J Shoulder Elbow Surg (2011) ■, 1-10

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Relationship of radiographic acromial characteristics and rotator cuff disease: a prospective investigation of clinical, radiographic, and sonographic findings

Nady Hamid, MD[a], Reza Omid, MD[b], Ken Yamaguchi, MD[c], Karen Steger-May, MA[d], Georgia Stobbs, RN[c], Jay D. Keener, MD[c,*]

[a]*Shoulder and Elbow Center, OrthoCarolina, Charlotte, NC, USA*
[b]*Department of Orthopaedic Surgery, University of Southern California, Los Angeles, CA, USA*
[c]*Department of Orthopaedic Surgery, Washington University, St. Louis, MO, USA*
[d]*Division of Biostatistics, Washington University School of Medicine, St. Louis, MO, USA*

Background: Many studies have attempted to correlate radiographic acromial characteristics with rotator cuff tears, but the results have not been conclusive. Therefore, the purpose of this study was to determine the relationship between rotator cuff disease and the development of symptoms with different radiographic acromial characteristics, including shape, index, and presence of a spur.
Materials and methods: The records of 216 patients enrolled in an ongoing prospective, longitudinal study investigating asymptomatic rotator cuff tears were reviewed. All patients underwent standardized radiographic evaluation, clinical evaluation, and shoulder ultrasonography at regularly scheduled surveillance visits. Three blinded observers reviewed all radiographs to determine the acromial morphology, presence, and size of an acromial spur, as well as the acromial index. These findings were analyzed to determine an association with the presence of a full-thickness rotator cuff tear.
Results: The 3 observers demonstrated poor agreement for acromial morphology ($\kappa = 0.41$), substantial agreement for the presence of an acromial spur ($\kappa = 0.65$), and excellent agreement for the acromial index ($\kappa = 0.86$). The presence of an acromial spur was highly associated with the presence of a full-thickness rotator cuff tear ($P = .003$), even after adjusting for age. No association was found between the acromial index and rotator cuff disease ($P = .92$).
Conclusion: The presence of an acromial spur is highly associated with the presence of a full-thickness rotator cuff tear in symptomatic and asymptomatic patients. The acromial morphology classification system is an unreliable method to assess the acromion. The acromial index shows no association with the presence of rotator cuff disease.
Level of evidence: Level III, Cross-Sectional Study Design, Epidemiology Study.

Keywords: Rotator cuff; acromial spur; acromial morphology; acromial index

This study was approved by the Washington University Human Research Protection Office (Investigational Review Board #201103230).

*Reprint requests: Dr. Jay D. Keener, Washington University, Department of Orthopaedic Surgery, CB #8233, St. Louis, MO 63110 USA.

E-mail address: keenerj@wudosis.wustl.edu (J.D. Keener).

Controversy still remains regarding the role of the acromion in rotator cuff disease. Neer described the pathologic interaction of the acromion and the rotator cuff in the so-called impingement syndrome. He stated that the

1058-2746/$ - see front matter © 2011 Journal of Shoulder and Elbow Surgery Board of Trustees.
doi:10.1016/j.jse.2011.09.028

anterior third of the acromion and coracoacromial ligament abutted against the tendinous portion of the rotator cuff, leading to rotator cuff tearing over time.[25] Since his findings in 1972, many other authors have found a close relationship between the radiographic appearance of the acromion and rotator cuff disease.[5,9,12,22,40]

Codman, however, believed that acromial changes were secondary to degeneration of the rotator cuff itself and that initiation of a rotator cuff tear was an intrinsic process.[8] This mechanism of disease progression has been further validated by investigations that showed poor vascularity, altered biology, and inferior mechanical properties of the aging rotator cuff.[2,7,11,14,18,33,38] Nevertheless, acromioplasty continues to be one of the most common orthopedic procedures performed in the United States.[39]

The traditional method of classifying the acromion is by the shape of its undersurface. First described by Bigliani[4] in 1986, the acromion can be classified as type I (flat), type II (curved), or type III (hooked) when viewed in the sagittal plane. Many studies showed a close correlation of type III acromions with rotator cuff disease.[5,9,20,40] However, the poor interobserver reliability using this classification system and the difficulty in standardizing radiographs has brought significant questions about the utility of this measurement.[6,15,27,41] Despite mounting controversial evidence, acromial morphology classification is still widely used in clinical practice and plays a large role in the consideration for acromioplasty.

Another acromial characteristic that has been implicated in the rotator cuff disease process is acromial spur formation. Neer described a traction spur at the anterior acromion along the coracoacromial ligament in stage III impingement syndrome, and several other studies have corroborated Neer's initial findings.[28-30] A recent study by Ogawa et al,[29] using a combination of control patients, operatively treated patients, and cadaveric specimens, showed a close association of acromial spurs with rotator cuff disease. Despite these findings, the interobserver reliability and general applicability of this measurement is still unknown.

Recently, Nyffeler et al[27] described a new acromial measurement—the acromial index—to assess the amount of lateral acromial extension. They found that the acromial index was closely associated with rotator cuff disease and provided a biomechanical theory of how lateral acromial extension can alter the deltoid muscle vector, leading to excessive forces on the rotator cuff insertion. This novel measurement tool requires further investigation and has yet to be incorporated into the mainstream of rotator cuff evaluation.

Despite numerous investigations, the role of the acromion in rotator cuff disease continues to be an enigma, and theories of intrinsic cuff degeneration have challenged the classic teachings of subacromial impingement as a primary etiology of rotator cuff disease. To advance our understanding of rotator cuff disease, further investigation of the radiographic characteristics of the acromion and their potential relationships to rotator cuff disease is needed. We also sought to determine what effect acromial characteristics would have on the development of pain in an asymptomatic patient with a rotator cuff tear, because this has not been previously investigated. Therefore, the purpose of this study was to determine the relationship between rotator cuff disease and development of symptoms with different radiographic acromial characteristics, including the shape, index, and presence of an acromial spur.

Materials and methods

Study subjects

Data for this investigation were obtained as a separate, specific aim of an ongoing prospective, longitudinal study of asymptomatic rotator cuff tears. To be included into this prospective study, patients had to have (1) presented for bilateral shoulder ultrasonography at our institution for investigation of unilateral shoulder pain secondary to rotator cuff disease, (2) been discovered to have a partial or full-thickness rotator cuff tear in the asymptomatic shoulder, (3) no history of trauma (fall, motor-vehicle accident, heavy lifting episode, or shoulder dislocation) to either shoulder and remained free of injury for the study duration. Patients found to have a rotator cuff tear on the asymptomatic shoulder were enrolled in a longitudinal, observational cohort. Subjects with an intact rotator cuff on the asymptomatic side were also recruited to serve as a control group. Exclusion criteria were (1) pain in the asymptomatic shoulder at the time of study enrollment, (2) previous surgery on either shoulder, (3) inflammatory arthropathy, (4) glenohumeral osteoarthritis, (5) previous shoulder trauma, (6) use of upper extremity for weight bearing.

At the time of this study, 250 patients had been enrolled into this cohort. All patients underwent annual surveillance, including clinical interview, examination, ultrasonography, and standardized radiographs. Patients were deemed to have become "symptomatic" if (1) shoulder pain on the visual analog scale was 3 or greater for at least 6 weeks, (2) pain level was considered greater than normally experienced as a part of daily living, (3) pain required the use of medications such as narcotics or nonsteroidal anti-inflammatory medications, or (4) pain prompted a visit to a physician.

A review of the medical records documented 250 subjects in this database, and 216 were used for analysis in this study. Of these, 25 shoulders were excluded due to poor quality radiographs, 5 shoulders did not have adequate radiographs, and 4 shoulders were excluded because the interval between radiographs and sonograms was more than 12 weeks. The most recent surveillance visit with complete clinical, radiographic, and sonographic data was used for analysis. Hence, this study used a cross-sectional analysis of all patients at one given time point and did not investigate temporal changes seen in each subject over the course of surveillance. The most recent surveillance visit was chosen for analysis to include as many patients as possible who had become symptomatic.

Ultrasonography

The ultrasonographic examinations were performed by 1 of 3 musculoskeletal radiologists with extensive experience in the use of high-resolution ultrasound imaging for evaluation of pathologic shoulder conditions. Ultrasound is used as the primary modality of screening for rotator cuff disease at our institution and has been validated as an accurate means to detect rotator cuff tears.[32,34,35] All patients underwent standardized bilateral shoulder examinations as previously described.[34] Ultrasound assessments were performed in real time with the use of 1 of 3 different sonographic machines (ATL HDI 5000, Phillips Healthcare, Andover, MA, USA; and Elegra and Antares, both Siemens Healthcare, Malvern, PA, USA).

Rotator cuff tears were assessed and measured using 4 parameters: (1) tear width (anterior to posterior), (2) tear length (lateral to medial tendon retraction), (3) distance from the biceps tendon to the anterior margin of the tear, and (4) distance from the biceps to the posterior margin of the tear. All measurements were made in real time by the examining radiologist.

Radiographic analysis

For all patients enrolled in the longitudinal cohort, standardized radiographs were performed at study enrollment and annually thereafter. Three radiology technicians were specifically trained to standardize the quality of the radiographs. The distance between the cassette and the x-ray beam was 40 inches for all images. The radiographic series included a true anterior-posterior view in the scapular plane with the arm in neutral rotation and in 0° elevation. A supraspinatus outlet view (SOV) was performed in the posterior-anterior direction, and the x-ray beam was directed with a 10° caudal tilt.[26]

All radiographs were reviewed by 3 independent observers blinded to the clinical and ultrasound data. Owing to the historically poor interobserver reliability of acromial measurements and classifications, 3 separate training sessions were conducted. These sessions allowed for collaboration and further clarification of the classification systems used in this analysis. All radiographs were reviewed after these training sessions, and there was no further collaboration after radiographic analysis had begun.

Acromial morphology analysis

All shoulders were classified into 1 of 3 acromial shapes using the SOV and the Bigliani classification system (Fig. 1).[4] This system classifies the shape of the undersurface of the acromion as flat (type I), curved (type II), or hooked (type III). For the purpose of analysis, a type III acromion was felt to be present if there was a distinct inferior projection of the anterior third of the acromion independent of the presence of an anterior projecting osteophyte. If one or more of the reviewers felt the SOV was inadequate to determine the acromial shape, it was excluded from analysis. Radiographs were acceptable for 208 of the 216 subjects for acromial morphology analysis.

Acromial spur analysis

The SOV was also used to assess for the presence of an acromial spur. A spur was defined as a boney projection along the insertion of the coracoacromial ligament that showed an abrupt change in the curvature of the anterior edge of the acromion, as described by Ogawa et al.[29] Spurs did not have the normal trabecular bone seen in the acromion and always projected toward the coracoid on the SOV (Fig. 2). Digital software was used to measure the length of the spur in millimeters. Spurs were measured in a single dimension from the base of the acromial attachment to the tip of the spur. The presence or absence of a spur had no bearing on the acromial morphology classification.

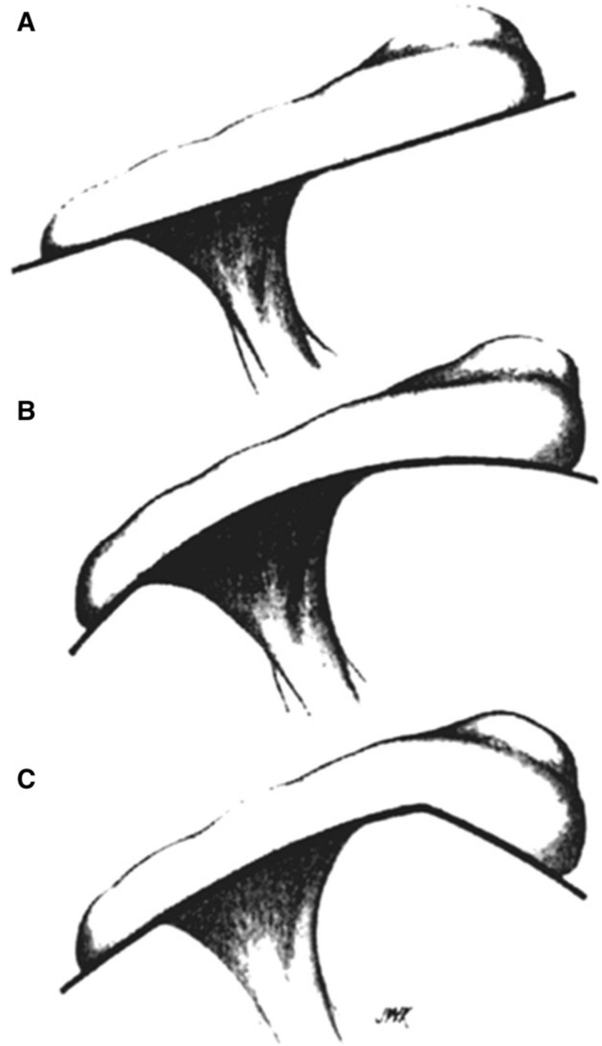

Figure 1 Acromial morphology classification system: (**A**) flat (type I), (**B**) curved (type II), or (**C**) hooked (type III).

Acromial index analysis

The acromial index is a method to quantify the amount of lateral extension of the acromion relative to the humeral head. Described by Nyffeler et al,[27] this calculation is done using the true anterior-posterior radiograph. All radiographs were taken with the arm in neutral rotation and adduction. Three parallel lines are drawn, with the first line connecting the superior and inferior glenoid margins. The second line is tangential to the lateral border of the acromion, and the third line is tangential and abutting the most lateral aspect of the proximal humerus (Fig. 3). The acromial

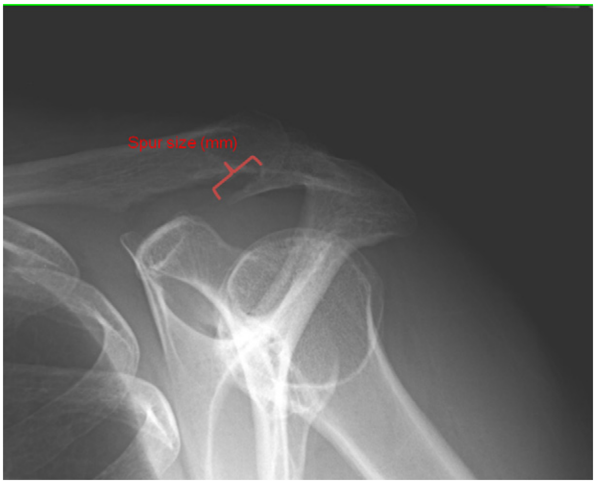

Figure 2 Acromial spur measurement method.

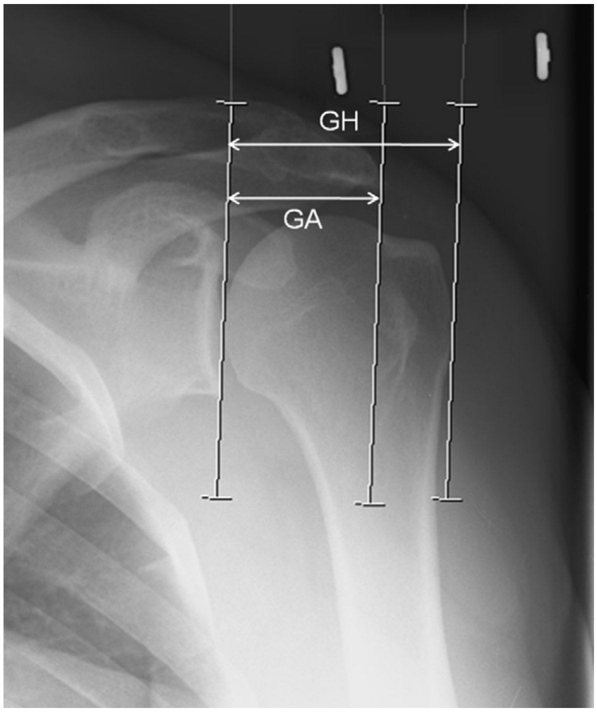

Figure 3 Acromial index measurement method. Acromial index = distance from glenoid plane to acromion (*GA*)/distance from glenoid plane to lateral aspect of humerus (*GH*).

index is the ratio of the distance to the lateral extent of the acromion over the distance to the lateral extent of the humerus.

In addition to the control group in the observation cohort, a second control group was included for acromial index investigation. The controls in the observation cohort had known rotator cuff tears on the nonstudy shoulder and might be predisposed to having lateral extension of the acromion (ie, a larger acromial index). Therefore, 43 patients with no rotator cuff disease were chosen as a second control group for this analysis. These patients were identified by Current Procedural Terminology (CPT, American Medical Association, Chicago, IL, USA) query for capsular release of adhesive capsulitis. All patients underwent surgical treatment of adhesive capsulitis and had an intact rotator cuff at the time of surgery. All radiographs were reviewed to confirm the absence of any underlying pathology, including fracture, osteoarthritis, and calcific tendinitis. Initially, 65 radiographs were screened, and 22 were excluded due to insufficient radiographic quality, leaving 43 for analysis.

Statistical analysis

Agreement among 3 raters' measurements of acromial spur size and acromial index was calculated with intraclass correlation coefficients (ICCs) and corresponding 95% confidence intervals (CIs). Acromial spur measurements were collapsed to create a dichotomous variable to represent spur presence (defined as a measurement greater than 0 mm) and an additional dichotomous variable to represent large spur presence (defined as a measurement greater than 5 mm). Agreement among 3 raters for spur presence and acromial morphology grade was expressed using Cohen's simple κ coefficients and percentage of perfect agreement with corresponding 95% CIs. Agreement coefficients were interpreted using the general guidelines suggested by Landis and Koch[19]: 0 = poor, 0 to 0.2 = slight, 0.21 to −0.40 = fair, 0.41 to 0.60 = moderate, 0.61 to 0.80 = substantial, and 0.81 to 1.0 = almost perfect agreement. However, these guidelines are arbitrary and are often adjusted to more accurately reflect the data being analyzed. Therefore, a value of less than 0.50 was considered "poor" in accordance with previous studies on this particular subject matter.[6,15,41]

Data for patients with and without a spur were compared using χ^2 tests for categoric variables and analysis of variance for continuous variables. Odds ratios (ORs) with corresponding 95% CIs are reported to express the association between the presence of a full tear and a spur. ORs reflect the increased likelihood for full tears to have a spur.

Multivariable stepwise logistic regression was used to compare patients with a full tear with patients with a partial tear or no tear. The model selected variables that contribute information that is statistically independent of the other variables in the model. On the basis of an a priori decision, spur presence, age, sex, and side dominance were included as possible predictors in the multivariable model. Adjusted ORs (aORs) are reported for variables selected, adjusted for all variables in the final model.

Unless otherwise indicated, the data are shown as mean ± standard deviation. The data analysis was generated using SAS 9.2 software (SAS Institute Inc, Cary, NC, USA). A large number of statistical tests were conducted, and as the number of tests increases, the likelihood increases that any one of these tests is significant by chance alone (type I error). Therefore, caution must be used in evaluating the significance of any individual test. More confidence can be had in patterns of similar results.

Results

Study subjects and tear characteristics

The analysis consisted of 216 subjects who were an average age of 64.8 ± 10 years (range, 37.1-90.2 years); of

Table I Rater agreement for acromial radiographic characteristics

Variable	Subjects (*N*)	Reliability coefficient		95% CI
		κ	ICC	
Acromial morphology	208	0.41	...	0.34-0.48
Acromial spur measurement	216	...	0.65	0.59-0.71
Acromial spur presence	216	0.59	...	0.52-0.66
Large acromial spur (>5mm) presence	216	0.61	...	0.52-0.71
Acromial index*	216	...	0.86	0.83-0.89

CI, confidence interval; *ICC,* intraclass correlation coefficient.
* Calculated variable: (acromial offset/humeral offset).

Table II Association of spur presence with patient and tear characteristics

Variable*	Overall sample (*N* = 216)	Spur presence		*P*
		Absent (*n* = 167)	Present (*n* = 49)	
Age, year	64.8 ± 10	64.0 ± 11	67.2 ± 8	.06†
Sex				
Male	128 (59)	102 (61)	26 (53)	.32‡
Female	88 (41)	65 (39)	23 (47)	
Dominant side				
No	136 (64)	109 (66)	27 (55)	.16‡
Yes	78 (36)	56 (34)	22 (45)	
Pain				
No	167 (77)	133 (80)	34 (69)	.13‡
Yes	49 (23)	34 (20)	15 (31)	
Tear type				
Control/partial	93 (43)	82 (49)	11 (22)	.0009‡
Full	123 (57)	85 (51)	38 (78)	
Tear measurements for full tears				
Tear length, mm	15.5 ± 9	15.0 ± 9	16.8 ± 10	.34†
Patients, *n*	120	83	37	
Tear width, mm	14.6 ± 9	14.1 ± 9	15.6 ± 9	.24†
Patients, *n*	120	82	38	

* For the entire sample and separately by spur presence group, categoric data are number of patients (% of group) or mean ± standard deviation.
† *P* compares groups with spur presence by analysis of variance. For tear size variables, size was log-transformed before analysis.
‡ *P* compares spur presence groups by χ^2 test.

these, 123 had full-thickness rotator cuff tears, 46 had partial-thickness tears, and 47 had no rotator cuff tear (control) at the most recent surveillance visit. The average age was 62.8 ± 10 years for the patients with an intact rotator cuff or partial-thickness tear, and 66.2 ± 10 years for patients with a full-thickness tear (P = .01). Of the 216 study subjects, 88 (41%) were women, and the dominant side was studied in 78 (36%; 2 patients did not report hand dominance).

During the surveillance period, 49 of the 216 patients became symptomatic. The average duration of follow-up for the newly symptomatic shoulders from the time of study enrollment to the onset of pain was 2.3 ± 1 years (range, 0.4-7.2 years). Subjects who developed shoulder pain were a mean age of 62.1 ± 10 years compared with 65.5 ± 10 years for who remained pain-free (P = .04).

Acromial morphology

The interobserver reliability for acromial morphology was poor, with κ = 0.41 (95% CI, 0.34-0.48; Table I). The percent perfect agreement was 72% (95% CI, 68%-75%). No further analysis was performed using the acromial morphology classification system due to the low interobserver agreement.

Acromial spur

The interobserver reliability for acromial spur measurement was substantial, with an ICC of 0.65 (95% CI, 0.59-0.71; Table I). For acromial spur presence greater than 5 mm in size, the κ was 0.61 (95% CI, 0.52-0.71), and the percent perfect agreement was 92% (95% CI, 90%-94%).

Table III Association of large acromial spur with patient and tear characteristics (spurs >5 mm)

Variable*	Large spur presence		P
	Absent (n = 190)	Present (n = 26)	
Age, year	64.4 ± 10	67.0 ± 7	.23†
Gender			
Male	112 (59)	16 (62)	.80‡
Female	78 (41)	10 (38)	
Dominant side			
No	123 (65)	13 (50)	.13‡
Yes	65 (35)	13 (50)	
Pain			
No	150 (79)	17 (65)	.12‡
Yes	40 (21)	9 (35)	
Tear type			
Control/partial	90 (47)	3 (12)	.0005‡
Full	100 (53)	23 (88)	
Tear measurements for full tears			
Tear length, mm	14.8 ± 9	18.4 ± 9	.053†
Patients, n	97	23	
Tear width, mm	14.0 ± 9	16.7 ± 8	.046†
Patients, n	97	23	

* Data are the number of patients (% of spur presence group) or mean ± standard deviation.
† P compares groups by analysis of variance. For tear size variables, size was log-transformed before analysis.
‡ P compares groups by χ^2 test.

As reported in Table II, at least 2 of the 3 readers found a spur (>0 mm) present in 49 subjects. Those with an acromial spur were slightly older (average age, 67.2; range, 53.1-82.9 years) than those without a spur (average age, 64.0; range, 37.1-90.2 years), but this did not reach statistical significance (P = .06). The presence of a full-thickness rotator cuff tear was seen in 85 of the 167 patients (51%) without an acromial spur and in 38 of the 49 patients (78%) with an acromial spur (P = .0009). The OR of having a full-thickness rotator cuff tear when a spur was present was 3.33 (95% CI, 1.60-6.96). The onset of pain was seen in 34 of 167 subjects (20%) without a spur and in 15 of 49 (31%) with an acromial spur (P = .13). A post hoc power analysis showed that the sample size was adequately powered (0.80) to detect an 18% between-group difference in the prevalence of pain (α = 0.05).

When acromial spurs were further subdivided, at least 2 of 3 readers found 26 subjects had a spur measuring greater than 5 mm (Table III). A full-thickness rotator cuff tear was seen in 100 of the 190 subjects (53%) without a large spur and in 23 of the 26 subjects (88%) with a large acromial spur (P = .0005). When a full-thickness tear was present, the tear width was greater when a large acromial spur was present (P = .046). There was also a trend noted with greater tear length (retraction) and the presence of a large acromial spur (P = .053). The onset of pain was seen in 40 of the 190 subjects (21%) without a large spur and in 9 of the 26 subjects (35%) with a large spur (P = .12).

Further investigation was performed to clarify the association of age, presence of an acromial spur, and rotator cuff disease. A univariate model showed spur presence and advancing age were associated with the presence of a full-thickness cuff tear (P = .0009 and P = .01, respectively) but gender was not (P = .09). A multivariable logistic regression model (Table IV) showed that the presence of an acromial spur, regardless of size, was highly associated with a full-thickness rotator cuff tear, even after adjusting for age, sex, and hand dominance (OR, 3.05; 95% CI, 1.42-6.52).

Acromial index

The interobserver reliability for the acromial index was excellent, with an ICC of 0.86 (95% CI, 0.83-0.89; Table I). The overall mean acromial index was 0.691 ± 0.06 (range, 0.540-0.884). As reported in Table V, the acromial index was higher in women than in men (0.705 vs 0.682, P = .01). The acromial index did not correlate with age (P = .25) or hand dominance (P = .08). The mean acromial index was 0.691 for subjects with no or partial rotator cuff tears, and 0.692 for those with full-thickness rotator cuff tears (P = .92). Subjects with new-onset pain had slightly larger values for the acromial index than those who remained asymptomatic (0.710 vs 0.686, P = .02). A post hoc power analysis (α = 0.05) showed that the given sample size and observed variability had adequate power of 0.80 to detect a minimum of 0.023 between-group

Table IV Multivariable logistic regression model of characteristics and adjusted odds ratios for the presence of a full tear ($N = 209$)

Variable	Adjusted OR (95% CI)*	Incremental R^2 (selection order)	P
Spur, presence vs. absence	3.05 (1.42-6.52)	0.05 (1)	.001
Age, 10-year increments	1.39 (1.04-1.86)	0.02 (2)	.03
Sex, male vs female	1.83 (1.02-3.31)	0.02 (3)	.03
Bilaterals coded as dominant	1.81 (0.98-3.32)	0.02 (4)	.055

CI, confidence interval; *OR,* odds ratio.

* Adjusted ORs reflect the increased odds of having a full tear. For categoric characteristics, reference categories were spur absence, female sex, and nondominant side.

difference in the acromial index. Also, a multivariable analysis of variance showed that pain was still associated with the acromial index, even after adjusting for sex ($P =$ .04).

The acromial index was also measured in 43 control patients without a history of rotator cuff disease in either shoulder. This control group was significantly younger than the rotator cuff observational cohort (50.6 ± 8 vs 64.8 ±10 years, $P < .0001$). The acromial index was 0.690 ± 0.07 in this group, showing no difference compared with the patients in the cohort with rotator disease ($P = .91$).

Discussion

The acromion has been implicated in the pathogenesis of rotator cuff disease for many years. Neer[24] investigated the mechanism of impingement and described a focal, critical area of contact between the supraspinatus tendon and the undersurface of the anterolateral acromion. Further cadaveric investigations showed a close relationship between acromial shape and rotator cuff disease.[4,23] These findings led to the widespread use of partial anterior acromioplasty to treat rotator cuff disease, and this procedure was associated with good clinical results.[3,10,13,31] Since Neer's original findings, many methods have been described to link the radiographic appearance of the acromion and coracoacromial arch with rotator cuff disease. Acromial shape,[4] acromial slope,[17] acromial angle,[36] acromial tilt,[1] acromiohumeral distance, acromial spur formation,[29] and acromial index[27] have all been proposed to predict which patients have rotator cuff tears. We chose to further investigate 3 particular methods of classifying the radiographic appearance of the acromion: acromial morphology, acromial spur, and the acromial index.

Acromial morphology was chosen for investigation because it is still widely used in clinical practice throughout the world. We found that the Bigliani acromial morphology classification system lacked interobserver reliability ($\kappa =$ 0.41), despite collaboration sessions conducted by the 3 reviewers before radiographic assessment. Also, radiographs were performed in a standardized fashion with a precise radiographic protocol by specially trained staff. Owing to the poor rater agreement, no further analysis was conducted using acromial morphology.

These results were not unanticipated, because others have reported poor interobserver reliability using this classification system. Jacobson et al[15] reviewed 126 SOV radiographs, and each acromion was classified as type I, II, or III by 6 fellowship-trained shoulder surgeons. The interobserver reliability coefficient was 0.516 and was lowest when delineation between type II and III was required. In another investigation, Zuckerman et al[41] conducted a cadaveric study of 110 scapulas, where the entire acromion was visually inspected by 3 shoulder surgeons and classified by the Bigliani system. They found poor agreement among the 3 reviewers, with an ICC similar to the one in our study ($\kappa = 0.41$). On the basis of these studies and our findings, we agree with previous investigators that acromial morphology is an unreliable method to characterize the acromion and a more objective system should be employed to determine the relationship of acromion characteristics and rotator cuff disease.

We also investigated the presence of an acromial spur along the coracoacromial ligament. We chose this method because it appeared to be a more reliable and consistent measure compared with acromial shape, and others have found it to be predictive of rotator cuff disease.[29] Our rater agreement was substantial, with an ICC of 0.65 for the spur measurement (mm), $\kappa = 0.59$ for spur presence, and $\kappa =$ 0.61 for presence of a large spur. We found that the presence of an acromial spur was highly associated with a full-thickness rotator cuff tear ($P = .0009$; Fig. 4). In addition, spurs larger than 5 mm were associated with larger tears. Our results coincide with those of Ogawa et al,[29] who found a high association between spurs measuring 5 mm or more and bursal or complete rotator cuff tears.

They also found that acromial spurs were more common in older patients. Our data showed a similar trend, with a mean age of 64 years for patients without the presence of a spur and 67 years for those with a spur ($P = .06$). We were concerned that age and the presence of an acromial spur would be closely linked and thus lead to a faulty assumption that rotator cuff disease was associated with

Table V Association of acromial index with patient and tear characteristics

Variable	Patients (*n*)	Acromial index* (mean ± SD)	*P*
Age, year	216	...[†]	.25
Pain			
No	167	0.686 ± 0.06	.02[‡]
Yes	49	0.710 ± 0.07	
Sex			
Male	128	0.682 ± 0.06	.01[‡]
Female	88	0.705 ± 0.07	
Dominant side			
No	136	0.697 ± 0.06	.08[‡]
Yes[§]	78	0.682 ± 0.07	
Tear type			
Control/partial	93	0.691 ± 0.06	.92[‡]
Full	123	0.692 ± 0.06	

SD, standard deviation.
* Calculated variable: (acromial offset/humeral offset).
† $r = -0.08$.
‡ *P*-value compares acromial index across groups by analysis of variance.
§ Bilaterals are coded as dominant.

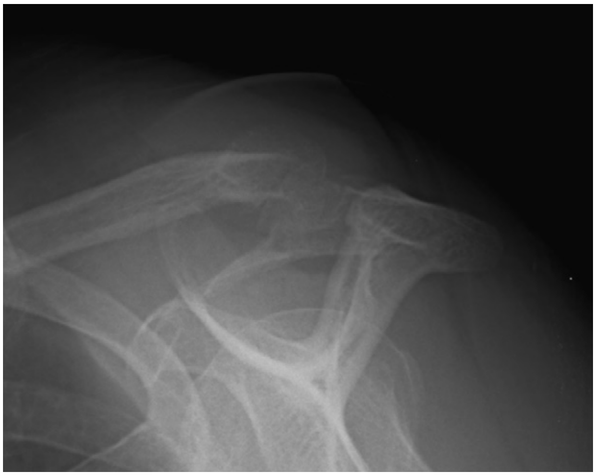

Figure 4 Supraspinatus outlet view shows a 15-mm acromial spur in a 72-year-old asymptomatic patient. Ultrasound examination revealed a full-thickness rotator cuff tear measuring 12 × 12 mm.

spur presence. Therefore, a multivariable analysis was performed to clarify the role of age, spur presence, and rotator cuff disease. We found that acromial spur presence was significantly associated with the presence of a full-thickness rotator cuff tear after adjusting for the potential influence of age, sex, and hand dominance.

The last method we investigated was the acromial index described by Nyffeler et al.[27] This novel measurement tool showed convincing evidence of a close relationship between lateral acromial extension and rotator cuff disease. Our interobserver reliability was excellent using this measurement tool (ICC, 0.86); however, we were unable to demonstrate a difference in the acromial index between patients with and without rotator cuff tears. To ensure that the control group in the observation cohort was not predisposed to a larger acromial index (because of known rotator cuff disease on the contralateral side), we studied control patients with no history of rotator cuff disease. The acromial index was nearly identical in all of these groups (means, 0.690 and 0.691).

These results conflict with those of Nyffeler et al.[27] They found the mean acromial index of patients without rotator cuff disease was 0.64 and the acromial index of those with full-thickness rotator cuff tears was 0.73 ($P < .0001$). These findings were later corroborated by Torrens et al.[37] Although our study and the Nyffeler et al study both used standardized radiographs, it is possible that subtle differences in the methods of radiographic assessment led to this disparity. However, we believe that the high interobserver reliability and narrow CIs found in our study suggest that no association exists between lateral acromial extension and rotator cuff disease.

We attempted to describe the association of various acromial radiographic variables with the development of pain in shoulders with asymptomatic cuff tears. This aim has not been previously investigated. Previous studies of this observational cohort have shown pain development to occur in short-term follow-up in approximately 20% of subjects.[21] Risk factors for the development of pain included the presence of a larger tear at the time of enrollment and tear enlargement over time. Furthermore, another study related to this cohort showed a higher likelihood of pain in the dominant shoulder.[16] In the present study, a slightly larger acromial index was seen in shoulders that became painful. Nonsignificant trends were also seen between the presence of an acromial spur and the development of pain. At this point, the potential role of the acromial architecture to the development of shoulder pain in patients with known cuff disease is still uncertain. Pain development in patients with degenerative cuff tears is likely complex and multifactorial; however, the findings of this study suggest that further investigation into the potential role of the acromion in the development of pain is warranted.

Our study investigated a unique cohort of asymptomatic patients that were identified by ultrasound imaging to have an intact, partially torn, or completely torn rotator cuff. These patients were followed up over time with annual sonographic, radiographic, and clinical assessments. We felt that these patients would be ideal to investigate the relationship between radiographic acromial findings and rotator cuff disease. Standardized radiographs were performed, and blinded reviewers evaluated all radiographs. High-resolution ultrasonography was used to evaluate the rotator cuff because this method and technique has been validated at our institution.[34,35] Although some of our findings have been previously shown in the literature, the methodology of this investigation, including its prospective design, blinded radiographic analysis, and standardized data acquisition, offers compelling validation to this controversial topic.

This study has several limitations. For the purposes of this study, the definition of an acromial spur was somewhat arbitrary. We sought to identify and measure irregular bone formation along the insertion of the coracoacromial ligament. Therefore, our conclusions cannot be extrapolated to any other type of acromial boney excrescence. Although, prospective protocols were in place to enhance radiographic reliability, 100% accuracy of radiographs could not be achieved and some variability in technique surely occurred.

Also, this investigation did not explore the temporal changes of subjects through their surveillance period. This information, which may be the subject of future research, might help to clarify the causal relationship of acromial spurs and rotator cuff disease. Therefore, the association of acromial spur presence with rotator cuff disease found in this study cannot be used to infer a causal relationship between these two variables.

Conclusions

The presence of an acromial spur at the acromial insertion of the coracoacromial ligament is highly associated with the presence of a full-thickness rotator cuff tear in both symptomatic and asymptomatic subjects, even after controlling for confounding variables such as age and sex. Spurs measuring greater than 5 mm are associated with larger rotator cuff tears. Acromial morphology is an unreliable classification system with poor interobserver reliability. The acromial index is associated with the development of pain in previously asymptomatic shoulders, but shows no association with the presence of rotator cuff disease.

Acknowledgments

The authors thank Tomoyuki Mochizuki, MD, and Chanteak Lim, MD, for their invaluable contributions to this study.

Disclaimer

The funding source for this study was an R01 grant (AR051026-01A1) from the National Institutes of Health.

Dr Yamaguchi receives royalties from Tornier, which is unrelated to the subject of this article. The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Aoki M, Ishii S, Usui M. Clinical application for measuring the slope of the acromion. In: Morrey RB, editor. Surgery of the shoulder. St. Louis: Mosby; 1990. p. 200.
2. Biberthaler P, Wiedemann E, Nerlich A, Kettler M, Mussack T, Deckelmann S. Microcirculation associated with degenerative rotator cuff lesions: in vivo assessment with orthogonal polarization spectral imaging during arthroscopy of the shoulder. J Bone Joint Surg Am 2003;85:475-80.
3. Bigliani LU, D'Alessandro DF, Duralde XA, McIlveen SJ. Anterior acromioplasty for subacromial impingement in patients younger than 40 years of age. Clin Orthop Relat Res 1989 Sep:111-6.
4. Bigliani LU, Morrison DS, April EW. The morphology of the acromion and its relationship to rotator cuff tears. Orthop Trans 1986;10: 216.
5. Bigliani LU, Ticker JB, Flatow EL, Soslowsky LJ, Mow VC. The relationship of acromial architecture to rotator cuff disease. Clin Sports Med 1991;10:823-38.
6. Bright AS, Torpey B, Magid D, Codd T, McFarland EG. Reliability of radiographic evaluation for acromial morphology. Skeletal Radiol 1997;26:717-21.
7. Chambler AFW, Pitsillides AA, Emery RJH. Acromial spur formation in patients with rotator cuff tears. J Shoulder Elbow Surg 2003;12:314-21. doi:310.1016/S1058-2746(1003)00030-00032
8. Codman EA. Rare lesions of the shoulder. In: Codman EA, editor. The shoulder: rupture of the supraspinatus tendon and other lesions in or about the subacromial bursa. Boston: Thomas Todd Co; 1934. p. 468-509.
9. Epstein RE, Schweitzer ME, Frieman BG, Fenlin JM, Mitchell DG. Hooked acromion: prevalence on MR images of painful shoulders. Radiology 1993;187:479-81.

10. Frieman BG, Fenlin JM. Anterior acromioplasty: effect of litigation and workers' compensation. J Shoulder Elbow Surg 1995;4:175-81.
11. Fukuda H, Hamada K, Yamanaka K. Pathology and pathogenesis of bursal-side rotator cuff tears viewed from en block histologic sections. Clin Orthop Relat Res 1990;254:75-80.
12. Gill TJ, McIrvin E, Kocher MS, Homa K, Mair SD, Hawkins RJ. The relative importance of acromial morphology and age with respect to rotator cuff pathology. J Shoulder Elbow Surg 2002;11:327-30. doi: 310.1067/mse.2002.124425
13. Ha'eri GB, Wiley AM. Shoulder impingement syndrome. results of operative release. Clin Orthop Relat Res 1982;168:128-32.
14. Huang CY, Wang VM, Pawluk RJ, Bucchieri JS, Levine WN, Bigliani LU. Inhomogeneous mechanical behavior of the human supraspinatous tendon under axial loading. J Orthop Res 2005;23:924-30. doi:910.1016/j.orthres.2004.1002.1016
15. Jacobson SR, Speer KP, Moor JT, Janda DH, Saddemi SR, MacDonald PB, et al. Reliability of radiographic assessment of acromial morphology. J Shouder Elbow Surg 1995;4:449-53.
16. Keener JD, Steger-May K, Stobbs G, Yamaguchi K. Asymptomatic rotator cuff tears: patient demographics and baseline shoulder function. J Shoulder Elbow Surg 2010;19:1191-8. doi:1110.1016/j.jse.2010.1107.1017
17. Kitay GS, Iannotti JP, Williams GR, Haygood T, Kneeland BJ, Berlin J. Roentgenographic assessment of acromial morphologic condition in rotator cuff impingement syndrome. J Shoulder Elbow Surg 1995;4:441-8.
18. Kumagai J, Sarkar K, Uhthoff HK. The collagen types in the attachment zone of rotator cuff tendons in the elderly. J Rheumatol 1994;21:2096-100.
19. Landis JR, Koch GG. The measure of observer agreement for catagorical data. Biometrics 1977;33:159-74.
20. MacGillivray JD, Fealy S, Potter HG, O'Brien SJ. Multiplanar analysis of acromion morphology. Am J Sports Med 1998;26:836-40.
21. Mall NA, Kim HM, Keener JD, Steger-May K, Teefey SA, Middleton WD, et al. Symptomatic progression of asymptomatic rotator cuff tears: a prospective study of clinical and sonographic variables. J Bone Joint Surg Am 2010;92:2623-33. doi:2610.2106/JBJS.I.00506
22. Mayerhoefer ME, Breitenseher MJ, Wurnig C, Roposch A. Shoulder impingement: relationship of clinical symptoms and imaging criteria. Clin J Sports Med 2009;19:83-9.
23. Morrison DS, Bigliani LU. The clinical significance of variations in acromial morphology. Orthop Trans 1987;11:234.
24. Neer CS. Impingement lesions. Clin Orthop Relat Res 1983 Mar:70-7.
25. Neer CS. Anterior acromioplasty for the chronic impingement syndrome in the shoulder. J Bone Joint Surg Am 1972;54:41-50.
26. Neer CS, Poppen NK. Supraspinatous outlet. Orthop Trans 1987;11:234.
27. Nyffeler RW, Werner CML, Sukthankar A, Schmid MR, Gerber C. Association of a large lateral extension of the acromion with rotator cuff tears. J Bone Joint Surg Am 2006;88:800-5. doi:810.2106/JBJS.D.03042
28. Ogata S, Uhthoff HK. Acromial enthesopathy and rotator cuff tear. Clin Orthop Relat Res 1990;254:39-48.
29. Ogawa K, Yoshida A, Inokuchi W, Naniwa T. Acromial spur: relationship to aging and morphologic changes in the rotator cuff. J Shoulder Elbow Surg 2005;14:591-8. doi:510.1016/j.jse.2005.1003.1007
30. Ozaki J, Fujimoto S, Nakagawa Y, Masuhara K, Tamai S. Tears of the rotator cuff of the shoulder associated with pathological changes in the acromion. J Bone Joint Surg Am 1988;70:1224-30.
31. Post M, Cohen J. Impingement syndrome. a review of late stage II and early stage III lesions. Clin Orthop Relat Res 1986;207:126-32.
32. Prickett WD, Teefey SA, Galatz LM, Calfee RP, Middleton WD, Yamaguchi K. Accuracy of ultrasound imaging of the rotator cuff in shoulders that are painful postoperatively. J Bone Joint Surg Am 2003;85:1084-9.
33. Sarkar K, Taine W, Uhthoff HK. The ultrastructure of the coracoacromial ligament in patients with chronic impingement syndrome. Clin Orthop Relat Res 1990;254:49-54.
34. Teefey SA, Hasan SA, Middleton WD, Patel M, Wright RW, Yamaguchi K. Ultrasonography of the rotator cuff. A comparison of ultrasonographic and arthroscopic findings in one hundred consecutive cases. J Shoulder Elbow Surg 2000;82:498-504.
35. Teefey SA, Rubin DA, Middleton WD, Hildebolt CF, Leibold RA, Yamaguchi K. Comparison of ultrasonographic, magnetic resonance imaging, and arthroscopic findings in seventy-one consecutive cases. J Bone Joint Surg Am 2004;86:708-16.
36. Toivonen DA, Tuite MJ, Orwin JF. Acromial structure and tears of the rotator cuff. J Shoulder Elbow Surg 1995;4:376-83.
37. Torrens C, Lopez J, Puente I, Caceres E. The influence of the acromial coverage index in rotator cuff tears. J Shoulder Elbow Surg 2007;16:347-51. doi:310.1016/j.jse.2006.1007.1006
38. Uhthoff HK, Hammond DI, Sarkar K, Hooper GJ, Papoff WJ. The role of the coracoacromial ligament in the impingement syndrome. Int Orthop 1988;12:97-104.
39. Vitale MA, Arons RR, Hurwitz S, Ahmad CS, Levine WN. The rising incidence of acromioplasty. J Bone Joint Surg Am 2010;92:1842-50. doi:1810.2106/JBJS.I.01003
40. Worland RL, Lee D, Orozco CG, Sozarex F, Keenan J. Correlation of age, acromial morphology, and rotator cuff tear pathology diagnosed by ultrasound in asymptomatic patients. J South Orthop Assoc 2003;12:23-6.
41. Zuckerman JD, Kummer FJ, Cuomo F, Greller M. Interobserver reliability of acromial morphology classification: an anatomic study. J Shoulder Elbow Surg 1997;6:286-7.