Relationship of individual scapular anatomy and degenerative rotator cuff tears

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\textbf{Background:} The etiology of rotator cuff disease is age related, as documented by prevalence data. Despite conflicting results, growing evidence suggests that distinct scapular morphologies may accelerate the underlying degenerative process. The purpose of the present study was to evaluate the predictive power of 5 commonly used radiologic parameters of scapular morphology to discriminate between patients with intact rotator cuff tendons and those with torn rotator cuff tendons.

\textbf{Methods:} A pre hoc power analysis was performed to determine the sample size. Two independent readers measured the acromion index, lateral acromion angle, and critical shoulder angle on standardized antero-posterior radiographs. In addition, the acromial morphology according to Bigliani and the acromial slope were determined on true outlet views. Measurements were performed in 51 consecutive patients with documented degenerative rotator cuff tears and in an age- and sex-matched control group of 51 patients with intact rotator cuff tendons. Receiver operating characteristic analyses were performed to determine cutoff values and to assess the sensitivity and specificity of each parameter.

\textbf{Results:} Patients with degenerative rotator cuff tears demonstrated significantly higher acromion indices, smaller lateral acromion angles, and larger critical shoulder angles than patients with intact rotator cuffs. However, no difference was found between the acromial morphology according to Bigliani and the acromial slope. With an area under the receiver operating characteristic curve of 0.855 and an odds ratio of 10.8, the critical shoulder angle represented the strongest predictor for the presence of a rotator cuff tear.

\textbf{Conclusion:} The acromion index, lateral acromion angle, and critical shoulder angle accurately predict the presence of degenerative rotator cuff tears.

\textbf{Level of evidence:} Level IV, Case-Control Design, Diagnostic Study.

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\textbf{Keywords:} Rotator cuff disease; scapular anatomy; acromial morphology; critical shoulder angle; acromion index; lateral acromion angle; acromial slope
Distinct anatomic variants of the scapula have been found to be associated with degenerative rotator cuff tears (RCTs). Neer\(^{14,15}\) described a bone spur at the anteroinferior acromion and attributed 95% of all RCTs to a mechanical conflict between the rotator cuff insertion and coracoacromial arch. Accordingly, Bigliani et al\(^{6}\) classified the shape of the acromion into 3 patterns that were more or less prone to rotator cuff disease. An increased prevalence of RCTs was then found in relation to a flatter slope of the acromion and a decreased lateral acromion angle.\(^{1,3}\)

Other authors focused on the inclination of the glenoid and hypothesized that an upward-facing glenoid would less efficiently resist the cranial pull of the deltoid muscle and therefore favor secondary impingement.\(^8,22\) A similar concept was introduced with the acromion index.\(^{18}\) Nyffeler et al postulated that a large lateral extension of the acromion results in a more vertical orientation of the force vector of the middle deltoid, necessitating higher loads of the rotator cuff to maintain the humeral head centered on the glenoid. More recently, the critical shoulder angle was introduced, and a strong association between large angles and degenerative RCTs was demonstrated.\(^{12}\)

The aims of the present study were to assess the inter-rater reliability of different radiologic parameters of scapular morphology and to determine their individual predictive power for the presence of degenerative rotator cuff disease. Because the critical shoulder angle represents the combination of glenoid inclination and acromial coverage, we hypothesized that this parameter is the most valuable measure to discriminate between patients with intact rotator cuff tendons and those with torn rotator cuff tendons.

**Materials and methods**

**Patient selection**

On the basis of the demographics of the RCT group, an age- and sex-matched control group was formed. These subjects were retrieved from a data registry of a consecutive series of patients treated for isolated osteoarthritis of the acromioclavicular joint or idiopathic frozen shoulder between January 2011 and December 2011. In all of these patients, the integrity of the rotator cuff was confirmed by gadolinium-enhanced magnetic resonance arthrography. Regarding the RCT group, only patients with available true anteroposterior and standardized lateral (outlet) views were included, whereas individuals with previous surgery were excluded. The average age of these 17 women and 34 men was 58.1 years (SD, 8.4; range, 41–76 years).

**Radiologic assessment**

Two independent readers (K.W. and S.B.), who were both blinded to the patients’ diagnosis, assessed all radiographs. Standardized, true anteroposterior radiographs with the arm in the neutral position were used to assess the acromion index (AI) as described by Nyffeler et al\(^{18}\) (Fig. 1, A), the lateral acromion angle (LAA) according to Banas et al\(^{1}\) (Fig. 1, B), and the recently introduced critical shoulder angle (CSA; Fig. 1, C).\(^{12}\) On standardized outlet views, the acromion morphology was classified according to Bigliani and Morrison into type I (flat), type II (curved), and type III (hooked).\(^{6}\) In addition, the acromial slope (AS), as described by Aoki et al,\(^{1}\) was determined (Fig. 1, D). All radiologic data were stored on a picture archiving and communication system (Cerner Corp, Kansas City, MO, USA) workstation, and the provider’s image analysis software was used for review and measurement of images.

**Statistics**

In the first step, we tested data for normality with the Kolmogorov-Smirnov test and performed quantile-quantile plots of dependent variables. Descriptive analysis was used to report medians and the interquartile range of the continuous variables as well as means and standard deviations, if appropriate. We compared groups by the univariate linear analysis as well as by logistic regression analysis. An adjustment for possible confounders was not performed because an age- and sex-matched control group was already formed a priori. Unadjusted differences and odds ratios between groups were presented with 95% confidence intervals (CIs). To assess the inter-rater reliability of the ratings, the intraclass correlation coefficients (ICC) of the different parameters were calculated. We considered ICs of 0.7 or higher to be sufficient for the reliability. The Spearman ρ correlation coefficient was calculated to determine the correlation among the different parameters. Receiver operating characteristic (ROC) analyses were performed to determine cutoff values and to assess the sensitivity and specificity of each individual parameter. Statistical significance was defined as a P value <.05. Statistical analysis was performed with the SPSS statistical software (SPSS Inc, Chicago, IL, USA) and STATA (version 11, Stata Corp, College Station, TX, USA).

**Results**

The data for all parameters (median and interquartile range) are summarized in Table 1.

ICCs were good to excellent for all parameters studied, with an ICC\(_{AI}\) and ICC\(_{CSA}\) of 0.98, ICC\(_{LAA}\) of 0.94, ICC\(_{Bigliani}\) of 0.79, and ICC\(_{AS}\) of 0.95.
The mean AI of the control and RCT groups was 0.66 (SD, 0.06; range, 0.53-0.79) and 0.75 (SD, 0.06; range, 0.63-0.87), respectively (P < .001). The mean LAA was 86° (SD, 7.7; range, 72°-103°) in the control group and 80° (SD, 6.3; range, 66°-93°) in the RCT group. Finally, we found a mean CSA of 33° (SD, 3.4; range, 26°-40°) in the control group and 38° (SD, 3.2; range, 31°-46°) in the RCT group (P < .001). A strong correlation was found between the AI and CSA (r = 0.895; P < .001), whereas there was a moderate negative correlation between the LAA and CSA (r = −0.551; P < .001).

The distribution of acromion morphologies classified according to Bigliani and Morrison was not significantly different between the two groups. Furthermore, there was no significant correlation between the different groups and the lateral slope according to Aoki.

ROC curve analysis determined cutoff values for discriminating the control and RCT groups for the AI (>0.68), LAA (≤83°), and CSA (≥35°). The area under the ROC curve was highest for the CSA (0.855 vs 0.826 and 0.280 for the AI and LAA, respectively), indicating that the CSA is the most valuable measure for discriminating between the RCT and control groups (Figs. 2 and 3). This was also reflected in the calculated sensitivity and specificity, which were revealed to be highest for the CSA (0.80 and 0.75) compared with 0.78 and 0.71 for the AI and 0.65 and 0.69 for the LAA, respectively. In agreement with these findings, a shoulder with a CSA ≥35° had an odds ratio of 10.8 (95% CI, 4.3-27.3; P < .001) to be part of the RCT group, whereas the odds ratio was 10.1 (95% CI, 3.9-26.3; P < .001) and 0.4 (95% CI, 0.2-0.9; P = .031) for the AI and LAA with their respective cutoff values.

**Discussion**

The influence of individual scapular morphology on the pathogenesis of RCTs remains controversial. Although some authors place great importance on anatomic variants,
particularly those of the acromion, other authors have suggested that these changes are the result of rather than the cause of degenerative rotator cuff disease.\textsuperscript{17,19,21,24} Since the introduction of the AI by Nyffeler in 2006, his concept was strengthened by the contribution of several authors.\textsuperscript{2,9,11,13,18,23,25} In 2007, Torrens et al confirmed the relationship between RCTs and a large coverage of the humeral head. Although those authors used a slightly modified technique to quantify the lateral extension of the acromion, their results were comparable to those of Nyffeler et al. A high AI was then found to be a risk factor for a re-tear after rotator cuff repair as well as an associated factor for progression of the tear size.\textsuperscript{9,25}

Contrary to these findings, Hamid et al\textsuperscript{7} found no association between a large lateral extension of the acromion and presence of rotator cuff disease, thereby challenging the concept of the acromial coverage. Finally, Miyazaki et al compared the AI in different races and suggested that it might be a predictive factor for RCTs in the Brazilian but not in the Japanese population.

The present study supports the findings of Nyffeler et al. A significant difference was found in the mean AI of the control group and RCT group, with values close to the findings of Nyffeler et al. Furthermore, we could confirm its excellent inter-rater reliability.

In addition, our study confirmed the results of Banas et al. Although the LAA was initially described on magnetic resonance images, several authors demonstrated its applicability on conventional radiographs.\textsuperscript{2,3,22} We found an excellent intraclass correlation of the LAA on conventional radiographs and corroborated its relationship with degenerative RCTs.

Finally, we confirmed the recently reported association between large CSAs and degenerative rotator cuff disease. As we hypothesized, it was the most powerful predictor of the presence of an RCT with an area under the ROC curve of 0.855 and an odds ratio of 10.8.

The CSA reflects not only lateral extension of the acromion but also glenoid inclination, integrating both potential risk factors into one radiologic parameter. The AI quantifies the acromial coverage, whereas the LAA reflects the glenoid inclination. The present study demonstrated an excellent correlation between the AI and CSA, whereas the Spearman $\rho$
correlation between the LAA and CSA was only moderate. This finding could therefore imply that the lateral extension of the acromion represents the more relevant risk factor for rotator cuff disease than an upward tilt of the glenoid fossa.

In contrast to other authors, we could not demonstrate a significant correlation between RCTs and hooked acromions or with RCTs and a flattened slope of the acromion on outlet views. Although the AS would be expected to be smaller in individuals suffering from rotator cuff disease, there was a surprising trend for larger angles in the RCT group. Regarding the Bigliani criteria, this discrepancy could be partially explained by its worse interobserver reliability. However, concerning the AS, the reported disagreement remains unclear, but it concurs with a previous article.

There are limitations. As already suggested by Bhatia et al., the morphology of the glenoid and also of the humeral head and acromion can be affected during the natural progression of rotator cuff disease. This is particularly true during the development of cuff tear arthropathy, in which progressive medialization of the superiorly migrated humeral head may have a serious impact on all of the assessed parameters. However, in the present study, only shoulders with repairable RCTs and an acromiohumeral distance >7 mm were included. Although discrete morphologic changes were possible, substantial modification of the bone anatomy by the presence of long-standing massive RCTs can be excluded. Nevertheless, the present study could not determine whether the demonstrated associations of different scapular morphologies with the presence of degenerative rotator cuff disease have a cause-effect relationship. In addition, our study group may have been subjected to selection bias, as only symptomatic shoulders were included. It is therefore possible that our findings would be different in a population of individuals with only asymptomatic RCTs.

Conclusion

This study confirms the previously reported association of the AI, LAA, and CSA with the occurrence of degenerative RCTs. Of all the assessed parameters, the CSA allowed the most accurate prediction of a patient’s individual risk of experiencing a RCT.

In contrast to these findings, neither the relationship between rotator cuff disease and different types of the acromion morphology according to Bigliani and Morrison nor the association of RCTs with flattened acromial slopes could be confirmed.

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