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Original Article

Association between the Critical Shoulder Angle and Rotator Cuff Tears in Japan

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Distinct anatomic variants of the scapula such as the critical shoulder angle (CSA) were found to be associated with rotator cuff tears (RCTs), but it is unclear whether the CSA is a risk factor in Japanese. Here we sought to determine whether the CSA is associated with RCTs in a Japanese population, and whether the CSA is a more useful parameter than the conventionally used parameters. Our RCT group and non-RCT group each consisted of 54 consecutive cases. We compared the groups' values of CSA, the acromion index (AI), and the lateral acromion angle (LAA) obtained by X-ray imaging. Receiver operating characteristic (ROC) analyses were performed to determine cutoff values and the area under the curve (AUC), and to assess the odds ratio. The means of the CSA and the AI in the RCT group were significantly larger (36.3° vs. 33.7°, 0.74 vs 0.68), but the LAA did not show a significant between-group difference. The AUCs for the CSA and AI were 0.678 and 0.658, the cut-off values were 35.0° and 0.72, and the odds ratios were 3.1 and 2.5, respectively. In conclusion, the CSA was a strong risk factor compared to the AI and LAA for rotator cuff tears.

Key words: rotator cuff tear, risk factor, critical shoulder angle, acromion index, lateral acromion angle

Degenerative rotator cuff tears (RCTs) are among the most frequent pathologies of the shoulder. Distinct anatomic variants of the scapula have been found to be associated with RCTs. Several parameters such as the lateral acromion angle [1] and the acromion index [2] are related to RCTs. It was also reported that the critical shoulder angle (CSA) and RCTs are closely related [3,4].

The finding that a higher CSA affects RCTs was supported by biomechanical studies. A recent study suggested that compared to a CSA of 33°, in cases with a CSA of 38° supraspinatus force had to be increased, and a higher CSA can induce supraspinatus overload [5]. In another study, higher CSA was the stronger risk factor for upward displacement of the humeral head compared to a higher AI or LAA [6]. It was thus speculated that RCTs are caused by overloading of the supraspinatus muscle and subacromial impingement [7].

However, several studies reported that the morphology of the scapula differs among races and countries, and the relationship between the morphology of the scapula and RCTs also varies among countries [8,9]. Recent research demonstrated that East Asians showed significantly higher CSA and AI values compared to those of North Americans [8]. Another observational study reported that when patients with RCTs were compared with individuals without RCTs, a significant difference in the AI was found in a Brazilian population but not in a Japanese population [9]. Parameters such as

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the AI and LAA are strong risk factors for RCTs [1-4] and prior research has indicated that findings regarding RCTs in individuals from countries other than Japan cannot be simply applied to Japanese RCTs. To our knowledge, there are only two studies of the CSA in a Japanese population [10, 11], and the number of similar reports from other countries is limited. The two reports from Japan showed that the CSA is an independent risk factor for RCTs, but the reports did not discuss a comparison with other parameters such as the AI and LAA. If the relationship between the CSA and RCTs in Japanese individuals can be clarified, it could be clinically meaningful to consider RCTs by evaluating radiophotographs even in primary institutions without magnetic resonance imaging (MRI).

It is not clear whether the CSA is a risk factor for RCTs in Japanese. Similarly, it is not clear whether the CSA would be a more powerful parameter than the conventionally used parameters such as the AI and LAA in Japanese. In this study, we attempted to determine whether the CSA is associated with Japanese RCTs, and we investigated whether the CSA is a more powerful parameter for predicting RCTs than the AI and LAA.

Subjects and Methods

Study subjects. Patients with primary complaints of shoulder pain were recruited from orthopedic clinics in rural areas of Japan, including cases that were included in the previous report by Watanabe *et al.* [10]. We divided the patients into 2 groups; those with RCTs (the RCT group) and those with an intact rotator cuff (non-RCT) group. To calculate the sample size, we performed a pre-hoc power analysis. This analysis determined that for a significance level of 5%, power of 95%, and effect size of 0.7, the appropriate sample size was calculated to be 54 cases in each group. Our exclusion criteria for each group were as follows: (1) a history of previous surgery, and (2) age < 40 years old.

The RCT group consisted of 54 consecutive patients who underwent arthroscopic rotator cuff surgery between January 2014 and December 2016. We included degenerative RCTs but excluded traumatic RCTs because the CSA was not related to traumatic RCTs [12]. Surgery was performed by the same orthopedic surgeon (T.H.) in all cases, and it was confirmed that there was a supraspinatus tendon tear in each case. The RCTs were diagnosed based on MRI findings and were corroborated at surgery. The MRI was performed with a 0.3T unit (Hitachi, Chiba, Japan), and the quality of the rotator cuff tendons was assessed on oblique coronal, oblique sagittal, and transverse T2-weighted images. The average age of the RCT group was 63.4 years (standard deviation (SD), 9.4; range, 42-78 years; 25 women and 29 men).

The non-RCT group consisted of 54 consecutive, age- and sex-matched patients in whom it was confirmed by MRI that the rotator cuff was intact among outpatients with shoulder pain visiting an orthopedic clinic during the period from March 2016 to December 2016. The same orthopedic surgeon (H.M.) interpreted and diagnosed the intact rotator cuffs. The patients' average age was 61.1 years (SD, 12.5; range, 42-89 years; 26 women and 28 men).

Measurement of parameters. Two observers (A.W. and Q.O.) independently assessed all radiophotographs, as in our previous study [10]. The radiophotography was performed by a Shimadzu RADspeed Pro (Shimadzu, Kyoto, Japan), and each parameter was measured by an FCR CAPSULA-2 radiography system (Fujifilm, Tokyo, Japan). Both observers were masked to the patients' MRI findings. In true antero- posterior radiophotographs, the CSA [3, 4] was measured. We confirmed very high reproducibility in our previous report [10]. Here, the intra- and inter-observer reliability (both ICC (1, 1) and ICC (2, 1)) were 0.99, and both 95% confidence intervals (95%CIs) were 0.97-1.00. Similarly, in true antero- posterior radiophotographs, the AI [2] and LAA [1] were measured (Fig. 1). Each parameter was assessed twice by the same observer, and the average values were calculated. Another observer performed the same measurement under the condition in which all parameters including the first observer were masked.

Statistical analyses. Each parameter was compared between the RCT group and non-RCT group by means of the two-tailed unpaired *t*-test, and Pearson correlation coefficients were calculated to analyze the relationships among the AI, LAA and CSA. Receiver operating characteristic (ROC) analyses were performed to determine cutoff values and to assess the sensitivity, specificity and odds ratio (OR) with 95%CI of each parameter. 'Cutoff value' was defined as the sum of the uppermost sensitivity and specificity values. The ratio of CSA ≥ 35.0° patients [3, 4, 13] in the RCT group was also calculated. All significance levels were set at

0.05, and were performed using R (ver. 3.4.1).

Ethics. This study was approved by the institutional ethics committee of Konan Women's University. Since the data for this study were obtained retrospectively and analyzed anonymously and the study does not report on a clinical trial, the requirement for written informed consent for participation in the study was waived. The study was conducted in compliance with the Declaration of Helsinki.

Results

The results of each parameter are summarized in Table 1. The means of AI and CSA in the RCT group were significantly larger than those in the non-RCT group (AI: 0.74 vs. 0.68, $p=0.002$; CSA: 36.3° vs. 33.7°, $p<0.001$), but there was no significant between-group difference in the LAA (81.2° vs. 82.6°, respectively; $p=0.17$).

A moderate correlation was found between the AI and the CSA ($r=0.61$, $p<0.001$), whereas there was a low negative correlation between the LAA and the CSA ($r=-0.38$, $p<0.001$), but not between the AI and the LAA ($r=-0.16$, $p=0.1$).

We analyzed only the AI and CSA by ROC analysis, because the LAA did not show a significant between-group difference. The cutoff values for discriminating the RCT and non-RCT groups were AI > 0.72 and CSA ≥ 35.0°. The area under the curve (AUC) was 0.658 for the AI and 0.678 for the CSA (Fig. 2). The sensitivity and specificity were AI (0.55 and 0.66) and CSA (0.63 and 0.65). The OR was 2.5 (95%CI 1.07-5.88) for AI and 3.1 (95%CI 1.35-7.41) for the CSA (Table 2). In addition, 63% of the patients in the RCT group had a CSA ≥ 35.0°.

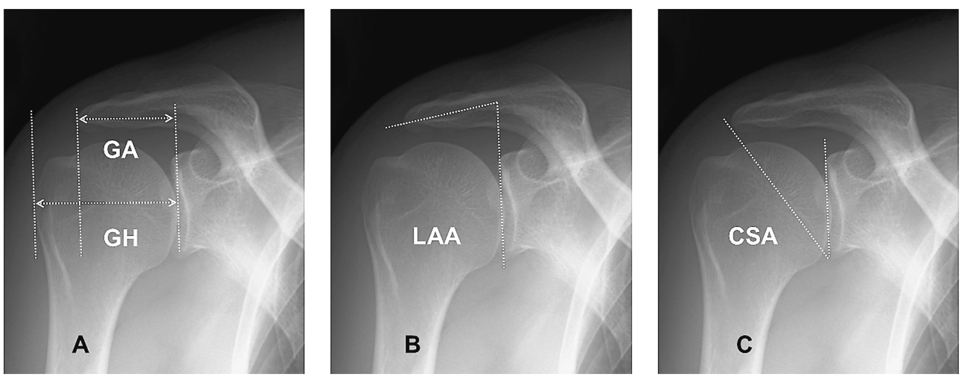

Fig. 1 A, The acromion index (AI): The ratio between the distance from the glenoid plane to the lateral edge of the acromion (GA) and the distance from the glenoid plane to the lateral aspect of the humeral head (GH). B, The lateral acromion angle (LAA): The angle between a line drawn parallel to the sclerotic line of the acromion undersurface and a second line connecting the superior to the inferior border of the glenoid fossa. C, The critical shoulder angle (CSA): The angle between a line connecting the superior and inferior border of the glenoid fossa and another line connecting the inferior border of the glenoid with the most infero-lateral point of the acromion.

Table 1 Summary of each parameter

	RCTs (n = 54)	Non-RCT (n = 54)	Difference (95%CI)	Cohen's d	*P* value
AI	0.74 ± 0.10 (0.67–0.79)	0.68 ± 0.11 (0.60–0.74)	0.06 (0.02 to 0.10)	0.60	**0.002**
LAA	81.2 ± 5.7 (78.0–85.9)	82.6 ± 5.0 (79.4–86.0)	−1.4 (−3.5 to 0.6)	0.27	0.17
CSA	36.3 ± 3.1 (34.1–38.6)	33.7 ± 3.9 (31.3–36.4)	2.6 (1.2 to 3.9)	0.73	**< 0.001**

[footnote] All results are mean±SD and range.
RCTs, rotator cuff tears; AI, acromion index; LAA, lateral acromion angle; CSA, critical shoulder angle.

Table 2 Summary of receiver operating characteristic findings

	AUC	Cut off point	Sensitivity	Specificity	Odds ratio (95%CI)
AI	0.658	0.72	0.55	0.66	2.5 (1.07 to 5.88)
CSA	0.678	35.0	0.63	0.65	3.1 (1.35 to 7.41)

AUC, area under the curves.

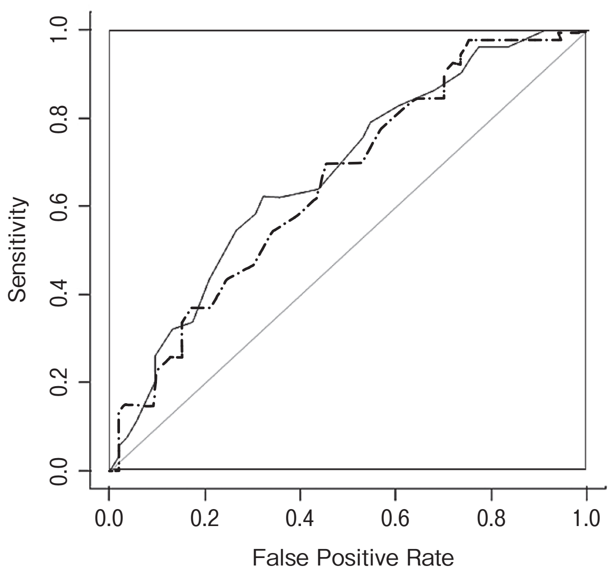

Fig. 2 Receiver operating characteristic (ROC) curves. *Dotted line*: The acromion index (AI). *Solid line*: The critical shoulder angle (CSA).

Discussion

Our analyses revealed 2 important clinical observations. (1) The CSA is also a risk factor for RCT in Japanese. (2) The CSA showed the same level of risk for RCTs as that of the AI, and was a greater risk factor than the LAA.

Regarding our first finding that the CSA was a risk factor for RCTs in Japanese, our results demonstrated that the CSA in the RCT group was higher than that in the non-RCT group (36.3° vs. 33.7°). This result supports the recent studies of the CSA in Japanese populations [10,11]. These findings in Japanese also support recent evidence in countries other than Japan that a high CSA is associated with RCTs [3,4,7,13-16], *i.e.*, all of the above reports showed that the CSA in patients with RCTs was higher than that in non-RCT patients. Since it was shown that the relationship between X-ray imaging parameters and RCTs differs from country to country [9], we believe it is meaningful to report our unique findings in Japanese patients. An epidemiological review indicated that the frequency of RCTs differs among reports [17]. Although it should be verified whether the size of the CSA of a population affects the frequency of RCTs (*e.g.*, East Asians who were originally reported to have large CSAs [8] have a high RCT frequency, whereas North Americans have smaller CSAs and a lower frequency of RCTs), there is a trend among different populations (including Japanese) for a large CSA to be commonly associated with RCTs. If a CSA is large in a radiophotograph, another physical examination such as MRI may contribute to the diagnosis. Due to its low statistical accuracy, the CSA may not be suitable for a definitive diagnosis.

Our second clinical finding was that the CSA showed the same level of risk for RCTs as that of the AI, and was a greater risk factor than the LAA. The CSA showed the highest effect size, and the effect sizes of the CSA and AI were similar in the RCTs measured by our ROC analysis. In addition, the correlation coefficient between the CSA and AI was moderate, whereas the correlation was low between the CSA and LAA. The CSA and AI were related to RCTs, whereas the LAA was not. The CSA and AI show lateral extension of the acromion [2,3], and the LAA showed the inclination of the glenoid [1]; therefore, a lateral extension of the acromion may be a stronger risk factor for RCTs compared to the inclination of the glenoid. These findings are supported by the recent study by Moor *et al.* [4], and to our knowledge, these are the first such findings for a Japanese population, and this is not discussed in recent Japanese studies [10,11]. It is clinically reasonable to measure the CSA, which is an index of the lateral extension of the acromion.

Several studies demonstrated the superiority of the CSA over the AI or LAA. A recent study showed that a higher CSA was more closely related to retear after rotator cuff repair than the AI or LAA, and it was correlated with worse postoperative function [18]. In Japan, it is also necessary to examine not only the onset of RCTs but also the prognosis of the functional recovery of RCTs by using the CSA.

However, the odds ratio at 35.0° and the proportion of patients with a CSA ≥ 35.0° in the present RCT group was small compared to a recent study (OR, 3.1 vs. 10.8 [4]; proportion, 63% vs. approx. 80% [3, 4, 13]). There are several reasons why discrepancies in these values may occur. In the present study, the patients recruitment site was a rural area where there are many elderly people, and the average age of the RCT group in our study was older than those in recent studies [3, 4, 13]. It is also possible that the mechanism differs between elderly patients' RCTs and younger patients' RCTs [10, 19]. As mentioned above, the morphology of the scapula may be different between Japan and other countries [8]. These reasons could partially explain the discrepant findings; further study is required.

Some study limitations should also be considered. Bias might have occurred because this was a retrospective case-control study. However, the surgeon who diagnosed cuff tears and the observers who measured each radiophotograph parameter were different examiners, and the value of each parameter was masked.

In conclusion, the present findings in Japanese support recent evidence that the CSA is a predictor of RCTs and was an equal or better parameter compared to the conventional AI and LAA. The odds ratio of the CSA for Japanese RCTs was small, and other risk factors such as age, occupation, and regional characteristics require further study.

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