7.33 ± 0.28**	**7.06 ± 0.28**	**0.042**
Length of the superior scapula	3.28 ± 0.45	3.35 ± 0.25	0.593
Length of the inferior scapula	7.89 ± 0.81	7.96 ± 0. 38	0.768
Short axis of the scapular spine	0.65 ± 0.12	0.60 ± 0.09	0.203
Long axis of the scapular spine*	**9.74 ± 0.66**	**9.35 ± 0.39**	**0.049**
Superior angle (°)	87.91 ± 12.03	87.05 ± 10.93	0.831
Inferior angle (°)	70.10 ± 7.08	67.81 ± 6.24	0.329
Long axis of the clavicle (cm)	13.72 ± 1.10	14.31 ± 0.77	0.081
Anteroposterior diameter of the clavicle*	**2.98 ± 0.55**	**3.35 ± 0.37**	**0.032**
Neck shaft angle (°)	25.51 ± 7.30	26.13 ± 7.01	0.701
Humeral head retroversion (°)	125.77 ± 6.95	124.68 ± 9.41	0.805
Length of the greater tubercle of the humerus	3.80 ± 0.45	4.01 ± 0.88	0.646
Length of the lesser tubercle of the humerus*	**1.15 ± 0.14**	**1.24 ± 0.11**	**0.039**
Humeral head length	3.01 ± 0.22	2.97 ± 0.13	0.552
Humeral head ratio*	**2.13 ± 0.29**	**1.92 ± 0.14**	**0.005**

***P < 0.05.** All length measurements, other than those for the long axes of the clavicles, were standardized by dividing each value by one-tenth of the length of the corresponding clavicular long axis.

was also measured.

In the clavicle, 2 parameters were measured (Fig. 2b). The long axis of the clavicle (12) was defined as the distance between the medial and lateral ends of the clavicle. The anteroposterior diameter of the clavicle (13) was determined by measuring the distance between the anterior and posterior ends of the clavicle.

In the humerus, 5 parameters were measured (Fig. 2c). The neck shaft angle (14) was defined as the angle between the long axis of the humerus and the long axis of the humeral head, in the frontal plane. Humeral head retroversion (15) was defined as the angle between the axis of the humeral head and the axis of the epicondyle, in the horizontal plane. The length of the greater tubercle of the humerus (16) was defined as its maximum width in the horizontal plane. Similarly, the length of the lesser tubercle of the humerus (17) was defined as its maximum width in the horizontal plane. The humeral head length (18) was defined as the distance from the anterior end of the greater tubercle of the humerus to the posterior end of its lesser tubercle, in the horizontal plane.

All measurements were taken using a digital vernier calliper and a digital goniometer. All scapulae were directly inspected to determine whether each contained an SS on the lower surface of the anterior end of the acromial process.

Considering the individual differences, all length values, other than those of the long axis of the clavicles (12), were standardized by dividing each value by one-tenth of the length of each corresponding the long axis of the clavicle (12).

To confirm the difference in the presence or absence of SS by grouping by acromial type, a chi-squared test was performed. Product-moment correlation coefficient of Pearson was used to determine the relationship between the size of the spur and the mean measurement values. After dividing the specimens into the SS present and SS absent groups, the mean measurement values were compared using a *t*-test. In addition, a logistic regression analysis was performed to assess the significance of each parameter as a predictor of SS formation. Finally, for parameters identified as significant factors in the logistic regression analysis, a receiver operating characteristic (ROC) curve analysis was used to determine the cut-off point and to assess the sensitivity and specificity of the parameters showing significant differences; a P-value < 0.05 was considered statistically significant. All statistical analyses were conducted using IBM SPSS Statistics for Windows, Version 24.0 (IBM, Armonk, NY).

RESULTS

SS were found in 16 scapulae (44.4%). As a result of the classification by Bigliani, there were 4 cases of typeI, 21 cases of typeII and 11 cases of typeIII. The frequency of SS in Bigliani classification was 0 in 4 cases in typeI (0%), 9 cases in 21 cases in typeII (42.9%), and 7 cases in 11 cases in typeIII (63.6%) ($p = 0.088$). SS in typeIII cases were significantly larger than those

Table 2 Logistic regression analysis regarding presence of a subacromial spur (SS)

	P	R^2
Acromion width	0.18	0.036
Short axis of the coracoid process*	**0.043**	**0.083**
Long axis of the coracoid process	0.08	0.062
Long axis of the scapular body	0.72	0.0026
Short axis of the scapular body*	**0.043**	**0.083**
Length of the superior scapula	0.60	0.0056
Length of the inferior scapula	0.78	0.0016
Short axis of the scapular spine	0.14	0.045
Long axis of the scapular spine*	**0.040**	**0.086**
Superior angle (°)	0.82	0.0010
Inferior angle (°)	0.31	0.021
Long axis of the clavicle (cm)	0.081	0.087
Anteroposterior diameter of the clavicle*	**0.026**	**0.10**
Neck shaft angle (°)	0.69	0.0032
Humeral head retroversion (°)	0.80	0.0013
Length of the greater tubercle of the humerus	0.63	0.0046
Length of the lesser tubercle of the humerus*	**0.030**	**0.096**
Humeral head length	0.56	0.0069
Humeral head ratio*	**0.0042**	**0.17**

***P < 0.05.** All length measurements, other than those for the long axes of the clavicles, were standardized by dividing each value by one-tenth of the length of the corresponding clavicular long axis.

in typeII (5.37 ± 1.67 vs 2.98 ± 0.83, p = 0.012). There was no other significant correlation between the size of SS and the measurement values. Five shoulder bone measurements were significantly different between the SS present and absent groups; i.e., the short axis of the coracoid process (2), the short axis of the scapular body (5), the long axis of the scapular spine (9), the anteroposterior diameter of the clavicle (13), and the length of the lesser tubercle of the humerus (17) (Table 1).

In the logistic regression analyses, significant differences were found for the same five measurements, with R^2 values of < 0.1 (Table 2). Notably, the humeral head ratio (calculated by dividing the greater tubercle length by the lesser tubercle length) was significantly different between the SS present and absent groups that it was determined to be the better parameter for use in the logistic regression model ($P = 0.0042$, $R^2 = 0.17$).

The ROC curve analysis determined that a humeral head ratio cut-off value of 1.97 was appropriate for discriminating between the presence and absence of an SS (sensitivity, 75.0%; specificity, 80.0%) (Fig. 3).

DISCUSSION

The present study revealed several morphometric values of the bones in the evaluated shoulder girdles that were significantly different between those with and without SS. The data indicated that there were characteristic parameters associated with the presence of SS in each shoulder girdle. Finally, the results showed that the presence of an SS may be predicted using the size measurements of the greater and lesser tubercles of the humeral head.

One of the most important points of the present study is that the presence of an SS is related to the balance of the sizes of the lesser and greater tubercles of the humerus. The muscles attached to these tubercles are the subscapularis, supraspinatus, infraspinatus, and the teres minor. The subscapularis, responsible for internal rotation of the shoulder joint, is attached to the lesser tubercle of humerus, whereas the supraspinatus, infraspinatus, and teres minor, responsible for the external rotation of the shoulder joint, are attached to the greater tubercle. During shoulder joint abduction and flexion, the humerus undergoes lateral rotation [15, 25], and the infraspinatus and teres minor muscles can rotate the humerus externally to increase the clearance between the greater tubercle and the acromion. However, if the activity of the subscapularis muscle is strong, the extrinsic rotation of the humerus decreases. A low humeral head ratio reflects the strong activity of the muscle responsible for internal rotation that is attached to the lesser tubercle of the humerus. Stokdijk *et al.* [15] reported that subjects unable to externally rotate the arm even minimally are at risk for impingement syndrome and other shoulder disorders. Yamamoto *et al.* [26] indicated that the impingement

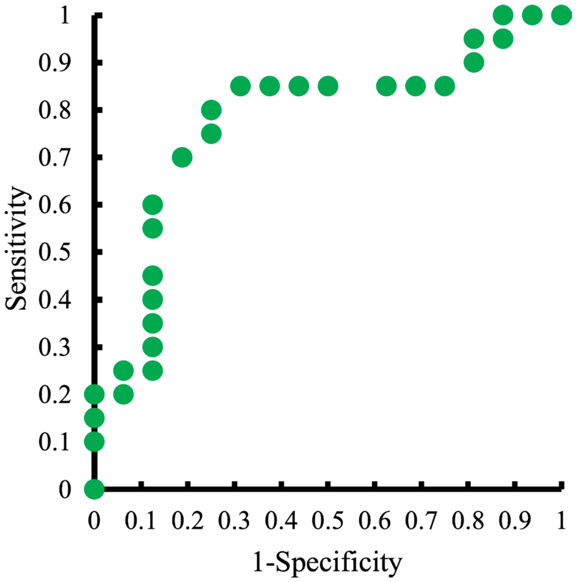

Fig. 3 A receiver operating characteristic (ROC) curve analysis of the humeral head ratio.

phenomenon is also observed in healthy shoulders. Thus, the present data suggest that decreased extrinsic rotation of the humerus occurs during physiological subacromial impingement, contributing to the development of SS.

In addition to the humeral head ratio, other parameters associated with SS formation were identified in the scapula (short axis of the coracoid process (2), short axis of the scapular body (5), and long axis of the scapular spine (9)) and clavicle. However, their correlations were insufficiently strong to be considered predictive of SS formation. The muscles attached to the coracoid process (pectoralis minor, short head of the biceps brachii, and coracobrachialis) provide the anterior/posterior tilt of the scapula. The muscles attached to the medial border of the scapula (rhomboid major and minor, and serratus anterior) enable the abduction/adduction of the scapula. The muscles attached to the scapular spine (the spinal and acromial parts of the deltoid, and the transverse and ascending parts of the trapezius) allow humeral elevation and downward/upward rotation of the scapula. The anteroposterior diameter of the clavicle may reflect the clavicular part of the pectoralis major and the descending part of the trapezius, to some degree. SS have been reported to cause rotator cuff tears [5–8]. Thus, the present results suggest that these muscle groups may contribute to both SS formation and rotator cuff tears. Diagnosing the likelihood of SS formation, using the humeral head ratio, may be useful in patients with shoulder disorders, other than impingement syndrome, such as rotator cuff tears.

The strength of the present study is that we measured dry bone specimens, whereas many previous SS studies have relied on radiography or magnetic resonance imaging to measure bone parameters. However, measurement errors are more likely to occur with these indirect methods [13, 14, 27] than when conducting direct measurements on dry bones. We expect that the parameters measured in this study, which were found to be related to SS formation, will facilitate the detection of SS.

Our study also has several limitations. First, the study has a small sample size. In this study, a total of 36 shoulder girdles were examined (28 men and 8 women), but it was impossible to consider the effect of sex on the cadaveric bones. Further studies, with a larger number of samples, will help in overcoming this limitation. Second, we were unable to investigate whether each sample showed degeneration or tear of the rotator cuff; only accurate measurements of the dry bones were possible. Given that there are morphometric characteristics of the shoulder girdle that are influenced by the muscles attached to the bones, the muscles are also considered to influence the development of SS. To elucidate the details of the relationship between the muscles and SS formation, magnetic resonance imaging will be necessary to measure muscle volumes and the size of their attachments to bone. Because recent clinical studies suggest that acromioplasty may not be needed in some cases of the impingement syndrome [28] and the rotator cuff tear [29] with SS, such a study may be useful to consider the clinical indication of acromioplasty. Further knowledge regarding the morphological characteristics of the shoulder girdle, as related to SS formation, will contribute to more rapid and accurate SS diagnoses than are currently possible. Finally, since we could not cut the precious cadaveric bone samples, the length of greater and lesser tubercles of the humerus was measured as the maximum values in the horizontal plane. Although we tried to measure them by the way using in the usual clinical situations, the measurement values might not be conformed to them by CT completely.

CONCLUSIONS

There were significant differences in the morphometry between shoulder girdles with and without SS. Furthermore, logistic regression analyses demonstrated the relationship between the humeral head ratio and the presence of SS, allowing the prediction of SS formation; the ROC analysis determined the humeral head ratio cut-off value for predicting the presence of SS. These data will provide simple, but highly useful, information for diagnosing SS.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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