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1 Relationship between Rotator Cuff Tears and Acromial Coverage of the Humeral Head on the Axial Plane

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Running title: 3DCT evaluation of acromial coverage
Abstract

Purpose Many authors have described the relationship between the radiographic morphology of the acromion and rotator cuff disease, but few studies have evaluated the relationship on the axial plane. We hypothesized that high acromial coverage of the humeral head or excessive lateral or anterior extension of the acromion would be an independent predictor of rotator cuff disease. This study aimed to clarify the relationship between rotator cuff tears and acromial coverage of the humeral head on the axial plane.

Methods Fifty shoulders were evaluated for acromial coverage of the humeral head on axial three-dimensional computed tomography images. The shoulders were divided into two groups: group F (n=25; mean age, 60.48 years; range, 49–73 years) with full-thickness rotator cuff tears, and group C (n=25; mean age, 58.96 years; range, 40–79 years) with intact cuffs as a control group. The acromial coverage of the humeral head was analyzed to determine the difference between the groups. Results There was no significant difference between the groups in the acromial coverage of the humeral head. Conclusions High acromial coverage of the humeral head on the axial plane did not appear to be associated with full-thickness tearing of the rotator cuff.

Key words: Rotator cuff tear, Acromial morphology, Acromial coverage, Radiography, Three-dimensional computed tomography
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Footnotes

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**Introduction**

Controversy remains about the role of the acromion in rotator cuff tears. The question of which came first, the rotator cuff tears or the acromial morphologic changes, also remains. Neer\(^1\) described that 95% of all tears are caused by impingement, and consequently that tears start at the bursal side secondary to wear and tear. Since these findings, many authors have focused on the relationship between the radiographic appearance of the acromion and rotator cuff tears. Specifically, the acromiohumeral distance (AHD), lateral acromial angle\(^2\), acromial coverage index\(^3\), and acromion index\(^4\) were evaluated on true anteroposterior (AP) radiographs (oblique coronal plane), and the acromial slope\(^5\), acromial shape\(^6,7\), acromial spur formation\(^8\), and acromial angle\(^6,7\) were evaluated on scapular Y radiographs (oblique sagittal plane). Because axial radiographic images require the arm to be in the abducted position and the structures to be viewed are superimposed and invisible, there are few reports on the acromial coverage of the humeral head on the axial plane. We suppose that new findings may be obtained about the relationship between the acromial morphology and rotator cuff tears by evaluating the axial plane.

We hypothesized that high acromial coverage of the humeral head or excessive lateral or anterior extension of the acromion would be an independent predictor of rotator cuff disease. The purpose of this study was to clarify the relationship between rotator cuff
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tears and acromial coverage of the humeral head on axial three-dimensional computed tomography (3DCT) images.

Materials and Methods

Fifty shoulders were evaluated for acromial coverage of the humeral head on axial 3DCT images. All included patients met the following criteria: shoulder injuries or disorders evaluated by 3DCT with a diagnosis of the absence or presence of rotator cuff tears confirmed by MRI at our institution.

We excluded patients with Grade 2–4B in the Hamada classification, fracture around the shoulder girdle, osteonecrosis, sequelae of infection, os acromiale, shoulder instability, and subacromial spurs measuring ≥2 mm. Measurement of the length of a spur was defined as the maximum distance from the point where the inclination of the anterior edge of the acromion abruptly increased to the tip of the spur in oblique coronal or sagittal 3DCT images, based on the method of Ogawa et al. The shoulders were divided into two groups: group F (n=25; mean age, 60.48 years; range, 49–73 years) diagnosed with full-thickness rotator cuff tears on MRI before surgery, and group C (n=25; mean age, 58.96 years; range, 40–79 years) with intact cuffs documented by MRI, such as frozen shoulder, clavicle fracture, and so on, as a control group. The total population for the study comprised 20 women and 30 men, with a mean age of 59.72 years. The two groups were matched by age, body mass index, and other acromial
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81 morphologic factors, including AHD, acromial slope, and acromial shape described by
82 Bigliani et al.\(^6\), such that these factors on the sagittal or coronal plane had no influence
83 on the acromial coverage on the axial plane. AHD was evaluated on true AP radiographs
84 of the shoulders. Acromial slope was evaluated on oblique sagittal 3DCT images, in
85 accordance with the method of Aoki et al.\(^5\). Acromial shape\(^6,7\) was classified into three
86 groups on scapular Y radiographs of the shoulders.
87 The 3DCT scans (Aquilion TSX-101/HA; Toshiba Medical Systems Co., Tokyo,
88 Japan) and true AP radiographs were obtained with the arm in neutral rotation. The data
89 sets obtained by the 3DCT scans were transferred to a 3D workstation (Ziostation;
90 Ziosoft, Tokyo, Japan). Using the Ziostation, the axial plane was defined as the plane in
91 which the scapula was aligned so that the infraglenoid tubercle matched the
92 supraglenoid tubercle. The oblique sagittal plane was aligned by rotation of 90 degrees
93 downward from the axial plane. A transmission image photography method for the
94 humeral head was used to measure the acromial coverage of the humeral head. To avoid
95 overlap errors while measuring the acromial coverage of the humeral head on the axial
96 plane, the distal area from the surgical neck of the humerus was trimmed off.
97 The acromial coverage of the humeral head on the axial plane was quantified by
98 measuring the acromial coverage area index (ACAI). For the ACAI, a coracoacromial
99 (C-A) line was drawn connecting the most lateral tip of the coracoid and the
100 anterolateral corner of the acromion as the coracoacromial arch. The ACAI was
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calculated by dividing the area of the humeral head within the coracoacromial arch by
the whole area of the humerus on axial 3DCT images (Fig. 1a). The acromial anterior
extension index (AAEI) was defined as the value for “anterior” acromial coverage. The
AAEI was calculated by dividing the distance (HA) from the tangent line (P line) to the
most posterior aspect of the humerus that was perpendicular to the glenoid plane to the
most anterior aspect of the acromion by the distance (HH) from the tangent line (A line)
to the most anterior aspect of the humerus that was perpendicular to the glenoid plane to
the P line on the axial 3DCT images (Fig. 1b). The acromial index on the axial plane
(AIAI) was defined as the value for “lateral” acromial coverage. The AIAI was
calculated by dividing the distance (A) from the most lateral aspect of the acromion to
the glenoid plane by the distance (H) from the most lateral aspect of the humerus to the
glenoid plane (Fig. 1c).

Statistical analyses were performed using IBM SPSS, version 21 (IBM, Armonk, NY).
Hypothesis testing between the two groups was performed when the data were normally
distributed according to a Kolmogorov–Smirnov/Shapiro–Wilk normality test
(describing on the sample size). An unpaired t-test if the normality assumption was
satisfied or a Mann–Whitney U test if the normality assumption was not fulfilled was
carried out to compare the differences in age, AHI, ACAI, AAEI, and AIAI between
the two groups. The $\chi^2$ for independent testing ($m \times n$ contingency table) indicated the
significance of the incidence of each acromial shape in the two groups. Values of $p<0.05$
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were considered to indicate significant differences. The reproducibility of the ACAI, AAEI, and AIAX measurements was examined by intraclass correlation coefficients (ICCs) for both interobserver reliability (measurements made by two different observers) and intraobserver reliability (measurements repeated by the same observer at different time points) for repeated measurements and 95% confidence intervals. We considered ICCs of 0.7 or higher to be sufficient for the reliability.

This study was conducted at the Department of Orthopaedic Surgery, Fukuoka University Faculty of Medicine, Fukuoka, according to approved medical and ethical guidelines, and the study protocols were approved by the Fukuoka University Institutional Review Board (IRB Approval Number: 15-8-18).

Results

There were no significant differences in age, AHD, and acromial angle between the two groups \((p=0.580, \ p=0.461, \ \text{and} \ p=0.483, \ \text{respectively})\). There was no significance difference of the incidence of each acromial shape between the two groups \((p=0.836)\) (Table 1).

The measurements for ACAI, AAEI, and AIAX showed high agreement for both intraobserver reproducibility and interobserver reproducibility (Table 2). The mean ACAI values were 0.538±0.07 in group F and 0.524±0.07 in group C. The mean AAEI values were 0.31±0.08 in group F and 0.28±0.09 in group C. The mean AIAX values
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were 0.66±0.05 in group F and 0.68±0.08 in group C. There were no significant
differences in ACAI, AAEI, and AIAX between the two groups (p=0.473, p=0.346, and
p=0.278, respectively) (Table 3).

Discussion

The acromial morphology as a risk factor for rotator cuff tears remains controversial.
In 1972, Neer\textsuperscript{1} reported that subacromial impingement syndrome on the rotator cuff was
caused by alterations to the undersurface of the anterior one-third of the acromion. Aoki
et al.\textsuperscript{5} found that patients with impingement had a more acute acromial slope compared
with normal volunteers. Prato et al.\textsuperscript{11} supported these studies with findings that the
mean acromial slope in 78 shoulders with a rotator cuff tear was significantly smaller
than that in 165 shoulders with an intact cuff. Bigliani et al.\textsuperscript{6} studied acromial structures
in cadavers, and found a high correlation between spur formation with type II and III
acromial structures and concomitant rotator cuff tears. Hirano et al.\textsuperscript{12} reported that the
type III acromion was the most common structure in patients with a rotator cuff tear.
Torrens et al.\textsuperscript{3} described that patients with a cuff tear had a significantly higher acromial
coverage index than a control group. Nyffeler et al.\textsuperscript{4} introduced the acromion index, and
described that the acromion in patients with a full-thickness rotator cuff tear appeared to
have a more lateral extension than that in patients with an intact cuff. Their results
support the presence of a close relationship between rotator cuff tears and narrowing of
the supraspinatus outlet or high acromial coverage. 3–7, 11, 12
In these previous studies3–7, 11, 12, the acromial morphology was evaluated on oblique
coronal or sagittal planes. There are few reports on the acromial morphology on the
axial plane17. It is difficult to evaluate the relationship between the acromial coverage of
the humeral head and rotator cuff tears on the axial plane of plain radiographs, MR
images, and 2DCT images. Therefore, we used a transmission image photography
method for the humeral head to evaluate the relationship on axial 3DCT images.
Evaluations of the acromial coverage on the axial plane have two essential advantages.
First, we can simultaneously evaluate a lateral extension of the acromion as well as an
anterior extension. Second, the ACAI obtained on axial 3DCT images can represent the
comprehensive acromial coverage of the humeral head, including the coverage by the
coracoacromial ligament.
However, we need to take into account the effects of both age and secondary
degenerative changes when evaluating the acromial morphology. Ogawa et al.8 showed
a relationship between age and acromial spurs, using a combination of control patients,
surgically-treated patients, and cadaveric specimens. MacGillivray et al.13 reported that
age distribution from the second to eighth decades demonstrated a generally consistent
and gradual translation from a flat acromion in the younger decades to a more hooked
acromion in the older decades. Balke et al.15 concluded that there was a good correlation
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between acromial shape and acromial slope on standard radiographs from 50 patients
with full-thickness rotator cuff tears, 50 patients with subacromial impingement, and 50
controls without subacromial pathology. Hirano et al.\textsuperscript{12} described that the occurrence
rate of the type III shape in patients with rotator cuff tears was not significantly high
when age-matched patients with and without rotator cuff tears were compared, and
implied that the hook type might be an age-related degenerative change. Moses et al.\textsuperscript{16}
described that the acromial slope reported by Aoki et al.\textsuperscript{5} would be an indirect measure
of the presence of an acromial spur or hooked morphology in a 3D analysis of the
acromion. Aoki et al.\textsuperscript{5} and Prato et al.\textsuperscript{11} did not describe acromial spur formation.
However, we occasionally felt that an increasing length of spur was associated with a
decreasing angle of the acromial slope. Therefore, we compared the acromial coverage
with age-matched normal controls and standardized the secondary degenerative
morphologic conditions of the acromion resulting from rotator cuff tears, e.g., acromial
spur\textsuperscript{8}, acromial slope\textsuperscript{13}, and AHD, between the groups.
In addition, evaluations of the acromial coverage on the axial plane have the
disadvantage of being influenced by individual morphologic narrowing in the
subacromial space. This is because the narrowing results in attrition between the rotator
cuff and the coracoacromial arch during abduction or flexion of the arm. Therefore, we
found it necessary to standardize the morphologic features of the acromion, e.g.,
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199 acromial slope\(^5\) and acromial shape described by Bigliani et al.\(^6\), between the two
200 groups.

201 Thus, we consider that it is important to standardize groups, such that complexly
202 intertwined factors have no influence on the target factor. An explanation for our
203 contradictory results with regard to previous studies\(^1-7, \ 9, \ 12, \ 13, \ 16, \ 17\) may be that
204 age-related degenerative changes and secondary degenerative conditions after rotator
205 cuff tears could be excluded in the present study.

206 Surprisingly, the type III acromial shape was only observed in one (4\%) of 25
207 shoulders with full-thickness rotator cuff tears with exclusion criteria for acromial spurs.
208 Because acromial spurs cannot be measured accurately on plain radiographs or MR
209 images, these methods may lead investigators to make mistakes over groupings of
210 acromial shapes under the influence of acromial spurs. Therefore, we evaluated the
211 acromial shapes on plain radiographs after measurement of the acromial spurs on 3DCT
212 images to avoid this mistake. Additional studies are required to clarify the
213 reproducibility of diagnosis for the acromial shape between plain radiographs and
214 3DCT images.

215 The results of several studies\(^{18-21}\) and our previous study\(^22\) have brought into question
216 the biomechanical theory proposed by Nyffeler et al.\(^4\) of a relationship between a large
217 acromion index and rotator cuff disease. From our findings, we conclude that there is no
218 significant difference in the AIAAX between the rotator cuff tear group and the intact cuff
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219 group matched by age-related factors, including age and acromial spurs, thus supporting
220 the previous studies\textsuperscript{18-21}. A lateral extension of the acromion may be a degenerative
221 change after a rotator cuff tear, but a definitive conclusion has not yet been reached with
222 regard to this matter.

223 Sakoma et al.\textsuperscript{23} reported that a greater anterior acromial projection was observed in the
224 tear group (n=7) compared with the normal group (n=35) in an unmatched study for age,
225 acromial shape, and AHD, based on a macroscopic examination of 42 cadaveric
226 shoulders on the oblique sagittal plane. However, we found that there was no significant
227 difference in the anterior acromial projection between the tear group (n=25) and the
228 normal group (n=25) in our matched study by age, acromial shape, and AHD. Age may
229 lead to morphologic changes of the acromion or coracoid. In addition, the acromial
230 shape may affect the measurement size of a circle fitted to the undersurface of the
231 coracoacromial arch. The AHD value may have a great effect on the measurement, and
232 they also recognized this limitation\textsuperscript{23}.

233 The strong points of the present study are that it is the first to evaluate the
234 relationship between rotator cuff tears and acromial coverage of the humerus on axial
235 3DCT images, and the first to perform evaluations in groups matched by other acromial
236 morphologic factors, which can have an influence on the values of the acromial
237 coverage.
This study had some limitations. First, the sample size was small. To be able to standardize multiple factors between the groups and fulfill the exclusion criteria, we could not obtain a large sample size. Second, the study was retrospective. Third, partial-thickness rotator cuff tears were not included in the study.

Conclusions

High acromial coverage of the humeral head on the axial plane did not appear to be associated with full-thickness tearing of the rotator cuff.

Conflict of Interest

The authors declare that they have no conflict of interest.
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References


5) Aoki M, Ishii S, Usui M: The slope of the acromion and rotator cuff impingement.


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**Figure Legends**

**Fig. 1**

(a) Diagrammatic representation of the ACAI on axial 3DCT images. First, a transmission image photographic method for the humeral head was performed. Second, the distal area from the surgical neck of the humerus was trimmed off. A coracoacromial (C-A) line was drawn connecting the lateral tip of the coracoid and the anterolateral tip of the acromion as the coracoacromial arch. The ACAI was calculated by dividing the area of the humeral head within the coracoacromial arch by the whole area of the humerus on the axial 3DCT images. (b) The AAEI was calculated by dividing the distance (HA) from the tangent line (P line) to the most posterior aspect of the humerus that was perpendicular to the glenoid plane to the most anterior aspect of the acromion by the distance (HH) from the tangent line (A line) to the most anterior aspect of the humerus that was perpendicular to the glenoid plane to the P line on the axial 3DCT images. (c) The AIAX was calculated by dividing the distance (A) from the most lateral aspect of the acromion to the glenoid plane by the distance (H) from the most lateral aspect of the humerus to the glenoid plane.
<table>
<thead>
<tr>
<th>Group</th>
<th>F (n=25)</th>
<th>C (n=25)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age* (years)</td>
<td>60.48±8.48</td>
<td>58.96±10.66</td>
<td>0.58</td>
</tr>
<tr>
<td>Male/Female</td>
<td>18/7</td>
<td>12/13</td>
<td>0.41</td>
</tr>
<tr>
<td>BMI*</td>
<td>25.08±3.09</td>
<td>24.18±2.78</td>
<td>0.29</td>
</tr>
<tr>
<td>AHD**</td>
<td>10.8 (7.66 to 18.79)</td>
<td>10.3 (7.72 to 14.40)</td>
<td>0.46</td>
</tr>
<tr>
<td>Acromial angle*</td>
<td>26.70±3.51</td>
<td>27.54±4.76</td>
<td>0.48</td>
</tr>
<tr>
<td>Acromial shape</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type I</td>
<td>3</td>
<td>3</td>
<td>0.84</td>
</tr>
<tr>
<td>Type II</td>
<td>21</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Type III</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

BMI: body mass index; AHD: acromiohumeral distance.
*The normality assumption is satisfied. An unpaired t-test was carried out to compare the differences. The measure of the central tendency median is the mean ± SD.
**The normality assumption is not satisfied. The Mann–Whitney U test was carried out to compare the differences. The measure of the central tendency median is the median (range).
Values of $p<0.05$ were considered to indicate significant differences.
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Table 2 Intraobserver and interobserver reproducibilities for each parameter

<table>
<thead>
<tr>
<th></th>
<th>Intraobserver reproducibility</th>
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<tr>
<td></td>
<td>ICC</td>
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<tr>
<td>ACAI</td>
<td>0.98</td>
<td>0.96–0.99</td>
</tr>
<tr>
<td>AAEI</td>
<td>0.94</td>
<td>0.89–0.97</td>
</tr>
<tr>
<td>AIAAX</td>
<td>0.97</td>
<td>0.95 to 0.98</td>
</tr>
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</table>

CI, confidence interval; ICC, interclass correlation coefficient.
<table>
<thead>
<tr>
<th>Group</th>
<th>F (n=25)</th>
<th>C (n=25)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACAI</td>
<td>0.54±0.07</td>
<td>0.52±0.07</td>
<td>0.47</td>
</tr>
<tr>
<td>AAEI</td>
<td>0.31±0.08</td>
<td>0.28±0.09</td>
<td>0.35</td>
</tr>
<tr>
<td>AIAX</td>
<td>0.66±0.05</td>
<td>0.68±0.08</td>
<td>0.28</td>
</tr>
</tbody>
</table>

ACAI: acromial coverage area index; AAEI: acromial anterior extension index; AIAX: acromial index on the axial plane. The normality assumption is satisfied. An unpaired t-test was carried out to compare the differences. The measure of the central tendency median is the mean ± SD. The normality assumption is not satisfied. The Mann–Whitney U test was carried out to compare the differences. The measure of the central tendency median is the median (range). Values of $p<0.05$ were considered to indicate significant differences.