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Morphologic features of humeral head and glenoid version in the normal glenohumeral joint

Noboru Matsumura, MD[a,*], Kiyohisa Ogawa, MD[b], Shuzo Kobayashi, MD[c], Satoshi Oki, MD[a], Anri Watanabe, MD[d], Hiroyasu Ikegami, MD[e], Yoshiaki Toyama, MD[a]

[a]*Department of Orthopedic Surgery, School of Medicine, Keio University, Tokyo, Japan*
[b]*Department of Orthopedic Surgery, Eiju General Hospital, Tokyo, Japan*
[c]*Kobayashi Clinic, Iwanai, Japan*
[d]*Department of Orthopedic Surgery, Ito Municipal Hospital, Ito, Japan*
[e]*Department of Orthopedic Surgery, Toho University Ohashi Medical Center, Tokyo, Japan*

Background: The morphologic features and clinical significance of version of the humeral head and glenoid remain unclear. The purpose of this study was to evaluate the normal values of humeral head version and glenoid version on computed tomography scans and to clarify their features in the normal glenohumeral joint.
Methods: Images for analysis were computed tomography scans of 410 normal shoulders from healthy volunteers. Values of humeral head and glenoid version were measured. In glenoid version measurement, 3-dimensionally corrected slices were reconstructed to eliminate scapular inclination. Differences in humeral head version and glenoid version were assessed between dominant and nondominant shoulders and between men and women. Correlation analyses were also performed in the values of version between dominant and nondominant shoulders and between humeral head version and glenoid version.
Results: The values of humeral head retroversion were widely distributed from −2° to 60°, with an average of 26° ± 11°. Average glenoid retroversion was 1° ± 3°, ranging from −9° to 13°. Both humeral head retroversion and glenoid retroversion were significantly higher on the dominant side than on the nondominant side and significantly higher in men than in women. Humeral head version and glenoid version values were well correlated with those of the contralateral shoulder. No correlation was found between humeral head version and glenoid version.
Conclusions: This study found differences in humeral head version and glenoid version by sex and shoulder dominance in a large sample. Both the humeral head and glenoid are thought to be more retroverted in high-demand shoulders.
Level of evidence: Basic Science Study, Anatomy, Imaging.

Keywords: Shoulder morphology; glenoid morphology; glenoid retroversion; humeral head retroversion; humeral torsion; humerus morphology; shoulder arthroplasty

This study was approved by the Institutional Review Board of Ito Municipal Hospital (reference study number 2012001).

*Reprint requests: Noboru Matsumura, MD, Department of Orthopedic Surgery, School of Medicine, Keio University, 35 Shinanomachi, Shinjuku-ku, Tokyo 160-8582, Japan.
E-mail address: noboru18@gmail.com (N. Matsumura).

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Numerous studies have investigated shoulder geometry and morphology, but most of these dealt with shoulders in pathologic states. Thus, details of the normal glenohumeral joint have not been sufficiently evaluated. It is important to understand the morphologic features of the normal shoulder for anatomic reconstruction of the glenohumeral joint. Furthermore, few studies have examined both the scapula and humerus in the same shoulder.

In past studies, computed tomography (CT) scans have been widely used to measure humeral head version[1,5,6,9,16] and glenoid version.[4,9,10,14,17] Humeral head retroversion varies widely among cases,[2,13,16] and throwing athletes are reported to have high retroversion of the humeral head and glenoid.[6,9,23,27] Some arthritic shoulders show severe glenoid retroversion, which could be a risk factor for poor outcomes after arthroplasty.[30,31] The normal values and range of version must be documented because it is not possible to determine which cases are abnormal without understanding normal shoulders. With a small number of studies involving the normal population, however, their morphologic features and clinical significance remain unclear. The purpose of this study was to evaluate the normal values of humeral head version and glenoid version on CT scans and to clarify their features in the normal glenohumeral joint.

Materials and methods

A total of 207 healthy volunteers ranging from 20 to 40 years of age were prospectively recruited for this study. All volunteers gave their informed consent to participate in this study, and candidates with any past illnesses or injuries in the shoulder girdles were excluded. Two cases were excluded after examination because an asymptomatic bone cyst in the humeral head was found on the CT scans of their right shoulders. Thus, 410 shoulders from 205 volunteers (mean age, 30.6 ± 5.0 years; age range, 20-40 years; 108 women, 97 men) were included in this study. The dominant shoulders were right in 194 and left in 11. In determining shoulder dominance, the throwing side was defined as the dominant shoulder. Ninety-four cases (51 women, 43 men) had played asymmetric overhead sports for more than 3 years before the age of 18 years. In this study, asymmetric overhead sports included baseball, softball, tennis, volleyball, and badminton. On the other hand, rugby, basketball, Judo, skiing, and the like were excluded from the overhead sports group. All volunteers were engaged in light work, and no one performed heavy labor or competitive sports activity at the time of investigation.

Bilateral axial CT scans including the whole scapula, proximal humerus, and distal humerus were taken with 3-mm-thick slices (GE Healthcare HiSpeed NX/i Pro, Amersham, England; or Toshiba Aquilion TSX-101A, Tokyo, Japan). During the examination, the volunteers were positioned with the elbow extended and the forearm supinated. To prevent arm motion, the palm was placed and fixed under the volunteer's buttock. The DICOM (Digital Imaging and Communication in Medicine) data were analyzed with OsiriX MD 1.4.1 software (Pixmeo, Geneva, Switzerland). Humeral head version and glenoid version were assessed in both sides of the shoulders. The humeral head axis was defined as the line perpendicular to the cord of the articular surface of the humeral head at the slice with the maximum humeral head diameter (Fig. 1, A). The margins of the anatomic neck of the humerus were indicated by the junctions between the articular surface of the humeral head and a depression corresponding to the insertion of the articular capsule. The elbow epicondylar axis was defined as the line drawn between medial and lateral epicondyles at the slice where the epicondyles were the most prominent (Fig. 1, B). When it was difficult to determine the anatomic neck margin or the epicondyles, other slices were checked to identify them. Humeral head retroversion was calculated as torsion of the humeral head axis with respect to the elbow epicondylar axis of the humerus (Fig. 1, C).[1,16] In glenoid version measurement, 3-dimensionally corrected slices were reconstructed to exclude the effect of scapular inclination. Because images taken in the clinical setting can result in invalid measurement of glenoid version,[3,17] the axial images were corrected for scapular inclination. First, 3 bone landmarks of the scapula were selected with use of the software to determine the scapular plane: the inferior tip of the scapular body, the center of the glenoid surface, and the medial pole of the scapula (Fig. 2, A).[8,15,18,21,26] Three-dimensionally corrected slices were reconstructed as the plane including the center of the glenoid surface and the medial pole of the scapula and perpendicular to the scapular plane (Fig. 2, B).[4] The glenoid line was the line connecting the anterior rim with the posterior rim of the glenoid. The scapular axis was defined as the line connecting the medial pole of the scapula and the center of the glenoid line. As Friedman et al[14] described, glenoid version was calculated as the angle between the glenoid line and the line perpendicular to the scapular axis (Fig. 2, C). Two-dimensional analysis of glenoid version was performed on the midglenoid slices in which scapular inclination was corrected 3-dimensionally. In this study, the values of version were calculated as retroversion. Thus, a positive number means retroversion, and a negative number means anteversion of the humeral head and glenoid. Two evaluators independently reviewed all measurements twice with a minimum of a 1-month interval between measurements. Each measurement started from slice selection in humeral head version and from slice reconstruction in glenoid version.

Statistical analyses were performed with IBM SPSS Statistics 20.0.0 software (IBM, Armonk, NY, USA). Intrarater and interrater reliabilities were evaluated with intraclass correlation coefficients (ICC) first. Version measurement reliability was examined in both humeral head version and glenoid version. Intrarater reliability for each of 2 observers was calculated by repeated measurements with a 1-month interval (ICC model 1,1). Interrater reliability was calculated by blinded measurements of 2 observers (ICC model 2,1). After assessment of reliability, the values of humeral head version and glenoid version were averaged across the 2 observers and their 2 measurements.

Humeral head version and glenoid version values were compared with the Wilcoxon signed rank test, and their distributions were compared with the *F* test. Differences in humeral head version and in glenoid version were then compared between the dominant shoulder and the nondominant shoulder by Wilcoxon signed rank tests and between men and women by Mann-Whitney *U* tests. For dominant shoulders, differences in a history of overhead sport participation were also assessed with Mann-Whitney *U* tests for humeral head version and glenoid version.

Finally, correlation analyses were performed with Spearman rank correlation tests. The correlations between dominant and nondominant shoulders were analyzed for humeral head version and glenoid version. Correlation analysis between the values of humeral

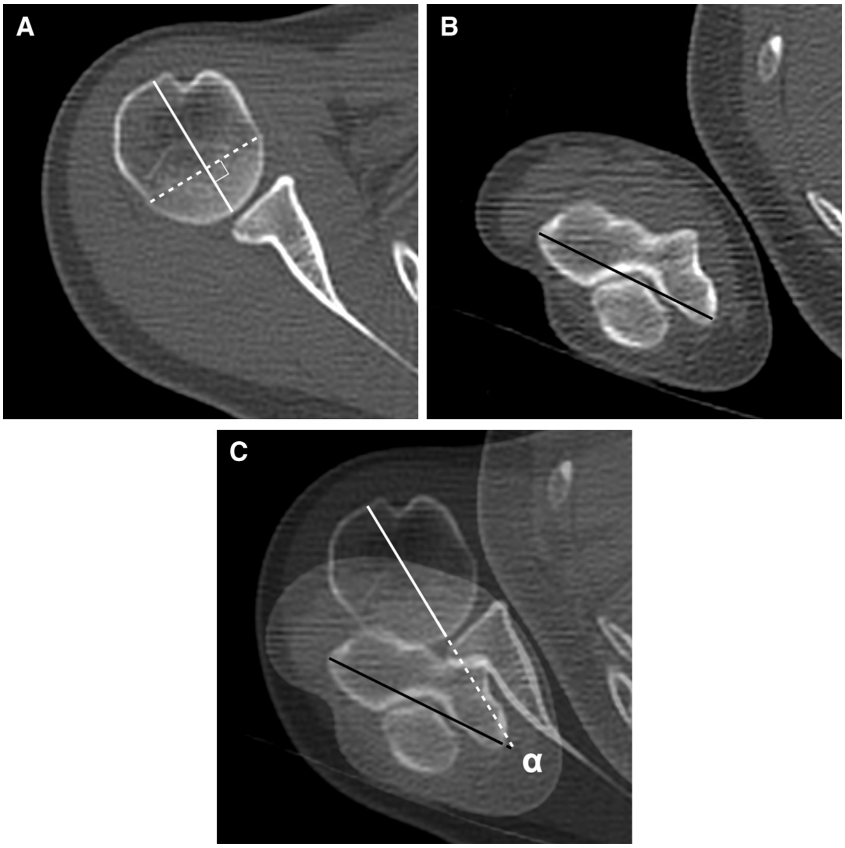

Figure 1 (**A**) The humeral head axis (*solid line*) is the line perpendicular to the cord of the articular surface of the humeral head (*dotted line*) at the slice with the maximum humeral head diameter. (**B**) The elbow epicondylar axis is the line drawn between the medial and lateral epicondyles (*line*) at the slice with the most prominent epicondyles. (**C**) Humeral head retroversion (α) is defined as the angle between the humeral head axis and the elbow epicondylar axis of the humerus. The humeral head shows 33° of retroversion.

head version and glenoid version was also performed. The significance level was set at .05 for all analyses.

Results

Intrarater reliability of the 2 observers was 0.952 (95% confidence interval [CI], 0.936-0.965) and 0.894 (95% CI, 0.858-0.921) for humeral head version and 0.923 (95% CI, 0.897-0.943) and 0.918 (95% CI, 0.890-0.939) for glenoid version, respectively. Interrater reliability was 0.887 (95% CI, 0.850-0.916) for humeral head version measurement and 0.921 (95% CI, 0.903-0.936) for glenoid version measurement. Intrarater and interrater reliabilities exceeded 0.85 for humeral head version and glenoid version measurements in all analyses. Because the intrarater and interrater reliabilities were sufficiently high, all values of version were averaged across the 2 observers and their 2 measurements.

The values of humeral head retroversion were widely distributed from −2° to 60°. The average humeral head retroversion was 26° ± 11°. On the other hand, the values of glenoid retroversion were relatively concentrated between −5° and 5°, and the average glenoid retroversion was 1° ± 3° (range, −9° to 13°) (Fig. 3). Humeral head retroversion was significantly higher than glenoid retroversion ($P < .001$), and the distribution of the values of version was significantly larger in the humeral head than in the glenoid ($P < .001$). The humeral head had significantly higher retroversion on the dominant side than on the nondominant side (28° ± 11° on the dominant shoulder and 25° ± 11° on the nondominant shoulder; $P < .001$). The glenoid also had higher retroversion on the dominant side than on the nondominant side (1° ± 3° on the dominant shoulder and 0° ± 3° on the nondominant shoulder; $P < .001$). The mean side-to-side difference, which was calculated by subtracting the values of the nondominant side from the values of the dominant side, was 3° ± 9° for humeral head version (range, −19° to 30°) and 1° ± 2° for glenoid version (range, −5° to 7°). Compared with women, men had significantly higher retroversion of both the humeral head (29° ± 11° in men and 24° ± 11° in women; $P = .006$) and glenoid (1° ± 3° in men and 0° ± 3° in women; $P < .001$) (Fig. 4). For the dominant shoulder, a history of overhead sport participation was not associated with any differences in humeral head retroversion (men: 30° ± 12° with participation and 32° ± 11° without participation, $P = .379$; women: 25° ± 10° with participation and 26° ± 10° without participation, $P = .483$) and in glenoid retroversion (men: 2° ± 3° with participation and 2° ± 3° without participation, $P = .620$; women: 0° ± 3°

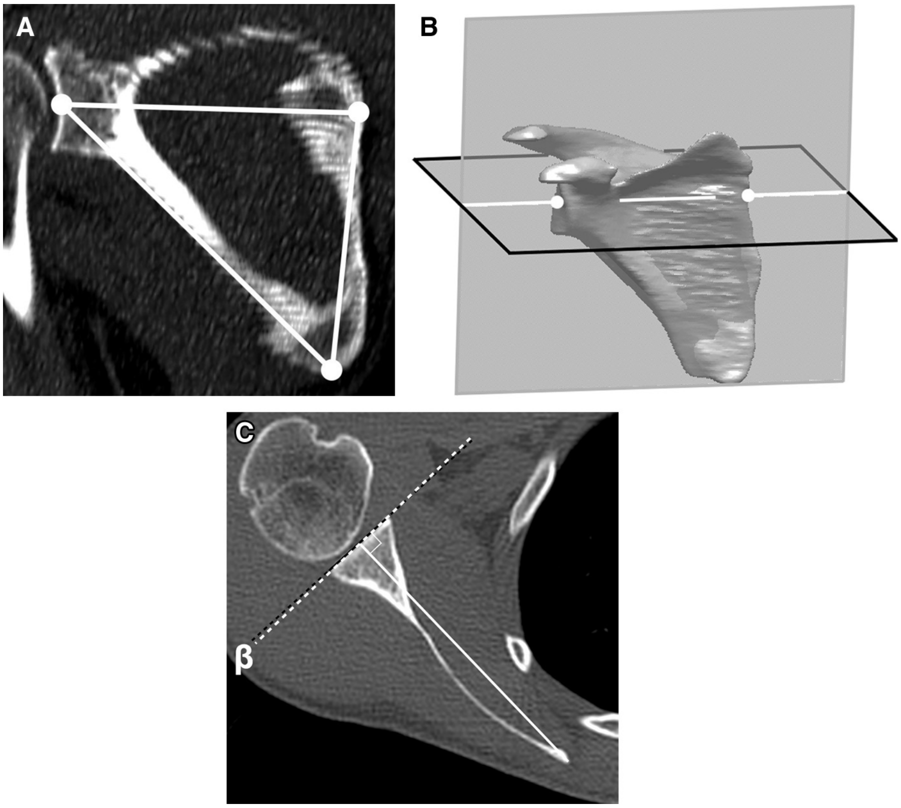

Figure 2 (**A**) The scapular plane is determined as the plane including the inferior tip of the scapular body, the center of the glenoid surface, and the medial pole of the scapula. (**B**) Three-dimensional corrected slices are reconstructed as the plane including the center of the glenoid surface and the medial pole of the scapula and perpendicular to the scapular plane. (**C**) The glenoid line is the line connecting the anterior and posterior rims of the glenoid (*black line*). The scapular axis is the line connecting the tip of the medial pole of the scapula and the center of the glenoid line (*white solid line*). Glenoid retroversion (β) is defined as the angle between the glenoid line and the line perpendicular to the scapular axis (*white dotted line*). The glenoid retroversion is $-1°$.

with participation and $0° \pm 3°$ without participation, $P = .302$). Both humeral head version and glenoid version values were well correlated with those of the contralateral side ($R = 0.643$ and $P < .001$, and $R = 0.688$ and $P < .001$, respectively) (Fig. 5). However, no correlation was found between humeral head retroversion and glenoid retroversion ($R = -0.065$ and $P = .189$) (Fig. 6).

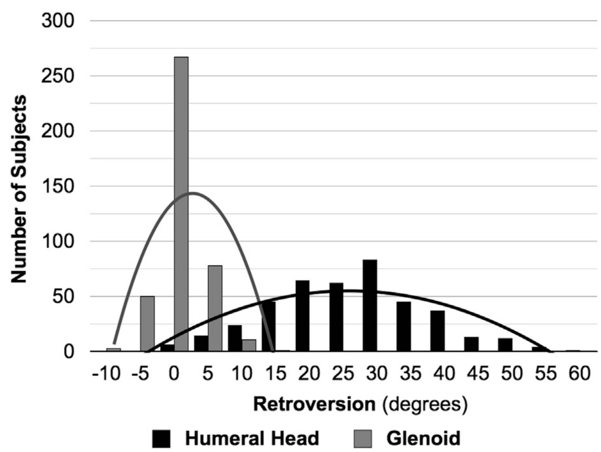

Figure 3 The histogram of humeral head version and glenoid version in normal shoulders. Humeral head retroversion is widely distributed, whereas glenoid retroversion is relatively concentrated between $-5°$ and $5°$. The distribution of the values of version is significantly larger in the humeral head than in the glenoid ($P < .001$).

Discussion

For anatomic reconstruction of the glenohumeral joint, it is important to understand normal shoulder morphology. However, the morphologic features of the normal glenohumeral joint have not been sufficiently evaluated. With a large number of samples, the present study revealed side-to-side and sex differences in humeral head version and glenoid version. The dominant sides and men had significantly higher retroversion than the nondominant sides and women. Both the humeral head and glenoid are thought to be more retroverted in high-demand shoulders.

Humeral head version is known to be highly variable.[2,13] In the present study, humeral head retroversion was widely distributed from $-2°$ to $60°$, with an average of $26°$ retroversion, and these results are consistent with past reports. Differences in humeral head version among ethnic groups,[13] between dominant and nondominant sides,[5,13,20]

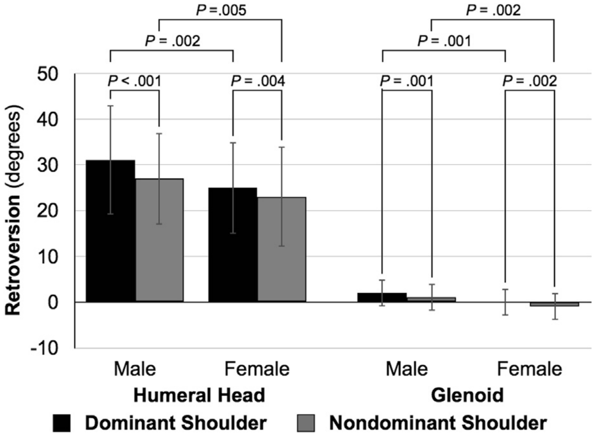

Figure 4 The average humeral head retroversion and glenoid retroversion in the normal population. Both the humeral head and glenoid have significantly higher retroversion in the dominant shoulder than in the nondominant shoulder as well as in men than in women.

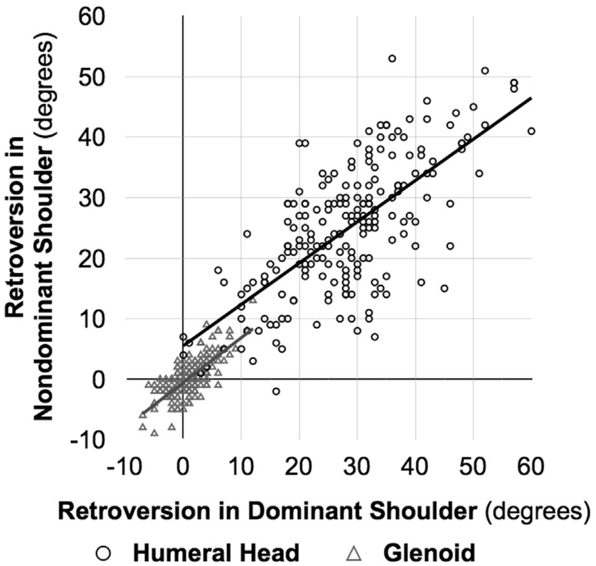

Figure 5 The relationship between the dominant side and nondominant side is plotted on a scatter diagram. Both humeral head version and glenoid version values are well correlated with those of the contralateral side ($R = 0.643$ and $P < .001$, and $R = 0.688$ and $P < .001$, respectively).

and between throwing and nonthrowing sides in overhead athletes[6,9,23,27] have been reported. Although a sex difference was noted in one report,[13] other studies did not find one.[16,20,25] The present study showed significant differences in humeral head version by shoulder dominance and sex. Humeral head retroversion is known to be high in the fetus and infant[13] and to become smaller with growth.[12,32] Thus, a high-demand situation is thought to obstruct normal derotation during growth. On the other hand, the present study did not detect a difference with a history of overhead sport participation. Because the present subjects did not include

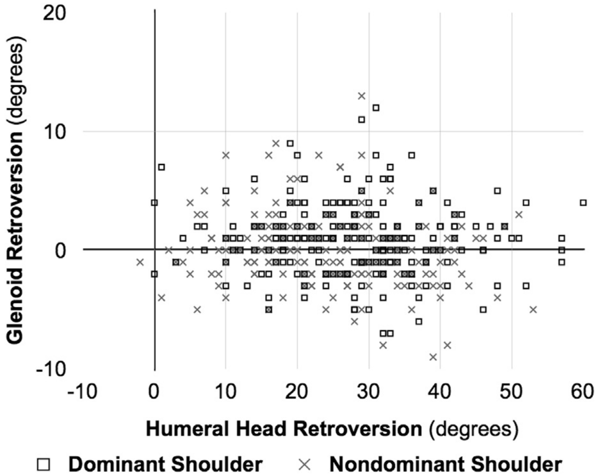

Figure 6 The scatter diagram describes the relationship between the values of humeral head version and glenoid version. No correlation is found between humeral head version and glenoid version in the normal glenohumeral joint.

competitive-level athletes, however, the effect of overhead sports activities on shoulder shape remains unclear. The present results suggest that not only throwing but also daily activities could affect version of the humeral head and glenoid. A side-to-side difference exists even in a normal population. Changes in humeral head version are supposed to affect the range of shoulder rotation. High retroversion increases external rotation and decreases internal rotation of the glenohumeral joint. Dominant shoulders had large retroversion greater than 20° compared with nondominant sides in 3.9% of our cases. It appears rare, but a side-to-side difference in version could possibly be a factor related to asymmetric shoulder range of motion in clinical cases.

The normal glenoid is supposed to be neutral in version, and it becomes retroverted in some arthritic shoulders.[30] Despite numerous reports involving arthritic shoulders, few studies have evaluated the normal glenoid.[7,10,14,28,29] De Wilde et al[10] reported higher retroversion in men than in women, but other studies[7,14,28,29] did not find a sex difference. The present study showed a significant difference in glenoid version between men and women, and it supports the report by De Wilde.[10] Regarding side-to-side differences, Crockett et al[9] reported that professional baseball pitchers had significantly higher glenoid retroversion in dominant shoulders than in nondominant shoulders. On the other hand, they did not find a side-to-side difference in version in the nonthrowing group. In the normal population, no past study has ever detected a difference in sides,[10,14,16] and therefore the present study is the first to report a side-to-side difference in glenoid version in a normal population. A sufficiently large sample and precise assessment of version with 3-dimensional correction were likely responsible for these results.

Because several studies stated the effect of scapular inclination on the values of glenoid version,[3,4,17] scapular inclination was corrected in measuring normal glenoid version. The present study showed that glenoid version is almost neutral, with an average of 1° of retroversion. This result was consistent with the past 2-dimensional studies of glenoid version.[7,14,21] However, glenoid version is known to vary from the top to the bottom of the glenoid, and the glenoid twists anteriorly to posteriorly.[11,19,22] The superior part has higher retroversion compared with the inferior part of the glenoid. With 3-dimensional analysis, Ganapathi et al[15] reported average retroversion of 6.9° of the glenoid of the nonpathologic side of patients with unilateral arthritis. Even with the 3-dimensional correction for scapular inclination used in the present study, a difference between the glenoid line defined in 2-dimensional analysis and the glenoid plane defined in 3-dimensional analysis could possibly lead to a difference in the values of glenoid version.

Both the humeral head and glenoid have higher retroversion in the dominant shoulder than in the nondominant shoulder and in men than in women. Nevertheless, no correlation was found between the values of humeral head version and glenoid version in the same shoulders. With 49 samples, De Wilde et al[10] also reported no correlation between humeral head version and glenoid version. The present result indicated that multiple factors independently caused differences of version of the humeral head and glenoid. High retroversion of the humeral head and glenoid appears to increase shoulder external rotation without anterior dislocation.[20,24] In a high-demand situation, it appears that the humeral head becomes retroverted to increase the range of external rotation, and the glenoid acquires retroversion to prevent anterior shoulder dislocation.

Although side-to-side differences were statistically significant both in humeral head version and in glenoid version, good correlations existed between dominant and nondominant shoulders in the present study. Anatomic reconstruction needs to be performed in shoulder arthroplasty, but the native version is not easily predicted in some clinical cases with glenohumeral arthritis or fracture. Hernigou et al[16] reported little side-to-side difference in humeral head version. In the present study, the mean side-to-side difference was 3° in humeral head version and 1° in glenoid version. Considering the wide variations in version, these differences appear to be relatively small. Although differences between sides in humeral head version exceeded 10° in 26.3% of our cases, only 11.2% showed differences greater than 15°, and 3.9% showed differences greater than 20°. It would seem appropriate for surgeons to refer to version of the contralateral shoulder if native version is not predictable in severe cases with arthritis or fracture.

The present study had several limitations. The 3-mm-interval thickness of CT scans is one possible limitation. More detailed scans might supply more precise results. However, because the present study dealt with healthy volunteers, 3-mm thickness was selected to minimize exposure to radiation. Nevertheless, version measurement in the humeral head and glenoid scored good to excellent intrarater and interrater reliabilities even with this thickness, and the results appeared reliable. Another limitation existed in humeral head version measurement. In determining the humeral head and epicondylar axes, the boundaries of the articular surface and the most prominent epicondyles were not always easily identified. Although other slices were checked in difficult cases, the choice of end points could affect the values of version. In this study, images were 3-dimensionally reconstructed for glenoid version measurement to exclude scapular inclination,[3,4,17] and 3-dimensional correction would be preferable for humeral head version. However, 2-dimensional CT measurement has been reported to be able to accurately assess humeral head version.[1,16] Except for direct measurement of cadaveric humeri,[2,13] 2-dimensional CT scans have been widely used to study humeral head version.[5,6,9,16] Sufficiently high intrarater and interrater reliabilities were also achieved in the present study. For these reasons, version was analyzed according to past morphologic studies.

Conclusion

With a large number of samples, the present study found differences in humeral head version and glenoid version by sex and shoulder dominance. Both the humeral head and glenoid are thought to be more retroverted in high-demand shoulders.

Disclaimer

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