Comparisons of acromiohumeral distance measurements between two- and three-dimensional imaging and between the supine and standing positions

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Research article

Keywords: normal shoulder, acromiohumeral distance, acromiohumeral interval, upright computed tomography, position, digitally reconstructed radiographs

DOI: https://doi.org/10.21203/rs.3.rs-34947/v1

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Abstract

Background

Narrowing of the acromiohumeral distance (AHD) implies a rotator cuff tear. However, AHD measurements on two-dimensional (2D) imaging or with the patient in the supine position might differ from that while standing during daily activity. This study aimed to accurately measure the distance between the acromion and the humeral head on three-dimensional (3D) imaging acquired in the standing position and to compare this with AHD measurements made on images acquired in the supine position and on 2D images.

Methods

Computed tomography (CT) images of 166 shoulders from 83 healthy volunteers (31 male and 52 female; mean age 40.1 ± 5.8 years; age range, 30–49 years) were prospectively acquired in the supine and standing positions using conventional and upright CT scanners, respectively. AHD was calculated as the minimum distance between the acromion and the humeral head on the 3D surface models. Two-dimensional AHD was measured on anteroposterior digitally reconstructed radiographs images. The AHD values were compared between the supine and standing positions and between the 2D and 3D measurements.

Results

The mean values of 2D AHD were 8.8 ± 1.3 mm (range, 5.9–15.4 mm) in the standing position and 8.1 ± 1.2 mm (range, 5.3–14.3 mm) in the supine position. The mean values of 3D AHD were 7.3 ± 1.4 mm (range, 4.7–14.0 mm) in the standing position and 6.6 ± 1.2 mm (range, 4.4–13.7 mm) in the supine position. The values of 3D AHD were significantly lower than those of 2D AHDs in both the standing and supine positions (P< 0.001). The values of 2D and 3D AHDs were significantly lower in the supine position than in the standing position (P< 0.001).

Conclusions

The present results indicated that assessments in the supine position can underestimate the value of the AHD compared with those made in the standing position and that assessments using 2D analysis can overestimate the value. It is necessary to understand that the anatomical distance of the subacromial space changes with images and gravity.

Background
Reduction of the subacromial space cause subacromial impingement and contribute to rotator cuff tear. It is important to know the subacromial space in healthy people is commonly evaluated to measure the acromiohumeral distance (AHD). The AHD is usually assessed on anteroposterior shoulder radiographs acquired in the standing position. Narrowing of this distance is widely considered to imply a rotator cuff tear [1–4]. However, the distances on radiographic two-dimensional (2D) measurements might differ from the actual distance between the humeral head and acromion [5]. Although the distance can be accurately measured on three-dimensional (3D) computed tomography (CT) images, conventional CT scanners acquire images of the shoulder girdle only in the supine position [6, 7]. Moreover, it is possible that the AHD could change between the supine and standing positions owing to the effect of gravity and the rotation of the upper arm. This study aimed to accurately measure the distance between the acromion and the humeral head in the standing position using a newly developed upright CT scanner [8, 9] and to evaluate differences in measurements of the AHD between the supine and standing positions and between 2D and 3D imaging.

Methods

Participants

This study was approved by the institutional review board, and written consent was obtained from all the participants (study protocol: #20160384). The study was conducted between June 2017 and July 2018.

A total of 134 healthy male and female volunteers aged 30–89 years with no past illnesses or injuries to the shoulder girdle were recruited from a volunteer recruitment company. Of these, 50 participants aged over 50 years were excluded because of the increased risk of an asymptomatic rotator cuff tear or other degenerative changes in the shoulder girdle [10–12]. In addition, one volunteer aged 33 years was excluded because of defects in the shoulder observed on CT image. Thus, 166 shoulders from 83 healthy volunteers (31 male and 52 female) were included in the analysis. The participants’ mean (± standard deviation) age, height, body weight, and body mass index (BMI) were 40.1 ± 5.8 years (range, 30–49 years), 162.9 ± 8.7 cm (range, 147.7–184.0 cm), 59.6 ± 12.5 kg (range, 37.8–106.8 kg), and 22.4 ± 3.7 kg/m² (range, 15.7–33.7 kg/m²), respectively.

Image acquisition

Imaging of the bilateral shoulders was acquired for each participant using a conventional 320-detector row CT scanner (Aquilion ONE; Canon Medical Systems Corporation, Otawara, Japan) in the supine position and an upright CT scanner (prototype TSX-401R; Canon Medical Systems Corporation, Otawara, Japan) in the standing position on the same day (Fig. 1a,b). During acquisition, the shoulders were adducted and the arms held in neutral position. The CT data were accumulated in Digital Imaging and Communication in Medicine (DICOM) data format.

Measurement of AHD
AHD was measured in 2D from digitally reconstructed radiograph (DRR) images of the anteroposterior (AP) shoulder radiographs, reconstructed from the DICOM data using ZedView software (version 12.5.0; LEXI, Tokyo, Japan). Multiplanar reformatting was used to create true AP shoulder DRR images, and scapula rotation was corrected for each individual glenoid version to provide a true AP view aligned parallel to the face of the glenoid (Fig. 2a). The bone window width set as 2000 Hounsfield units (HU) and the window level as 200 HU. The AHD was measured from the dense cortical bone at the inferior aspect of the acromion to the most proximal articular cortex of the humeral head, with the shortest distance recorded as the 2D AHD (Fig. 2b) [2, 3, 5, 13].

The 3D AHD measurements were calculated from 3D surface models of the acromion and humeral head, which were extracted from the DICOM data using AVIZO software (version 9.3.0; Maxnet, Tokyo, Japan). Bone part segmentation was performed to observe each slice of multiplanar reformatting carefully, with the bone window width set as 2000 HU and the window level as 200 HU (Fig. 3a). The bone surface model was generated with the smoothing level setting of 1.75, and the scapula and the humerus surface models were exported as Standard Triangulated Language (STL) data (Fig. 3b). To evaluate the 3D distance between the acromion and the humeral head, the STL data for the glenoid and coracoid parts of the scapula surface model were removed using Meshlab software (version 1.3.3; ISTI, Pisa, Italy). The minimum distance between the acromion and the humeral head in three dimensions was calculated using the Meshlab software as the Hausdorff distance; this was recorded as the 3D AHD (Fig. 3c).

**Statistical analysis**

SPSS Statistics 25.0.0.0 software (IBM Corp., Armonk, NY, USA) was used for the statistical analyses. The intra- and inter-observer reliabilities for the 2D and 3D AHD values were assessed by calculating intraclass correlation coefficient (ICC) based on 20 randomly selected shoulders. The measurements were made blind by two shoulder surgeons (ICC model 2,1) and repeated after a three-month interval by one shoulder surgeon (ICC model 1,1). After the reliabilities were determined to be acceptable, the 2D and 3D AHD values for all 166 shoulders were assessed by a single shoulder surgeon.

The AHDs data did not present normal distribution using the Shapiro–Wilk test (P < 0.05), and nonparametric tests were performed. The differences in age, height, weight, BMI, and AHD values between the men and women were assessed using the Mann–Whitney U test. The differences in the AHD values between the 2D and 3D measurements and between those measured in the supine and standing positions were evaluated using Wilcoxon signed-rank tests. Correlations in AHD values between the right and left shoulders were analyzed using Spearman's rank correlation analysis. The relationships between the AHD values and the participants' heights, weights, and BMI were also evaluated using Spearman's rank correlation analysis. The significance level was set at 0.05 for all the analyses.

**Results**
The intra- and inter-observer correlation coefficients for the 2D AHD measurements were 0.865 (95% confidence interval [CI], 0.695–0.944) and 0.831 (95% CI, 0.662–0.930), respectively. Those for the 3D AHD measurements were 0.979 (95% CI, 0.940–0.992) and 0.992 (95% CI, 0.981–0.997), respectively. These results confirmed that the measurements of 2D and 3D AHD were highly reproducible.

The mean values for the 2D AHDs were significantly higher in the standing position than in the supine position, at 8.8 ± 1.3 mm (range, 5.9–15.4 mm) and 8.1 ± 1.2 mm (range, 5.3–14.3 mm), respectively; similarly, the mean values for the 3D AHDs were significantly higher in the standing position than in the supine position, at 7.3 ± 1.4 mm (range, 4.7–14.0 mm) and 6.6 ± 1.2 mm (range, 4.4–13.7 mm), respectively (Fig. 4). The 3D AHD values were significantly lower than those for the 2D AHDs in both the standing and supine positions (both \(P < 0.001\)). The individual differences between the 2D and 3D AHD values obtained in the standing position ranged widely from −0.4 mm to 3.3 mm (Fig. 5a). The individual differences between the 3D AHD values obtained in the supine position and those obtained in the standing position showed even more variation, from −4.9 mm to 0.8 mm (Fig. 5b).

The mean values of both the 2D and the 3D AHD measurements were significantly lower for the women than for the men in both the standing and supine positions (Table 1).

![Table 1](image)

Table 1
Participant characteristics and two-dimensional (2D) and three-dimensional (3D) measurements of the acromiohumeral distance (AHD) made from images acquired in the standing and supine positions

| Characteristic     | All N = 83 | Male n = 31 | Female n = 52 | P (sex difference) |
|-------------------|------------|-------------|---------------|-------------------|
| Age, years        | 40.2 ± 5.8 | 39.4 ± 4.9  | 40.7 ± 6.2    | .154              |
| Height, cm        | 163.0 ± 8.8| 171.5 ± 6.0 | 157.9 ± 5.6   | <.001 ***         |
| Weight, kg        | 59.7 ± 12.5| 69.7 ± 11.8 | 53.8 ± 8.5    | <.001 ***         |
| BMI, kg/m\(^2\)   | 22.4 ± 3.7 | 23.7 ± 3.8  | 21.6 ± 3.5    | <.001 ***         |
| 2D AHD, mm        |            |             |               |                   |
| Standing position | 8.8 ± 1.3  | 9.1 ± 1.4   | 8.7 ± 1.3     | .034*             |
| Supine position   | 8.1 ± 1.2  | 8.5 ± 1.3   | 7.8 ± 1.1     | .001**            |
| 3D AHD, mm        |            |             |               |                   |
| Standing position | 7.3 ± 1.4  | 7.7 ± 1.5   | 7.1 ± 1.4     | .003**            |
| Supine position   | 6.6 ± 1.2  | 7.0 ± 1.4   | 6.3 ± 1.1     | <.001 ***         |

The data are presented as mean ± standard deviation. BMI, body mass index. * \(P < .05\), ** \(P < .01\), *** \(P < .001\)

AHD, acromiohumeral distance
Strong correlations were observed between the right and left shoulders for both the 2D and 3D AHDs, standing and supine (2D AHD: standing, $R = 0.794$, $P < 0.001$; supine, $R = 0.780$, $P < 0.001$; 3D AHD: standing, $R = 0.711$, $P < 0.001$; supine, $R = 0.742$, $P < 0.001$) (Fig. 6a,b). There was a weak correlation between the participants’ height and the standing 3D AHD values, but not with any of the other AHD values (2D AHD: standing, $R = 0.098$, $P = 0.211$; supine, $R = 0.137$, $P = 0.079$; 3D AHD: standing, $R = 0.161$, $P = 0.038$; supine, $R = 0.149$, $P = 0.055$). Weak correlations were observed between the ADH values and the participants’ weight (2D AHD: standing, $R = 0.299$, $P < 0.001$; supine, $R = 0.386$, $P < 0.001$; 3D AHD: standing, $R = 0.319$, $P < 0.001$; supine, $R = 0.310$, $P < 0.001$) and BMI (2D AHD: standing, $R = 0.303$, $P < 0.001$; supine, $R = 0.386$, $P < 0.001$; 3D AHD: standing, $R = 0.284$, $P < 0.001$; supine, $R = 0.290$, $P < 0.001$).

**Discussion**

This study used imaging from a newly developed upright CT scanner [8, 9] to accurately measure AHD in the standing position, which is better representative of daily living than is AHD measured when supine. The mean value of the AHD measured this way in healthy participants without previous injuries was 7.3 mm, ranging from 4.7 mm to 14.0 mm. The AHD was greater in men than in women.

These results were compared with values of AHD calculated using a 2D method in both the standing and supine positions and using a 3D method in the supine position. The 2D measurements were significantly higher than the 3D measurements, and the supine measurements were significantly lower than the standing measurements. This indicated that the 2D analysis can overestimate the actual AHD, and that assessment in the supine position can underestimate the AHD compared with the standing position. To evaluate the precise distance between the acromion and the humeral head during daily activity, measurements based on a 3D assessment of imaging acquired in the standing position would be desirable.

The normal value of AHD calculated using anteroposterior radiographs has been reported as 6–14 mm [1–4, 14, 15]. The values of 2D AHD evaluated in the present study were consistent with these previous reports, but they were significantly greater than the values for 3D AHD, which are a more accurate assessment of the actual minimum distance between the acromion and the humeral head. The individual differences between the 2D and 3D AHD values measured in the standing position varied widely by up to 3.3 mm. The present findings indicated that 2D analysis can overestimate the accurate shortest AHD, perhaps because of the overlap of bone structures on the 2D images.

The values of both 2D and 3D AHDs in the standing position were significantly higher than those in the supine position. In the standing position, gravity is likely to result in the humeral head moving downwards. The individual differences in 3D AHD between the standing and supine positions also varied widely, by up to 4.9 mm, suggesting that the alignment changes in the glenohumeral joint between positions varies between individuals. In cases of rotator cuff tear, the patients often suffer from pain during the night and sleep disturbance when lying in the supine position [16]. Different positions can change the subacromial pressure [17, 18], and the narrowing of the AHD in the supine position might...
increase pain. Therefore, Railhac et al. [19] advocated the AHD was more reliable in the supine position to detect rotator cuff tear.

This was the first study to evaluate the AHD in the standing position using CT imaging. Saupe et al. [13] and Werner et al. [20] reported that 3D AHD measurements on magnetic resonance imaging acquired in the supine position were 2.8 mm and 0.6 mm lower, respectively, than 2D AHD measurements made on radiographs in the standing position. Similarly, Ongbumrungphan et al. [7] reported that 3D AHD measurements on CT imaging acquired in the supine position were 1.7 mm lower than 2D AHD radiograph measurements in the standing position. These differences may be due to a combination of an overestimation of AHD by the 2D analysis and an underestimation of AHD from supine position. We believe that 3D AHD measured in the standing position, which reflects the actual distance between the acromion and the humeral head during daily activity, would be beneficial and helpful for clarifying the complex function of the shoulder in future studies.

Similar to the past reports [3, 21], the values of AHD in the present study varied greatly between individuals, and the AHD values were smaller in women than in men. The values of 3D AHD had a weak but significant correlation with the participants’ height, weight, and BMI. This showed that the values of AHD differ with individual physical status, but that other factors including the shape of acromion and rotation of the scapula affect the values. The values of AHD were strongly correlated between sides, confirming that the AHD of the contralateral shoulder can act as a reference when assessing the AHD in cases of unilateral shoulder pathology.

The present study had several limitations. First, although the participants were healthy volunteers without any shoulder symptoms, we could not evaluate whether they had asymptomatic rotator cuff tears. The age of the volunteers was limited to 30–49 years because of high correlation between the onset of rotator cuff tears and increasing age and because rotator cuff tears are clinically associated with lower AHD values. Yamaguchi et al. [12] reported that the mean age for individuals with no rotator cuff tear was 48.7 years, whereas for those with a unilateral tear it was 58.7 years, and for those with a bilateral tear it was 67.8 years. We excluded the volunteers over 50 years of age to ensure we avoided including shoulders with asymptomatic rotator cuff tear or other shoulder pathology. The comparisons between 2D and 3D measurements and between positions in the present study may differ from those that would be obtained for shoulders with rotator cuff tear; further studies are needed to investigate this. The measurement of 2D AHD might be another limitation. This was evaluated on DRR images reconstructed from CT data. DRR can be used to obtain a true anteroposterior view [22] and a past validation study [23] demonstrated that DRR can substitute for radiographs; however, the images obtained in this way may differ from the conventional radiographs used in previous 2D analyses.

**Conclusions**

The present results indicated that, compared with the measurement of AHD made in the standing position with 3D analysis, measurements with 2D analysis can overestimate the value of AHD and
assessments in the supine position can underestimate the value. This study has shown that the same technique used for the measurement of AHD is better to be used for accurate evaluation of the subacromial space.

**Abbreviations**

AHD  
acromiohumeral distance
BMI  
body mass index
CT  
computed tomography
DICOM  
Digital Imaging and Communication in Medicine
DRR  
digitally reconstructed radiograph
HU  
Hounsfield units
ICC  
intraclass correlation coefficient
STL  
Standard Triangulated Language
2D  
two-dimensional
3D  
three-dimensional

**Declarations**

*Ethics approval and consent to participate*

This study was approved by the Institutional Review Board of Keio University School of Medicine (Reference study number 20160384), and written consent was obtained from all participants.

*Consent for publication*

Not applicable.

*Availability of data and materials*

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.


**Competing interests**

Masahiro Jinzaki has received a grant from Canon Medical Systems. However, Canon Medical Systems was not involved in the design and conduct of the study; in the collection, analysis, and interpretation of the data; or in the preparation, review, and approval of the manuscript. The remaining authors have no conflicts of interest to declare.

**Funding**

This study was supported by Japan Society for the Promotion of Science (JSPS) KAKENHI (grant number JP17H04266 and JP17K16482, and 20K08056), Uehara Memorial Foundation, and Canon Medical Systems (Otawara, Japan).

**Authors’ contributions**

Yoshida: concept/design, data analysis, drafting of the manuscript, critical revision of the manuscript, approval of the article. N. Matsumura: concept/design, validation, critical revision of the manuscript, approval of the article. Y. Yamada: data collection, critical revision of the manuscript, approval of the article. M. Yamada: data collection, approval of the article. Y. Yokoyama: data collection, approval of the article. M. Matsumoto: supervision, approval of the article. M. Nakamura: supervision, approval of the article. T. Nagura: supervision, critical revision of the manuscript, approval of the article. M. Jinzaki: supervision, approval of the article.

**Acknowledgments**

None

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Figures
Figure 1

“320-row conventional and upright computed tomography (CT) scanners.” CT images of the bilateral shoulders were obtained with the shoulders adducted and the arms held in a neutral position, both in the supine position using a conventional scanner (a) and in the standing position using an upright scanner (b).
Sagital view

Axial view

Digitally reconstructed radiograph

b
Figure 2

“The process of measurement the two-dimensional acromiohumeral distances (2D AHD).” (a) Creating true anteroposterior shoulder digitally reconstructed radiograph (DRR) image from the CT data using ZedView software. Scapula rotation was corrected to align parallel to the inferior aspect of the acromion in sagittal view and aligned parallel to the face of the glenoid in axial view. (b) The acromiohumeral distance was measured in two-dimensional on DRR images of the anteroposterior shoulder reconstructed from the CT scans. The 2D AHD was defined as the shortest distance from the dense cortical bone at the inferior aspect of the acromion to the most proximal articular cortex of the humeral head (white line with arrow).
Figure 3

“The process of calculating the three-dimensional acromiohumeral distances (3D AHD)” (a) Creating 3D surface models of the scapula and humerus from the CT data to observe three views of multiplanar reformatting carefully using AVIZO software. (b) Bone surface model of the scapula and proximal humerus. (c) After removing the glenoid and coracoid parts of the surface model, the AHD was calculated three-dimensionally as the minimum distance between the acromion and the humeral head. The red areas indicate where the distance between the acromion and the humeral head is at a minimum.
Figure 4

“Differences in acromiohumeral distances (AHD) between 2D and 3D measurements and between the supine and standing positions.” The 3D AHD values were significantly lower than the 2D AHD values in both the standing and supine positions. The 2D and 3D AHD values were significantly lower in the supine position than in the standing position. ***P < 0.001.
Figure 5

“Histogram of the individual differences in acromiohumeral distance (AHD)” (a) Histogram of the individual differences in AHD in the standing position between the 2D and 3D measurements. Positive values indicate the 2D value is greater than the 3D value. (b) Histogram of the individual differences in 3D AHD between the supine and standing positions. Positive values indicate that the standing value is greater than the supine value. The differences varied widely.
a

![Graph a](image)

- ○ 2D AHD in standing position
- × 2D AHD in supine position

b

![Graph b](image)
Figure 6

“Linear regression plots of acromiohumeral distance (AHD) values compared between the right and left shoulders.” (a) Linear regression plots of acromiohumeral distance (AHD) values measured in two dimensions in the supine and standing positions, compared between the right and left shoulders. The values showed a strong correlation between the sides (standing: R = 0.794, P < 0.001; supine: R = 0.780, P < 0.001). (b) Linear regression plots for AHD values measured in three dimensions in the supine and standing positions, compared between the right and left shoulders. The values showed a strong correlation between the sides (standing: R = 0.711, P < 0.001; supine: R = 0.742, P < 0.001).

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