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*Original Research*

# Association Between Acromiohumeral Distance, Shoulder Rotational Strength, and Range of Movements in University Basketball Players: A Cross-Sectional Study

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**Abstract**

**Objectives:** Limited information exists regarding the sports-related adaptations at the shoulder complex in university basketball players. Therefore, this study aimed to evaluate the shoulder rotational muscle strength, range of movements (ROM), and acromiohumeral distance (AHD) values to interpret side-to-side differences regarding injury risk factors in dominant and non-dominant shoulders of university basketball players.
**Materials and Methods:** Twenty university basketball players (10 males, 10 females; age=20.2±1.8 years; body mass index=21.1±2.22 kg/m$^2$) were included. AHD values, isometric and concentric strengths of shoulder external (ER) and internal rotation (IR), and shoulder ER, IR, and total rotational ROM were measured bilaterally.
**Results:** AHD was greater on the dominant side at 0° ($p<0.001$) and 60° of shoulder abduction positions ($p<0.001$). However, dominant shoulders demonstrated more AHD reduction from 0° to 60° of shoulder abduction ($p=0.01$). We found greater isometric ER strength ($p=0.006$), ER/IR ratio ($p=0.001$), concentric ER strength ($p<0.001$), concentric ER/IR ratio ($p<0.001$), and ER ROM ($p<0.001$) in the dominant shoulders. Besides, AHD was correlated with isometric ER strength on the dominant side ($p=0.012$, $r=0.552$) and non-dominant side ($p=0.041$, $r=0.461$), also, isometric ER/IR strength ratio on the dominant side ($p=0.017$, $r=0.526$) and the non-dominant side ($p=0.013$, $r=0.545$).
**Conclusion:** University basketball players demonstrated stronger ER muscle strength, higher ER/IR strength, increased ER ROM, and wider AHD values on the dominant shoulders. Moreover, greater ER muscle strength and ER/IR strength ratio were associated with greater AHD.

***Keywords:*** *shoulder joint, muscle strength, subacromial space, overhead athlete*

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## Introduction

Shoulder injuries are often seen in basketball players, as the shoulder complex is at risk of injury during high loads and forces during overhead athletic performance (Bonza et al., 2009; Burkhart et al., 2003; Tooth et al., 2020). Players sustain at least one shoulder injury during their athletic career regardless of their sports participation level: professional or amateur (Bonza et al., 2009; Tooth et al., 2020). Repetitive overhead activities - with high velocity and an extreme range of shoulder movements - could yield sport-specific shoulder adaptations that make the players more likely to suffer from shoulder injuries (Tooth et al., 2020). The most commonly observed shoulder injury in basketball players is rotator cuff tendinopathy, which requires the shoulder to perform similar motions repeatedly during athletic performance (Kibler et al., 2023; Owens & Itamura, 2000). The rotator cuff tendinopathy is a result of soft tissue compression within the subacromial space (Michener et al., 2003).

Acromiohumeral distance (AHD), the two-dimensional measure of the subacromial space, is a commonly investigated variable in overhead athletes (Mayerhoefer et al., 2009; Michener et al., 2003). Since abnormal subacromial space narrowing is linked to possible mechanisms in the etiology of rotator cuff tendinopathy, AHD is believed to be clinically important (Mayerhoefer et al., 2009; Michener et al., 2003). From a biomechanical perspective, the force coupling function of the rotator cuff muscles opposes the superior migration force that is generated by the deltoid muscle, helping maintain AHD and preventing abnormal subacromial space narrowing during overhead activities (Myers et al., 2009). However, imbalance among the rotator cuff muscles can result in abnormal subacromial space narrowing, leading to the rotator cuff tendon compression secondary to superior translation of the humeral head (Mayerhoefer et al., 2009; Michener et al., 2003). Similarly, rotator cuff strength deficiency could be another implication of a pathological decrease of the AHD, thereby developing rotator cuff tendinopathy (de Oliveira et al., 2017; Myers et al., 2009).

Previous studies have established the rotator cuff muscles' role in dynamically controlling glenohumeral kinematics during overhead athletic performance (Leong et al., 2012; Mackenzie et al., 2015; Myers et al., 2009). One study conducted on volleyball players indicated that a shoulder external rotator strength deficit or an imbalance in the strength ratio of the shoulder external (ER) and internal rotators (IR) might decrease the AHD (Leong et al., 2012). Yet, no study reports any information on whether the strength and strength ratio of the shoulder rotators is related to AHD values in basketball players. Even volleyball and basketball are both considered overhead sports; in fact, each sport's demands on the shoulder joint or

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throwing patterns are completely different (Mondal et al., 2016; Ohuchi et al., 2023). Volleyball players perform asymmetrical throwing patterns, whereas basketball players use their dominant and non-dominant shoulders more symmetrically (Mondal et al., 2016). Basketball players engage both shoulders in cyclical movements, which could lead to different adaptations of the strength and strength ratio between ER and IR, and the asymmetry of strength between the dominant and non-dominant sides can be demonstrated (Mondal et al., 2016). Besides, more engagement of the non-dominant side could further result in similar sports-specific adaptations, which are predicted to be seen on the dominant side. Due to these controversies of a sports nature, such investigation would yield more information on the pathogenesis of rotator cuff tendinopathy in basketball players, thereby underpinning preventive programs.

The relationship between shoulder rotational strength deficiency and AHD values in basketball players might not exhibit similarity to what has been reported in volleyball players (Leong et al., 2012). To date, the association between AHD values and shoulder rotational muscle strength and range of movement (ROM) in university basketball players has not yet been evaluated. Therefore, we purposed to evaluate AHD values and shoulder ER and IR muscle strength and ROM side-to-side in dominant and non-dominant shoulders of university basketball players and see whether any associations would be between AHD values and shoulder rotational strength & strength ratios and ROM. We primarily hypothesized that greater shoulder rotational muscle strengths and strength ratio were associated with a greater AHD in university basketball players. Besides, the secondary hypothesis was that shoulder rotational strength and AHD would be greater on the dominant shoulders than on the non-dominant side due to the sports-specific loading.

## Materials and Methods

This study was carried out at Ankara Medipol University. The University Institutional Review Board approved the protocol (date: March 15, 2023, approval number: 0036), and the study was conducted in accordance with the Declaration of Helsinki. Players were informed of the protocol and signed a consent form before the study.

### Participants

Twenty university basketball players (10 males, 10 females) aged 18 to 22 were included. They were semi-professionals on the university basketball team with a declared amount of four hours of training per week in addition to weekly matches. Players with previous shoulder pain (a positive Hawkins, Neer, or Jobe test), shoulder fractures, and shoulder instabilities (a positive Apprehension or O'Brien's test) were excluded. The experienced investigator (I.D.), who had 25 years of clinical experience as a physiotherapist treating patients with shoulder pathologies, conducted the clinical tests to ensure eligibility for the study. Demographic information of the players (age, body mass index (BMI), dominant shoulder (the side on which they throw a ball), and years of sports experience were recorded (Fieseler et al., 2015). In this study, all players used their right shoulder as a dominant shoulder.

**Procedure**

This study used a cross-sectional study design. All players were instructed to avoid vigorous shoulder activities to avoid muscular fatigue. The AHD, the isometric and concentric strengths of the shoulder rotators, the passive ER and IR range ROM, and total rotational ROM were measured.

***Acromiohumeral Distance*** was measured using real-time ultrasonography (Siemens Acuson S2000 (Siemens Medical Systems, Erlangen, Germany) with a 6.5-13 MHz adjustable linear array transducer set at 8.0 MHz). Previous studies have shown good reliability and validity for the ultrasound measurement of AHD in healthy individuals (Kumar et al., 2010; Kumar et al., 2011). Measurements were obtained on the dominant and non-dominant shoulders at 0° and 60° of shoulder abduction positionings in the coronal plane. Prior to measurements, the player's positioning was standardized in the following: standing upright with their feet shoulder-width apart, upper limbs at their sides, and flexing elbow at 90° with the thumb pointing upwards (for the 60° of shoulder abduction angles, the players were asked to raise their arms to 60° of shoulder abduction actively, as determined with a goniometer). Players were also asked to keep their neutral trunk posture and head facing forward throughout the measurements. To correctly visualize the subacromial space, the ultrasound transducer was positioned on the most anterior aspects of the acromion in line with the longitudinal axis of the humerus (Cholewinski et al., 2008b). The shortest linear distance between the superior humeral head and the acromion's inferior edge was defined as an AHD (in millimeters) (Figure 1).

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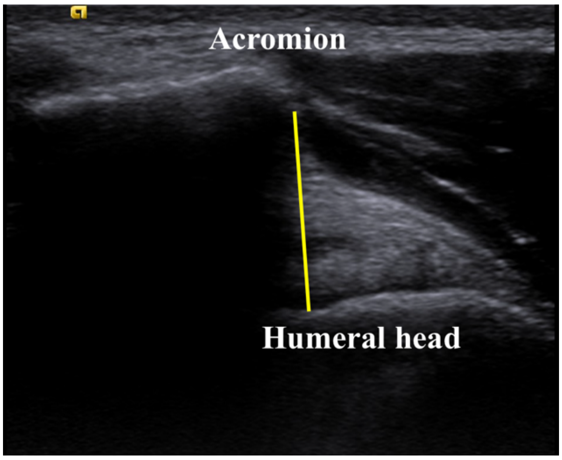


**Figure 1.** Measurement of The Acromiohumeral Distance Using an Ultrasound. The Line Illustrates the Shortest Distance Between the Acromion and the Humeral Head

First, the ultrasound image of the AHD was obtained at 0° and 60° of shoulder abduction angles in the coronal plane, respectively, starting from the dominant shoulder and proceeding to the non-dominant shoulders. AHD was recorded at each shoulder position. The same measurement order was strictly followed by the dominant and non-dominant shoulders of the players. The assessor removed the ultrasound transducer from the shoulder between measurements for each trial. Between the trials, players were asked to return to their resting position and then repositioned for further measurements. For all shoulder positionings, three consecutive ultrasound images were captured for each shoulder positioning, and the mean was recorded for data analysis.

All ultrasound images were obtained by an experienced radiologist (O.Y.), blinded to the testing procedure, with more than ten years of clinical experience in musculoskeletal ultrasound imaging to minimize inter-rater variability. In our preliminary study, the test-retest between-day reliability of our procedure revealed excellent reliability ($ICC_{(2,3)}$ for AHD at 0° and 60° of abductions were 0.95 and 0.87, respectively) (Eraslan et al., 2022).

Additionally, we computed the rate of change in AHD (ΔAHD) using the following equation.

$\Delta AHD\ (\%) = [(AHD_{0°} - AHD_{60°})\ x\ AHD_{0°}^{-1}]\ x\ 100$

***Shoulder Rotational Strength Measurements*** Isometric and concentric strengths of shoulder ER and IR were measured using an isokinetic dynamometer (model; IsoMed®2000; DR Performance GmbH, Dusseldorf, Germany). Players were seated with their shoulders at 45° of abduction in the scapular plane, elbows at 90° of flexion, forearms in a neutral position, and hands grasping the handle of the upper limb test adapter (Figure 2).

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**Figure 2.** Isokinetic Evaluation of Shoulder Rotational Strength in the Scapula Plane

The reason why the shoulders were positioned at 45° of abduction in the scapular plane rather than the coronal plane was that it was reported to be more physiological; the length-tension relationships of the shoulder rotators are optimized in the scapular plane (Greenfield et al., 1990), and the capsular fibers of the glenohumeral joint are relaxed (Edouard et al., 2011). Furthermore, this positioning showed good to excellent reliability in measuring peak torques of shoulder ER (ICC:0.81-0.94) and IR (ICC:0.92) (Edouard et al., 2011; Greenfield et al., 1990).

During testing, players were stabilized to the seat by using the adhesive straps; first, they were placed horizontally across the chest, and second, they were placed pelvis on the pelvis to stabilize the trunk to the seat to minimize the trunk's compensatory movements. Additionally, arm and forearm stabilization straps and pads were used. We applied the gravity correction with the arm relaxed position (shoulder at 45° of abduction and the forearm in a neutral position). Prior to measurements, players were informed about the testing procedure, the required effort, and the commands that would be used to start and complete each testing sequence. Following a 6-minute global warm-up using an arm ergometer, we evaluated shoulder ER and IR's isometric and concentric strengths.

**Isometric Muscle Strength.** The test was started at 45° of shoulder abduction in the neutral position. For familiarization, the players were asked to perform three submaximal repetitions, and then three maximal isometric IR strength tests were performed, followed by three maximal isometric ER strength tests. Two minutes rest was given between each strength test. Players were asked to pull as hard as possible during the test.

The peak isometric torque of ER and IR muscles were measured from the isokinetic dynamometer and was normalized to each player's body mass (in newton-meter/kilogram [Nm/kg]). The strength ratio of peak ER/peak IR was also calculated as follows:

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The ratio of peak torque ER to IR peak torque= (peak torque ER/ peak torque IR) ×100

**Concentric Muscle Strength.** The strengths of concentric ER (conER) and concentric IR (conIR) were tested at 60°/s angular velocity through a ROM of 70°, consisting of 30° for IR and 40° for ER, from a reference point with the forearm positioned horizontally at 0°. For familiarization, the players were asked to perform five submaximal repetitions. After 2 minutes of rest, five maximal reciprocal repetitions were performed at 60°/s angular velocity. The players were also verbally encouraged to use maximal strength during each contraction sequence.

Because the slower test speed allows for a more sensitive assessment of the conER/conIR ratio suggested from previous findings, the angular velocity of 60°/s was chosen (Aagaard et al., 1996; Ellenbecker & Davies, 2000; Greenfield et al., 1990). Moreover, test-retest reliability of shoulder conER and conIR testing in the scapular plane at 60°/s angular velocity has been shown good reliability (ICC:0.87) (Durall et al., 2001).

The peak concentric torques obtained from the isokinetic dynamometer were normalized against players' body mass (in newton-meter/kilogram [Nm/kg]), and the strength ratios were calculated in the concentric contraction mode (conER/conIR ratio) for analysis.

The ratio of peak torque conER to conIR peak torque= (peak torque conER/ peak torque conIR) ×100

Each player followed the same standardized procedure, and all isokinetic testing was performed by the main investigator (L.E.), who had 14 years of clinical experience as a physiotherapist, in order to minimize inter-rater variability.

***Shoulder Rotational Range of Motions*** Shoulder passive ER and IR ROM were measured using a standard goniometer before isokinetic strength testing. Players were laid in a supine position with their shoulders abducted at 90°, elbows flexed at 90°, forearms in neutral, and knees flexed. During the measurements, the goniometer's axis location was placed on the olecranon, the stationary arm was placed vertically on the floor, and the movement arm followed in line with the ulnar side of the forearm. The passive ER ROM was recorded when reaching the firm capsular end-feel, and the passive IR ROM was recorded when scapulothoracic movement occurred (Sauers et al., 2014). All measurements were taken by the same investigator (L.E.). The total rotational movement was calculated by summing the ER and IR ROMs of each side. Additionally, glenohumeral internal rotation deficit (GIRD) was calculated (the difference in IR ROM between the dominant and non-dominant sides). Pathological GIRD was defined in players presenting an IR deficit>18° and a total rotational movement difference of 5° between the shoulders (Borsa et al., 2008; Maenhout et al., 2012). Three measurements were obtained, and the mean was used for analysis.

**Sample Size Calculation**

The sample size was calculated using the G*Power for Mac (Version 3.1.9.6; Universitat Dusselfodorf, Germany). Shoulder ER/IR strength ratio and AHD on the dominant side were determined with correlation coefficient (correlation value= 0.793) in agreement with the study by Schmidt et al. (Schmidt et al., 2021). The priori sample size calculation was conducted as follows: a) effect size of 0.5, b) significance level of 5%, c) power of 80% (Hinkle et al., 2003). After all, a post-hoc power calculation revealed that our final sample size (twenty basketball players) provided 81% power at the end of the study.

**Data Analysis**

Statistical analyses were performed using SPSS Statistics (Version 24 for Mac; IBM Corp., Armonk, NY, USA). Demographic characteristics of the players (continuous data, i.e., age, BMI, weekly sports exposure) were presented descriptively as means with standard deviation (x (SD) with 95% confidence intervals. Categorical data, namely, dominancy and gender, were presented in numbers. The normal distribution of the data was analyzed using the Shapiro–Wilk test. Since the normal distribution was observed, a paired samples *t*-test was used to examine the AHD values, shoulder rotational muscle strength, and ROM between the dominant and non-dominant shoulders (side differences). Then, a Pearson rank correlation coefficient (rho) test was used to determine if there were any associations between the AHD values (0° and 60° of shoulder abduction positions) and the rate of AHD changes between positions and shoulder rotation strengths, and ER/IR strength ratios. The relationship was defined as positive or negative based on the value of the rho. The strength of the correlation was interpreted as “strong” (rho>0.5), “moderate” (0.5≥rho≥0.3), or “poor” (rho<0.3) (Mukaka, 2012). The significance level for all tests was set at 0.05.

## Results

Between April 2023 and July 2023, twenty-two potential candidates playing a university basketball team were assessed for eligibility at baseline. However, two players were excluded from the study since they had attended vigorous upper-limb activities prior to the measurements. Of 20 players participating in the study, their demographic information was as follows: mean age: 20.2±1.8 years., BMI: 21.1±2.22 kg/m$^2$, mean sports experience: 5.4±2.1 years, mean sport exposure: 4.1±1.3 h/week).

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Data on AHD values, shoulder rotational muscle strength and ER/IR strength ratios, and shoulder ER and IR ROMs are summarized in Table 1.

AHD was greater on the dominant side at 0° (t=9.405, p<0.001) and 60° of shoulder abduction positions (t=5.295, p<0.001) than on the non-dominant side. Yet, when comparing ΔAHD, dominant shoulders demonstrated more reduction (t=2.826, p=0.01). Isometric ER strength and ER/IR ratio were higher for the dominant sides than the non-dominant sides (t=3.090, p=0.006; t=3.373, p=0.001, respectively). Besides, higher peak torque in shoulder concentric ER strength (t=4.544, p<0.001) and concentric ER/IR ratio (t=5.743, p<0.001) were observed for the dominant shoulder at 60°/s when compared with non-dominant side. Additionally, ROM for ER was greater (t=4.566, p<0.001), whereas ROM for IR was less (t=-4.747, p<0.001) on the dominant side. Yet, no other side–side differences were observed.

**Table 1.** Acromiohumeral Distance values, External- and Internal-Rotator Strength and Strength Ratios, and External- and Internal-Rotation Range of Movement of the Dominant and Non-dominant Shoulders with 95% Confidence Intervals

| **Measurements** | | Shoulder (mean ± SD) | | **95% Confidence Interval** | **t** | **p value** |
|---|---|---|---|---|---|---|
| | | dominant | non- dominant | | | |
| AHD, mm | 0° | 11.07 ± 1.7 | 9.4 ±1.7 | 1.313, 2.066 | **9.405** | **<0.001*** |
| | 60° | 7 ± 1.6 | 6.3 ± 1.4 | 0.398, 0.918 | **5.295** | **<0.001*** |
| | ΔAHD (%) | 36.88 ± 10.6 | 32.4 ± 8.9 | 1.205, 7.77 | **2.826,** | **p=0.01*** |
| ER, Nm/kg | iso | 0.28 ± 0.83 | 0.21 ±0.09 | -0.023, 0.119 | **3.090** | **0.006** |
| | con, 60°/s | 0.23 ± 0.08 | 0.18 ± 0.07 | 0.029, 0.081 | **4.544** | **<0.001*** |
| | con, 180°/s | 0.19 ± 0.06 | 0.16 ± 0.06 | -0.0003, 0.047 | 2.060 | 0.053 |
| IR, Nm/kg | iso | 0.51 ± 0.14 | 0.53 ± 0.12 | -0.042, 0.007 | -1.448 | 0.164 |
| | con, 60°/s | 0.57 ± 0.15 | 0.56 ± 0.13 | -0.032, 0.043 | 0.323 | 0.75 |
| | con, 180°/s | 0.53 ± 0.15 | 0.49 ± 0.15 | -0.002, 0.665 | 1.944 | 0.067 |
| ER/IR ratio | iso | 50.28 ± 13.46 | 40.74 ± 14.41 | 4.192, 14.9 | **3.732** | **0.001*** |
| | con, 60°/s | 40.44 ± 8.88 | 31.36 ± 11.03 | 5.773, 12.392 | **5.743** | **<0.001*** |
| | con, 180°/s | 36.28 ± 7.9 | 34.41 ± 10.9 | -3.375, 7.102 | 0.744 | 0.466 |
| ROM, ° | ER | 105.7 ± 12.8 | 98.8 ± 13.05 | 3.737, 10.063 | **4.556** | **<0.001*** |
| | IR | 70.5 ± 5.2 | 76.3 ± 6.1 | -8.357, -3.243 | **-4.747** | **<0.001*** |
| | total rotation | 176.2 ± 14.3 | 175.1 ± 12.2 | -1.691, 3.891 | 0.825 | 0.42 |

* indicates a statistically significant difference (p< 0.05)
**Note:** values are indicated as mean ± standard deviation (X ± SD)
**Abbreviations:** ROM= range of movements; ER: External Rotation; IR: Internal Rotation; iso: isometric; con: concentric; ΔAHD=rate of change in AHD; mm=millimeter; Nm/kg= newton-meter/kilogram; °/s=degree/second.

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The Pearson's correlation coefficient results are presented in Table 2.

**Table 2.** Correlations Between Isokinetic Shoulder Rotational Strength Ratios and US Measurements of AHD

| **variables** | | AHD, mm | | | | | |
|---|---|---|---|---|---|---|---|
| | | dominant | | | non- dominant | | |
| | | 0° | 60° | ΔAHD (%) | 0° | 60° | ΔAHD (%) |
| ER | iso | **p=0.012*, r=0.552** | p=0.473, r=-0.170 | p=0.746, r=-0.077 | **p=0.041*, r=0.461** | p=0.378, r=0.208 | p=0.171, r=0.318 |
| | con, 60°/s | p=0.138, r=0.343 | p=0.27, r=0.259 | p=0.993, r=0.002 | p=0192, r=0.304 | p=0.454, r=0.177 | p=0.589, r=0.129 |
| | con, 180°/s | p=0.064, r=0.422 | p=0.481, r=0.167 | p=0.460, r=0.175 | p=0.797, r=0.061 | p=0.368, r=-0.212 | p=0.088, r=0.392 |
| IR | iso | p=0.73, r=0.082 | p=0.673, r=0.101 | p=0.899, r=-0.03 | p=0.804, r=0.059 | p=0.814, r=0.056 | p=0.94, r=0.018 |
| | con, 60°/s | p=0.551, r=0.220 | p=0.630, r=0.115 | p=0.743, r=0.078 | p=0.629, r=0.115 | p=0.558, r=0.139 | p=0.918, r=-0.025 |
| | con, 180°/s | p=0.398, r=0.200 | p=0.288, r=0.25 | p=0.591, r=-0.128 | p=0.228, r=0.282 | p=0.287, r=0.251 | p=0.998, r=-0.004 |
| ER/IR ratio | iso | **p=0.017*, r=0.526** | p=0.204, r=0.297 | p=0.561, r=0.138 | **p=0.013*, r=0.545** | p=0.351, r=0.220 | p=0.078, r=0.403 |
| | con, 60°/s | p=0.094, r=0.384 | p=0.134, r=0.347 | p=0.743, r=-0.078 | p=0.106, r=0.372 | p=0.435, r=0.185 | p=0.447, r=0.18 |
| | con, 180°/s | p=0.121, r=0.358 | p=0.889, r=-0.033 | p=0.123, r=0.356 | p=0.517, r=0.154 | p=0.052, r=-0.44 | p=0.39, r=0.264 |

* indicates a statistically significant difference ($p < 0.05$).
**Abbreviations:** ER: External Rotation; IR: Internal Rotation; iso: isometric; con: concentric; ΔAHD=rate of change in AHD; mm=millimeter; °/s=degree/second

A significant positive, strong correlation existed between AHD (0° of shoulder abduction) and isometric ER muscle strength on the dominant side (p=0.012, r=0.552) and a positive moderate correlation on the non-dominant side (p=0.041, r=0.461). Besides, a significantly positive strong correlation was also found between AHD (0° of shoulder abduction) and the isometric ER/IR strength ratio on the dominant side (p=0.017, r=0.526) and the non-dominant side (p=0.013, r=0.545). However, no other correlations were detected between the AHD values and shoulder rotational strengths and strength ratios.

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## Discussion and Conclusion

The study findings partly confirmed our primary hypothesis that a greater AHD was related to the greater isometric ER strength and ER/IR strength ratios. As to our secondary hypothesis, higher AHD values, greater ER strengths, and ER/IR strength ratios were found on the dominant shoulder compared with the non-dominant side (except for concentric mode at 180°/s). Yet, similar side-to-side IR strength was observed. Although the change in the AHD, namely ΔAHD (from the arm at the side to 60° of shoulder abduction), was more on the dominant side, interestingly, it was not related to shoulder rotational strength data**.** Our findings underpin the importance of the shoulder ER muscle strength and ER/IR strength ratio in depressing the humeral head against the deltoid muscle activity for the purpose of preventing superior migration of the humeral head in university basketball players during their athletic performance.

To our knowledge, this study is the first to investigate the relationship between shoulder rotational strength (isometric and concentric) and AHD values in university basketball players. Previous studies have reported that a greater ER strength and ER/IR strength ratio is associated with larger AHD in volleyball and badminton players (Leong et al., 2012; Schmidt et al., 2021). Even though we did not prefer the similar testing procedure for shoulder rotational strength measurements, consistent with the previous findings, our present study adds new information that larger AHD was related to greater shoulder isometric ER strength and ER/IR ratios in both dominant and non-dominant shoulders in university basketball players. However, findings from our study demonstrated that the ER and IR strength and strength ratio was not associated with the amount of AHD reduction (ΔAHD). This result is somehow surprising when considering the rotator cuffs' and deltoid muscle's relative contribution in maintaining the subacromial space during arm elevation. In our study, we only assessed isometric and concentric ER and IR muscular strength and strength ratios. Yet, we did not investigate the relationship between eccentric ER and IR muscular strength and strength ratios with the amount of AHD changes. The potential explanation behind our finding could have been observed due to the antagonistic effect of the rotator cuff muscles, which was capable of opposing superior migration of the humeral head against the deltoid muscle activity (Alizadehkhaiyat et al., 2015; Burkhart, 1992; Halder et al., 2001). It could be speculated that the antagonistic activation of the ER and IR muscles could be associated with the change in AHD values during shoulder elevation. Consequently, the eccentric activation or strength of the rotator cuff muscles may contribute to frontal plane force coupling and, therefore, maintain the AHD. We believe that the eccentric

ER/IR strength ratio or dynamic control ratio could be more associated with the amount of AHD reduction, and it should be investigated in the overhead athletic population.

Based on our AHD findings on twenty university basketball players revealed greater AHD values in both arms at the side and 60° of shoulder abduction positions in the dominant than the non-dominant shoulder. Our findings were consistent with previous studies in which they found significantly larger AHD values in volleyball and baseball players (Leong et al., 2012; Schmidt et al., 2021). However, contrary to our findings, smaller AHD values on the dominant shoulder than on the non-dominant shoulder were also reported in the overhead athletes in other studies (Maenhout et al., 2012; Silva et al., 2010). The heterogeneity of the above studies can be explained as follows. The first reason is that studies may have preferred different upper body postures, measurement planes, and scapular muscle activity that would affect the AHD values.  Another reason is the sports nature or demands and sports-specific adaptations (due to sports exposure), such as glenohumeral internal rotation deficit (GIRD), that negatively impact the AHD values, which may contribute to these controversies (Borsa et al., 2008; Maenhout et al., 2012; Silva et al., 2010). In our study, we may have found greater AHD values on the dominant side because the GIRD values of basketball players did not exceed the average GIRD (>10°±2°) (Borsa et al., 2008; Maenhout et al., 2012). Therefore, we cannot comment on the side-to-side AHD differences of basketball players with pathological GIRD. Further studies are required to clarify this.

In our study, both shoulders showed a notable reduction in AHD values than the reported clinically meaningful difference (MCID=2.1 mm) between shoulders - which can provide a value to reflect a real change rather than a measurement error - in the literature (Cholewinski et al., 2008a). Recent studies have reported an AHD difference of more than 2.1 mm between shoulders, which may indicate clinically significant shoulder pathology (Cholewinski et al., 2008a; Leong et al., 2012). In our study, the dominant shoulders of the basketball players demonstrated more reduction in AHD (mean difference=4.07 mm) than the non-dominant shoulders (mean difference=3.1 mm) when the shoulder moved from 0° to 60° of shoulder abduction. This threshold difference observed between the shoulders can be thought to give more objective insight to university basketball players. Previous studies have indicated superior migration of the humeral head that contributes to the dynamic narrowing of the subacromial space when the rotator cuff is fatigued or damaged (Leong et al., 2012; Tooth et al., 2020). Muscle strength deficit, imbalance, or fatigue of rotator cuff muscles may contribute to the excessive dynamic narrowing of the subacromial space that could lead to rotator cuff

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tendinopathy. The results of this study add to the evidence that both dominant and non-dominant shoulders of basketball players did not sufficiently control the dynamic maintenance of the AHD as a result of basketball practice. Even though the nature of sports is different, we highlighted some deficits in the dynamic control of AHD in our study population, consistent with the previous findings (Leong et al., 2012).

The present results further demonstrated side-to-side differences in isometric and concentric ER strength and ER/IR strength ratios (except 180°/s) and ER/IR ROM in favor of the dominant side. Based on our findings regarding ER strengths and ER/IR strength ratios, we found an isometric ER increase of 25% and a concentric ER increase of 21.7% in favor of the dominant shoulders compared to the non-dominant shoulders. Besides, a concentric ER/IR ratio of 40.5% and an isometric ER/IR ratio of 50.3% of the dominant side were obtained. Previous studies have presented shoulder strength profiles in overhead athletes as criteria for improving performance, preventing injuries, and returning to training or competition (Baltaci & Tunay, 2004; Cools et al., 2015). Generally, an isometric ER/IR ratio of 75% and an isokinetic ER/IR ratio of 66% are recommended, with a general rotator cuff strength increase of 10% on the dominant side. Furthermore, it has been reported that sports-specific adaptations cause a decrease in the strength of ER, which could result in deficiencies in ER muscle performance and injuries. Based on the cut-off values mentioned above, it should be noted that our study population has demonstrated an increased ER strength that may be important to the injury prevention strategy of their athletic career. However, decreased muscular balance ratios between the ER and IR could be a precursor to rotator cuff injury. Therefore, we suggest that university basketball players should restore the shoulder ER/IR ratios so as to provide muscular balance and improve their injury-free dominant performance.

The present study showed an increased ER ROM (6.9°) and decreased IR ROM (5.8°) in the dominant shoulders. Yet, university basketball players did not have a side-to-side total ROM deficit (1.1°), meaning no pathological GIRD was seen (ER ROM>7°, IR ROM<10° and total ROM>5°) (Gouveia et al., 2022). Current literature on GIRD prevalence in basketball players is very limited. Only one study has investigated the GIRD prevalence between baseball players and other sports (such as basketball, tennis, etc.) (Ohuchi et al., 2023). They have indicated that overhead sports like baseball or volleyball were vulnerable to the risk factor for GIRD (Ohuchi et al., 2023). In other words, any athletes who were performing a throwing movement similar to the overhead pitching motion repeated were the risk factor for pathological GIRD (Ohuchi et al., 2023). In our study group, GIRD was higher in the dominant shoulder but

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not pathological GIRD. This finding could be associated with the asymmetry of shooting dominance and could be considered a common adaptation seen in the shoulder joint due to the overhead sport-specific adaptation (Gouveia et al., 2022). Identifying athletes at risk of injuries based on pathological or anatomical GIRD is important because these deficits should be corrected to prevent sports-related injuries. For this reason, we believe that our findings are valuable as they interpret the GIRD in semi-professional basketball players who use their upper limbs more symmetrically than in other overhead sports. In summary, based on our findings, we can comment that university basketball players had adequate ER ROM gain (6.9°), IR ROM loss (5.8°), and no presence of total ROM deficit (1.1°) between the dominant and non-dominant shoulders which did not predispose athletes to an increased risk of injury (Gouveia et al., 2022).

**Limitations**

This study had limitations. First, the AHD values were measured arm at side and arm at 60° of shoulder abduction, which are the most preferred positions in the coronal plane. Therefore, this study showed the relationship between the ER and IR muscle strength and strength ratios and AHD values in the early phase of shoulder elevation. Since assessing the effects of rotator cuff muscle strength on the subacromial space with the arm abducted beyond 90° requires other measuring tools, such as magnetic resonance imaging, our findings did not reflect the relationship between the AHD values above 60° of shoulder abduction and rotator cuff strength measurements. Second, in this study, all participants were young, healthy individuals without shoulder pathology who were participating in the university basketball team. It is well known that patients with rotator cuff pathologies exhibit the altered force-coupling function of the rotator cuff muscles or muscular imbalance (or both) (Michener et al., 2003; Myers et al., 2009; Navarro-Ledesma & Luque-Suarez, 2018). As such, it is possible that the influence of shoulder ER and IR muscle strength and strength ratios on AHD values may differ in players with rotator cuff pathology. Finally, we did not investigate the factors such as posterior shoulder tightness, scapular dyskinesis, or pathological GIRD that may impact the AHD values. Therefore, our findings did not generalize the basketball athletes with scapular dyskinesis, posterior shoulder tightness, or pathological GIRD.

In conclusion, a weaker isometric ER muscle strength and decreased ER/IR strength ratio were associated with more reduction in the AHD at 0° of shoulder abduction position. In light of the study findings, the role of shoulder ER muscle strengthening and improving shoulder ER/IR strength ratio in shoulder rehabilitation and injury-prevention programs in

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overhead athletes merits further research. However, university basketball players have demonstrated an asymmetry with stronger ER muscle strength, higher ER/IR strength, increased ER ROM, and wider AHD values on the dominant side. This asymmetry could be thought to be muscular adaptations caused by the weight of the ball and its control during basketball practice or as a result of sport-specific adaptation due to habitual overhead loading of the shoulder over a longer time.

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**Declaration of Competing Interest**

The authors declare no conflict of interest.

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