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ORIGINAL ARTICLE

A simple method to directly evaluate the lateral extension of the acromion: an anatomic study of 128 cadaveric scapulae

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Background: The lateral extension of the acromion from the glenohumeral joint is the critical variable that both the acromial index and critical shoulder angle reflect. The purpose of this study was to establish a simple and reproducible method to directly measure the lateral extension of the acromion that will be independent of patient demographic characteristics, scapular rotation, or other morphologic features of the shoulder.

Methods: This study used 128 unpaired cadaveric scapulae with a mean age of 69.4 ± 11.1 years (66 right and 62 left scapulae, 65 female and 63 male cadaveric specimens). The lateral extension of the acromion was measured from the supraglenoid tubercle to the most lateral point of the acromion with a digital caliper placed perpendicular to the scapula long axis. This distance was called the "lateral offset of the acromion."

Results: The lateral offset was 2.62 ± 0.72 cm in men and 2.69 ± 0.73 cm in women. The offset was 2.61 ± 0.66 cm in right and 2.70 ± 0.78 cm in left scapulae. The offset in the group aged 46-60 years was 2.85 ± 0.76 cm; in the group aged 61-75 years, it was 2.62 ± 0.76 cm; and in the group aged 76 years or older, it was 2.54 ± 0.60 cm. No significant difference was found between any of the groups.

Conclusions: This study established a simple method to directly measure the lateral extension of the acromion based on the longitudinal axis of the scapula, which eliminates bias that may exist in the acromial index and critical shoulder angle from the position of the scapula and glenoid inclination. The lateral offset was found to be independent of sex, side, or age, limiting bias in a potential future clinical application.

Level of evidence: Anatomy Study; Cadaveric Dissection

Keywords: Acromial index; critical shoulder angle; rotator cuff tear; anatomy; cadaveric; lateral offset of acromion; normative data

The pathogenesis of rotator cuff tears (RCTs) is poorly understood and may include both intrinsic and extrinsic factors. Extrinsic factors that contribute to rotator cuff pathology are faulty posture, altered scapular or glenohumeral

This study was deemed exempt from institutional review board approval because it involves only cadaveric scapulae.

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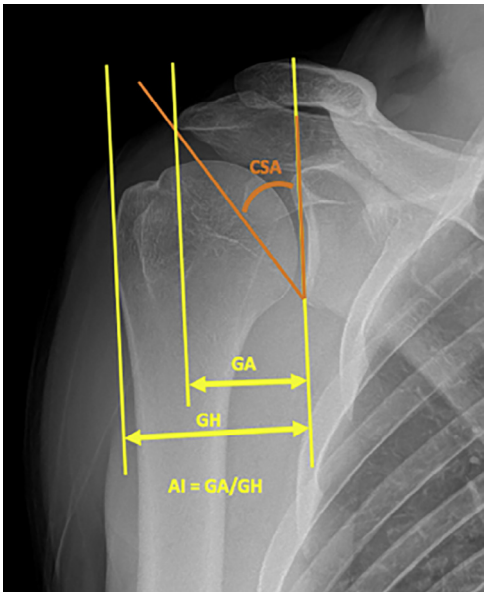

Figure 1 Measurements of acromial index (*AI*) and critical shoulder angle (*CSA*) on anteroposterior shoulder radiograph. The AI is the ratio of the distance between the glenoid plane and acromial plane (*GA*) to the distance between the glenoid plane and humeral plane (*GH*). The CSA is the angle formed by a line connecting the superior and inferior aspects of the glenoid and a line connecting the inferior aspect of the glenoid fossa to the lateral-most point of the acromion.

kinematics, posterior capsular tightness, and anatomic variations of the acromial or glenoid morphology. Many indices have been proposed to account for these anatomic factors as they relate to RCTs, such as the acromial index (AI) and critical shoulder angle (CSA).[17,22] The AI, initially described by Nyffeler et al,[22] is the ratio of the distance between the glenoid plane and the lateral border of the acromion to the distance between the glenoid plane and the lateral aspect of the humeral head. This measurement represents the lateral extension of the acromion in relation to the humeral head on an anteroposterior shoulder radiograph.[22] The CSA, as proposed by Moor et al,[17,18] relates the lateral acromial extension to the plane of the glenoid. This is measured as the angle between a first line connecting the inferior border to the superior border of the glenoid fossa and a second line connecting the inferior border of the glenoid to the inferolateral aspect of the acromion (Fig. 1).

Both the AI and CSA have been correlated with shoulder pathologies.[1,2,6,9,10,12,17,25,26] The lateral extension of the acromion from the glenohumeral joint is more commonly used as the critical variable involved in the assessment of the association between those 2 indices and rotator cuff pathology. Previous studies have shown that lateral acromial resection, in combination with anterolateral acromioplasty, improves outcomes in the treatment of rotator cuff pathologies.[16] Accurate measurement of this parameter will better indicate the need for these procedures.[22]

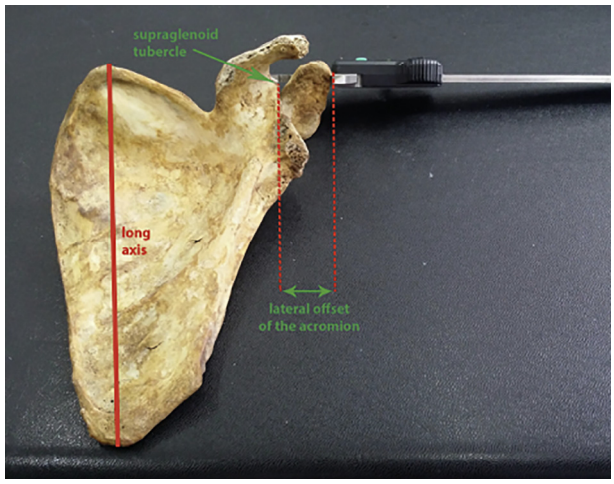

Figure 2 Measurement of lateral offset of acromion. The scapula was placed on a flat table with the longitudinal axis (an imaginary line connecting the superior and inferior scapular angles) perpendicular to the table margin. The lateral offset of the acromion was measured from the supraglenoid tubercle to the most lateral point of the acromion, with the digital caliper placed parallel to the table margin.

The 2 indices that reflect the lateral extension of the acromion may be affected by scapular rotation during measurements or by the inclination of the glenoid.[17,27] In addition, there is debate as to whether patient demographic characteristics, such as sex, age, and laterality, influence the AI and CSA.[5,9,11,15,28]

The purpose of this study was to establish a simple and reproducible method to directly measure the lateral extension of the acromion that will be independent of patient demographic characteristics, scapular rotation, or other morphologic features of the shoulder. We call this distance the "lateral offset of the acromion."

Methods

This was an anatomic study performed on cadaveric scapulae. Specimens having any evidence of fracture, surgery, postmortem damage, or arthritis, which would prevent accurate measurements, were excluded. The study sample included 128 unpaired dried human cadaveric scapulae, comprising 66 right and 62 left scapulae, with 65 female and 63 male cadaveric specimens. The donors had a mean age of 69.4 ± 11.1 years (range, 46-96 years). The medical history of the donors was unknown.

Each scapula was placed with its posterior surface lying on a flat table, having the longitudinal axis (an imaginary line connecting the superior and inferior scapular angles) perpendicular to the table margin. The lateral offset of the acromion was measured from the supraglenoid tubercle to the most lateral point of the acromion, with the digital caliper placed parallel to the table margin and therefore perpendicular to the longitudinal axis of the scapula (Fig. 2). All bone measurements were done by the same investigator using a digital caliper with a resolution of 0.001 cm (Mitutoyo, Kanagawa, Japan).

Statistical analysis

All analyses were conducted using SPSS software (version 19.9; IBM, Armonk, NY, USA). The Student *t* test was used to examine for significant differences between the sexes and between the 2 sides of the body, whereas the 1-way analysis of variance test was used for the age groups. $P < .05$ was considered statistically significant.

Results

The lateral offset of the acromion from the supraglenoid tubercle was 2.65 ± 0.72 cm across all subsets. The lateral offset in men was 2.62 ± 0.72 cm, while that in women was 2.69 ± 0.73 cm ($P = .620$). The offset in right shoulders was 2.61 ± 0.66 cm, whereas that in left shoulders was 2.70 ± 0.78 cm ($P = .479$). The offset in the group aged 46-60 years was 2.85 ± 0.76 cm; in the group aged 61-75 years, it was 2.62 ± 0.76 cm; and in the group aged 76 years or older, it was 2.54 ± 0.60 cm ($P = .154$). These data are summarized in Table I. Figure 3 shows the distribution of the results. No significant difference was found in lateral offset within the sex, sidedness, or age groups.

Discussion

Previous studies that evaluated the lateral extension of the acromion from the glenohumeral joint focused on 2 shoulder indices, the AI and the CSA.[2,6,9,12,21,25] This anatomic study established a simple method to directly evaluate the lateral extension of the acromion. The measurement was applied in 128 cadaveric scapulae and demonstrated that the lateral extension of the acromion is not affected by sex, side, or age.

Previous epidemiologic studies on radiographic parameters have been performed. Hamid et al[9] measured the relationship between the AI and sex, age, and hand dominance. They found that the AI was statistically higher in women than in men (0.705 vs 0.682, $P = .01$) but did not correlate with age or hand dominance. The diameter of the humeral head is a component of the AI and has been established to be different between the sexes.[3,23] King[13] found strong significance in the difference between the diameter of the humeral head between the sexes, with men having a greater diameter. This finding supports that the aforementioned sex discrepancy in the AI may be due to the wider diameter of the humeral head instead of variances in the acromial offset. Glenoid inclination, the angle from the vertical plane and the line connecting the superior and inferior aspects of the glenoid, affects the measurement of CSA and has demonstrated some correlation to sex, although this was statistically insignificant.[5] Habermeyer et al[8] also found no statistical difference in glenoid inclination between the sexes in a cohort of patients with osteoarthritis. The direct measurement of the lateral extension of the acromion performed in our study does not involve the humeral head diameter, is not based on the glenoid plane, and is not influenced by sex ($P = .620$).

Age groups (46-60 years, 61-75 years, and ≥76 years) and upper-extremity laterality also did not show any statistically significant differences in the lateral offset of the acromion ($P = .154$ and $P = .479$, respectively). Although shoulder morphology appears symmetrical,[7,19] other morphologic characteristics of the shoulder change with age, such as acromial type.[4,19,20] Since the lateral offset of the acromion is not affected by aging, a potential future correlation between this morphologic feature and shoulder pathology will not need any age correction.

The AI and CSA, which are used to represent the lateral extension of the acromion, may be affected either by scapular rotation during measurements or by the inclination of the glenoid. Malrotation of the radiographs by greater than 20°, albeit easy to recognize, was found to reduce the reproducibility of the CSA, although interobserver reliability was still high.[17,24] Spiegl et al[25] concluded that magnetic resonance imaging had greater interobserver and intraobserver agreement by removing the rotational component to imaging. They reported that the mean CSAs measured were significantly different between radiographs and magnetic resonance imaging studies. Since CSA represents the relative

Table I Acromion lateral offset measurements with comparisons within sex, side, and age groups

		Acromion lateral offset, cm						
	n	Mean	SD	Minimum	Median	Maximum	*P* value	Test
Sex								
Men	63	2.62	0.72	1.32	2.66	3.96	.620	Independent-samples *t* test
Women	65	2.69	0.73	1.15	2.81	3.90		
Side								
Right	66	2.61	0.66	1.20	2.62	3.63	.479	Independent-samples *t* test
Left	62	2.70	0.78	1.15	2.81	3.96		
Age group								
46-60 yr	35	2.85	0.76	1.22	2.91	3.90	.154	One-way ANOVA
61-75 yr	49	2.62	0.78	1.15	2.66	3.96		
≥76 yr	44	2.54	0.60	1.34	2.64	3.43		

SD, standard deviation; *ANOVA*, analysis of variance.

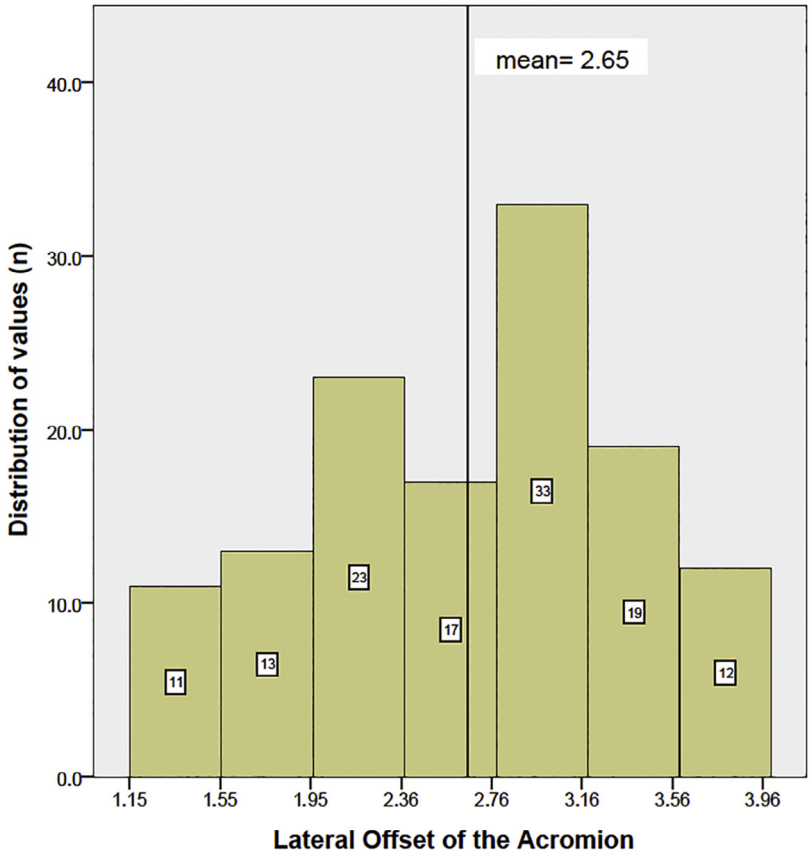

Figure 3 Histogram showing distribution of values of lateral offset of acromion in total sample (mean value, 2.65 cm).

relationship of the lateral extension and glenoid inclination, a downward-facing glenoid inclination may under-represent an overly extended acromion and vice versa. The AI also must depend on the glenoid inclination since the plane of the glenoid serves as a reference for all measurements.[21] The direct measurement of the acromion lateral offset from the supraglenoid tubercle is independent of any other morphologic feature of the shoulder and radiographic parameter. The longitudinal axis of the scapula is defined as the longest dimension of the scapula, which connects the superior and inferior angles of the scapula.[27] This axis was used as a reference plane to measure the lateral offset because it controls for scapular rotation. Thus, the measurement of the lateral offset of the acromion used landmarks (supraglenoid tubercle, most lateral point of acromion) and a reference plane (longitudinal axis) that were consistently identifiable to ensure reproducible measurements.

The relationship of the AI and CSA with shoulder pathology has been thoroughly studied.[1,2,6,9,10,12,17,25,26] A reduced CSA has been associated with osteoarthritis, whereas most studies have found a positive correlation between a greater CSA or AI and RCTs.[10,14,17,18] The CSA has been shown to best predict and differentiate cuff tear arthropathy, osteoarthritis, RCTs, impingement, and tendinitis calcarea from analysis of the area under the receiver operating characteristic curve.[10] The incorporation of age into this predictive model improved specificity for all 5 pathologies above 70%, although sensitivity was poor for RCTs and impingement.[10] However, the use of both indices in clinical practice is still limited. Meanwhile, the lateral extension of the acromion from the glenohumeral joint is more commonly used as the critical variable involved in the assessment of the association between those 2 indices and rotator cuff pathology.[1] In the assessment of RCTs, a greater acromion lateral extension may be associated with an increased number of torn tendons and number of anchors required for repair.[9] In addition, it may cause a reduction in the arthroscopic window for visualization of the articular margin[1] and significantly increase the retear rate following rotator cuff repair.[28] The measurement of lateral offset can influence the decision to perform lateral acromial resection in addition to a routine acromioplasty in the treatment of rotator cuff pathologies.[16] Katthagen et al[12] found lateral acromial resection in combination with anterolateral acromioplasty to be protective against RCTs because of decreasing the lateral extension of the acromion from a cadaveric, anatomic standpoint.

The main limitation of this study is that measurements were performed on cadaveric scapulae, while in clinical practice, they are performed on radiographs. Using a different method for the same anatomic measurement may not provide the same values. However, the finding that lateral extension of the acromion is independent of sex, side, or age is more important

than the absolute values found in this study. Because acromial extension is independent of sex, side, and age, the same relationship must be true for radiographic measurements of the lateral offset of the acromion. An additional limitation is that the medical history of the cadavers was unknown, and as a result, no clinical findings were directly related to the lateral offset of the acromion. Thus, it is impossible at the moment to evaluate the clinical utility of the lateral offset. Future studies are necessary to determine the lateral offset measurement on radiographs and explore any potential association with rotator cuff pathology or efficacy of rotator cuff treatments. In vivo evaluation of the lateral offset would require the entire scapula to be included in the anteroposterior shoulder radiograph so that the scapular longitudinal axis can be identified.

Conclusion

The lateral extension of the acromion from the glenohumeral joint is the critical variable of both the AI and CSA. This study established a simple and reproducible method to directly measure this morphologic feature of the scapula—the lateral offset of the acromion—and provided normative data on a cadaveric sample. This measurement was not significantly associated with sex, side, or age, which appropriately limits bias in a potential future clinical application of the lateral offset including evaluations for RCTs and acromioplasty.

Disclaimer

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References

1. Ames JB, Horan MP, Van der Meijden OA, Leake MJ, Millett PJ. Association between acromial index and outcomes following arthroscopic repair of full-thickness rotator cuff tears. J Bone Joint Surg Am 2012;94:1862-9. http://dx.doi.org/10.2106/JBJS.K.01500
2. Balke M, Schmidt C, Dedy N, Banerjee M, Bouillon B, Liem D. Correlation of acromial morphology with impingement syndrome and rotator cuff tears. Acta Orthop 2013;84:178-83. http://dx.doi.org/10.3109/17453674.2013.773413
3. Bass WM. Human osteology: a laboratory and field manual. Springfield, Mo: Missouri Archaeological Society; 2005. p. 365. ISBN-13: 978-0943414966.
4. Bigliani LU, Ticker JB, Flatow EL, Soslowsky LJ, Mow VC. Relationship of acromial architecture and diseases of the rotator cuff. Orthopade 1991;20:302-9.
5. Churchill RS, Brems JJ, Kotschi H. Glenoid size, inclination, and version: an anatomic study. J Shoulder Elbow Surg 2001;10:327-32.
6. Dietrich TJ, Moor BK, Puskas GJ, Pfirrmann CWA, Hodler J, Peterson CK. Is the lateral extension of the acromion related to the outcome of shoulder injections? Eur Radiol 2015;25:267-73. http://dx.doi.org/10.1007/s00330-014-3403-7
7. Getz JD, Recht MP, Piraino DW, Schils JP, Latimer BM, Jellema LM, et al. Acromial morphology: relation to sex, age, symmetry, and subacromial enthesophytes. Radiology 1996;199:737-42.
8. Habermeyer P, Magosch P, Luz V, Lichtenberg S. Three-dimensional glenoid deformity in patients with osteoarthritis: a radiographic analysis. J Bone Joint Surg Am 2006;88:1301-7. http://dx.doi.org/10.2106/JBJS.E.00622
9. Hamid N, Omid R, Yamaguchi K, Steger-May K, Stobbs G, Keener JD. Relationship of radiographic acromial characteristics and rotator cuff disease: a prospective investigation of clinical, radiographic, and sonographic findings. J Shoulder Elbow Surg 2012;21:1289-98. http://dx.doi.org/10.1016/j.jse.2011.09.028
10. Heuberer PR, Plachel F, Willinger L, Moroder P, Laky B, Pauzenberger L, et al. Critical shoulder angle combined with age predict five shoulder pathologies: a retrospective analysis of 1000 cases. BMC Musculoskelet Disord 2017;18:259. http://dx.doi.org/10.1186/s12891-017-1559-4
11. Jacobson A, Gilot GJ, Hamilton MA, Greene A, Flurin P-H, Wright TW, et al. Glenohumeral anatomic study: a comparison of male and female shoulders with similar average age and BMI. Bull Hosp Jt Dis (2013) 2015;73:S68-78.
12. Katthagen JC, Marchetti DC, Tahal DS, Turnbull TL, Millett PJ. The effects of arthroscopic lateral acromioplasty on the critical shoulder angle and the anterolateral deltoid origin: an anatomic cadaveric study. Arthroscopy 2016;32:569-75. http://dx.doi.org/10.1016/j.arthro.2015.12.019
13. King C. Osteometric assessment of 20th century skeletons from Thailand and Hong Kong. Irvine, CA: Universal-Publishers; 1997.
14. Kircher J, Morhard M, Gavriilidis I, Magosch P, Lichtenberg S, Habermeyer P. Is there an association between a low acromion index and osteoarthritis of the shoulder? Int Orthop 2010;34:1005-10. http://dx.doi.org/10.1007/s00264-009-0898-7
15. Matsumura N, Oki S, Ogawa K, Iwamoto T, Ochi K, Sato K, et al. Three-dimensional anthropometric analysis of the glenohumeral joint in a normal Japanese population. J Shoulder Elbow Surg 2016;25:493-501. http://dx.doi.org/10.1016/j.jse.2015.08.003
16. Milano G. Editorial commentary: is lateral acromioplasty effective and safe? Arthroscopy 2016;32:576-7. http://dx.doi.org/10.1016/j.arthro.2016.01.008
17. Moor BK, Bouaicha S, Rothenfluh DA, Sukthankar A, Gerber C. Is there an association between the individual anatomy of the scapula and the development of rotator cuff tears or osteoarthritis of the glenohumeral joint? A radiological study of the critical shoulder angle. Bone Joint J 2013;95-B:935-41. http://dx.doi.org/10.1302/0301-620X.95B7.31028
18. Moor BK, Wieser K, Slankamenac K, Gerber C, Bouaicha S. Relationship of individual scapular anatomy and degenerative rotator cuff tears. J Shoulder Elbow Surg 2014;23:536-41. http://dx.doi.org/10.1016/j.jse.2013.11.008
19. Natsis K, Tsikaras P, Totlis T, Gigis I, Skandalakis P, Appell HJ, et al. Correlation between the four types of acromion and the existence of enthesophytes: a study on 423 dried scapulas and review of the literature. Clin Anat 2007;20:267-72. http://dx.doi.org/10.1002/ca.20320
20. Nicholson GP, Goodman DA, Flatow EL, Bigliani LU. The acromion: morphologic condition and age-related changes. A study of 420 scapulas. J Shoulder Elbow Surg 1996;5:1-11.
21. Nyffeler RW, Meyer DC. Acromion and glenoid shape: why are they important predictive factors for the future of our shoulders? EFORT Open Rev 2017;2:141-50. http://dx.doi.org/10.1302/2058-5241.2.160076
22. 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. http://dx.doi.org/10.2106/JBJS.D.03042
23. Olivier G. Practical anthropology. Springfield, IL: Charles C. Thomas; 1969.

24. Pandey V, Vijayan D, Tapashetti S, Agarwal L, Kamath A, Acharya K, et al. Does scapular morphology affect the integrity of the rotator cuff? J Shoulder Elbow Surg 2016;25:413-21. http://dx.doi.org/10.1016/j.jse.2015.09.016
25. Spiegl UJ, Horan MP, Smith SW, Ho CP, Millett PJ. The critical shoulder angle is associated with rotator cuff tears and shoulder osteoarthritis and is better assessed with radiographs over MRI. Knee Surg Sports Traumatol Arthrosc 2016;24:2244-51. http://dx.doi.org/10.1007/s00167-015-3587-7
26. Torrens C, López JM, Puente I, Cáceres E. The influence of the acromial coverage index in rotator cuff tears. J Shoulder Elbow Surg 2007;16:347-51. http://dx.doi.org/10.1016/j.jse.2006.07.006
27. Von Schroeder HP, Kuiper SD, Botte MJ. Osseous anatomy of the scapula. Clin Orthop Relat Res 2001;383:131-9.
28. Zumstein MA, Jost B, Hempel J, Hodler J, Gerber C. The clinical and structural long-term results of open repair of massive tears of the rotator cuff. J Bone Joint Surg Am 2008;90:2423-31. http://dx.doi.org/10.2106/JBJS.G.00677