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Methodological aspects of the acromiohumeral distance measurement with ultrasonography—Reliability and effects of extrinsic and intrinsic factors in overhead and non-overhead athletes

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Abstract

Introduction: To improve comparability and interpretation of acromiohumeral distance (AHD) measurements, consequences of varying methodological approaches and population specific effects have to be known. This study aimed to investigate the intra- and inter-rater reliability of different AHD ultrasound image analysis approaches in asymptomatic overhead- and non-overhead athletes. Furthermore, the impact of shoulder muscle activity as well as relationships between AHD and individual factors were examined in different measurement positions.

Methods: Isometric shoulder strength, shoulder range of motion (ROM) and AHD were measured in 27 male and female participants (14 overhead athletes; 13 non-overhead athletes, age = 27.8 ± 5.2 years).

Results: Intra-rater reliability ($ICC_{3,1}$ 0.996) was excellent. Inter-rater reliability for the AHD defined as shortest distance between the most infero-lateral edge of the acromion and the most superior aspect of the humerus ($ICC_{2,1}$ 0.997) was minimally higher than for the AHD defined as perpendicular distance ($ICC_{2,1}$ 0.959). Increased shoulder muscle activity led to larger AHD reductions with abduction. Higher shoulder strength was associated with larger AHD, while larger shoulder ROM led to shorter AHD, dependent on measurement position and population.

Conclusion: While shoulder muscle activity and ROM had a pronounced effect on AHD, effects of shoulder strength and population appeared to be marginal.

KEYWORDS
musculoskeletal imaging, shoulder, shoulder injuries, sports, subacromial impingement syndrome, subacromial space

1 | INTRODUCTION

Overhead sports such as handball and volleyball are characterized by repetitive high-velocity overhead motion, imposing high stresses on tissues of the upper extremity.[1,2] In addition to the increased risk of traumatic injuries,[3,4] chronic overuse may lead to a high prevalence of pathologic shoulder conditions in overhead athletes (OHA).[4,5] Even the shoulders of asymptomatic OHA show structural abnormalities traced back to sport-specific loading.[5] Hence, early and simple identification of structural abnormalities by regular screening of such athlete's shoulders may be a valuable option to assist the prevention, diagnosis and rehabilitation of shoulder injuries.

The subacromial space, which has been shown to reduce during shoulder abduction and elevation,[6] plays an important role in the shoulder health of OHA whose sport-specific motions are frequently performed in shoulder abduction and external rotation.[7] Reduced subacromial space has been associated with subacromial impingement syndrome which may lead to structural damage of structures such as the subacromial bursa or the rotator cuff tendons.[8] To prevent an impingement of the rotator cuff tendons, it appears to be crucial for athletes to conserve the subacromial space as much as possible[9] and appropriate interventions may assist in this process.

A method to quantify the subacromial space by measuring the linear distance between the acromion and the humeral head, called the acromiohumeral distance (AHD), has been established using various radiological methods.[10] The advantages of ultrasonography (US) such as low costs, high practicability and the absence of radiation outdo other methods especially when applied in healthy participants.[10,11]

To provide realistic data with AHD measurements, it is important to utilize reliable and valid measurement techniques. Several studies investigated the reliability of the US image acquisition and demonstrated high intra-rater and inter-rater reliability for this technique.[11-13] However, precise information on the subsequent image analysis process, including localizing the anatomical landmarks between the acromion and the humeral head on the US image, is missing in some studies.[10] In addition, studies differ in terms of AHD definition. For example, some studies measure the tangential or nearest distance from the humeral head to the tip of the acromion whereas others measure the point of entry of the tendon into the acoustic shadow to the humeral head.[14] However, reliability and accuracy of the image analysis may depend on the choice of specific landmarks, which has not been investigated sufficiently.

For a precise and reliable determination of the AHD factors that may affect the measurement should be taken into account. The AHD has been shown to change with muscle contraction.[15] Measurements of the AHD while the shoulder muscles are contracting when holding the weight of the arm or even an additional load may thus differ from measurements during which the arm is resting passively, and muscles are not actively contracting. However, the effect of the activity level of the shoulder muscles on the AHD measurement has not been described conclusively.

Repetitive loading commonly leads to sports-related structural adaptations.[16] In overhead athletes the shoulder range of motion (ROM) is one component that has been shown to adapt according to prolonged and repeated overhead motion. Adaptions primarily present as glenohumeral internal rotation deficit (GIRD) of the dominant shoulder, defined as a loss of internal rotation (IR) of at least 20° or greater compared to the contralateral shoulder.[17] Furthermore, external rotation (ER) weakness and lower ratios of ER to IR strength (ER/IR ratio) have been reported in OHA. These sports-related adaptations of the shoulder as a consequence of repetitive loading in OHA have been shown to be risk factors for overuse injuries.[16] Adaptive changes and their effects on AHD have not been investigated in experienced OHA on competitive amateur level. Those are in comparison to professional elite athletes a much larger but far less well investigated study population, being exposed to many years of repetitive loading with a high prevalence of injuries.[18]

The first objective of this study was to assess the intra-rater and inter-rater reliability of the AHD measurement by US image analysis, comparing differences in reliability when using two different anatomical landmarks in neutral shoulder position. Secondly, the effect of the activity level of the shoulder muscles on the AHD measurement were assessed. Third, potentially confounding factors such as strength and ROM contributing to adaptive changes due to overhead motion and their relation to the AHD were examined in groups with different training experience: competitive amateur overhead athletes and non-overhead athletes (NOHA).

2 | MATERIALS AND METHODS

2.1 | Study design and participants

The study protocol was approved by the Ethics Committee of the Faculty of Humanities and Social Sciences of the Humboldt-Universität zu Berlin (HU-KSBF-EK_2018_0018). All participants voluntarily participated and provided written informed consent. Participants were recruited from sports associations and via personal contacts of university staff. Exclusion criteria were shoulder pain (current or during the last six months), systemic diseases, previous shoulder surgery and known anatomical alterations or damage of the shoulder joint. Participants were divided into two groups: The OHA group ($n = 14$) included handball or volleyball players who played at competition levels with at least two training sessions per week. The NOHA group ($n = 13$) included athletes (e.g., fitness, running and soccer), who did not perform any movements typically associated with overhead sports such as throwing or spiking movements (Table 1).

To identify shoulder impairments, all participants were asked to complete the German version of the Quick Disabilities of the Shoulder, Arm and Hand score. OHA were additionally asked to complete the German version of the Kerlan-Jobe orthopaedic clinic shoulder and elbow score (KJOC-G)[19] to identify impairments, activity limitations or participation restrictions, which was confirmed by KJOC-G scores of 98.6 ± 1.6 for the dominant and 98.4 ± 2.1 for the non-dominant arm.

The participants took part in one experimental session, in which anthropometric measures (body height, body mass, arm and forearm length), shoulder muscle strength, ROM and AHD were determined.

2.2 | Strength measurement

Tests of maximum isometric shoulder strength were performed by an experienced sports therapist (investigator 1) using a microFET2 handheld dynamometer (HHD) (Hoggan Health Industries Inc., West Jordan, UT, USA) measuring abduction (ABD), ER and IR strength of the shoulders.[20,21] The HHD is regarded as a reliable and valid instrument for muscle strength assessment.[22,23] To avoid investigator-dependent effects, a wall was used as the external resistance. To measure ABD-strength, participants were seated close to a wall with 90° hip, knee and

TABLE 1 Demographic and sports-related characteristics of the participants

	All participants	Overhead athletes	Non-overhead athletes
Number	27 (100%)	14 (51.9.1%)	13 (48.1%)
Sex, males/females	14/13 (51.9%/48.1%)	8/6 (57.1%/42.9%)	6/7 (46.2%/53.8%)
Age, y	27.8 ± 5.2	26.6 ± 5.2	29.1 ± 5.1
Height, cm	173.5 ± 10.7	176.0 ± 9.9	170.7 ± 11.1
Body mass, kg	74.4 ± 12.0	76.1 ± 11.7	72.5 ± 12.5
BMI, kg/m^2	24.8 ± 3.5	24.6 ± 3.1	24.9 ± 3.9
Overhead sports	14 (51.9%)	14 (100%)	N.A.
Handball	6 (42.9%)	6 (42.9%)	N.A.
Volleyball	8 (57.1%)	8 (57.1%)	N.A.
Overhead sports activity, No./week	N.A.	2.4 ± 0.7	N.A.
Overhead sports activity, h/week	N.A.	4.6 ± 2.6	N.A.
Experience overhead sports, y	N.A.	10.4 ± 5.2	N.A.
Other sports	14 (51.9%)	6 (42.9%)	8 (61.5%)
Fitness	5 (35.7%)	2 (33.3%)	3 (37.5%)
Running	3 (21.4%)	1 (16.7%)	2 (25.0%)
Swimming	1 (7.1%)	–	1 (12.5%)
Soccer	2 (14.3%)	–	2 (25.0%)
Hockey	1 (7.1%)	1 (16.7%)	–
Climbing	1 (7.1%)	1 (16.7%)	–
Yoga	1 (7.1%)	1 (16.7%)	–
Sports activity, No./week	1.9 ± 0.9	2.5 ± 1.4	1.2 ± 1.2
Sports activity, h/week	2.3 ± 1.6	2.6 ± 1.7	1.5 ± 1.8
Quick DASH score D	1.0 ± 1.5	1.4 ± 1.8	0.7 ± 1.1
Quick DASH score ND	2.8 ± 5.3	2.3 ± 4.3	3.5 ± 6.3

Note: Data are given as mean and SD (±) or as counts and percentages (%).
Abbreviations: D, dominant arm; N.A., not applicable; ND, non-dominant arm; Quick DASH, Quick Disabilities of the Shoulder, Arm and Hand DASH score.

ankle angles, with the shoulder in neutral position and the elbow fully extended. ER- and IR-strength were tested in standing position with the shoulder in 90° abduction and 0° horizontal extension and the elbow in 90° flexion. The HHD was placed ventrally (IR-strength) or dorsally (ABD- and ER-strength) on the forearm, with the dynamometer's center placed 2 cm proximal of the ulnar styloid process. After a standardized warm-up and a familiarization trial, three 5 s isometric maximum voluntary contractions against the HHD were performed for each arm and movement direction with at least one-minute break for each muscle group in between. Peak force values in Newton (N) were obtained from the dynamometer and subsequently converted to torque (Nm) by multiplying the values by the length of the respective lever arm (forearm in ER- and IR-strength measurement and full arm in ABD-strength measurement). The joint torques were normalized to body mass (Nm/kg).[20] Furthermore, the ratio of peak isometric external- to internal-rotation strength (ER/IR ratio) was calculated. Data of each movement direction were averaged over the three trials.

2.3 | ROM measurement

The active glenohumeral internal and external ROM of both shoulder joints were measured by an experienced physiotherapist (investigator 2) with a digital goniometer (Baseline Absolute Axis 360 Grad-Digital-Goniometer, model 1013990) in supine position with the shoulders abducted to 90° and the elbows flexed to 90° with a neutral wrist position. Participants were instructed to internally/externally rotate the arm while maintaining position. The absolute ROM was additionally converted to the total range of motion (TROM) (sum of IR + ER).[24] Furthermore, GIRD (difference between IR of the dominant and non-dominant shoulder) was calculated.[25]

2.4 | Ultrasound measurement

Sonographic measurements (mobile Echo Blaster 128 CEXT, Telemed Ltd, Vilnius, Lithunia and 5.0- to 8.0-MHz linear transducer LV7.5/60/128Z-2) of five standardized positions with participants sitting upright, were obtained of both shoulders in a randomized order: (1) Shoulder neutral position, (2) loaded shoulder neutral position, (3) 60° of passive abduction in the coronal plane, (4) 60° of active abduction in the coronal plane, and (5) 60° of active loaded abduction in the coronal plane.

The shoulder neutral position measurement was performed with the arms positioned alongside the body. For passive and active shoulder abduction positions, the 60° abduction angle was determined by a digital goniometer. For passive abduction the forearm and elbow joint rested on a table. Throughout the loaded positions, the participants held a weight while keeping the arm in a neutral position or holding the arm in a 60° abduction position respectively. To ensure loads were relative to the shoulder strength of individuals, the respective weight for each participant was determined according to the measured ABD-strength: 1 kg for <75 N, 2 kg for 76–150 N, 3 kg for 151–200 N, 3 kg for >200 N. The measurement of each position was repeated three times for every shoulder. All sonographic measurements were performed by investigator 2, who is a licensed physiotherapist with specific ultrasound training and physiotherapy experience with US of more than 5 years. During the ultrasound assessment, AHD was measured in the coronal plane by placing the transducer on the center of the acromion parallel to the longitudinal axis of the humerus (Figure 1A). Between each measurement, the transducer was removed from the shoulder. The ultrasound images were saved and analysed within one week after the measurement by quantifying two different distances between the hyperechoic landmarks within the subacromial space (Image J 1.32 software): (1) the shortest distance between the most infero-lateral edge of the acromion and the most superior aspect of the humerus and (2) the perpendicular distance (90 ± 5°) between the most infero-lateral edge of the acromion and the humeral head (Figure 1B,C). For intra-rater reliability, a blinded trained sports therapist analysed images of the same participants twice after a time period of one week. For inter-rater reliability the same images were additionally analysed by a blinded trained physiotherapist.

2.5 | Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics software for Mac, Version 24.0 (Armonk, NY: IBM Corp). Data normality was assessed by the Shapiro–Wilk test and frequency histograms. The significance level (α) was set at $p \leq 0.05$ for all statistical procedures.

The intra-rater reliability of the AHD measurement (first and second analysis by rater 2 of distance 1 of the dominant arm in neutral position) was assessed using a two-way, mixed-effects single measure absolute agreement model $ICC_{.3,1}$[26] The inter-rater reliability of the AHD measurement for distance 1 and 2 between rater 1 and 2 (dominant arm, neutral position) was assessed using a two-way, random-effects single measure absolute agreement model $ICC_{2,1}$. ICC values were classified as follows: <0.5 = poor reliability; 0.5–0.75 = moderate reliability; 0.75–0.9 = good reliability; >0.90 = excellent reliability.[27] The SE of measurement $SEM = SD \times \sqrt{(1 - ICC)}$ and the minimal detectable change $MDC_{95\%} = 1.96 \times \sqrt{2} \times SEM$ were calculated.[28]

Group and sex differences were analysed using independent *t*-tests. Differences between the shoulder sides were analysed by paired *t*-tests. Mann–Whitney-*U*-Test and Wilcoxon signed-rank test, respectively, were used in case of non-normally distributed variables.

The associations between strength, ROM and AHD were assessed using Pearson's correlation coefficients (r) or nonparametric Spearman's rank correlation coefficients (r_s). Classifications were used as follows: <0.10 = negligible, 0.10–0.39 = weak, 0.40–0.69 = moderate, 0.70–0.89 = strong and > 0.90 = very strong correlation.[29]

3 | RESULTS

Demographic characteristics did not differ significantly between OHA and NOHA (Table 1).

3.1 | Reliability of the AHD image analysis

The intra-rater reliability for repeated quantification of the AHD by the same rater was excellent ($ICC_{3,1}$ 0.996; CI95% 0.991–0.998), with absolute mean differences being 0.02 ± 0.30 mm. The SEM was 0.02 mm and the MDC was 0.05 mm.

For both AHD quantification approaches, the inter-rater reliability was excellent (distance 1: $ICC_{2,1}$ 0.997; CI95% 0.993–0.999; distance

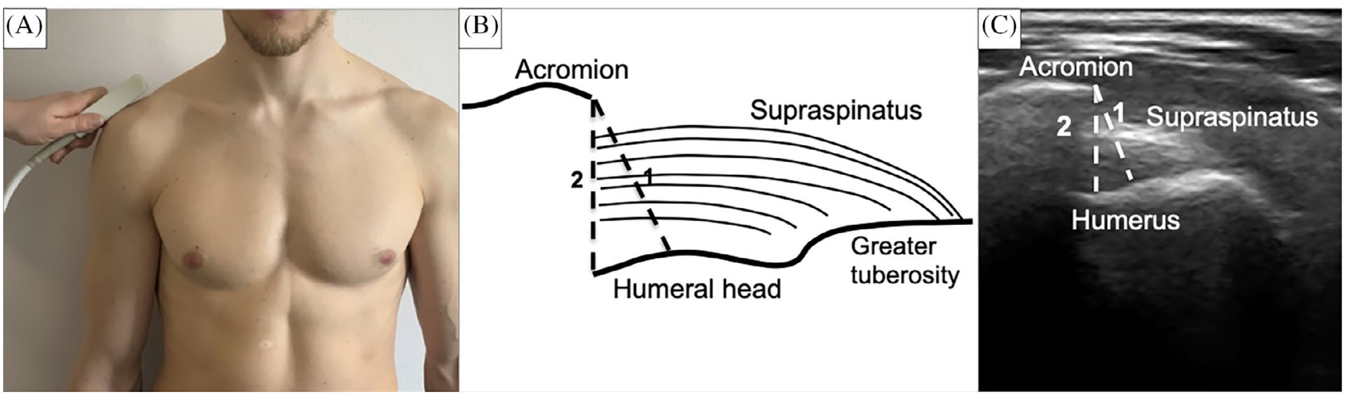

FIGURE 1 (A) Ultrasound measurement setting for AHD measurement in neutral shoulder position; (B) Schematic illustration of the two different distances (1) the shortest distance between the most infero-lateral edge of the acromion and the most superior aspect of the humerus and (2) the perpendicular distance (90 ± 5°) between the most infero-lateral edge of the acromion and the humeral head; (C) Ultrasound image for AHD measurement in neutral shoulder position. AHD, Acromiohumeral distance

2: $ICC_{2,1}$ 0.959; CI95% 0.759–0.988). The absolute difference between the mean values obtained by the two raters was significantly smaller for distance 1 (0.02 ± 0.27 mm) compared to that for distance 2 (0.37 ± 0.42 mm) ($p = 0.01$) (Figure 2). The SEM and MDC for distance 1 were 0.02 mm and 0.04 mm respectively and those for distance 2 were 0.08 mm and 0.23 mm respectively.

3.2 | Effects of shoulder muscle activity level

The AHD absolute values and the AHD changes with abduction in any measurement position and shoulder side did not significantly differ between the OHA and the NOHA groups (Figure 3). In both groups, increased shoulder muscle activity (active and loaded positions) significantly increased the AHD reductions with shoulder abduction. This was also indicated by significant shorter AHD at 60° compared to 0° (Figure 3). AHD changes with abduction in the passive position (OHA: dominant 0 mm and non-dominant 0.3 mm; NOHA: dominant 0.3 mm and non-dominant 0.7 mm) were significantly smaller than in active (OHA: dominant −3.1 mm and non-dominant −3.0 mm; NOHA: dominant −1.6 mm and non-dominant -1.7 mm) and loaded positions (OHA: dominant −2.8 mm and non-dominant −2.8 mm; NOHA: dominant −2.9 mm and non-dominant −2.3 mm) in both shoulder sides and groups. Differences between the loaded and the active position were exclusively detected in the dominant shoulder of NOHA with larger AHD reductions in loaded (−2.9 mm) compared to active abduction (−1.6 mm). Regarding differences between the shoulder sides, in NOHA, the AHD at loaded 60° of abduction was significantly shorter in the dominant compared to the non-dominant shoulder (Figure 3).

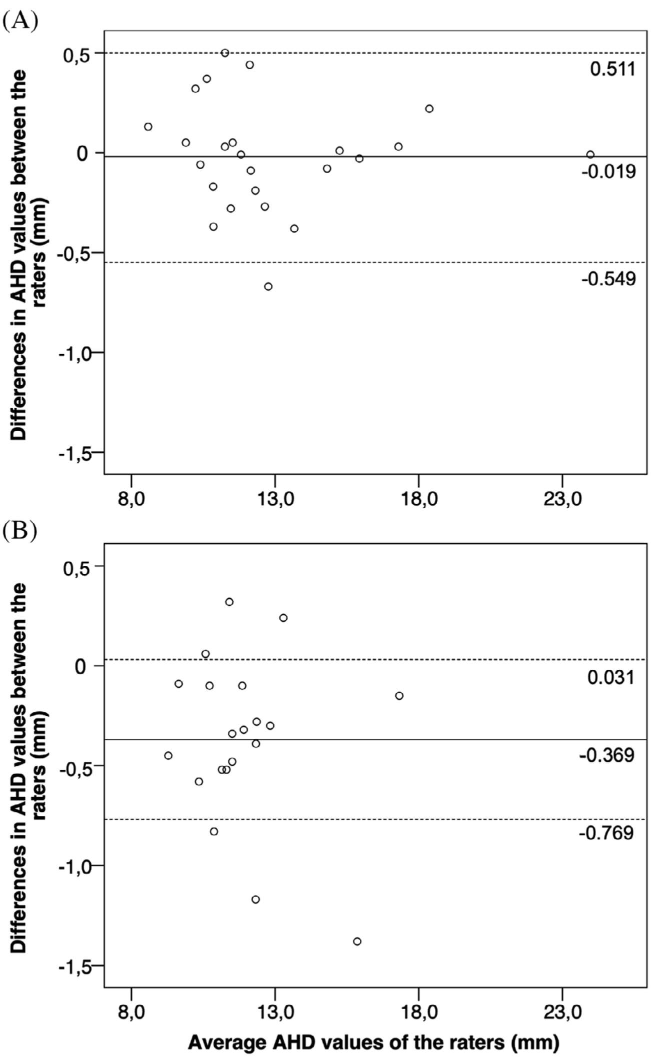

FIGURE 2 Bland-Altman plots showing the difference of the AHD (in mm) between the two raters for distance 1 (A) and distance 2 (B) plotted against their mean. Solid line: Mean difference of AHD between the raters. Horizontal dashed lines: 95% limits of agreement. AHD, Acromiohumeral distance

3.3 | Relationships of shoulder strength and ROM with AHD

There were no significant differences in absolute strength, normalized peak torque values and ratios or ROMs between OHA and NOHA (Table 2).

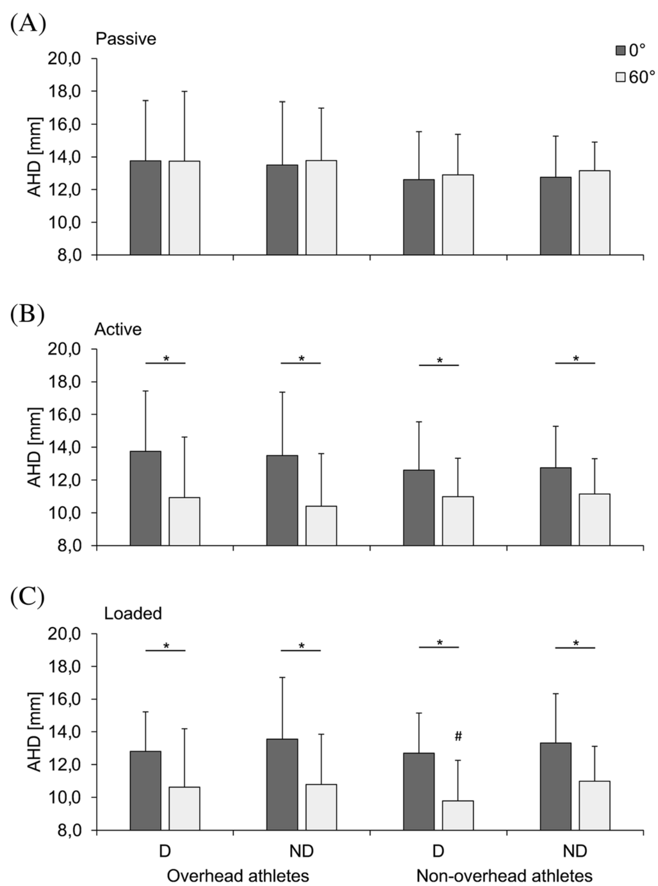

FIGURE 3 AHD (in mm) in 0° and 60° of passive (A), active (B) and loaded abduction (C) of the dominant and non-dominant shoulder in overhead athletes and non-overhead athletes. AHD, Acromiohumeral distance; D, dominant shoulder; ND, non-dominant shoulder. *Significant difference between 0° and 60°; # significantly different to ND (p values <0.05)

AHD was positively correlated with shoulder strength in two positions: larger AHD was related to higher normalized ABD peak torques ($r = 0.448$; $p = 0.02$) in a passively abducted shoulder position of the dominant shoulder in both groups and to higher IR peak torques ($r_s = 0.550$; $p = 0.04$) in a neutral shoulder position of the dominant shoulder in OHA only.

Furthermore, AHD was positively correlated to ER/IR strength ratios ($r = 0.656$; $p = 0.01$) in a passively abducted position of the dominant shoulder in OHA only.

AHD was negatively correlated with shoulder ROM in several positions: in the dominant shoulder of both groups shorter AHD was related to larger IR-ROM ($r_s = -0.437$; $p = 0.02$) in a passively abducted position and to larger ER-ROM ($r_s = -0.434$; $p = 0.03$) in a loaded abducted position.

In NOHA only, shorter AHD of the dominant shoulder was related to larger ER-ROM in a neutral ($r_s = -0.560$; $p = 0.046$) and in an actively abducted ($r = -0.679$; $p = 0.01$) position while it was related to larger TROM in passively ($r = -0.631$; $p = 0.02$), actively ($r = -0.564$; $p = 0.045$) and loaded ($r = -0.658$; $p = 0.01$) abducted positions.

3.4 | Sex differences

Regarding anthropometric measures, as expected, males were compared to females displaying a significantly larger body height (181.7 cm > 164.6 cm), mass (82.0 kg > 66.2 kg), arm (dominant: 55.9 cm > 49.8 cm; non-dominant: 56.0 cm > 49.2 cm) and forearm lengths (dominant: 27.1 cm > 23.8 cm; non-dominant: 26.9 cm > 23.5 cm). Absolute strength and normalized peak torque were higher in male compared to female participants. However, ROM, AHD and relationships between ROM and AHD did not significantly differ between male and female participants at passive and active positions.

4 | DISCUSSION

This study focused on the methodological aspects of the AHD measurement obtained with ultrasonography.

4.1 | Reliability of the AHD image analysis

We tested two different ultrasound methods of AHD measurement that had been previously been described in the literature in enough detail to be replicated.[13,14] The agreement between the two different AHD measurement approaches justifies the application of both analysis techniques. However, based on the smaller absolute mean difference, using the shortest distance between the most infero-lateral edge of the acromion and the most superior aspect of the humerus as a landmark (distance 1) should be preferentially used when measuring the AHD on ultrasound images.

Our inter-rater reliability was similarly high as in a previous study.[30] However, high reliability may depend on short time intervals between the measurements and the degree of shoulder pathology. Long time intervals between image analyses may reduce reliability. For example, when images were analysed six months apart, inter-rater reliability (ICC 0.50) and intra-rater reliability (ICC 0.56 and 0.57) was just moderate.[11] Pathologies may similarly reduce reliability as bony structures used as distance borders might be more difficult to identify due to inflammatory reactions and soft tissue alterations.[11] That our study focused on healthy shoulders, which were analysed one week apart, may thus have contributed to higher reliability.

TABLE 2 Strength, peak torque and range of motion values of the dominant and non-dominant shoulder in overhead and non-overhead athletes (Mean ± SD)

	Overhead athletes		Non-overhead athletes	
Movement direction	D	ND	D	ND
ABD-strength, N	110.2 ± 33.3*	101.9 ± 29.8	117.5 ± 39.8	116.8 ± 42.0
ER-strength, N	59.2 ± 21.3*	51.6 ± 18.7	62.0 ± 17.4*	55.8 ± 18.2
IR-strength, N	48.2 ± 18.5	45.9 ± 15,7	52.7 ± 15.0	49.4 ± 15.0
ER/IR strength ratio	1.27 ± 0.32	1.15 ± 0.32	1.20 ± 0.21	1.15 ± 0.22
Normalized ABD peak torque, Nm/kg	0.78 ± 0.20*	0.72 ± 0.17	0.83 ± 0.20	0.82 ± 0.21
Normalized ER peak torque, Nm/kg	0.20 ± 0.07*	0.17 ± 0.05	0.22 ± 0.05*	0.19 ± 0.05
Normalized IR peak torque, Nm/kg	0.16 ± 0.05	0.15 ± 0.04	0.18 ± 0.04	0.17 ± 0.04
ER-ROM, °	100.1 ± 10.8*	91.3 ± 14.5	98.3 ± 10.7*	90.7 ± 8.5
IR-ROM, °	57.9 ± 9.7*	65.7 ± 13.9	62.1 ± 12.4	66.6 ± 10.5
TROM, °	158.0 ± 13.1	157.0 ± 17.2	160.4 ± 18.2	157.3 ± 14.4

Abbreviations: ABD, abduction; D, dominant shoulder; ER, external rotation; IR, internal rotation; ND, non-dominant shoulder; ROM, range of motion; TROM, total range of motion.

*Significantly different to the non-dominant shoulder ($p < 0.05$).

4.2 | Effects of shoulder muscle activity level

Our study demonstrated that increased shoulder muscle activity increased the AHD reduction with abduction. Active and loaded positions led to larger AHD reductions compared to passive positions. This is in accordance with Thompson, Landin[31] who demonstrated significantly reduced AHDs at loaded abduction compared to unloaded positions in healthy baseball players performing scaption exercises with normalized additional loads. The absent activity of humeral head depressors such as the infraspinatus muscle may contribute to larger AHDs. How decreased muscle activity affected the subacromial space was underlined by the absence of an AHD reduction when the shoulder abduction was performed passively. This finding is in accordance with Wang et al.,[32] who detected a significant increase of the subacromial space width of injured baseball players supporting the arm during measurement.

The difference between the passive position and positions with higher muscle activity (active/loaded) in our study was clearly evident irrespective of study population or shoulder side. While this points towards a general effect of muscle activity on AHD, enhancing muscle activity further by adding load does not seem to provoke a pronounced additional reduction. It was only in the dominant shoulder of NOHA that added load led to a further reduction in AHD while in the non-dominant side and OHA this did not provoke any further reduction. Thus, it may be questioned, if performing the measurement with added load does provide any relevant information over and above the active position.

4.3 | Relationships of shoulder strength and ROM with AHD

Larger ROM may impair the preservation of the subacromial space and subsequent prevention of impingement-related conditions. Our study exclusively showed negative correlations between ROM and AHD. This is in agreement with Mackenzie, Herrington,[33] who showed that the AHD was preserved less with larger ER-ROM and TROM in non-athletes. As shoulder hypermobility is assumed to contribute to the development of a subacromial impingement,[7] enlarged shoulder ROM may be associated with increased risks of impingement-related conditions. As a consequence the detection of enlarged shoulder ROM warrants joint stabilizing interventions.

The AHD is influenced by muscle strength and strength ratios of the respective shoulder. Increased rotator cuff muscle strength may contribute to preserve the subacromial space, thereby preventing impingement-related conditions. As we detected that higher IR strength and higher ER/IR strength ratios of the dominant shoulder were associated with larger AHD in neutral respectively passively abducted shoulder position in OHA, this supports the effect of the muscular characteristics on the subacromial space. This is confirmed by Leong et al.,[34] similarly describing higher ER strength and ER/IR strength ratios being related to larger AHD in neutral shoulder position in volleyball players. Both, ER and IR strength appear to affect the AHD, underlining the importance of muscle strength for the preservation of the subacromial space and consequently the relevance for preventing injuries.

4.4 | Effect of training experience on AHD

The finding of no significant differences between the AHD in the OHA and NOHA groups suggests that loading-dependent adaptations in NOHA do not impact on the AHD. Other studies have reported greater AHD in college baseball players compared to controls,[32] and shorter AHD in tennis players compared to controls.[35] These inconsistent results across studies of overhead athletes suggest factors other than training experience are impacting on AHD measurements.

4.5 | Limitations

Reliability was tested only for the image analysis process of the AHD measurements; therefore results of this study cannot be extended to the image acquisition process of the measurements. We did not measure abduction angles higher than 60°, which may better reflect sport-related movements, as acoustic shadows typically occur in higher ranges of shoulder abduction.[13] As a result, potential adaptations or changes may have been missed, if those occurred at higher degrees of abduction only. Scapular kinematics have not been measured within this study. However, scapular movement is considered to affect the AHD in a manner of adapted kinematics that may preserve the AHD for example, in athletes.[36] Furthermore, bony[37] and tendinous[32] characteristics and muscular modifications have not been taken into account. Anatomical abnormalities could thus have affected the subacromial space and its variation over position changes in individual cases. Moreover, this study investigated healthy shoulders only. Results and assumptions of this study cannot be extended to pathological shoulders.

5 | CONCLUSIONS

Measuring the shortest distance between the most infero-lateral edge of the acromion and the most superior aspect of the humerus can be advised as preferred image analysis procedure for AHD measurement.

Shoulder muscle activity had an effect on the AHD, implying the use of active and passive positions during AHD measurement. However, enhancing muscle activity beyond the active position by adding load may not provide further relevant information. While sex and overhead sports related training experiences were not decisive, reduced shoulder muscle strength and increased ROM negatively affected the preservation of the subacromial space, constituting risk factors that need to be addressed by athletes and coaches. While our study provides data that allow implementation of routine screening in healthy athletes, future studies should consider the effect of shoulder pathology on AHD measurement reliability.

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CONFLICT OF INTEREST

The authors report no conflict of interest.

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