Original Article

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Transcending Patient Morphometry: Acromiohumeral Interval to Glenoid Ratio as a Universal Diagnostic Tool for Massive Rotator Cuff Tears

Chidchanok Sakdapanichkul, MD*,†, Napat Chantarapitak, MD*, Nichaphat Kasemwong, MD*, Janyavath Suwanalai, MD*, Triwish Wimolsate, MD*, Thunwarath Jirawasinroj, MD*, Thitiporn Sakolsujin, MD*, Pinkawas Kongmalai, MD*,‡

*Center of Excellence in Upper Extremity Reconstruction and Sports Medicine, HRH Princess Maha Chakri Sirindhorn Medical Center, Department of Orthopaedics, Faculty of Medicine, Srinakharinwirot University, Nakhon Nayok,
†Department of Orthopaedics, Nopparat Rajathanee Hospital, Bangkok,
‡Department of Orthopedics, Faculty of Medicine, Kasetsart University, Bangkok, Thailand

Background: Morphological differences among various ethnicities can significantly impact the reliability of acromiohumeral interval (AHI) measurements in diagnosing massive rotator cuff tears. This variation raises questions about the generalizability of AHI studies conducted in Western populations to the Asian population. Consequently, the primary objective of this study was to develop a novel parameter that can enhance the diagnosis of massive rotator cuff tears, irrespective of morphometric disparities between individuals of different ethnic backgrounds.

Methods: A 10-year retrospective analysis of shoulder arthroscopic surgery patients was conducted, categorizing them into 3 groups based on intraoperative findings: those without rotator cuff tears, those with non-massive tears, and those with massive tears. AHI-glenoid ratio (AHIGR) was measured by individuals with varying academic backgrounds, and its diagnostic performance was compared to AHI. Sensitivity, specificity, accuracy, and intra- and inter-rater reliability were evaluated.

Results: AHIGR exhibited significantly improved sensitivity, specificity, and accuracy as a diagnostic tool for massive rotator cuff tears, compared to AHI. A proposed cut-off point of AHIGR ≤ 0.2 yielded comparable results to AHI < 7 mm. Intra- and inter-rater reliability was excellent among different observers.

Conclusions: AHIGR emerges as a promising diagnostic tool for massive rotator cuff tears, offering improved sensitivity and specificity compared to AHI. Its reproducibility among diverse observers underscores its potential clinical utility. While further research with larger and more diverse patient cohorts is necessary, AHIGR offers significant potential as a reference for enhancing the assessment of massive rotator cuff tears.

Keywords: *Rotator cuff injuries, Acromiohumeral interval to glenoid ratio, Body constitution, Diagnostic tool*

There are many investigations aiding in the diagnosis of rotator cuff tears. Predominantly, magnetic resonance imaging (MRI) has been invaluable in diagnosis, surgical planning, and prognostic evaluation. However, one of the more accessible tools is the acromiohumeral interval (AHI) measured via simple radiography. This method serves as a non-invasive diagnostic tool, particularly valuable in situa-

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Correspondence to: Pinkawas Kongmalai, MD
Department of Orthopedics, Faculty of Medicine, Kasetsart University, 50, Ngamwongwan Rd, Lat Yao, Chatuchak, Bangkok 10900, Thailand
Tel: +66-8-1570-3867
E-mail: pinkawass@hotmail.com

tions where MRI may not be immediately accessible.

In shoulders with an AHI of ≤ 7 mm, 90% and 67% of individuals have full-thickness tears of the supraspinatus and infraspinatus tendons, respectively.[1] Furthermore, a decrease in AHI has been found to be significantly associated with advanced retraction of the supraspinatus tendon.[2] AHI has also been utilized as one of the parameters for diagnosing subacromial impingement syndrome.[3] Additionally, postoperative AHI can be used to evaluate the risk of supraspinatus retear after repair, achievement possibility after tendon transfer, and range of motion after reverse total shoulder arthroplasty.[4-6]

The reliability of using AHI for measurements has been a subject of controversy. While Gruber et al.[7] reported no statistically significant difference in interobserver and intraobserver measurements among 5 board-certified orthopedic surgeons. Bernhardt et al.[8] found the opposite results, with statistically significant differences in interobserver and intraobserver variabilities. AHI reliability is considered a concerning issue since it is used in clinical decision-making and as a variable in research.

Several factors can affect the reliability of AHI measurement. In addition to the measurement error, an arm position and morphometry of bones around the shoulder can also impact AHI values. AHI has been found to be higher in an upright position than in a supine position due to the gravity and weight of the upper extremity.[9,10] Furthermore, research comparing North American and East Asian populations has shown that bony morphometry, such as variations in humeral and scapular measurements, can differ significantly between ethnic groups like Caucasians and Mongolians.[11] These anatomical differences, particularly in height and other skeletal dimensions, could lead to variations in AHI measurements. Therefore, the application of AHI values derived from Western populations may require careful consideration when diagnosing rotator cuff tears in Asian populations, due to these morphometric disparities.

The objective of this study was to develop a new parameter that can help diagnose massive rotator cuff tears regardless of patient morphometry. The secondary aim was to determine the values of this new parameter for each severity of rotator cuff tear. The new parameter is called the AHI-glenoid ratio (AHIGR).

METHODS

This is a descriptive study based on 10 years of recorded data from patients who underwent shoulder arthroscopic surgery at HRH Maha Chakri Sirindhorn Medical Center between January 2012 and December 2022. The Strategic Wisdom and Research Institute and the Ethics Committees of Srinakharinwirot University approved the study for ethics review (IRB No. SWUEC-M-010/2565E). The Board waived the requirement for written informed consent. Patients who did not have a true anteroposterior plain film of the affected shoulder taken before surgery were excluded from the study. All patients were categorized into 3 groups based on their intraoperative diagnosis: the first group consisted of patients with conditions requiring surgery other than rotator cuff tears, such as shoulder instability, labral tears, adhesive capsulitis, and impingement syndrome; the second group included patients with non-massive rotator cuff tears; and the third group consisted of patients with massive rotator cuff tears, characterized by arthroscopically diagnosed full-thickness tears of 2 or more tendons.[12] Demographic data, including sex and height, were also obtained.

The AHIGR was determined using plain radiographs obtained from the true anteroposterior view of the affected shoulder, with patients in an upright standing position (Fig. 1). AHI was measured from the inferior cortex of the acromion (not from the tip of the subacromial spur) to the topmost point of the humeral head, while glenoid height was measured from the top to the bottom of the glenoid rim. AHIGR was measured by 3 individuals, who were categorized by their academic level: medical student,

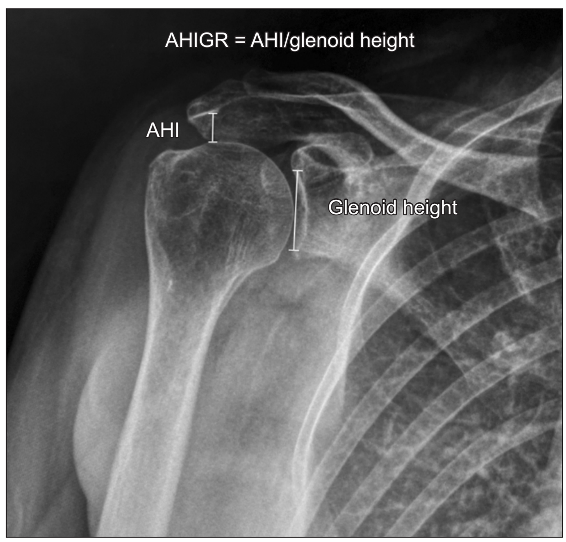

Fig. 1. Measurement of acromiohumeral interval (AHI) and glenoid height for calculating AHI-glenoid ratio (AHIGR). AHI was measured from the inferior cortex of the acromion to the topmost of the humeral head, while glenoid height was measured from the topmost to the bottom of the glenoid rim. AHIGR was calculated by dividing AHI by glenoid height.

orthopedic surgery resident, and board-certified orthopedic surgeon. Each person measured AHIGR twice, with a 1-month interval between measurements. The patients were also divided into 3 groups based on their height for subgroup analysis: 145–158 cm, 159–166 cm, and 167–185 cm.

The primary outcome was sensitivity and specificity of AHIGR in diagnosing massive rotator cuff tears, with reference from arthroscopy, which is a gold standard for the diagnosis of rotator cuff tears. The secondary outcome was the cut point of AHIGR that tells massive rotator cuff tears. AHIGR was also compared among the 3 groups. Subgroup analysis in sensitivity and specificity of AHIGR and AHI for diagnosis of massive rotator cuff tears in 3 different groups of height was evaluated. Intra-rater and inter-rater reliabilities for AHIGR were also assessed.

To calculate the sample size, we employed the formula $(Z_{\alpha/2}^2 S_N [1 - S_N]) / d^2$ for determining the necessary sample size to estimate sensitivity, where $Z_{\alpha/2}$ represents the Z-score corresponding to the desired confidence level (α), S_N denotes sensitivity, and d is the margin of error. For specificity, the formula $N = (n \times 100) / P$ was utilized, with N indicating the total sample size needed, n the sample size derived from the sensitivity calculation, and P the prevalence of the condition. In our calculations, S_N was set at 50% based on findings from Razmjou et al.[13] and the prevalence of massive rotator cuff tears was set to 0.75 based on a study by Nove-Josserand et al.[14] We used a d value of 0.125 and an α level of 0.05 to ensure statistical rigor in our analysis. After correcting with prevalence, at least 83 patients were required for the study.

The demographic data were presented as frequency, percentage, and mean with standard deviation. Sensitivity, specificity, and accuracy of AHIGR were determined by the cut point obtained from receiver operating characteristic (ROC) analysis. A *t*-test was used to compare AHIGR among the 3 groups. The intra-rater and inter-rater reliabilities were reported as concordance correlation coefficients with confidence intervals (CIs). All statistical analyses were performed using Stata version 14.0 (Stata Corp.).

RESULTS

From January 2012 to December 2022, a total of 145 patients were included in our study, encompassing all eligible individuals who underwent shoulder arthroscopic surgery at HRH Maha Chakri Sirindhorn Medical Center and met our inclusion criteria. Table 1 displays the demographic data, which include 41 patients without rotator cuff tears, 42 patients with non-massive rotator cuff tears, and 62 patients with massive rotator cuff tears. There was no significant difference in sex distribution between the 3 groups ($p = 0.144$); however, there was a significant difference in height among the groups ($p < 0.05$).

The mean AHIGR along with the standard deviation was 0.288 ± 0.058, 0.305 ± 0.064, and 0.252 ± 0.92 for the no rotator cuff tear, non-massive rotator cuff tear, and massive rotator cuff tear groups, respectively (Table 2). There were statistically significant differences between the massive rotator cuff tear group and the other 2 groups (no rotator cuff tear vs massive rotator cuff tear, $p < 0.05$; non-massive rotator cuff tear vs massive rotator cuff tear, $p < 0.05$). However, no significant difference was noted between the no rotator cuff tear and non-massive rotator cuff tear groups.

ROC analysis (Supplementary Material 1) was used to determine the cut-off point for AHIGR and AHI in the diagnosis of massive rotator cuff tear. The AHIGR cut-off point of 0.20 was found to have a sensitivity of 22.58% (95% confidence interval [CI], 15.78%–29.39%), specificity of 98.80% (95% CI, 97.02%–100%), and accuracy of 66.20%. Similarly, the AHI cut-off point of ≤ 7 mm was found to have a sensitivity of 24.29% (95% CI, 17.22%–31.16%), specificity of 96.39% (95% CI, 93.35%–99.42%), and accuracy of 65.51%. Table 3 summarizes these results.

Table 1. Demographic Data

Variable	Total (n = 145)	No RCT (n = 41)	Non-massive RCT (n = 42)	Massive RCT (n = 62)	*p*-value
Sex					0.144
Male	81 (55.86)	28 (68.3)	20 (47.6)	33 (53.2)	
Female	64 (44.14)	13 (31.7)	22 (52.4)	29 (46.8)	
Height (cm)	161.8 ± 8.7	166.0 ± 9.4	159.9 ± 7.5	160.3 ± 8.1	0.001

Values are presented as number (%) or mean ± standard deviation.
RCT: rotator cuff tear.

Table 2. *t*-Test Results Comparing AHIGR among 3 Groups

Group	AHIGR	*t*	*p*-value
No RCT (n = 41)	0.288 ± 0.058	No RCT vs. non-massive RCT: –1.210 No RCT vs. massive RCT: 2.407 Non-massive RCT vs. massive RCT: 3.398	No RCT vs. non-massive RCT: 0.229 No RCT vs. massive RCT: 0.017 Non-massive RCT vs. massive RCT: 0.001
Non-massive RCT (n = 42)	0.305 ± 0.064		
Massive RCT (n = 62)	0.252 ± 0.92		

Values are presented as mean ± standard deviation.
AHIGR: acromiohumeral height-glenoid ratio, RCT: rotator cuff tear.

Table 3. Diagnostic Value of AHIGR and AHI

Variable	Sensitivity (%)	95% CI (%)	Specificity (%)	95% CI (%)	Accuracy (%)
AHIGR ≤ 0.20	22.58	15.78–29.39	98.80	97.02–100	66.20
AHI ≤ 7 mm	24.19	17.22–31.16	96.39	93.35–99.42	65.51

AHIGR: acromiohumeral height-glenoid ratio, AHI: acromiohumeral interval, CI: confidence interval.

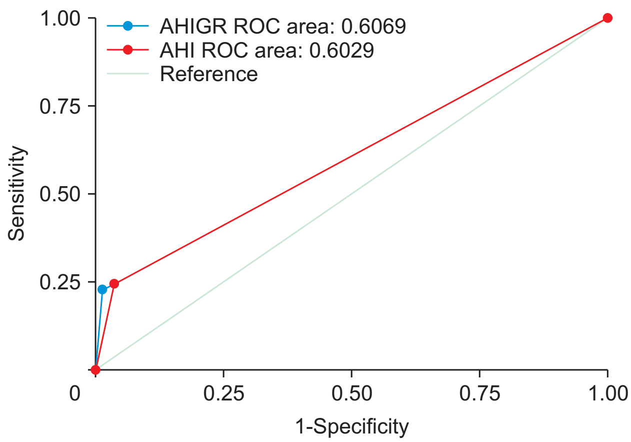

Fig. 2. Receiver operating characteristics (ROC) area of acromiohumeral interval (AHI)-glenoid ratio (AHIGR). AHIGR and AHI using Stata program.

The ROC area of AHIGR and AHI for the diagnosis of massive rotator cuff tear was compared (Fig. 2). The ROC area of AHIGR was 0.6069 (95% CI, 0.5531–0.6606) while that of AHI was 0.6029 (95% CI, 0.5455–0.6603). Based on the higher ROC area, AHIGR was found to be a better diagnostic tool for massive rotator cuff tears compared to AHI.

In the subgroup analysis stratified by patient height (Table 4), a total of 145 patients were divided into 3 groups based on their height. Group 1 (145–158 cm) consisted of 54 patients, group 2 (159–166 cm) included 53 patients, and group 3 (167–185 cm) had 38 patients. AHIGR ≤ 0.20 and AHI ≤ 7 mm were utilized for diagnosing massive rotator cuff tears in this analysis.

Using AHIGR, in group 1, the sensitivity, specificity, and accuracy were 20.00% (95% CI, 9.33%–30.67%), 96.55% (95% CI, 91.69%–100%), and 61.11%, respectively. In group 2, the sensitivity, specificity, and accuracy were 24.00% (95% CI, 12.5%–35.5%), 100%, and 64.15%, respectively. In group 3, the sensitivity, specificity, and accuracy were 25.00% (95% CI, 11.23%–38.77%), 100%, and 76.31%, respectively.

When using AHI, in group 1, the sensitivity, specificity, and accuracy were 28.00% (95% CI, 16.02%–39.98%), 93.10% (95% CI, 86.34%–99.86%), and 62.96%, respectively. In group 2, the sensitivity, specificity, and accuracy were 20.00% (95% CI, 9.23%–30.77%), 96.43% (95% CI, 91.43%–100%), and 60.37%, respectively. In group 3, the sensitivity, specificity, and accuracy were 25.00% (95% CI, 11.23%–38.77%), 100%, and 76.31%, respectively.

The concordance correlation coefficient (CCC) and Bland-Altman plots were utilized to demonstrate the correlation for intra-rater and inter-rater measurements, as presented in Table 5 and Fig. 3, respectively. In the results of intra-rater measurements for AHIGR, the CCC for the medical student, the orthopedic surgery resident, and the board-certified orthopedic surgeon were 0.923 (95% CI, 0.899–0.947), 0.749 (95% CI, 0.679–0.819), and 0.866 (95% CI, 0.828–0.905), respectively. The correlation was considered very high for the medical student, high for the orthopedic surgery resident, and very high for the board-certified orthopedic surgeon.

Regarding inter-rater measurements for AHIGR,

Table 4. Subgroup Analysis of Sensitivity and Specificity of AHIGR and AHI for Diagnosis of Massive Rotator Cuff Tear in 3 Different Groups of Height

Subgroup	Group 1 (n = 54)	95% CI	Group 2 (n = 53)	95% CI	Group 3 (n = 38)	95% CI
Height (cm, range)	145–158		159–166		167–185	
AHIGR ≤ 0.20						
Sensitivity (%)	20.00	9.33–30.67	24.00	12.5–35.5	25.00	11.23–38.77
Specificity (%)	96.55	91.69–100	100		100	
Accuracy (%)	61.11		64.15		76.31	
AHI ≤ 7 mm						
Sensitivity (%)	28.00	16.02–39.98	20.00	9.23–30.77	25.00	11.23–38.77
Specificity (%)	93.10	86.34–99.86	96.43	91.43–100	100	
Accuracy (%)	62.96		60.37		76.31	

AHIGR: acromiohumeral height-glenoid ratio, AHI: acromiohumeral interval, CI: confidence interval.

Table 5. Intra-rater and Inter-rater Reliabilities in Measurement of AHIGR

Variable	CCC	95% CI	Interpretation	*p*-value
Intra-rater reliability				
Medical student	0.923	0.899–0.947	Very high	< 0.001
Orthopedic surgery resident	0.749	0.679–0.819	High	< 0.001
Board-certified orthopedic surgeon	0.866	0.828–0.905	Very high	< 0.001
Inter-rater reliability				
Medical student vs orthopedic surgery resident	0.796	0.737–0.856	High	< 0.001
Medical student vs board-certified orthopedic surgeon	0.898	0.867–0.929	Very high	< 0.001
Orthopedic surgery resident vs. board-certified orthopedic surgeon	0.711	0.634–0.788	High	< 0.001

AHIGR: acromiohumeral height-glenoid ratio, CCC: concordance correlation coefficient, CI: confidence interval.

the correlation between the medical student and the orthopedic surgery resident was high with a CCC of 0.796 (95% CI, 0.737–0.856). The correlation between the medical student and the board-certified orthopedic surgeon was very high with a CCC of 0.898 (95% CI, 0.867–0.929). The correlation between the orthopedic surgery resident and the board-certified orthopedic surgeon was high with a CCC of 0.711 (95% CI, 0.634–0.788).

DISCUSSION

Our study marks the first attempt to investigate the AHI in relation to a patient-specific parameter, which is the glenoid height, measured on the same radiograph, leading to the development of the AHIGR. We found that AHIGR in cases of massive rotator cuff tears was significantly lower compared to those without rotator cuff tears and those with non-massive rotator cuff tears. Furthermore, AHIGR demonstrated higher sensitivity, specificity, and accuracy in diagnosing massive rotator cuff tears compared to AHI, as shown by ROC analysis. Our analysis suggests that AHIGR may offer certain benefits in diagnosing massive rotator cuff tears compared to AHI. However, these findings do not conclusively establish the superiority of AHIGR, and further in-depth research is essential to validate and clarify these initial observations.

Moreover, the results of the CCC and Bland-Altman plots demonstrated that AHIGR exhibits high to very high

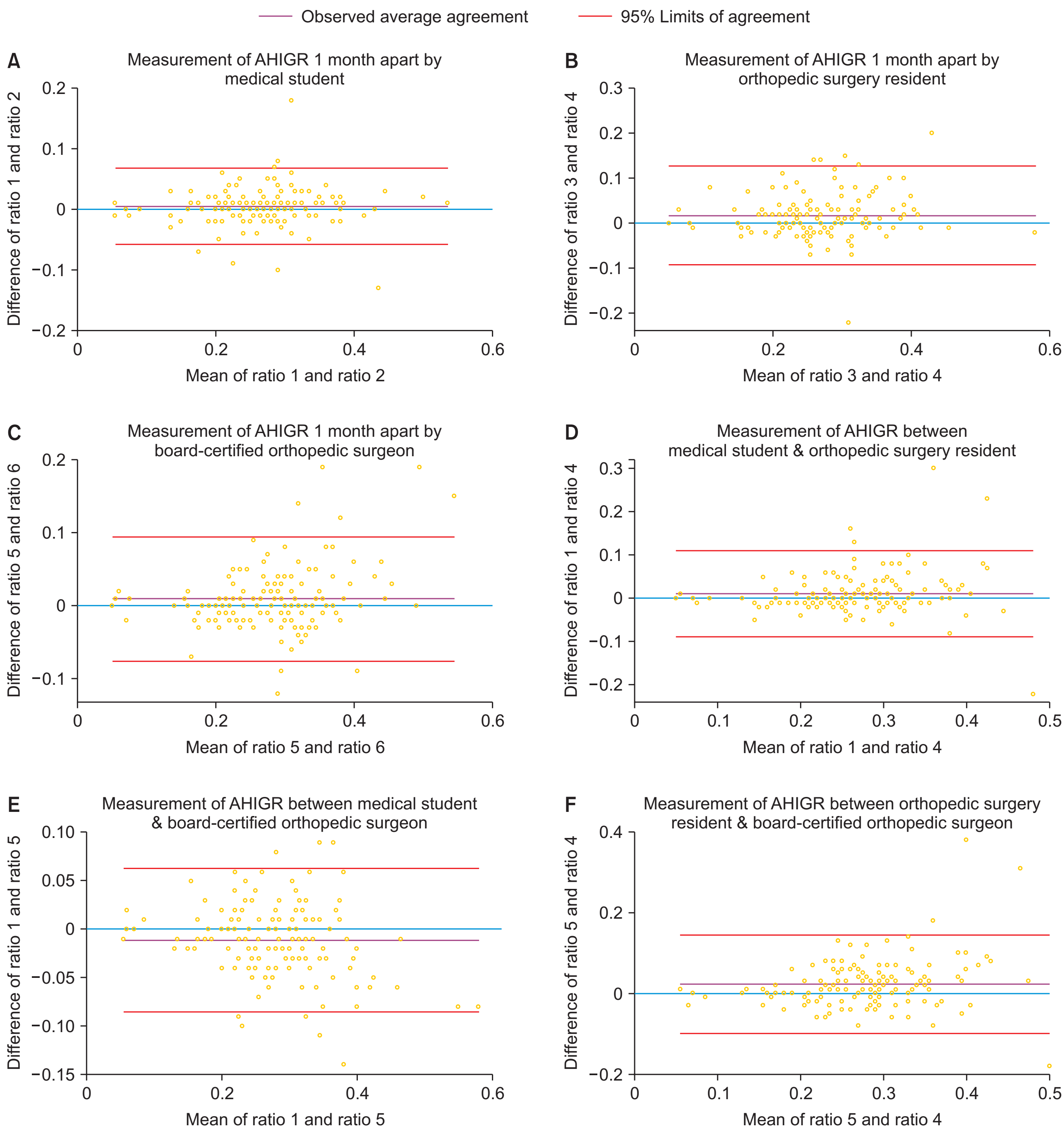

Fig. 3. The Bland-Altman plots were used to display the difference between 2 measurements of acromiohumeral interval-glenoid ratio (AHIGR) against their mean. (A-C) These plots assess intra-rater reliability for AHIGR measurements. (A) Measurements taken by a medical student 1 month apart, (B) by an orthopedic surgery resident, and (C) by a board-certified orthopedic surgeon. The good reliability across these panels is indicated by most of the data points being well within the upper and lower limits of agreement, marked by gray bold lines. These lines demonstrate consistent measurements over time by the same observer. (D-F) These plots evaluate inter-rater reliability for AHIGR measurements. (D) Comparison of measurements between a medical student and an orthopedic surgery resident, (E) between a medical student and a board-certified orthopedic surgeon, and (F) between an orthopedic surgery resident and a board-certified orthopedic surgeon. Good reliability in these panels is also demonstrated by the majority of data points clustering within the limits of agreement, marked by gray bold lines. This indicates consistent measurements across different observers. Y = 0 is line of perfect average agreement.

levels of intra- and inter-rater reliability among medical students, orthopedic surgery residents, and board-certified orthopedic surgeons. These findings indicate strong correlation and good agreement, implying the reproducibility of AHIGR measurements. Consequently, AHIGR could be considered as an intriguing and reliable measurement for assessing massive rotator cuff tears.

We proposed a cut-off point for AHIGR to identify the presence of a massive rotator cuff tear, with an AHIGR ≤ 0.2 yielding a sensitivity of 22.58% and a specificity of 98.80%. These values are comparable to those obtained for AHI < 7 mm. Initially, we hypothesized that there might be differences in sensitivity and specificity when comparing AHI across patient height groups. However, subgroup analysis revealed no significant differences between AHIGR ≤ 0.2 and AHI < 7 mm in all height groups. This outcome might be attributed to the relatively small variation in patient heights within our cohort. In future studies, we plan to explore AHIGR in taller subjects and those with more diverse morphometric characteristics.

In 2017, Singleton et al.[15] introduced a new radiographic measurement, the Acromiohumeral Centre Edge Angle (ACEA), which is not affected by shoulder rotation. While ACEA exhibits high reproducibility, a definitive cut-off point indicating the severity of acute rotator cuff tears was not determined. Subsequently, in 2020, Park et al.[16] investigated radiological parameters related to the superior migration of the humeral head in massive rotator cuff tears, including the AHI, inferior glenohumeral distance, and upward migration index. While these parameters were highly correlated, no specific cut-off values were established. In contrast, our study demonstrates that AHIGR exhibits high intra- and inter-rater concordance, and an AHIGR value of ≤ 0.2 provides a sensitivity of 22.58% and a specificity of 98.80% for detecting massive rotator cuff tears.

Our study has some limitations. Firstly, it is a single-center study, which may potentially affect its generalizability. Future research on AHIGR should involve multicenter studies or include patients with more diverse morphometric characteristics to enhance generalizability. Secondly, our study did not reveal a significant difference between the no rotator cuff tear and non-massive rotator cuff tear groups. However, the lack of distinction may be attributed to factors that warrant further investigation. Additionally, our study did not investigate the potential impact of patient positioning, arm orientation, and variations in radiographic beam angles on the cut-off point of AHIGR. These factors could introduce variability in measurements and are important areas for future research to explore. Understanding how these variables might affect AHIGR measurements could provide further insights into its diagnostic accuracy and utility. The last limitation is the influence of adhesive capsulitis present in 6 cases in group 1 on AHI measurements. Adhesive capsulitis can cause upward humeral migration, potentially altering AHI independently of rotator cuff pathology. To mitigate this, future studies should consider separately analyzing cases with known adhesive capsulitis or adjusting the AHI interpretation criteria for such conditions.

The AHIGR stands out as a promising tool for the diagnosis of massive rotator cuff tears, with improved sensitivity, specificity, and accuracy over the traditional AHI. Its consistent reproducibility across observers of varying experiences enhances its clinical utility. Although further validation is required through research involving larger and more diverse patient groups, AHIGR proves to be a significant addition to the existing methods for assessing massive rotator cuff tears.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

ORCID

Chidchanok Sakdapanichkul https://orcid.org/0000-0002-7508-1437
Napat Chantarapitak https://orcid.org/0009-0004-2843-4692
Nichaphat Kasemwong https://orcid.org/0009-0009-6772-3637
Janyavath Suwanalai https://orcid.org/0009-0009-5412-3982
Triwish Wimolsate https://orcid.org/0009-0004-0161-3949
Thunwarath Jirawasinroj https://orcid.org/0009-0002-5104-2545
Thitiporn Sakolsujin https://orcid.org/0009-0009-9834-0217
Pinkawas Kongmalai https://orcid.org/0000-0003-3397-6600

SUPPLEMENTARY MATERIAL

Supplementary material is available in the electronic version of this paper at the CiOS website, www.ecios.org.

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