Manual Therapy 23 (2016) 1–8

Contents lists available at ScienceDirect

Manual Therapy

journal homepage: www.elsevier.com/math

Original article

Relationship between extrinsic factors and the acromio-humeral distance

Tanya Anne Mackenzie [a,*], Lee Herrington [b], Lenard Funk [c], Ian Horsley [d], Ann Cools [e]

[a] Salford University, Health, Sports and Rehabilitation Sciences, Manchester, M5 4WT, United Kingdom
[b] Salford University, School of Sport, Exercise and Physiotherapy, Salford, Manchester, United Kingdom
[c] University of Salford, Salford, M6 6PU, United Kingdom
[d] English Institute of Sport, United Kingdom
[e] Ghent University, Dept of Rehabilitation Science and Physiotherapy, Belgium

ARTICLE INFO

Article history:
Received 19 August 2015
Received in revised form
19 December 2015
Accepted 14 February 2016

Keywords:
Impingement
Shoulder
Acromio-humeral distance

ABSTRACT

Background: Maintenance of the subacromial space is important in impingement syndromes. Research exploring the correlation between biomechanical factors and the subacromial space would be beneficial.
Objectives: To establish if relationship exists between the independent variables of scapular rotation, shoulder internal rotation, shoulder external rotation, total arc of shoulder rotation, pectoralis minor length, thoracic curve, and shoulder activity level with the dependant variables: AHD in neutral, AHD in 60° arm abduction, and percentage reduction in AHD.
Design: Controlled laboratory study.
Method: Data from 72 male control shoulders (24.28years STD 6.81 years) and 186 elite sportsmen's shoulders (25.19 STD 5.17 years) were included in the analysis. The independent variables were quantified and real time ultrasound was used to measure the dependant variable acromio-humeral distance.
Results: Shoulder internal rotation and pectoralis minor length, explained 8% and 6% respectively of variance in acromio-humeral distance in neutral. Pectoralis minor length accounted for 4% of variance in 60° arm abduction. Total arc of rotation, shoulder external rotation range, and shoulder activity levels explained 9%, 15%, and 16%–29% of variance respectively in percentage reduction in acromio-humeral distance during arm abduction to 60°.
Conclusion: Pectorals minor length, shoulder rotation ranges, total arc of shoulder rotation, and shoulder activity levels were found to have weak to moderate relationships with acromio-humeral distance. Existence and strength of relationship was population specific and dependent on arm position. Relationships only accounted for small variances in AHD indicating that in addition to these factors there are other factors involved in determining AHD.

1. Introduction

The exact cause of shoulder impingement syndrome remains controversial, and possibly the causes are multifactorial (Wilk et al., 2009). Reduced acromio-humeral distance (AHD) has been associated with subacromial impingement syndrome participants compared to healthy participants in studies using RTUS, MRI and x-ray (Graichen et al., 1999; Hebert et al., 2002; Girometti et al., 2006; Pijls et al., 2010), and proposed as a predictive marker (Cholewinski et al., 2008). If maintenance of the subacromial space is important in impingement syndromes regardless of whether it is a cause or consequence, research exploring the correlation between biomechanical factors and the subacromial space, using the latter as the outcome measure, would be beneficial (Mackenzie et al., 2015). Ultrasound (US) measures of the acromial humeral distance have been used to quantify the subacromial space and construct validity established with a phantom model (McCreesh et al., 2014a). Extrinsic factors considered to influence the AHD, and often targeted in rehabilitation programs, include scapular rotation, shoulder rotation ranges, pectoralis minor length, thoracic curve, and load.

* Corresponding author.
E-mail addresses: t.a.mackenzie@edu.salford.ac.uk (T.A. Mackenzie), l.c.herrington@salford.ac.uk (L. Herrington), lenfunk@shoulderdoc.co.uk (L. Funk), Ian.Horsley@eis2win.co.uk (I. Horsley), anncools@ugent.be (A. Cools).

http://dx.doi.org/10.1016/j.math.2016.02.005
1356-689X/

As the arm elevates, the scapula has been shown to rotate progressively upwardly in healthy individuals (Ludewig et al., 1996; Groot et al., 1999), in contrast, in impingement subjects it has been noted that the scapula has decreased upward rotation (Flatow et al., 1994; Kibler, 1998; Ludewig and Cook, 2000; Endo et al., 2001; Hebert et al., 2002; Thigpen et al., 2006; Struyf et al., 2011). These authors suggest that scapular upward rotation lifts the acromion for increased subacromial space. The relationship between scapular position and AHD has been explored by two previous authors (Silva et al., 2010; Thomas et al., 2013). One of the articles (Silva et al., 2010) investigate this relationship in a non-skeletally mature population and the other article (Thomas et al., 2013) reported no relationship in resting and in 90° of arm abduction. However, previous authors have reported that the measure of AHD in 90° of arm abduction with US is unreliable due to acoustic shadowing (Duerr, 2010). On manual upward rotation of the scapula during the Scapular Assistance Test the AHD was reported to increase although not significantly (Seitz et al., 2012). It was deemed necessary to evaluate if a significant relationship existed between scapular upward rotation and the AHD in a skeletally mature population and in an arm position which has a high reported reliability for the measure of AHD with US. Decrease in shoulder internal rotation has been associated with shoulder impingement in overhead athletes (Harryman et al., 1990; Tyler et al., 2000; Borich et al., 2006), an increase in internal rotation after stretching was found to increase the AHD in female athletes (Maenhout et al., 2012) this was a pre-test post-test study and as such association between shoulder internal rotation and AHD has not yet been reported. A possible explanation for why internal shoulder rotation influences the AHD is that increased tension in the posterior shoulder capsule may cause anterior superior migration of the humeral head thus reducing the subacromial space, alternately this increased tension may restrict scapular motion and cause depression of the acromion further reducing the subacromial space. The instability theorem proposes that athletes requiring greater shoulder ranges of external rotation in order to perform develop occult or subtle shoulder instability (Jobe and Lannotti, 1995). In theory, this capsular laxity may have a contagion effect as excess humeral head translations may compromise the subacromial space. For optimal scapular function the pectoralis minor must lengthen during arm elevation in healthy individuals (Ludewig and Cook, 2000; Borstad and Ludewig, 2002; McClure et al., 2004), but if this muscle has an increase in passive tension, this will restrict scapular upward rotation (Flatow et al., 1994; Ludewig and Cook, 2000; Borstad and Ludewig, 2002; Kibler and Sciascia, 2009; Lucado, 2011) which may restrict upward motion of the acromion during arm elevation and in turn could result in loss of AHD (Borstad and Ludewig, 2002). Studies found that scapular position is in part influenced by pectoralis minor muscles but as yet, a direct relationship between the resting position variables of pectoralis minor length and AHD has not been established. Previous authors (Greenfield et al., 1995; Lewis et al., 2005) evaluating the relationship between thoracic posture and the presence of pathology in impingement patients found no relationship. Despite these results, in practice an increase in thoracic kyphosis is associated with impingement syndromes and possibly to subacromial width (Gumina et al., 2008; Kalra, 2010). Lastly, it is asserted that the biomechanics of the shoulder girdle are influenced by load and sport demands with two previous authors (Thompson et al., 2011; McCreesh et al., 2014b) reporting that AHD reduced further with load. Although these extrinsic factors have been proposed as predictive of the AHD, no previous authors have tested the cause–effect relationship of this group of factors on AHD in a variety of sportsman whose shoulders are exposed to varying sporting demands and skills.

The aim of this study is to establish if relationship exists between the independent variables of scapular rotation, shoulder rotation, pectoralis minor length, thoracic curve, and shoulder activity level with the dependant variables: AHD in neutral, AHD in 60° arm abduction, and percentage reduction in AHD.

2. Method

2.1. Participants

Based on pilot study data it was calculated that 37 subjects were required to achieve a 70% power to show that the correlation is greater that 0.4 (which indicates that the correlation is at least substantial) and a 0.05 significance level, assuming the true correlation is 0.8. Data from 72 male control shoulders (24 STD 7 years) and 186 elite sportsmen's shoulders (25 STD 5 years) were included in analysis (Table 1.). Sportsman consisted of golfers professionals playing on the (European) Challenge tour other athletes represented the Great Britain team Olympians (podium and podium potentials). Participants included in the study were of full musculoskeletal development, and had healthy shoulders. Participants were excluded from the study if they had: cervical, shoulder, or elbow pain within six months before testing; previous shoulder girdle or spinal fractures; shoulder surgery; or dislocation of the upper limb; scoliosis; leg length discrepancy; or a rheumatologic condition. XXXXXX Research Ethics Committee granted ethical approval for the study.

2.2. Procedures

In a pilot study intra-rater reliability 24 h apart was established for all instruments and procedures (Table 2). ICC3.1 values for all protocols and instrumentation used were more than 0.9, indicating excellent inter-session intra-rater reliability.

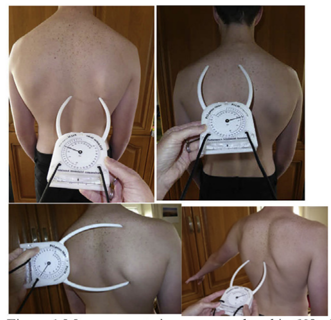
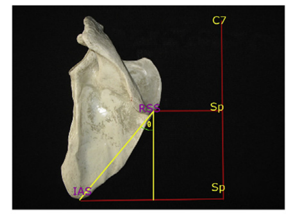
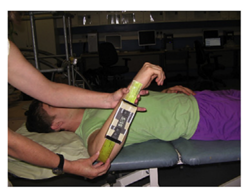
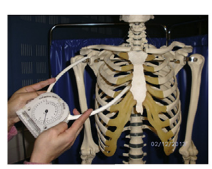
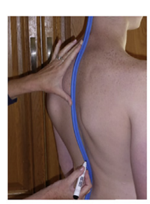
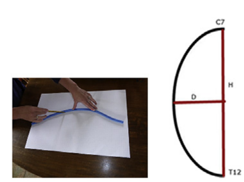
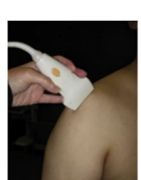
Participant position for the procedures: *PALM to quality scapular rotation, flexicurve to quantify thoracic curve, and US to measure AHD.*

Participants removed their shoes and assumed a normal standing posture looking ahead. No attempt was made to modify the participants' posture during testing or to make any participant conform to a single standardised posture. Two arm positions were used during testing: one, shoulder neutral, and two, 60° of active arm abduction in the coronal plane. For the neutral position, participants allowed the arm to hang naturally at the side of the body. For the 60° of arm abduction position, the participant's arm was abducted to 60° as determined by an inclinometer, the thumb pointing forwards. The participant maintained this position actively. In order to ensure that the participant maintained the correct angle of arm abduction, a marker tape was placed on an adjacent wall at the level of the participant's finger tips. The examiner could then visually ensure that the correct angle was being maintained while measuring. Between each measurement the participant rested the arm by the side to avoid the effects of fatigue.

Table 1
Summary participants included in the study. Golfers were professionals playing on the (European) Challenge tour. The other athletes represented the Great Britain team Olympians (podium and podium potentials).

Group	Total n = shoulders	Subgroup n = shoulders
Male controls	72	
Male sportsman	186	90 golfers
		30 gymnasts
		16 canoeists
		36 boxers
		14 archers

Table 2
Summary of instruments, methods, and intra-rater reliability.

Variable	Instrumentation Intra-rater 24 h apart ICC3.1 (95% CI)	Procedure 3 Repeated measures (Participant position)	Images	Measurements and calculations	
Scapular rotation	PALM palpation meter (Performance Attainment Associate, St.Paul, MN, USA) 0.92 (0.87–0.96)	*Measurement 1*. Distance between the inferior angle of the scapula and the closest horizontal spinous process of thoracic spine (IAS-Sp). *Measurement 2*. Distance between the root of the spine of the scapula and the closest horizontal spinous process of the thoracic spine (RSS-Sp). *Measurement 3*. Distance from the inferior angle of the scapula to the root of the spine of the scapula (RSS-IAS) (Standing)	 Figure 1. Measurements in arm neutral and in 60° of arm abduction.	 Figure 2. Calculation of scapular rotation	If a perpendicular line is dropped down from the root of the spine of the scapula (RSS) to intersect the horizontal line between the inferior angle of the scapula and the closest spinous process of the thoracic spine (IAS-Sp), a right angle triangle is created. The hypotenuse is the distance IAS to RSS. The side opposite the angle θ was defined as the angle between the hypotenuse and the vertical and the vertical is the distance IAS-Sp minus the distance RSS-Sp. To calculate the angle one can apply: $sin\ \theta = \frac{opposite}{hypotenuse}$
Shoulder rotation ranges	A 360° inclinometer with digital protractor and angle finder gauge (Universal Supplies Limited). 0.91 (0.85–0.96)	The inclinometer was adapted with a 30 cm plastic ruler attached along the length of the inclinometer, and the ruler was used to align the inclinometer between the olecranon process and the ulnar styloid. The angle was measured in the vertical plane.(Supine)	 Figure 3. Measure of shoulder rotation		
Pectoralis minor length	PALM(Performance Attainment Associate, St.Paul, MN, USA) 0.98 (0.96–0.99)	PALM measured the distance between the two palpated landmarks of the anterior aspect of the acromion and the ipsilateral fourth rib sternal notch. (Supine)	 Figure 4. Measure of pectoralis minor length		
Thoracic curve	A 40 cm Helix flexicurve ruler 0.98 (0.97–0.99)	The flexi curve was moulded to the contour of the participants' thoracic spine and the previously marked bony landmarks of C7 and T12 were transferred over to the flexicurve with a water soluble pen. (Standing)	 Figure 5. Measure of thoracic curve.	 Figure 6. Calculation of thoracic curve angle	The concave side of the flexicurve was traced onto the graph paper. The corresponding levels of C7 and T12 were also transcribed on the graph paper. Calculation of thoracic ratio. $\theta = 4 \times$ [arctan (2D/H)].
AHD	Portable RTUS scanner M Turbo with HFL38/13-6 MHz linear transducer (Sonosite Limited. Hitchen, UK),	US transducer placed in the coronal plane parallel with the longitudinal axis of the humerus. (Standing)	 Figure 7. US transducer placement	 Figure 8. US image	The shortest tangential measure between of the hyper echoic landmarks of the most superior aspect of the humerus and acromion are shown on the US image. Electronic line callipers

(*continued on next page*)

Table 2 (*continued*)

Variable	Instrumentation Intra-rater 24 h apart ICC3.1 (95% CI)	Procedure 3 Repeated measures (Participant position)	Images	Measurements and calculations
	Pre-set parameters for musculoskeletal shoulder settings. 0.92 (0.84–0.96)			were used to make the measurements.

2.3. Measure of scapular rotation

The following anatomical landmarks were repeatedly palpated by the examiner: the inferior angle of the scapula (IAS), the root of the spine of the scapula (RSS), and the spinous process of the thoracic spine (Sp) (Table 2 Figure 1). The PALM callipers were used to measure the distances between these landmarks and horizontal distance was ensured by the analogue inclinometer on the PALM (Table 2 Figure 1). Using the sin rule these measures could be used to calculate the angle of scapular rotation (Table 2 Figure 2).

2.4. Measure of thoracic curve

Validation with x-ray of the flexicurve to measure thoracic angle has been established (Teixeira and Carvalho, 2007; de Oliveira et al., 2012). The bony landmarks of the spinous processes of cervical vertebra(C)7 and thoracic vertebra1 (T)2 were palpated and marked on the skin. C7 was located by asking the participant to flex and extend the neck and identified as the spinous process that remained prominent during this motion. T12 was located by location of the lumbar vertebra 4–5 inter-space, considered to be midline on an imaginary line running from the superior aspect of the participant's illac crests. Once this space was located, the examiners palpated up five spinous processes to locate the T12 spinous process. The flexi curve was moulded to the contour of the participant's thoracic spine and the previously marked bony landmarks of C7 and T12 were transferred to the flexicurve (Table 2, Figure 5). The flexicurve was then carefully moved from the participants' spine as not to alter the shape, and placed on mm graph paper (Table 2, Figure 6). The corresponding levels of C7 and T12 were transcribed on the graph paper. On each transcribed curve on the graph paper, a line was drawn intersecting the points demarking C7 to the point demarking T12. This was considered to represent the height of the curve (H). A set square was used to determine the point perpendicular to the mid line of H to measure the depth of the curve (D) (Table 2, Figure 6). These measures were used to calculate the angel of the curve (Table 2).

2.5. Measure of pectoralis minor length

Measurement of pectoralis minor length with the PALM was done with the participant in the supine position on an examination plinth. A small pillow was placed under the participant's head for comfort, taking care to ensure that the pillow was not under the shoulder girdle. The participant's arm was passively placed along the side of the body in the neutral position resting on the plinth. The PALM was used to measure the distance between the two palpated landmarks of the anterior aspect of the acromion and the ipsilateral fourth rib sternal notch. Palpation of the fourth rib sternal notch was done via palpation of the suprasternal notch above the sternum, then palpation inferiorly identified a ridge (Angle of Louis). Palpating laterally located the second intercostal space along the sternal border further palpation of the spaces downwards was done until the fourth intercostal space was reached.

2.6. Measure of shoulder rotation range

Measurement of shoulder rotations was undertaken with the participant in the supine position on an examination plinth (Table 2, Figure 3). The arm on the side being tested was abducted to 90° of abduction and positioned with the humerus in a horizontal position in line with the acromion. The elbow was flexed to 90°. To determine this position, an inclinometer and goniometry were used. For measures of shoulder external rotation, the examiner moved the glenohumeral passively to end of range, while noting that no compensatory movement occurred at the shoulder girdle. If resistance was felt or the shoulder girdle moved this was considered the end point of range. For shoulder internal rotation range, the examiner palpated the anterior aspect of the acromion with one hand and moved the shoulder into passive internal rotation. End of range was considered to be the last point in range before the acromion started to move. Between measures the arm was repositioned in the neutral position.

2.7. Roa-marx shoulder activity scale

To measure the impact of activity as a variable, the Roa-marx activity scale was used to collect data on the load, frequency, and level of activity to which the participant's shoulder was exposed. The Roa-marx activity scale was developed (Brophy et al., 2005) by previous authors and reliability and validity established. Five activities are rated: carrying an object 8lb or heavier by hand, handling objects overhead, weight-training with arms, swinging motion (i.e. hitting a tennis ball or golf ball), and lifting objects 25lb or heavier. Numerical sums of scores for the five activities are rated on a five-point frequency scale from never performed (0) to daily (4). Two multiple choice questions score participation in contact and overhead sports with possible responses being: (A) No; (B) Yes, without organised officiating; (C) Yes, with organised officiating; or (D) Yes, at a professional level (i.e. paid to play).

2.8. Measure of AHD

Participants removed their shoes and assumed a normal standing posture looking ahead. No attempt was made to modify the participants' posture during testing or to make any participant conform to a single standardised posture. Two arm positions were used during collection of US images: one, shoulder neutral, and two, 60° of active arm abduction in the coronal plane. For the neutral position, participants allowed the arm to hang naturally at the side of the body. For the 60° of arm abduction position, the participant's arm was abducted to 60° as determined by an inclinometer, the thumb pointing forwards. The participant maintained this position actively. In order to ensure that the participant maintained the correct angle of arm abduction, a marker tape was placed on an adjacent wall at the level of the participant's finger tips. The examiner could then visually ensure that the correct angle was being maintained while measuring. Between each measurement the participant rested the arm by the side to avoid the effects of fatigue. The US transducer was placed in the coronal plane, parallel with the longitudinal axis of the humerus and positioned to visualize the shortest tangential distance between of the hyper echoic landmarks of the most superior aspect of the humerus and acromion on the US screen (Table 2, Figure 7) (McCreesh et al., 2014a). Three repeated images were collected in each arm position. Images were converted and saved as jpeg files, and were randomised by a third party. As a result, the investigator was blinded to subject identity, order of collection of images, side and shoulder position the image was captured in. The stored images were reviewed using Image J 1.32 software. Hyper echoic landmarks were consistently marked to identify the inferior aspect of the acromion and the most superior aspect of the humerus, thus yielding the shortest distance between the two hyper echoic landmarks (Table 2, Figure 8).

2.9. Data analysis

Statistical Package for Student Statistics for Windows version 20.0 (SPSSinc. Chicago, IL), was used for statistical analysis. Outliers for each variable were computed and removed. Scatterplots to illustrate the best fit linear relationship and ensure data met with inclusion criteria were generated. Normality of distribution was ensured with The Correlation Coefficient [r], which is known as the Pearson product-moment, was calculated to determine the relationship between independent variables and dependant variables. The significance level was set at $p < 0.05$. To estimate the variation in AHD attributed to the independent variables, data of variables which had a significant Pearson correlation ($p < 0.05$), were subject to a simple linear regression analysis. To confirm that linear regression model was appropriate for the data, suitability of the model was assessed by defining residuals and examining residual plots. The correctness of the linear regression was confirmed with the mean of all the residuals equalling zero, being homoscedastic, and no outliers were present.

3. Results

Descriptive statistics for all variables are reported in Table 3. Significant Pearson's correlation coefficient [r] and simple regression analysis results are reported in Table 4. Independent variables which showed no correlation to AHD in either group, nor in either arm position, nor to percentage reduction in AHD, were scapular rotation (controls: neutral arm position $r = 0.16$ $p = 0.18$, 60° abducted arm position $r = 0.05$ $p = 0.70$. Sportsmen: neutral arm position $r = 0.03$, $p = 0.74$, 60° abducted arm position $r = -0.14$, $p = 0.08$) and thoracic curve (neutral arm position $r = 0.18$, $p = 0.27$; 60° arm abduction $r = -0.06$, $p = 0.72$). A positive significant weak Pearson's correlation was found in sportsman between AHD in 0° with shoulder internal rotation ($r = 0.29$, $p = 0.01$) and pectoralis minor length ($r = 0.24$, $p = 0.01$), with linear regression the overall model fit was $R^2 = 0.08$ for shoulder internal rotation and $R^2 = 0.06$ pectoralis minor length. A positive significant weak Pearson's correlation was found in sportsman between AHD in 60° arm abduction with pectoralis minor length ($r = 0.20$, $p = 0.02$) with linear regression the overall model fit was $R^2 = 0.04$. A positive significant weak Pearson's correlation was found in controls between percentage reduction in AHD with total arc of rotation ($r = 0.32$, $p = 0.01$) and shoulder external rotation range ($r = 0.39$, $p = 0.01$), with linear regression the overall model fit was $R^2 = 0.09$ for total arc of rotation and $R^2 = 0.15$ for shoulder external rotation range. A significant moderate Pearson's correlation was found in both controls ($r = 0.40$, $p = 0.01$) and sportsman ($r = -0.54$, $p = 0.01$) between percentage reduction in AHD with shoulder activity scores, although the relationship was positive in controls and negative in sportsman, with linear regression the overall model fit was $R^2 = 0.16$ for controls and $R^2 = 0.15$ for sportsman.

Table 3
Descriptive statistics for variables.

Variable	Group	Mean	STD
Scapular rotation with 0° arm abduction	Controls	3.04°	3.84°
	Sportsmen	4.15°	3.42°
Scapular rotation in 60° arm abduction	Controls	9.34°	5.18°
	Sportsmen	8.55°	3.90°
Shoulder internal rotation	Controls	55.59°	18.74°
	Sportsmen	54.18°	13.45°
Shoulder external rotation	Controls	80.21°	10.99°
	Sportsmen	84.74°	11.16°
Total arc of shoulder rotation	Controls	132.93°	13.55°
	Sportsmen	138.99°	18.88°
Pectoralis minor length	Controls	16.21 cm	1.43 cm
	Sportsmen	16.04 cm	1.45 cm
Thoracic curve	Controls	43.77°	9.08°
Shoulder activity level	Controls	12.16/26	4.45/26
	Sportsmen	22.00/26	1.89/26
AHD with 0° arm abduction	Controls	1.69 cm	0.22 cm
	Sportsmen	1.64 cm	0.24 cm
AHD with 60° arm abduction	Controls	1.13 cm	0.22 cm
	Sportsmen	1.13 cm	0.23 cm
% reduction in AHD	Controls	33.00%	11.34%
	Sportsmen	30.38%	14.62%

Abbreviations: STD standard deviation; % = percentage; AHD = acromio-humeral distance; ° = degrees; cm = centimetres.

4. Discussion

The aim of this study was to establish if relationship exists between the independent variables of scapular rotation, shoulder rotation, pectoralis minor length, thoracic curve, and shoulder activity level with the dependant variables: AHD in neutral, AHD in 60° arm abduction, and percentage reduction in AHD. Pectorals minor length and shoulder internal rotation ranges were found to have a weak positive relationship and contribute to variance in AHD in elite male athletes. Total arc of shoulder rotation and shoulder external rotation range were found to have a weak positive relationship with percentage reduction in AHD during arm abduction in male controls. Shoulder activity levels were found to have a positive moderate relationship with percentage reduction in AHD during arm abduction in male controls and a negative moderate relationship in elite male sportsman. Independent variables which showed no correlation to AHD were scapular rotation and thoracic curve. These findings support the assertion that extrinsic factors and the strength of influence on AHD appear to be multifactorial and possibly population specific.

Linear regression estimated the variation in AHD attributed to each independent variable. Shoulder internal rotation and pectoralis minor length, explained 8% and 6% respectively of variance in AHD in 0° arm abduction in sportsman while pectoralis minor length accounted for 4% of variance in 60° arm abduction in sportsman. Total arc of rotation and shoulder external rotation ranges explained 9% and 15% respectively of variance in the percentage reduction in AHD during arm abduction to 60° in controls. Shoulder activity scores explained 16% and 29% of variance in the percentage reduction in AHD during arm abduction to 60° in both

Table 4
Results of Pearson's correlation and simple liner regression analysis.

Dependent variable	Independent variable	Sub group	Pearson's correlation		Interpretation	Simple regression analysis		
			r	p		F	p	R^2
AHD with 0° arm abduction	Shoulder internal rotation	Sportsmen	0.29	0.01	+ significant weak	7.41	0.01	0.08
	Pectoralis minor length	Sportsmen	0.24	0.01	+ significant weak	8.79	0.01	0.06
AHD with 60° arm abduction	Pectoralis minor length	Sportsmen	0.20	0.02	+ significant weak	5.78	0.02	0.04
% reduction AHD	Total arc of rotation	Controls	0.32	0.01	+ significant weak	6.74	0.01	0.09
	Shoulder external rotation	Controls	0.39	0.01	+ significant weak	10.95	0.01	0.15
	Shoulder activity level	Controls	0.40	0.01	+ significant moderate	8.70	0.01	0.16
	Shoulder activity level	Sportsman	minus 0.54	0.01	− significant moderate	14.55	0.01	0.29

Abbreviations: AHD = acromio-humeral distance; % = percentage; ° = degrees; + = positive; − = negative.

controls and sportsman, although direction of relationship was the opposite between the two groups. The variation in these findings support the assertion that extrinsic factors and the strength of influence on AHD appear to be multifactorial, dependant on arm position, and possibly population specific.

Loss of shoulder internal rotation is reported in athletes (Harryman et al., 1990; Tyler et al., 2000; Burkhart et al., 2003; Borich et al., 2006; Laudner et al., 2006) with a loss of 20° or more correlated to injury (Wilk et al., 2011). In an *in vitro* study a simulated tight posterior capsule led to increased contact pressure under the subacromial arch (Huffman et al., 2006; Muraki et al., 2010). In the present study range of shoulder internal rotation was found to have a weak influence on resting AHD in sportsman, however no correlation was noted in 60° of arm abduction. Results support the pathogenic explanation that loss of internal rotation could be influential in subacromial impingement syndrome in the sporting population in lower ranges of arm elevation. However, when the arm is abducted other factors may play a part in determining AHD.

For optimal performance the pectoralis minor must lengthen during arm elevation in healthy individuals (Ludewig and Cook, 2000; Borstad and Ludewig, 2002; McClure et al., 2004) to enable optimal scapular position The current study illustrates that longer pectoralis minor length, which would influence optimal scapular position, is associated with greater AHD in elite male sportsman in both the resting arm position and in early ranges of arm abduction and, therefore, may have a pathogenic role in subacromial impingement syndrome.

Greater total arc of rotation and greater ranges of external rotation were associated with greater reduction in AHD during abduction in controls but not in sportsman who were all undergoing supervised prehab. This may imply that motor control programmes planned to control excessive shoulder joint rotational range may be beneficial in limiting AHD compromise and avoiding injury (Herrington, 1998; Chen et al., 1999; Burkhart et al., 2003; Reinold et al., 2009). This is conjecture but worthy of further investigation.

Sportsman represent a population whose shoulders are exposed to the extremes of load which may lead to adaptive changes in the athletes shoulder (Sell et al., 2007; Borsa et al., 2008). Previous authors have reported that short term loading decreased the acromio-humeral distance (McCreesh et al., 2014b) in non-sportsmen by as much as 11% (Thompson et al., 2011), a process that, if not counteracted, could be pathogenic in impingement syndrome. Preservation of the acromio-humeral distance in athletes is important to prevent impingement of the rotator cuff tendons in the subacromial space (Burns and Whipple, 1993). In the current study, a high shoulder activity score evaluated with the Roa-Marx activity scale was associated with a greater percentage reduction in AHD in male controls but the inverse was noted in sportsman. This may suggest that in order to maintain AHD sportsmen may biomechanically adapt to the demands of load. This is in keeping with previous authors who report that compared to controls the acromio-distance in athletes is greater (Wang et al., 2005; Maenhout et al., 2012).

Independent variables which showed no correlation to AHD were scapular rotation and thoracic curve. The results of the present study concur with those of previous authors (Silva et al., 2010; Thomas et al., 2013) who found no correlation between scapular upward rotation in the coronal plane and AHD, though, it must be borne in mind that in the present study only one component of the five possible degrees of freedom of scapular motion is examined. Previous authors report no relationship between thoracic posture and the presence of pathology (Greenfield et al., 1995; Lewis et al., 2005) while others report that the AHD is reduced in patients with more than 50° hyper kyphosis (Gumina et al., 2008). The present study highlights that the influence of thoracic posture on the AHD in inconclusive.

The current study has limitations that should be borne in mind when interpreting the results. AHD is a two dimensional measure of a three dimensional space. Compromise of this volume cannot be totally quantified by measure of AHD alone; it can only be used as guide. A second limitation is that the range of arm elevation in which the US measure of AHD is possible is limited to a maximum of 60° of elevation because of acoustic shadows in higher ranges of arm elevation and although the AHD is reported to be at its smallest at 60° of abduction, when the rotator cuff is reported to be at its peak activity (Alpert et al., 2000; Thompson et al., 2011), to what extent the relationship between variables and AHD can be extrapolated in higher ranges of arm elevation is unclear. Limiting the extrapolation of these results is the fact that asymptomatic subjects were used in this study; thus, a direct relationship between impairment cannot be assumed. Lastly, all athletes were assessed during tournament or training camps and measures of variables may vary over the course of a season (Dwelly et al., 2009; Thomas et al., 2009). Muscle strength, although not investigated in this study, is considered an important extrinsic factors and often targeted in rehabilitation. Further research to investigate the influence of muscle strength on the AHD is warranted.

5. Conclusion

Pectorals minor length and shoulder internal rotation ranges were found to have a weak positive relationship and contribute to variance in AHD in elite male athletes. Total arc of shoulder rotation and shoulder external rotation range were found to have a weak positive relationship with percentage reduction in AHD during arm abduction in male controls. Shoulder activity levels were found to have a positive moderate relationship with percentage reduction in AHD during arm abduction in male controls and a negative moderate relationship in elite male sportsman. These findings support the assertion that extrinsic factors and the strength of influence on

AHD appear to be multifactorial and possibly population specific. Although these factors should be considered in prevention and treatment programs, in this study the factors investigated only account for small variances in AHD indicating that there are additional factors involved in determining AHD.

Author statement

All authors contributed to the conception and design of the study, or analysis and interpretation of the data. All authors were involved in the critical evaluation of the paper and contributed to the intellectual content. All authors have given final approval of the article for publication.

Conflict of interest

None.

Funding source

None.

Acknowledgements

Fujifilm Sonosite Limited. Hitchen, UK. The English Institute of Sport. Members of the Challenge Tour (golf), the ETPI (European Tour Performance Institute) Doctor Roger Hawkes, Doctor Andrew Murray, and Poura Sing.

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