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ORIGINAL ARTICLE

Are acromiohumeral distance measurements on conventional radiographs reliable? A prospective study of inter-method agreement with ultrasonography, and assessment of observer variability

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ABSTRACT

Objectives: This study aims to investigate the reliability of acromiohumeral distance (AHD) measurements using conventional radiographs and to compare non-standardized and standardized radiographs with intra-/interobserver reliability measurements.

Patients and methods: Between February 2021 and January 2022, a total of 110 shoulders of 55 patients (25 males, 30 females; mean age: 49.7±12.6 years; range, 25 to 77 years) were included. Radiographs were taken in four different positions: primarily shoulder anteroposterior (AP), true AP, standardized true AP, and standardized outlet views. The AHD was measured by three orthopedists. A prospective ultrasonography (US) evaluation was performed by an experienced physiatrist, and the relationship between US and radiographic measurements was evaluated. The intra- and interobserver reliability of radiographic measurements was assessed.

Results: On the standardized true AP view measurements, all observers showed a moderate to good agreement with US measurements (intraclass correlation coefficients [ICC]: 0.68-0.75). There was no significant difference between the AHD measurements of the senior orthopedist on standardized true AP and outlet views, and the US measurements. The intraobserver agreement of US measurements was excellent (ICC: 0.98, 95% confidence interval [CI]: 0.98-0.99), and the intraobserver agreement level of measurements on radiographs were good to excellent with a wide range of ICC values (ICC: 0.79-0.97). Interobserver reliability was the highest on the standardized outlet view, with an ICC of 0.91 and 0.88 in two measurement times. Interobserver reliability of other measurements were good with ICC values ranging from 0.82 to 0.88.

Conclusion: The AHD measurements on radiographs are compatible with US measurements within up to 2 mm difference if standardization is ensured. Also, measurements on standardized views have a superior consistency with lower standard error of measurement and minimal detectable change values. Therefore, we recommend using standardized true shoulder AP and standardized outlet radiographs in clinical practice and studies, as these are the most accurate in demonstrating true AHD.

Keywords: Acromiohumeral distance, radiographic measurement, reliability, rotator cuff pathologies, subacromial distance, ultrasonographic measurement.

Rotator cuff diseases are among the most prevalent conditions affecting the shoulder girdle, with the supraspinatus tendon being the most commonly affected.[1] As a consequence of the progression of supraspinatus and infraspinatus tendon tears, there is a reduction in the resistance to the upward pulling force exerted by the deltoid muscle on the humerus.[2] This biomechanical alteration leads to the proximal migration of the humeral head, and this can be most effectively assessed by measuring the acromiohumeral distance (AHD) on conventional radiographs. The AHD measurement not only indicates the presence

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of pathology, but also provides an insight into the reparability of any existing tears.[3]

The AHD is defined as the shortest distance between the sclerotic inferior border of the acromion and the superior border of the humeral head.[4] In studies involving healthy individuals, AHD has been found to range between 6 and 14 mm, with considerable variability.[5] Measurements below 6 to 7 mm are typically indicative of rotator cuff pathology.[6-8] Besides aiding in diagnosis and treatment decision-making, AHD is also valuable for assessing surgical outcomes. It facilitates the evaluation of re-ruptures by comparing AHD measurements in early postoperative radiographs with subsequent images. Additionally, AHD measurements are frequently employed in the assessment of the success of salvage surgical procedures for irreparable tears.[9-11] Therefore, the reliability of this measurement is of utmost importance. The AHD measurements have been reported to be feasible using various imaging modalities, including conventional radiographs,[12,13] magnetic resonance imaging (MRI),[14] computed tomography (CT),[15,16] and ultrasonography (US)[17-19] with at least good and acceptable reliability. However, in the only systematic review on this subject, AHD measurement made on US was the most reliable method, whereas measurements on CT and MRI were problematic due to positional factors, measurements made with conventional radiography were less reliable.[20] These discrepancies were attributed to the methodological limitations of studies conducted on radiographic measurements. It is well-established that AHD values can vary depending on the chosen imaging technique or positional changes during the same imaging session. Therefore, measuring AHD in the same sitting position using US offers advantages and has been demonstrated as the most reliable method.

In the present study, we hypothesized that measurements on standardized radiographs could yield results comparable to those obtained with US and exhibit the highest intraclass correlation coefficients (ICC). In this study, we, therefore, aimed to investigate the relationship between US and standardized/non-standardized conventional radiographs, and to assess the intraobserver and interobserver reliability of AHD measurements obtained from conventional radiographs.

PATIENTS AND METHODS

This single-center, prospective study was conducted at Istanbul University-Cerrahpaşa, Cerrahpaşa Medical Faculty, Department of Orthopedics and Traumatology between February 2021 and January 2022. A total of 110 shoulders of 55 patients (25 males, 30 females; mean age: 49.7±12.6 years; range, 25 to 77 years) were included in the study.

Inclusion criteria were as follows: age 18 years, having non-specific shoulder pain for more than three weeks, and undergoing conventional direct radiography. Exclusion criteria were as follows: the presence of or a history of glenohumeral arthrosis, adhesive capsulitis, rheumatological disease, shoulder instability, fractures within the shoulder region, previous operations due to rotator cuff tears or subacromial impingement, or tumors.

Both shoulder anteroposterior (AP), true AP, standardized true AP, and standardized outlet radiographs were displayed. Then, US assessment was performed by a physiatrist, who has more than 10 years of experience in shoulder and circumferential pathologies. The AHD measurement by US was done three times in 1-min intervals, assuming that the obtained mean AHD measurement was accurate. We attempted to create two groups by comparing this measurement with the measurements on the radiographs done by three orthopedic surgeons of different seniority (orthopedic specialist with more than 10 years of experience in shoulder surgery, observer 2; orthopedic specialist, observer 3; senior orthopedics resident, observer 1). In addition, we evaluated the intraobserver and interobserver reliability of AHD measurements on the radiographs, these measurements were done two times at one-month intervals. All measurements were done in double-blinded fashion.

Data including age, sex, painful side, duration of pain, height, weight, and body mass index (BMI) were recorded. Any potential secondary factors that may influence AHD measurement were identified.

Radiological evaluation

Conventional radiography and AHD measurements

Radiographs of all patients included in the study were performed with the same device (OPTIMA™ XR646 HD; GE Healthcare, Chicago, Illinois, USA) and by a single radiology technician. Acquisitions were performed with the same position and tube angle to provide standardized exposure, as AHD measurement is known to be affected by these factors.

Radiographs were taken in four different positions: Shoulder AP, where the patient's scapula

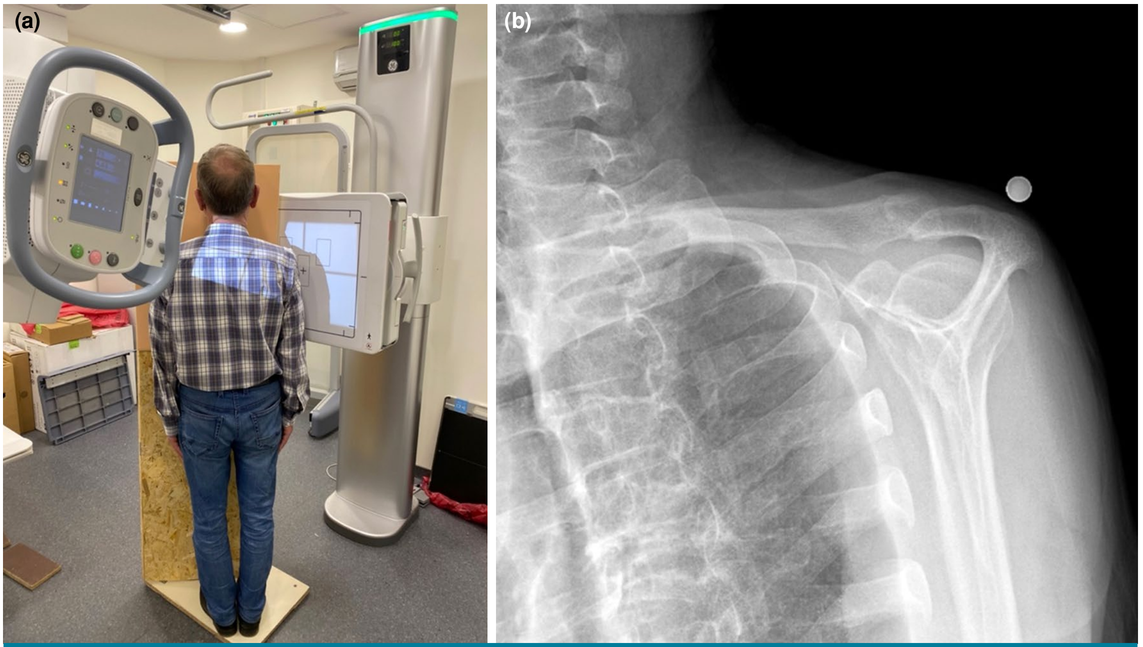

FIGURE 1. (a) Standardized outlet radiography positioning and **(b)** image.

was in complete contact with the cassette and the tube was targeted at the coracoid process, with the palms facing straight ahead. True AP, where the patient's body was turned 45 degrees toward the affected shoulder, and the tube was focused on the glenohumeral joint, with the arms in external rotation and the palms facing straight ahead. Standardized true AP (with apparatus), where the patient's body was positioned at a 45-degree angle toward the affected shoulder using a pre-prepared block, the arms were placed in external rotation with the palms facing forward, and the tube was inclined 15 degrees craniocaudal. Standardized outlet, where the patients leaned against the prepared block at a 45-degree angle toward their affected shoulders in the PA position, and the tube was inclined 10 to 15 degrees caudally, targeting the acromioclavicular joint (Figure 1).

Although the actual size and exact size can be obtained in the measurements made on the radiograph when shots are taken from 100 cm using the device's feature, we placed an iron ball with a known diameter of 1 cm on the patients' shoulders in all shots (Figure 2). This was done to confirm that the measurements made on the radiograph were in actual values. The AHD measurements were assessed using the ExtremePACS® version 4.3 software (ExtremePACS®, Çankaya, Ankara, Türkiye), measuring the closest distance between the dense cortical bone under the acromion and the subchondral lamina of the humeral head, as recommended in the literature.[3,12]

Ultrasonography and AHD measurement

All US evaluations were performed by a physiatrist with more than 10 years of experience in US shoulder examinations using a 7 to 13 MHz linear probe (LOGIQ P5; GE Healthcare, Chicago,

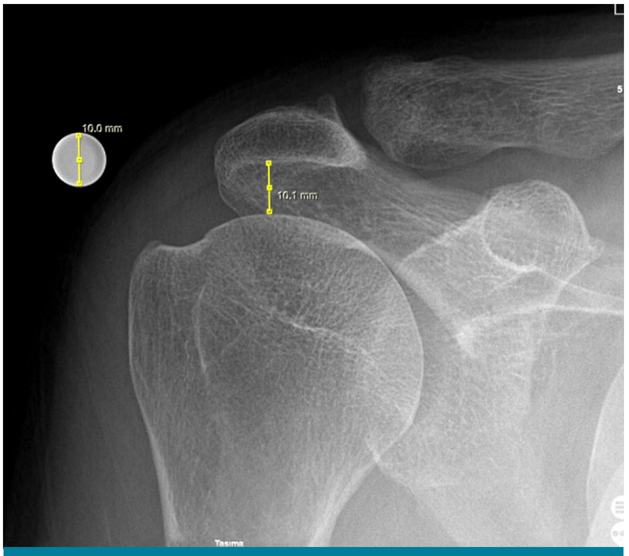

FIGURE 2. Acromiohumeral distance measurement on shoulder anteroposterior X-ray and confirmation of magnification with 1 cm iron ball.

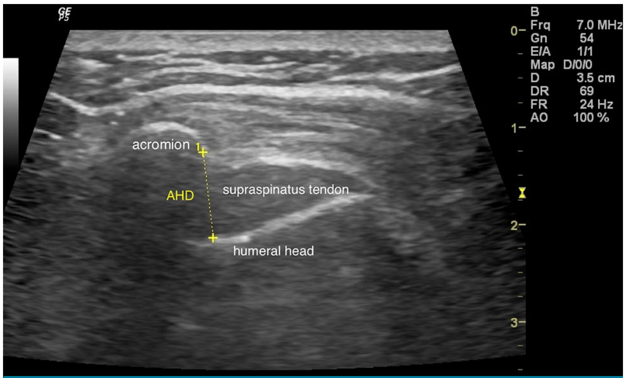

FIGURE 3. Acromiohumeral distance measurement on ultrasonography image.

Illinois, USA). All patients were evaluated in the sitting position. Supraspinatus, infraspinatus, and subscapularis tendons were evaluated in detail in the patient's arm in Crass and modified Crass positions. Then, to evaluate the AHD, the patients were seated in the upright position without back support. The shoulder was placed in the neutral and the scapular retraction position and the forearm in the flexion and supination position, and the probe was placed in the middle of the acromion parallel to the longitudinal axis of the humerus in the coronal plane. The vertical distance between the most inferolateral edge of the acromion and the humeral head was measured three times (Figure 3). Before each measurement, the probe was removed from the shoulder, and after waiting for 1 min,[18] the distance was found again, and the new measurement was made. The distance was determined by taking the average of measurements.

Statistical analysis

The study power and sample size calculation were performed using the G*power version 3.1.7 software (Heinrich Heine University, Düsseldorf, Düsseldorf, Germany). The results revealed that minimum 38 participants were required to achieve 95% power (α=0.01), when minimum clinically important difference (MCID) of 1.4 units for AHD was considered based on the study by Mayerhoefer et al.[12] Therefore, we planned to include 50 patients in the study.

Statistical analysis was performed using the IBM SPSS version 26.0 software (IBM Corp., Armonk, NY, USA) and STATA version 15.0 software (StataCorp LLC, TX, USA). Continuous data were expressed in mean ± standard deviation (SD) or median (min-max), while categorical data were expressed in number and frequency. The histogram, Kolmogorov-Smirnov, or Shapiro-Wilks tests were used to determine whether the continuous variables fit the normal distribution, and the Levene t-test was used to evaluate group homogeneity. The Friedman non-parametric analysis of variance was used to compare the measurement results between observers, and post-hoc pairwise comparisons

TABLE I
Demographic and baseline data of patients

	n	%	Mean±SD	Median	
Age (year)			49.7±12.6	50.0	
Male			46.3±12.2	46.0	0.088
Female			52.5±12.4	52.0	
Sex					
Male	25	45.5			
Female	30	54.5			
Height (cm)			167.25±10.56	159.0	
Male			175.68±9.21	175.0	**<0.001**
Female			160.23±5.05	160.0	
Weight (kg)			80.41±13.72	68.0	
Male			85.04±13.26	84.0	0.025
Female			76.56±13.09	73.5	
BMI (kg/m^2)			28.81±4.80	27.7	
Male			27.53±3.88	26.9	0.083
Female			29.87±5.29	29.72	

SD: Standard deviation; BMI: Body mass index.

were made with the Wilcoxon test in cases where there was a statistically significant difference. Intra- and interobserver agreement analyses were assessed by the ICC, which data is used for relative random consistency in light of the overall variability within the population studied, with 95% confidence interval (CI). For interpretation, we used the following criteria to the ICC: less than 0.5, poor; 0.5-0.75, moderate; 0.75-0.9, good; and 0.91-1.0, excellent.[21] In addition, the standard error of mean (SEM) and minimum detectable variability (MDC) depending on the measurements were calculated, which are used for absolute random errors (absolute consistency) that may occur after repeated measurements in the data.[22] The relationships between the demographic data of the patients and the measurements were evaluated with the Spearman non-parametric correlation analysis. A *p* value of <0.05 was considered statistically significant.

RESULTS

Demographic and baseline characteristics of the patients are shown in Table I.

In the three US measurements, no significant difference was found between them (p=0.242), and excellent agreement was observed (ICC: 0.987, p<0.001, 95% CI: 0.98-0.99) with very low SEM and MDC values (SEM: 0.17 mm, MDC: 0.47 mm). The mean and median AHD values obtained from US measurements were 10.19±1.46 and 10.4, respectively. The US evaluation of rotator cuff integrity revealed that 59% intact, 38% partial thickness supraspinatus rupture, and 3% full-thickness supraspinatus tendon rupture. The maximum intraobserver difference was 1.3 (range, 0 to 1.3) mm.

Relationship between BMI - height and AHD measurements via US

A low positive correlation (r=0.202, p=0.044) was found between the mean of US measurement and BMI. On the other hand, a low positive (r=0.087) and insignificant correlation (p=0.388) was observed between the mean of US measurement and height.

Interobserver evaluation of AHD measurements on conventional radiographs

Although statistically significant differences were observed in all measurement positions (p<0.001), interobserver reliability was good to excellent on outlet radiographs, with an ICC of 0.91 and 0.88 in the first and second measurements, respectively (p<0.001). A good correlation was observed in the other three different positions, but with lower ICC values ranging from 0.82 to 0.87 (Table II), and small SEM values ranging from 0.58 to 0.94, as well as low MDC values between 1.59 and 2.59. The mean maximum interobserver difference for the same AHD was 1.4±2 mm, as observed between measurements of observer 1 and observer 3 on the shoulder AP view.

Intraobserver evaluation of AHD measurements on conventional radiographs

The highest correlation was observed in the outlet radiographs, with no statistical difference (p>0.05). The observers' measurements on the standardized outlet radiographs demonstrated good to excellent agreement, with ICC values of 0.94, 0.98, and 0.85, respectively, along with very low SEM values ranging from 0.34 to 0.81 and low MDC values ranging from 0.93 to 2.25. Other radiograph positions also showed a good to excellent level of agreement, with ICC values ranging from 0.79 to 0.94. Moreover, the most senior observer had the best ICC value in all

TABLE II
Interobserver and intraobserver measurement reliability of AHD on different projections

	Shoulder AP		Shoulder true AP		Standardized true AP		Standardized outlet	
	ICC	95% CI	ICC	95% CI	ICC	95% CI	ICC	95% CI
Interobserver reliability								
1st set	0.84	0.78-0.88	0.87	0.82-0.90	0.84	0.78-0.89	0.91	0.88-0.93
2nd set	0.82	0.75-0.87	0.85	0.80-0.89	0.85	0.79-0.89	0.88	0.83-0.91
Intraobserver reliability								
Observer 1	0.83	0.75-0.88	0.92	0.89-0.94	0.90	0.85-0.93	0.94	0.90-0.95
Observer 2	0.94	0.91-0.96	0.94	0.91-0.96	0.94	0.91-0.96	0.98	0.97-0.98
Observer 3	0.79	0.69-0.85	0.85	0.79-0.90	0.84	0.76-0.90	0.85	0.78-0.90

AHD: Acromiohumeral distance; AP: Anteroposterior; ICC: Interclass correlation coefficient; CI: Confidence interval.

measurements made at four different radiographic views (Table II). The maximum measured mean difference for the intraobserver examination was -0.98±1.7 mm, observed in observer 1's shoulder AP measurements.

Comparison of AHD measurements with US and conventional radiographs

While examining all data, a significant difference was found between US and radiography measurements. However, no statistically significant difference was observed between standardized shoulder true AP and outlet view measurements performed by the senior orthopedist and US measurements. The highest agreement was observed in the standardized shoulder true AP view measurements of all observers, with a moderate level of agreement (ICC: 0.68-0.75). In other X-ray positions, a generally fair to good level of agreement

TABLE III
Comparison of ultrasonographic and radiographic measurements of AHD and mean values for radiographic measurements of AHD

	Mean±SD	SEM (mm)	MDC (mm)	Difference (p)	ICC	95% CI	*p*
Ultrasonography	10.19±1.46	**0.17**	**0.47**		0.98	0.98-0.99	<0.001
Observer 1, 1st set							
AP	8.14±2.35	1.43	3.95	<0.001	0.63	0.45-0.75	<0.001
True AP	8.50±2.00	1.09	3.00	<0.001	0.70	0.56-0.80	<0.001
Standardized true AP	9.65±1.54	**0.77**	**2.12**	<0.001	**0.75**	0.63-0.83	<0.001
Standardized outlet	9.76±1.98	1.15	3.18	0.002	0.66	0.50-0.77	<0.001
Observer 1, 2nd set							
AP	9.12±2.14	1.15	3.18	<0.001	0.71	0.57-0.80	<0.001
True AP	8.49±2.08	1.15	3.19	<0.001	0.69	0.54-0.79	<0.001
Standardized true AP	9.47±1.77	**0.69**	**1.90**	<0.001	**0.75**	0.62-0.83	<0.001
Standardized outlet	9.59±2.09	1.30	3.60	<0.001	0.61	0.38-0.72	<0.001
Observer 2, 1st set							
AP	9.75±2.12	1.19	3.28	<0.001	0.68	0.53-0.78	<0.001
True AP	8.72±2.27	1.35	3.73	<0.001	0.62	0.43-0.74	<0.001
Standardized true AP	10.09±2.03	**1.12**	**3.10**	**0.853**	**0.69**	0.54-0.79	<0.001
Standardized outlet	10.43±2.27	1.53	4.22	0.636	0.54	0.32-0.69	<0.001
Observer 2, 2nd set							
AP	9.68±2.13	1.16	3.20	<0.001	0.70	0.56-0.80	<0.001
True AP	8.55±2.34	1.33	3.66	<0.001	0.67	0.52-0.78	<0.001
Standardized true AP	10.21±2.10	**1.13**	**3.11**	**0.779**	**0.71**	0.57-0.80	<0.001
Standardized outlet	10.36±2.39	1.60	4.42	0.666	0.55	0.33-0.69	0.003
Observer 3, 1st set							
AP	9.57±1.65	**0.97**	**2.68**	<0.001	0.65	0.48-0.76	<0,001
True AP	9.15±1.67	0.98	2.72	<0.001	0.65	0.48-0.76	<0,001
Standardized true AP	9.65±1.89	1.01	2.80	0.002	0.71	0.39-0.72	<0,001
Standardized outlet	9.83±2.13	1.49	4.11	0.036	0.51	0.25-0.66	0,007
Observer 3, 2nd set							
AP	9.27±1.50	1.05	2.89	<0.001	0.51	0.17-0.62	0,002
True AP	9.33±1.67	1.10	3.04	<0.001	0.56	0.35-0.70	0,001
Standardized true AP	9.43±1.69	**0.95**	**2.62**	<0.001	**0.68**	0.42-0.73	<0,001
Standardized outlet	9.80±1.88	1.36	3.76	0.004	0.47	0.13-0.60	0,004

AHD: Acromiohumeral distance; SD: Standard deviation; SEM: Standard error of mean; MDC: Minimum detectable change; ICC: Interclass correlation coefficient; CI: Confidence interval; AP: Anteroposterior; Difference (p): P value for difference between AHD measurements on ultrasonography and conventional radiographs; * Wilcoxon test-ICC.

was assessed, with ICC values ranging from 0.47 to 0.71. SEM and MDC values were higher compared to intra- and interobserver analyses (Table III, which also includes the average values of all measurements). The maximum measured mean difference for the inter-method examination was 1.99±2.09 mm, as observed between observer 1's shoulder AP measurement and US measurement.

DISCUSSION

Our study demonstrated that standardized radiographs provided the most reliable conventional radiographic position for AHD measurement, consistent with our expectations. We found that standardized true shoulder AP radiographs yielded the highest level of agreement with US measurements. Furthermore, although a good to excellent level of agreement was observed in all positions in the interobserver evaluation, outlet views yielded higher ICC values. Based on the intraobserver evaluations, we concluded that standardized outlet imaging was superior, consistent with our expectations. Both intraobserver evaluations and evaluations between observers and US showed high agreement in the measurements of senior observers, allowing us to clearly see the effect of experience on the measurements. Additionally, the data obtained in our study once again demonstrated the accuracy of using US in AHD measurement in the hypothesis stage, with excellent intraobserver agreement in US measurements (ICC: 0.98, $p<0.001$). The lack of significant difference in demographic data increases the power of our study. Furthermore, achieving statistically significant results even with data showing a low correlation level indicates the adequacy of the sample size and the study's power.

The mean value obtained for AHD measurements on US was 10.19±1.46 mm, which is consistent with other AHD measurement studies in the literature on US.[17,23,24] The excellent intraobserver agreement with a correlation value of 0.98 in the measurements we made with US in the neutral shoulder position also supports the studies in the literature with similar results.[17-19,25-27] Kim et al.[28] showed that the intraobserver correlation value with humeral flexion and rotation could be as low as 0.86. In another study, Bağcıer et al.[27] performed AHD measurements on US in the shoulder impingement syndrome group and showed an intra- and interobserver correlation with a perfect confidence interval. Although the AHD values in their study were higher than ours, Hunter et al.[29] showed that AHD increased with thickened tendons in patients with impingement syndrome, which may explain the high results of Bağcıer et al.[27]

While examining the measurements made by three observers on shoulder AP radiographs separately, the data obtained varies between 8.14-9.75 mm on average, and the results vary in the studies in the literature. Mayerhoefer et al.,[12] in their reliability study with 47 patients, reported lower measurement results with a mean of 7.6±2.3 mm with the standardized radiographs that they reported. On the other hand, the study of Saupe et al.[3] obtained similar results to our study an average AHD value of 8.7 mm on shoulder AP radiographs, but they mentioned giving a twenty-degree craniocaudal inclination to the X-ray beam. In another reliability study, Gruber et al.[30] obtained similar results to our study, with an average of 9.5 mm in the perfect confidence interval on shoulder AP radiographs. However, the ICC values of this view were significantly lower than the other positions in our study. The reason for this result was that the subacromial distance could not be clearly distinguished due to the superposition between the anterior and posterior parts of the acromion. Bernhardt et al.[31] showed that six different intervals could be evaluated as AHD in the shoulder AP views, and they reported that the correct measurement could only be made in the standardized true shoulder AP views. They emphasized that it was the responsibility of the measuring clinician to ensure this standardization.

Considering the true shoulder AP measurements, the measurements made on the standardized radiographs gave the most reliable results. Although good to excellent intraobserver agreement was observed in both measurements, in standardized measurements the mean AHD values of three different observers were in the range of 9.43 to 10.21 mm, and they were in a narrower range and closer to US measurements than non-standardized measurements. Several studies have shown that measurements made on true shoulder AP radiographs are reliable with a good and excellent level of agreement.[32,33] In a study comparing proximal migration measurement methods on standardized true AP radiographs, Kolk et al.[34] showed that AHD measurement with an ICC of 0.96 was achieved with excellent consistency, similar to our study. Furthermore, their SEM and MDC values, which were used for absolute consistency, are also consistent with our study. They also compared four different superior migration measurement methods in addition to the AHD measurement and showed that the most consistent values were obtained with the AHD measurement. These data also indicate the value of the method chosen in our study. However, we could not find any other study that compared two different true AP imaging and confirmed the obtained result with US measurements, which strengthened the reliability of the measurement. Non-standardized true shoulder AP view include many variables due to the differences in both the angle made by the patient with the cassette and the angle that the radiology technician gives to the tube in his routine practice. Some studies also used non-standardized positioning, and the measurements in those studies were also consistent with the measurements on non-standardized images in this study.[33,35]

In the measurements we made on the outlet radiographs, both intra- and interobserver measurements showed a good to excellent level of agreement, reaching up to an ICC of 0.98. These findings are consistent with those of Saupe et al.,[3] who reported excellent observer agreement in unspecified outlet radiographs. Sasiponganan et al.[14] also reported that they achieved a good level of agreement in shoulder "y" radiographs, but they also reported values even below their shoulder AP X-ray measurements with an average of 8.15 mm.

Considering the compatibility of direct radiographic measurements with US measurements, we observed that the level of correlation decreased. If the p value is greater than 0.05, it suggests that, in general, there is no significant difference in terms of average and standard deviation values. Therefore, this analysis should be given initial consideration. The ICC provides a more in-depth, case-by-case comparison. Excellent ICC values can be attained when most of the measurements closely align with each other. However, if there are outliers that substantially impact the average values, this may influence the p-value in the opposite direction. The most dependable scenario is one where the p-value exceeds 0.05 and the ICC is high.

Two important data revealed after these analyses: First, all observers had the highest ICC values on true shoulder AP views between 0.68 and 0.75 ICC. Second, even measurements were significantly different compared to US, standardized true shoulder AP and outlet measurements of the most senior observer was not different ($p>0.05$). In his two sets of measurements standardized shoulder AP view has higher p and ICC values than his outlet view measurements, which make this view much more consistent with US measurement. In the measurements with a significant difference, the mean measurement difference is around 1.5 mm, although the measurements are significantly different, and it should be investigated whether it creates a significant difference in the clinical evaluation. Despite this difference, it is noteworthy that there was a generally good level of agreement between US and all radiographic measurements. The correlation coefficient between the measurement methods is in a wide range (ICC: 0.47-0.75). Two variables could have played a role in the wide range of this confidence interval: the first one was the inconsistency of the shoulder AP and true AP views, and the second was the positive effect of experience on the correlation of the measurements. To the best of our knowledge, no other English source comparing US and conventional radiography measurements could be found in the literature, which indicates that our study is a first in this regard.

Furthermore, AHD measurements on standardized true shoulder AP and standardized outlet views had a higher level of agreement than other views in all analysis types. Although shoulder AP radiographs can be described as standardized imaging, the subacromial space image obtained in this position does not provide an appropriate measurement due to the superposition of the bones. The AHD is not only used as an indicator of rotator cuff pathology but also as a quantitative value in follow-up after rotator cuff repair or pre- and postoperative comparisons of patients' radiographic measurements, particularly after salvage procedures. However, in most of these studies, the measurement methods were not detailed or were based on non-standardized shoulder AP and true shoulder AP radiograph.[9-11,36,37] Based on the data from our study, we recommend that AHD measurements in future studies should be made on standardized radiographs, particularly true shoulder AP and outlet radiographic views.

Despite the strengths of our study, there are some limitations that need to be acknowledged. First, while our study aimed to assess the reliability of direct radiographic measurements, it would have been beneficial to include US measurements in various positions and by different observers to increase the power of the study. However, previous studies have shown that the level of experience with US imaging does not affect the results.[19] Second, since this study was designed purely as an imaging study, we did not have any clinical scores to correlate with our findings. Finally, while the observers made their measurements blindly and independently, randomization could have been implemented to reduce the possibility of bias.

In conclusion, our study results confirm the good level of agreement between conventional radiographs and US measurements, but emphasizes the need for standardized true shoulder AP or outlet radiographs to ensure accurate measurements. The level of experience also plays a role in the reliability of radiograph measurements. Although US is preferred for its advantages of cost-effectiveness, reliability, reproducibility, and soft tissue evaluation without radiation exposure; limited access, lack of experience, and time constraints are its drawbacks. Our findings suggest that standardized shoulder true AP and outlet radiographs can yield similar results as US for AHD measurement.

Ethics Committee Approval: The study protocol was approved by the Cerrahpaşa Medical Faculty Clinical Research Ethics Committee (date: 05.01.2021, no: 1214). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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