Dominant vs non-dominant shoulder morphology in volleyball players and associations with shoulder pain and spike speed

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Abstract

Background: The aims of our study were to compare the dominant (DOM) and non-dominant (NDOM) shoulders of high-level volleyball athletes and identify possible associations of shoulder adaptations with spike speed (SS) and shoulder pathology.

Materials-Methods: A total of 22 male volleyball players from two teams participating in the first division of the Cypriot championship underwent clinical shoulder tests and simple measurements around their shoulder girdle joints bilaterally. SS was measured with the use of a sports speed radar.

Results: Compared with the NDOM side, the DOM scapula was more lateralised, the DOM dorsal capsule demonstrated greater laxity, the DOM dorsal muscles stretching ability was compromised, and the DOM pectoralis muscle was more lengthened. Players with present or past DOM shoulder pain demonstrated greater laxity in their DOM dorsal capsule, tightening of their DOM inferior capsule, and lower SS compared with those without shoulder pain. Dorsal capsule measurements bilaterally were significant predictors of SS. None of the shoulder measurements was associated with team roles or infraspinatus atrophy, while scapular lateralisation was more pronounced with increasing years of experience, and scapular antetilting was greater with increasing age.

Conclusions: Adaptations of the DOM shoulder may be linked to pathology and performance. We describe simple shoulder measurements that may have the potential to predict chronic shoulder injury and become part of injury prevention programmes. Detailed biomechanical and large prospective studies are warranted to assess the validity of our findings and reach more definitive conclusions.

Keywords: volleyball, shoulder, spike, ball velocity, pain, dominant, adaptations

1. Introduction

Volleyball is a highly-technical sport that involves powerful overhead movements performed repetitively, therefore exerting significant loads on the athletes' shoulders. An elite volleyball attacker may perform as many as 40,000 spikes a year, which may result in shoulder injuries as well as various adaptations of the hitting shoulder, as described in the relevant literature (Borsa et al., 2006; Schwab&Blanch, 2009; Forthomme et al., 2013).

While performing an attack (spike), the player aims to produce high velocities and large forces of the arm and transmit them to the ball while concurrently trying to maintain a maximal level of accuracy. This is achieved by initially abducting and externally rotating the dominant arm at maximal positions and subsequently adducting and internally rotating it rapidly (Reeser et al., 2010; Rokito et al., 1998). The speed of the ball is one of the most important characteristics of a spike and very limited data exist that aimed to identify associations between spike speed (SS) and players' characteristics (Forthomme et al., 2005). To the best of our knowledge, studies investigating a possible influence of glenohumeral joint and/or scapular adaptations on SS have not been previously performed.

Similarly to other overhead sports, such as baseball, tennis and handball, the dominant (DOM) shoulder of the volleyball athlete, and especially the spiker, has been found to be different than the non-dominant (NDOM) shoulder in terms of its morphology, strength, range of motion, and muscular balance (Borsa et al., 2008; Crockett et al., 2002; Myers et al., 2006; Pieper et al., 1998; Yildiz et al., 2006). In particular, as described in the majority of the studies, the hitting shoulder may exhibit an external rotation gain (ERG) and a glenohumeral internal rotation deficit (GIRD), imbalance of the glenohumeral joint due to greater concentric strength of internal rotators compared to eccentric strength of external rotators, scapular dyskinesis, and infraspinatus atrophy (Alfredson et al., 1998; Kugler et al., 1996; Lajtai et al., 2009; Martelli et al., 2013).

Scapular alterations in volleyball players and their association with injury and performance is a topic that received very limited attention if one takes into account the importance of the scapula in overhead movements. In an early study, Kugler et al. (1996) assessed the shoulder morphology of volleyball players by simple measurement techniques and identified significant differences between the DOM and NDOM shoulders of volleyball players and associations with shoulder injuries. Reeser et al. (2010) reported similar results in their large study describing a significant link between shoulder injury and the extent of scapular malposition and its associated symptoms and signs.

The aims of the present study comprised 6 research questions (RQs). Five measurements of different characteristics of the shoulder girdle of our population (both DOM and NDOM) were performed, SS was recorded, and the following hypotheses were investigated: 1) shoulder morphology is different on the DOM vs the NDOM side; 2) those with vs those without a) shoulder pain history (SPH) and b) infraspinatus atrophy (IA) have different shoulder morphology; 3) SS is different in those with and those without a) SPH and b) IA; 4) SS is correlated with shoulder morphology; 5) demographic characteristics are associated with shoulder morphology; and 6) players in different team roles have different a) SS, b) shoulder morphology.

2. Materials-Methods

2.1. Participants

During the 2014-2015 season, 22 male volleyball players from two teams participating in the first division of the Cypriot championship were included in the study. The right arm was the dominant (and hitting) arm in all participants and none of the athletes participated in any overhead activities other than volleyball and weight-training. The players were either professionals (n=8) or semi-professionals (n=14); fifteen of them were Cypriots and the rest “foreign” (one Canadian, two Serbians, one Slovakian, one Brazilian, one Venezuelan and one Latvian).

2.2. Tests

A short standardised questionnaire enquired about the players’ age, team role, years of volleyball experience, weekly hours of practising volleyball and weight-training, and present or past shoulder pain (SPH).

Following the interview, each player was weighed with simple weighing scales and had his height measured with a tape measure attached on the wall. Initial shoulder examination included inspection of the scapulae bilaterally for winging or IA, Hawkins-Kennedy, Jobe, palm-up, infraspinatus and lift-off tests for shoulder impingement bilaterally (Gilcreest, 1936; Hawkins & Kennedy, 1980; Jobe & Jobe, 1983; Gerber & Krushell, 1991; Leroux et al., 1995). The tests used to screen for shoulder impingement are illustrated and described in table I.

Subsequently, additional measurements around the shoulder girdle joint were taken bilaterally with a tape measure similar to the study by Kugler et al. (1996) to assess and compare the musculature and joint capsule of the two shoulders: Measurement I, the horizontal distance between the spinous process of the thoracic spine T5 and the medial border of the scapula with the arms relaxed by the side of the body (scapular lateralization); Measurement II, the distance between the lateral epicondyle and the opposite acromion during maximum horizontal adduction (dorsal capsule laxity); Measurement III, the vertical distance between the tip of the index finger and the spinous process of L5 vertebra behind the neck (inferior capsule laxity); Measurement IV, the vertical distance between the tip of the index finger and the spinous process of C7 vertebra during maximum internal rotation of the shoulder up the back (dorsal muscles stretch).

Finally, an additional measurement was performed to assess static scapular positioning: Measurement V, the distance between the posterior acromion and the wall with the participant resting his back against the wall with relaxed shoulders (scapular antetilting and pectoralis muscle length). All measurements were performed in both shoulders in a standing position.

Measurements I-V are illustrated in figure 1; the reader is also referred to the article by Kugler et al. (1996). We note that the landmark vertebrae used by Kugler et al. (1996) for measurements III and IV (C7 and L5 respectively) were reversed in our study merely for the ease of measurements and this is unlikely to have affected the results as neither vertebra C7 or L5 change positions during the two measurements.

Subsequently, the maximum SS of each player was measured with a speed radar (Supido Multi Sports Personal Speed Radar) which was placed close to the 9-metre line just outside of the playing court directly opposite the players, who were instructed to spike the ball set by the setter as forcefully as possible down-the-line towards the radar (figure 2). All players, regardless of team role (incl. setters and liberos), performed 3 spikes at the position they usually spike according to their team role (left corner, middle and right corner) and the highest SS of each player was recorded. All non-spiking players (liberos and setters) chose to spike at the left corner (position "4") of the court.

The data for each team was collected before (interview and examination) and during (SS) a single training session towards the end of the championship by a single examiner and an assistant. Informed consent was obtained verbally from each player separately prior to data collection after the aims and methods of the study were described. Ethical approval was granted by the Cyprus Volleyball Federation.

2.3. Statistical Analysis

Statistical analysis was performed using the base installation of R 3.1.2, with the installation of some extra packages. For univariate hypothesis tests we tested normality using Shapiro-Wilk test (Shapiro&Wilk, 1965), for symmetricity using the MGG test (Miao et al., 2006). If data were normal we then used t-test statistics: paired t-test in RQ 1 (morphology in DOM vs NDOM shoulder), two independent samples t-test (either pooled or unpooled depending on the outcome of the F-test for equal variances) in RQs 2 (associations of shoulder morphology with SPH and IA) and 3 (associations of SS with SPH and IA) or ANOVA for RQ 6 (associations of team roles with shoulder morphology and SS). If data were not normal but symmetric then we used nonparametric tests (Wilcoxon signed rank test for RQ 1, Wilcoxon rank sum test for RQs 2 and 3 or Kruskal-Wallis for RQ 6). If symmetry was not a reasonable assumption then we used permutation tests. For RQs 1 and 2 we ran multivariate hypothesis tests. We checked for multivariate normality using a majority vote between Mardia's, Henze-Zirkler's and Royston's multivariate normality tests (Korkmaz et al., 2014). If normality was assumed then we used either a paired multivariate test (RQ 1) or Hotelling's T^2 test

(RQ 2). If normality was not assumed then a nonparametric multivariate test on ranks as per Puri&Sen (1971) was used.

For RQs 4 and 5 we used multivariate multiple regression and univariate multiple regressions to check the relationship between variables. Regression assumptions were checked and verified.

Results were considered to be significant at the 5% critical level (*P*<0.05).

3. Results

The demographics and anthropometrics of the population are shown in table II. The results of shoulder impingement tests, shoulder girdle measurements and SS are presented in table III. Of the 6 players with DOM SPH (present pain n=3, past pain n=3), one had all shoulder impingement tests negative and 5 had positive Hawkins-Kennedy test, of which 4 had positive Jobe test, one positive infraspinatus test and one positive palm-up test (one had both positive Jobe and infraspinatus tests). One athlete in the no SPH group had a positive lift-off test on the DOM side.

With regards to the 5 measurements of the shoulder girdle, greater values reflected the following: Measurement I, greater scapular lateralisation; Measurement II, lesser laxity of the dorsal capsule; Measurement III, lesser laxity of the inferior capsule; Measurement IV, lesser ability of dorsal muscles to stretch; Measurement V, greater scapula antetilting/greater pectoralis lengthening.

The findings for each of the six RQs will be presented separately.

3.1. Dominant vs non-dominant shoulder morphology

Significant differences between the mean DOM and NDOM shoulder measurements were detected in I (*P*<0.001), II (*P*=0.015), IV (*P*<0.001), and V (*P*=0.009). For measurements I and IV the DOM values were significantly larger while for II and V the DOM values were significantly smaller. Measurement III was found to be statistically non-significant between the two sides (*P*=0.257). A non-parametric multivariate test returned a *P*=0.008.

3.2. Shoulder pain history and shoulder morphology

The mean values of all 5 measurements were similar in the DOM shoulders of those with vs those without SPH (I: *P*=0.744; II: *P*=0.088; III: *P*=0.280; IV: *P*=0.462; V: *P*=0.068). A non-parametric multivariate test showed no significance (*P*=0.166).

Furthermore, the difference of the mean DOM minus the mean NDOM (μDOM-μNDOM) measurements in those with vs those without DOM SHP was statistically significant only in Measurement II (-4.60cm vs -0.97cm respectively) and Measurement III (4.70cm vs -0.37cm respectively; I: *P*=0.711; II: *P*=0.024; III: *P*=0.007; IV: *P*=0.308; V: *P*=0.507). A non-parametric multivariate test revealed a significant difference (*P*=0.038).

IA was identified in 13.6% of our population and was isolated in all cases (no supraspinatus atrophy). The mean values of the DOM shoulders of players with IA compared with the DOM shoulders of those without IA in the 5 measurements were non-significant (I: *P*=0.963; II: *P*=0.132; III: *P*=0.591; IV: *P*=0.676; V: *P*=0.153). A non-parametric multivariate test yielded a *P*=0.784.

Similarly, the μDOM-μNDOM difference of those with and those without IA were similar in all measurements (I: *P*=0.961; II: *P*=0.059; III: *P*=0.068; IV: *P*=0.702; V: *P*=0.579). A non-parametric multivariate test confirmed the absence of significant differences in any of the tests (*P*=0.177).

3.3. Shoulder pain history and spike speed

The group of players with IA had a similar mean SS (μSS) to those without IA (*P*=0.827).

On the other hand, those with DOM SPH had a significantly lower μSS than those without DOM SPH (80.13km/h vs 94.67km/h respectively; *P*=0.027).

3.4. Shoulder morphology and spike speed

We initially performed multiple regression analysis where we used all 5 DOM-NDOM measurements differences as predictors and SS as the response. We found that none of the DOM-NDOM differences was significant in predicting SS (*P*>0.05).

We then performed the same analysis using the measurements of the DOM shoulder only instead of the DOM-NDOM difference and found that Measurement II was a significant predictor of SS (*P*=0.040). Specifically, longer distances between the DOM lateral epicondyle and the opposite acromion measured during maximum horizontal adduction were associated with higher SS. No other measurements of the DOM shoulder girdle appeared to be predictors of SS at statistical significance (*P*>0.05).

Since the DOM but not the DOM-NDOM measurement appeared to be a significant predictor of SS, we repeated the analysis with NDOM shoulder measurements to confirm that NDOM Measurement II was significantly associated with SS in the same manner (*P*=0.021). The rest of the NDOM shoulder measurements yielded non-significant associations with SS (*P*>0.05).

Table IV shows the results of the multiple regression analysis of the 5 DOM and NDOM shoulder measurements on SS and figure 3 the Ordinary Least Squares Regressions lines of Measurement II vs SS.

3.5. Associations of demographic characteristics

IA was not significantly associated with any of age, years of experience, hours of weekly volleyball practice and hours of weekly weight-training (*P*>0.05).

For the DOM-NDOM difference of the 5 shoulder measurements, years of experience and age appeared to be significant predictors for greater lateralisation of the scapula (Measurement I; *P*=0.019) and greater scapular antetilting (Measurement V; P=0.019) respectively. Years of experience was an almost-significant (*P*=0.057) predictor of scapular antetilting. No other significant associations were identified.

3.6. Team roles

Initially, we stratified all players into a spiking group (middle, outside and opposite hitters; n=17) and a non-spiking group (liberos and setters; n=5) and found that the μSS of the former (86.88 km/h) was significantly higher than that of the latter (74.6 km/h; *P*=0.016). The players in the spiking group were taller and had a lower BMI than those in the non-spiking group (1.95cm vs 1.85cm; 23.2kg/m^2 vs 25.2kg/m^2 respectively).

Subsequently, using the same two groups, we investigated for differences in the 5 μDOM-μNDOM measurements of the shoulder girdle and we found that none of them was different between spiking and non-spiking athletes (I: *P*=0.749; II: *P*=0.575; III: *P*=0.969; IV: *P*=0.666; V: *P*=0.107).

Finally, using data from the spiking group only, we tested for differences in μSS and the 5 μDOM-μNDOM measurements in middle vs opposite vs outside hitters. μSS was highest in opposite (100.50 km/h), followed by outside (90.38 km/h) and middle hitters (79.85 km/h). None of the differences of the 5 μDOM-NDOM measurements was statistically significant in the three sub-groups.

4. Discussion

The volleyball spike belongs to the overhead movements and is performed by initially abducting and externally rotating the dominant arm (cocking phase) and then adducting and internally rotating it rapidly and forcefully (acceleration phase) (Rokito et al., 1998). After impact of the hand with the ball, the arm decelerates (deceleration phase) and finally stops by the side of the body and this is achieved by dynamic eccentric forces at the posterior shoulder girdle muscles and the biceps (Escamilla&Andrews, 2009; Kugler et al., 1996; Reeser et al., 2010). Alterations in any of the components of the shoulder joint may result in shoulder motion abnormalities, and changes in static and dynamic scapular positioning specifically have been associated with several types of shoulder disorders, such as instability and impingement (Borsa et al., 2008; Kibler et al., 2002).

Chronic shoulder injuries are relatively common in volleyball players with a prevalence of 15-20% (Ferretti et al., 1998). They may have a significant impact on performance or in severe cases they may even lead to interruptions and/or termination of an athlete’s career. For these reasons, injury prevention should have an important role in high-level volleyball players and, according to our findings and those of previous studies, simple shoulder tests and measurements may have the potential to diagnose shoulder injuries or tendency for shoulder pathology at early stages (Kugler et al., 1996; Reeser et al., 2010).

Our study identified significant differences between the DOM and NDOM shoulders of high-level volleyball players and associations between shoulder morphology, demographic characteristics and SS.

SPH was found to be associated with increased laxity in the dorsal capsule and decreased laxity in the inferior capsule on the DOM vs the NDOM side, as well as a lower μSS. Although it would be logical to conclude that the lower μSS of players with DOM SPH may be a direct result of the shoulder pain/injury, similar associations cannot be made for shoulder morphology. The looser dorsal capsule and tightneded inferior capsule on the DOM vs the NDOM side in those with DOM SPH may be either the result or the aetiology of injury/pain, or even an adaptation mechanism to maintain performance.

With respect to the morphological differences, the increased scapular lateralisation on the DOM side (Measurement I) suggests lengthening of the trapezius and rhomboids, while the greater posterior tilting of the DOM scapula implies lengthening of the pectoralis muscle compared with the NDOM side (Measurement V). We speculate that the reduced dorsal muscles stretching of the DOM side (Measurement III) is secondary to serving and/or spiking, as the high loads placed on the dorsal shoulder during the eccentric deceleration forces of the overhead movement may stiffen the dorsal musculature.

With regards to predictors of spike performance, other than SPH, the distance between the lateral epicondyle and the opposite acromion with the arm in maximum horizontal adduction (Measurement II) bilaterally was positively associated with SS. The significant effect of the DOM and NDOM measurements separately on SS as opposed to the absent relationship of their difference (DOM-NDOM) with SS implies broadening of the shoulders rather than dorsal capsule laxity being involved. Broader shoulders result in a greater distance between the right and left acromion and therefore higher values in Measurement II bilaterally. This is most likely the result of weight-training and is in accordance with the results of Forthomme et al. (2005) who found that weekly hours of weight-training have a positive association with SS.

We recommend continuous encouragement of volleyball players with and without shoulder injuries to stretch their shoulders and strengthen the scapular fixation muscles, ideally with the use of ropes (Duzgun et al., 2010; Kugler et al., 1996). These simple measures, in combination with an optimised spike and serve technique, can be used both for prevention and treatment of shoulder pain in volleyball.

Notarnicola et al. (2012) compared the supraspinatus tendons of volleyball players of different team roles and reported interesting findings. Supraspinatus perfusion (and hence neovascularisation) was measured by oximetry and, while no significant associations were detected between oximetry data and demographic characteristics including years of experience, higher values were identified in the DOM arm of outside hitters vs players in other team roles except setters. These variations may indicate the response to specific biomechanical demands of the shoulders of athletes in different overhead roles and may be determined by the overuse conditions typical of each team role.

Kugler et al. (1996) were the first to conduct a study assessing the DOM and NDOM shoulder girdle joints of volleyball players and compare them with recreational, non-overhead athletes. The authors reported increased scapular lateralisation on the DOM vs the NDOM side in volleyball players and a diminished ability to stretch the DOM vs the NDOM dorsal muscles, which was more pronounced in those with shoulder pain; both are in accordance with our findings. However, in contrast to our results, Kugler et al. (1996) described a tightened dorsal capsule on the DOM vs the NDOM side, which was most marked in players with shoulder pain, and a more marked lateralisation of the DOM vs the NDOM scapula in those with shoulder pain, which led them to the assumption that shoulder pain may be the result of disruptions in the normal gliding and rolling motion of the humeral head that is secondary to tightened inferior and posterior structures, shoulder depression and scapular lateralisation.

Beyond the shoulder girdle measurements performed by Kugler et al. (1996), we went a step further and assessed static scapular positioning, which revealed a lengthened pectoralis muscle on the DOM vs the NDOM side of our population, most likely due to the repetitive concentric loads placed on the pectoralis muscle in the wind-up, cocking, and acceleration phases of the serve and spike (Escamilla&Andrews, 2009; Rokito et al., 1998). Even though the original test assessing static scapular positioning initially proposed by Host (1995) is performed by measuring the distance between the posterior border of the acromion and the table with the subject lying supine, its validity is questioned because of the influence of the table on scapular position, which is likely to locate the scapula into a correct position, and the alteration of the effect of gravity (Borstad, 2006; Nijs et al., 2007). The test we performed with the participants in a standing position against the wall overcomes this bias and has been found to display fair to good interobserver agreement (Nijs et al., 2007).

Reeser et al. (2010), in their large study of 276 collegiate volleyball players, identified significant risk factors of shoulder pain/dysfunction: a) attacking role, b) “jump” serve), c) increasing age (but not years of experience), d) increasing SICK scapula score (Scapula malposition, Inferior medial border prominence, Coracoid pain and malposition, and scapular dysKinesis), e) presence of shoulder strength imbalance of external rotators and/or internal rotators between the two sides and f) increasing scapular lateralization.

To the best of our knowledge, this is the first study to assess correlations of shoulder girdle measurements with IA and SS. Isolated IA is a relatively common finding in volleyball players as opposed to other overhead sports and is thought to be caused by traction/stretching of the suprascapular nerve at the spinoglenoid notch (Reeser et al., 2013; Witvrouw et al., 2000). The exact aetiology of the syndrome remains unclear, however authors have implicated the inferior transverse (spinoglenoid) ligament, the “float” serve, the “manchete”, and extreme shoulder positions, with the latter currently being the most favourite mechanism (Aiello et al., 1982; Ferretti et al., 1987; Sandow&Ilic, 1998; Reeser et al., 2013; Tengan et al., 1993). The prevalence of IA in volleyball appears to be between 13% and 33% (vs around 4.4% in baseball), which is in accordance with our data (13.6%) (Cummins et al., 2004; Holzgraefe et al., 1994; Lajtai et al., 2009; Lajtai et al., 2012). The majority of the literature supports no effects of isolated IA on shoulder function, except for a strength deficit of the external rotators, and this is in agreement with our findings (Ferretti et al., 1998; Witvrouw et al., 2000).

In a well-designed biomechanical study, Forthomme et al. (2005) investigated the factors correlated with volleyball SS and reported a number of factors being significant predictors of SS, including the external rotators/internal rotators (ER/IR) peak torque ratio, the height at which the ball is contacted, the weekly hours of weight-training performed and the BMI. Players with a history of shoulder tendinosis displayed a trend of weakened ER/IR ratio, which supports our result of a lower μSS in those with DOM SPH. The overall μSS of their division 1 and division 2 players was 100.9km/h and 90.4km/h respectively, which was higher than the μSS in our study (84.1km/h), possibly due to the higher level of their participants and/or methodological differences.

The major limitation of our study is unquestionably its small population and hence limited power. This may have resulted in type 2 errors, especially where sub-groups had a particularly small size (e.g. IA, opposite hitters). In addition, allocating semi-professional, non-elite volleyball players into a spiking and non-spiking group may not have yielded accurate results as non-elite players may have held spiking roles for a number of years at the start of their careers, unlike elite players who are usually trained at specific team roles from early on and remain at those throughout their careers. In addition, the small number of athletes with SPH did not allow for possible associations of specific shoulder tests to be tested for, and finally other factors that could be associated with SS, such as height, BMI and vertical jump height were not adjusted for. Nevertheless, we did adjust for other important demographic characteristics (e.g. years of experience and amount of weight-training) and, overall, performed a thorough and accurate statistical analysis which included both multivariate and univariate hypothesis tests and regression analyses. Other methodological strengths include the additional test employed to assess static scapular positioning, recording SS with players spiking from their usual spike position (e.g. outside players through court position "4", opposite players through court position "2" etc), as opposed to the study by Forthomme et al. (2005) in which everyone spiked through "4", and comparing shoulder morphology of players in different team roles, which has never been performed elsewhere to the best of our knowledge.

5. Conclusions-Perspectives

Based on the existing literature, the continuous repetition of forceful overhead movements in volleyball may result in adaptations of the player's DOM shoulder and it remains unclear whether these changes affect performance or are associated with shoulder pathology.

In our study we detected differences between the DOM and NDOM shoulder girdle joints of high-level volleyball athletes and significant associations with pathology and performance. The exact mechanism of these shoulder changes is unclear and well-designed, detailed biomechanical and prospective studies are warranted to give answers to the aetiology and/or purposes of these adaptations and identify potential risk factors of shoulder injuries and compromised performance.

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Conflict of Interest

None

References

Aiello GS, Traina GC, Tugnoli V. Entrapment of the Suprascapular Nerve at the Spinoglenoid Notch. Ann Neurol 1982;12:313-316.

Alfredson H, Pietila T, Lorentzon R. Concentric and eccentric shoulder and elbow muscle strength in female volleyball players and non-active females. Scand J Med Sci Sport. 1998;8(5 Pt 1):265-270.

Borsa PA, Laudner KG, Sauers EL. Mobility and stability adaptations in the shoulder of the overhead athlete: a theoretical and evidence-based perspective. Sports Med. 2008;38(1):17-36.

Borstad JD. Resting position variables at the shoulder: evidence to support a posture-impairment association. Phys Ther 2006;86:549-557.

Crockett HC, Gross LB, Wilk K. Osseous adaptation and range of motion at the glenohumeral joint in professional baseball players. Am J Sports Med. 2002;30 (1):20-26.

Cummins CA, Messer TM, Schafer MF. Infraspinatus atrophy in professional baseball players. Am J Sports Med. 2004;32:116-120.

Duzgun I, Baltaci G, Colakoglu F, Tunay VB, Ozer D. The effects of jump-rope training on shoulder isokinetic strength in adolescent volleyball players. J Sport Rehabil 2010;19(2):184-199.

Escamilla RF, Andrews JR. Shoulder muscle recruitment patterns and related biomechanics during upper ectremity sports. Sports Med 2009;39(7):569-590.

Ferretti A, Cerullo G, Russo G. Suprascapular neuropathy in volleyball players. J Bone Joint Surg 1987;69A(2):260-263.

Ferretti A, De Carli A, Fontana M. Entrapment of suprascapular nerve at spinoglenoid notch. Am J Sports Med. 1998;26(6):759-63.

Forthomme B, Croisier JL, Ciccarone G, Crielaard JM, Cloes M. Factors correlated with volleyball spike velocity. Am J Sports Med. 2005;22(10):1513-9.

Forthomme B, Wieczorek V, Frisch A, Crielaard JM, Croisier JL. Shoulder pain among high-level volleyball players and preseason features. Med Sci Sports Exerc. 2013;45(10):1852-1860.

Gerber C, Krushell RJ. Isolated rupture of the tendon of subscapularis muscle. Clinical features in 16 cases. J Bone Joint Surg Br. 1991;73(3):389-394.

Gilcreest EL. Dislocation and elongation of the long head of the biceps brachii: an analysis of six cases. Ann Surg. 1936;104(1):118-138.

Hawkins RJ, Kenndy JC. Impingement syndrome in athletes. Am J Sports Med. 1980.8(3):151-158.

Holzgraefe M, Kukowski B, Eggert S. Prevalence of latent and manifest suprascapular neuropathy in high-performance volleyball players. Br J Sports Med 1994;28:177-179.

Host HH. Scapular taping in the treatment of anterior shoulder impingement. Phys Ther 1995;75:803-812.

Jobe FW, Jobe CM. Painful athletic injuries of the shoulder. Clin Orthop Relat Res. 1983;(173):117-124.

Kibler WB, Uhl TL, Maddux JW, Brooks PV, Zeller B, McMullen J. Qualitative clinical evaluation of scapular dysfunction: a reliability study.J Shoulder Elbow Surg 2002;11(6):550-556.

Korkmaz S, Goksuluk D, Zararsiz G. MVN: An R Package for Assessing Multivariate Normality. The R journal 2014;6(2):151-162.

Kugler A, Krüger-Franke M, Reininger S, Trouillier HH, Rosemeyer B. Muscular imbalance and shoulder pain in volleyball attackers. Brit J Sports Med. 1996;30(3):256-259.

Lajtai G, Pfirrmann CW, Aitzetmuller , Pirkl C, Gerber C, Jost B. The shoulders of professional beach volleyball players: high prevalence of infraspinatus muscle atrophy. Am J Sports Med. 2009;37(7):1375-1383.

Lajtai G, Wieser K, Ofner M, Raimann G, Aitzetmuller G, Jost B. Electromyography and nerve conduction velocity for the evaluation of the infraspinatus muscle and the suprascapular nerve in professional beach volleyball players. Am J Sports Med. 2012;40(10):2303-8.

Leroux JL, Thomas E, Bonnel F, Biotman F. Diagnostic value of clinical tests for shoulder impingement syndrome. Rev Rhum Engl Ed. 1995;62(6):423-428.

Martelli G, Ciccarone G, Grazzini G, Signorini M, Urgelli S. Isometric evaluation of rotator cuff muscles in volleyball athletes. J Sports Med. 2013;53(3):283-288.

Miao W, Gel YR, Gastwirth JL. A new test of symmetry about an unknown median. In: Hsiung A, Zhang C-H, Ying Z, editors. Random Walk, Sequential Analysis and Related Topics—A Festschrift in Honor of Yuan-Shih Chow. World Scientific; Singapore 2006.

Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. Am J Sports Med. 2006;34(3):385-391.

Nijs J, Roussel N, Struyf F, Mottram S, Meeusen R. Clinical assessment of scapular positioning in patients with shoulder pain: state of the art. J Manipulative Physiol Ther 2007;30(1):69-75.

Notarnicola A, Fischetti F, Gallone D, Moretti L, Pignataro P, Tafuri S, et al. Overload and neovascularization of shoulder tendons in volleyball players. BMC research notes. 2012;5:397.

Pieper HG. Humeral torsion in the throwing arm of handball players. Am J Sports Med. 1998;26(2):247-253.

Puri ML, Sen PK. Nonparametric Methods in Multivariate Analysis. John Wiley & Sons, New York 1971.

Reeser JC, Fleisig GS, Bolt B, Ruan M. Upper limb biomechanics during the volleyball serve and spike. Sports Health. 2010;2(5):368-374.

Reeser JC, Fleisig GS, Cools AM, Yount D, Magnes SA. Biomechanical insights into the aetiology of infraspinatus syndrome. Brit J Sports Med. 2013;47(4):239-244.

Reeser J, Joy EA, Porucznik CA, Berg RL, Colliver EB, Willick SE. Risk factors for volleyball-related shoulder pain and dysfunction. PM R 2010;2(1):27-36.

Rokito AS, Jobe FW, Pink MM, Perry J, Brault J. Electromyographic analysis of shoulder function during the volleyball serve and spike. J Shoulder Elbow Surg. 1998;7(3):256-63.

Sandow MJ, Ilic J. Suprascapular nerve rotator cuff compression syndrome in volleyball players. J Shoulder Elbow Surg. 1998;7(5):516-521.

Schwab LM, Blanch P. Humeral torsion and passive shoulder range in elite volleyball players. Phys Ther Sport. 2009;10(2):51-56.

Shapiro SS, Wilk MB. An analysis of variance test for normality (complete samples). Biometrika 1965: 52(3–4): 591–611.

Tengan CH, Oliveira AS, Kiymoto BH, Morita MP, De Medeiros JL, Gabbai AA. Isolated and painless infraspinatus atrophy in top-level volleyball players. Report of two cases and review of the literature. Arq Neuropsiquiatr 1993;51(1):125-129.

Witvrouw E, Cools A, Lysens R, Cambier D, Vanderstraeten G, Victor J, et al. Suprascapular neuropathy in volleyball players. Brit J Sports Med. 2000;34(3):174-180.

Yildiz Y, Aydin T, Sekir U, Kiralp MZ, Hazneci B, Kalyon TA. Shoulder terminal range eccentric antagonist/concentric agonist strength ratios in overhead athletes. Scand J Med Sci Sports. 2006;16(3):174-180.

Table legends

Table I: **Description and illustration of shoulder impingement tests.**

Table II: **Demographic and anthropometric characteristics of our population**; sd: standard deviation.

<u>Table III</u>: Shoulder examination findings and spike speed measurement; Measurement I: lateralisation of scapula; Measurement II: dorsal capsule laxity; Measurement III: dorsal muscles stretch; Measurement IV: inferior capsule laxity; Measurement V: static scapular positioning. DOM: dominant shoulder; NDOM: non-dominant shoulder; sd: standard deviation.

<u>Table IV:</u> Results of the multiple regression of the five measurements on spike speed. DOM: dominant shoulder; NDOM: non-dominant shoulder.

Figure Legends

<u>Figure 1 (a-e).</u> Measurements I-V shown by the arrows; a: Measurement I (scapular lateralization); b: Measurement II (dorsal capsule laxity); c: Measurement III (inferior capsule laxity); d: Measurement V (dorsal muscles stretching ability); e: Measurement V (Static scapular positioning).

<u>Figure 2.</u> Spike speed measurement. Each athlete spiked the ball set by the setter over the net straight-ahead (dotted arrow) towards the stationary speed radar which was placed down the line just outside the court as shown. The setter was instructed to set the ball in a fast pace, simulating a real game attack.

<u>Figure 3.</u> Ordinary Least Squares Regression lines of test II (dorsal capsule) as predictor of spike velocity. Dominant Shoulder: P=0.040, Non-Dominant Shoulder: P=0.021.