

Mobility impairment, muscle imbalance, muscle weakness, scapular asymmetry and shoulder injury in elite volleyball athletes

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Background. The aim of this study was to evaluate the relationship between shoulder mobility, rotator muscles' strength and scapular symmetry, and shoulder injuries and/or pain in elite volleyball athletes.

Methods. An isokinetic shoulder muscle strength test, which was performed at speeds of 60/sec and 180/sec, and shoulder mobility and scapula lateral slide tests were conducted bilaterally on 16 subjects, who represented the England elite volleyball players. The subjects also prospectively completed monthly questionnaires during the competition season to report on their shoulder condition.

Results. The results showed that the active range of shoulder internal rotation and concentric external rotators' strength in the dominant arm were significantly less, than in the non-dominant arms, but the internal rotators were significantly stronger in both concentric and eccentric tests at both testing speeds. Seven of 16 subjects indicated overt shoulder injury or pain during their training season, nine subjects had shoulder mobility impairment, seven had muscle imbalance, 13 had relative muscle weakness and five had scapular asymmetry. The association between shoulder muscle strength imbalance (eccentric external < concentric internal) of rotators in the dominant arm and shoulder injuries was statistically significant (Fisher's exact test, $p < 0.05$).

Conclusions. We conclude that rotator muscle strength imbalance may play an important role in shoulder injuries in high-level volleyball players.

KEY WORD: Volleyball - Muscle imbalance - Shoulder injuries.

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Shoulder injuries in elite overhead athletes are mainly reported to result from overuse leading to rotator cuff tendinitis, coracoacromial impingement and glenohumeral joint instability.¹⁻³ These overuse injuries, which are frequently associated with joint hyperlaxity, mobility impairment or muscle imbalance, threaten athletes' careers.^{1,4,5} Overuse dominant shoulder injuries in elite overhead athletes are believed not to happen purely at random, but are contributed to by injury risk factors. Several factors, including poor mobility, muscle imbalance, muscle weakness and scapular asymmetry (malalignment) have been suggested as the intrinsic etiologic factors that contribute to such injuries.⁶⁻⁹ It has been shown that there is a moderate negative correlation between dominant internal rotation and years of play in overhead athletes.¹⁰ Moreover, a decreased shoulder range of internal rotation in the playing arm has been reported in baseball pitchers, swimmers, tennis and volleyball players but a strong association with shoulder overuse injury has not been confirmed.^{6,11-13} Bak and Magnusson's study showed a strength but not a flexibility dif-

ference between the symptomatic and symptom-free swimmers' shoulders.⁶

Shoulder rotator muscle imbalance has been used to describe an unbalanced force couple that occurs between agonist and antagonist muscles around the playing arm's shoulder joint⁶ or to describe the relative weakness of a specific muscle group when there is a comparison of strength values between the dominant and non-dominant sides.¹⁴ These imbalance and weakness may be caused by sports training or eccentric overload and were found in overhead and wheelchair athletes and quantified by the strength ratio of eccentric external/concentric internal and concentric external/concentric internal contraction forces respectively.^{6, 14, 15} The results of previous research has shown that muscle imbalance and muscle weakness, low shoulder rotator muscle strength ratios and relatively weak shoulder external rotators, are possible shoulder injury risk factors for overhead athletes.^{9, 13, 15} It is accepted that a low concentric external/internal strength ratio may lead to or allow excessive humeral head anterior displacement and increase the loading on the biceps long head tendon. Furthermore, the eccentric strength of the external rotator is not only important for acceleration in the cocking phase of throwing and the entering phase of swimming but also for deceleration and control in the follow-through and the recovery phase.¹⁶⁻¹⁸ It is also believed that it is necessary for eccentric strength to be as strong as concentric internal rotation to maintain normal shoulder function.¹⁷⁻¹⁹ However, more direct evidence is needed to support the belief that the extreme shoulder strength ratio or a low eccentric external/concentric internal contraction strength ratio (<1) is correlated to shoulder injury in sports.

A depressed lateralized or unstable scapula with-
enon in overhead athletes and is thought to be related to shoulder impingement by narrowing of the sub-acromial space.⁷ Furthermore, scapular dyskinesis, caused by imbalance or weakness of parascapular muscles, may result in impingement due to the fact that the acromion does not rotate out of the way of the humeral head. Delayed parascapular muscle firing in swimmers with present or previous shoulder pain may suggest that the synchronisation of these muscles may play an important role in shoulder stabilisation to prevent pain or injury in these sport populations.²⁰ These findings suggested that the asymmetric scap-

ular positions or motions are associated with the main shoulder injuries, impingement and instability, of elite overhead athletes.²¹ Kibler believes that a higher potential of shoulder injury happens when the asymmetry between the two scapulas is larger than 1 cm.²²

There is little research which combines isokinetic and mobility testing of shoulder rotators and symmetry measurement of scapulas with a longitudinal study to assess the relationship between strength ratio (imbalance of), mobility impairment, relative muscle weakness, asymmetry of scapulas and shoulder injury. The relative contributions of each of these factors to shoulder injury have not been confirmed. The object of the present study is to discover the long-term effects of the four overuse intrinsic risk factors: poor flexibility, muscle imbalance, relative muscle weakness and scapular asymmetry, to the shoulder pain or injury in the England elite male volleyball players. Furthermore, the relationships between these injury risk factors are also discussed in this study.

Materials and methods

Subjects

Sixteen athletes who were trained or played for the England National Men's volleyball squad between 1997 and 1998 were recruited for this study. No subjects had had shoulder surgery before this study. These players all completed a brief personal history questionnaire and monthly questionnaires to report their shoulder musculoskeletal pain or injury, if they had any. The definition of sports injury or pain in the questionnaires was given as: an incident or period occurring in connection with volleyball during training or com-

pletely prevents players from playing or 3) requires special treatment in order for players to continue playing.²³ A visual prompt and analogue scale and figures were used to help subjects to describe their present pain and its location. The subjects' shoulder mobility, and the symmetry of the two scapulas and shoulder rotator strength were also measured once at the beginning of their national and club training sessions. All subjects used the right arms as their dominant side furthermore, there was no history of treatment in the dominant side two months prior to the tests. There were no specific exclusions as all the numbers of the

elite squad were able to complete all aspects of the study. However, it was agreed in advance that, during the tests, subjects who reported or complained of shoulder pain would be excluded from further participation in this study.

Range of motion

Active shoulder internal and external rotation range of motion was carried in a shoulder abduction position and was recorded bilaterally using the standard goniometer technique.

Isokinetic test

Concentric and eccentric parameter measures on the dominant and non-dominant shoulder were performed on an isokinetic dynamometer - Kin-Com AP Muscle Testing System (Chattecx Corp., Hixson, Tennessee) - at the speeds of 60 and 180° per second. The subjects completed 3-5 submaximal contractions trials to familiarise themselves with the procedure and to warm up their muscles. During the test, the subjects were supine and restrained by straps across their shoulder girdle and chest with the shoulder abducted at 90, the elbow flexed at 90; 0° of shoulder rotation was defined with the forearm in the neutral position. The range of test was between 50 external rotation and 50 internal rotation. For example, in the internal concentric/external eccentric tests, test started from 50 external rotation and the movement rotated through to 50 internal rotation. The dominant arm was assessed first, then the non-dominant arm. Internal rotation was always tested first, followed by external rotation and eccentric measurement immediately followed the concentric measurement. Subjects were given a 10 - second and 30 - second rest between each trial and two speeds, respectively. Subjects performed at least three maximal contractions in each test, which did not vary from each other by more than 10%, to get a consistent result. High test-retest reliability (intra-class correlation coefficients, ICC) for concentric and eccentric internal and external rotation in this position (90/90 position) at the speeds of 60/sec and 180/sec have been reported by Hellwig *et al.*²⁵ To prevent skewing the results from torque overshoot and a unreproducible repetition, the range of test was from 50 external rotation to 50 internal rotation.²⁶ Fifty N of mechanical preloading force was established for all test

conditions. Each test began at 60/sec and was repeated at 180/sec. Gravity compensation was not included in any parameters in these tests because the testing movements were not parallel with the direction of gravity and it has not been used in recent similar research.²⁷

Scapula lateral slide test

The evaluation of scapular symmetry was as described by Kibler.²² The symmetry was determined

The distances between the spinous process of T7 and the inferior angle of each scapula were measured in three different positions, S1, S2 and D1. In position S1, a position of relative rest, two arms are in neutral rotation at bilateral sides. Position S2 is achieved by placing the hands on the hips with the thumbs pointing posteriorly. In position D1, the arms are abducted 90 and are maximally internally rotated. During the testing, the subjects were fully relaxed with no distractions in S1 and S2 positions, and without any compensatory scapula elevation in the D1 testing position. The intraclass coefficient (ICC) ranged from 0.88 to 0.95 in our pilot works.

Statistical method

Paired "t"-tests (with 95% confidence limits) were used to test for differences between dominant and non-dominant shoulders. The association between injury or pain and muscle imbalance, relative muscle weakness, scapular asymmetry, mobility impairment was assessed by the Fisher's exact test. The definition of muscle imbalance in this study was that, in the dominant arm, the average external rotation eccentric torque was less than the average internal rotation concentric torque at either of the test speeds. Relative muscle weakness was defined when the relative average concentric strength of shoulder external rotators between the two arms exceeded 15% at either of the test speeds. In a shoulder abduction position, a difference of range of shoulder internal or external rotation between the dominant and the non-dominant arms which was larger than 10° was defined as impaired mobility. Scapular asymmetry as described by Kibler, is when the difference of the distance between the spine (T7) and the inferior angle of each scapula is larger than 1 cm.²²

TABLE I.—Physical characteristics and experience of volleyball players. Figures in brackets represent standard deviation.

Value	Body height in cm	Body weight in kg	Training history in year	Training hours per week
Mean (SD)	194.7(5.7)	86.4(6.7)	6.1(2.0)	7.6(2.3)

Results

Mean physical characteristics

The physical characteristics of the players who took part in these studies are shown in Table I.

Questionnaire analysis

From the completed questionnaires, seven of 16 subjects indicated a shoulder pain problem during

their training season. Three of these seven players reported their shoulder pain had been diagnosed as an overuse injury. The diagnosis for these three overuse injuries was tendinitis. One reported pain was in the upper trunk and upper arm area. The diagnoses for the remaining injuries included the traumatic shoulder glenoid lesion and muscle strain.

Mobility

Figure 1 shows that the active ranges of internal rotation on the dominant side, in a shoulder abduction position, were significantly smaller than on the non-dominant side ($p < 0.001$). The difference in external rotation between two arms was not significant ($p = 0.072$). Nine players had impaired mobility in internal rotation of the dominant arm.

Muscle strength

The results of the mean peak strength of internal/external, concentric and eccentric contraction at speeds of 60/sec and 180/sec in the dominant and the non-dominant shoulders are summarised in Figs. 2A and B. At both rotation speeds, the mean peak strength in internal rotation for both concentric and eccentric contraction on the dominant side was greater than on

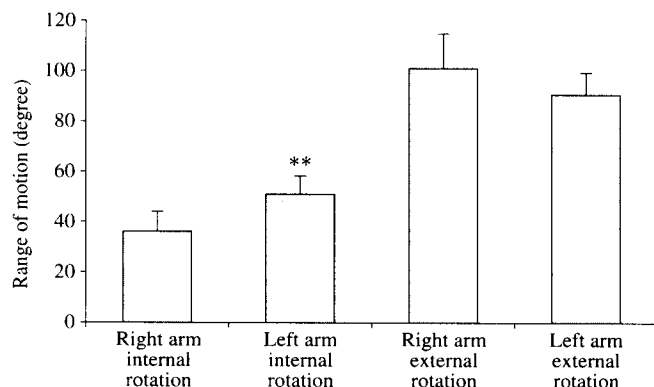


Fig. 1.—Active range of shoulder internal and external rotation in the dominant and non-dominant shoulders. Error bars indicate standard error. $p < 0.05$ is significant, $**p < 0.01$.

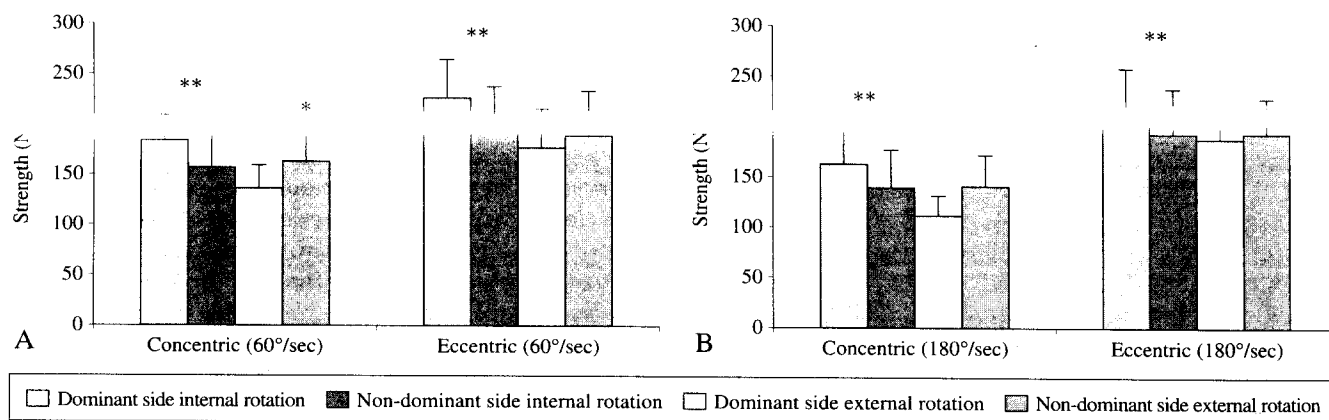


Fig. 2A, B.—Isokinetic profile of average peak strength at different speeds in the dominant and the non-dominant arms. Error bars indicate standard error. Asterisks mean statistical significance between the two arms. $**p < 0.01$, $*p < 0.05$.

TABLE II.—Isokinetic rotator muscle strength ratios of average torque in two arms.

Parameters	Dominant		Non-dominant	
	60°/sec	180°/sec	60°/sec	180°/sec
Concentric external/internal	0.73(0.11)	0.70(0.10)	1.06(0.17)	1.04(0.20)
Eccentric external/concentric internal	0.96(0.18)	1.17(0.16)	1.22(0.22)	1.42(0.26)

Figures in brackets represent standard deviation. All p values ≤ 0.001 for the dominant vs non-dominant arms.

the non-dominant side ($p \leq 0.01$). This data also indicates that the external rotators in the dominant arm were weaker in concentric contraction than those of the non-dominant arms ($p = 0.026$ and 0.009 , respectively). Thirteen players had relative muscle weakness in their dominant arms' external rotators. The differences in mean peak strength at the two test speeds in eccentric external rotation between the dominant and the non-dominant side were not significant.

Strength ratios

The strength ratios of average torque in the dominant and the non-dominant arms, at two test speeds, are presented in Table II. Eight players had muscle imbalance.

Scapula lateral slide test

The results of this measurement are shown in Figure 3 and are compared with the findings of Davies and

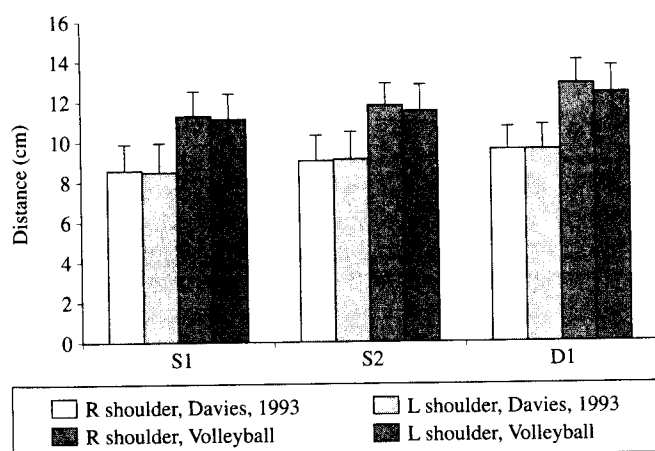


Fig. 3.—The results of scapula lateral slide tests in different positions, compared to Davies and Dickoff-Hoffman, 1993.²⁸ Error bars indicate standard error.

TABLE III.—Numbers in different risk factor groups (muscle balance, relative muscle weakness, mobility and scapular symmetry) and

Parameters	Injury		Significance (Fisher's exact test)
	No	Yes	
Muscle strength:			
—Balance	7	1	0.041
—Imbalance	2	6	
Relative muscle weakness:			
—No	2	1	1.000
—Yes	7	6	
Mobility:			
—Normal	5	2	0.358
—Impairment	4	5	
Scapular:			
—Symmetry	6	5	1.000
—Asymmetry	3	2	
Sum	9	7	

Dickoff-Hoffman.²⁸ Five players showed an asymmetrical scapula.

Correlation

Table III shows the numbers of people in each group and the statistical correlation values of these groups to injury. Only the association between muscle imbalance and injury was statistically significant ($p = 0.041$). There was no significant association between injury and mobility impairment, muscle imbalance, relative muscle weakness and scapular asymmetry (all p values > 0.05).

Discussion

Injury and risk factor

Risk factors for shoulder overuse injury have been divided into two groups: extrinsic and intrinsic. Mobility impairment, muscle imbalance, muscle weakness and scapular asymmetry are considered to belong

to the intrinsic factor group.⁹ Muscle imbalance between shoulder rotation force couples and relative external rotator muscle weakness are believed to be the causes of secondary impingement and dynamic instability.^{8,14} Mobility impairment and scapular asymmetry have been found in the patients with shoulder impingement.^{8,21,22} The prevalences of these four risk factors in this study were: mobility impairment (9/16), muscle imbalance (8/16), relative muscle weakness (13/16) and scapular asymmetry (5/16), respectively. The shoulder injury showed a statistically significant association with muscle imbalance but not with mobility impairment, muscle weakness or scapular asymmetry (Table III). This may indicate that the contribution of dynamic muscle balance in spiking may be relatively more important than the other three risk factors (mobility impairment, muscle weakness and scapular asymmetry). Furthermore, muscle imbalance may be more important in the aetiology of shoulder injuries than the other factors.

Muscle imbalance

For normal shoulder function, it is believed that the antagonist's eccentric force should be as strong as agonists' concentric strength. Many researchers also believe eccentric strength is an important factor in decelerating the limb following the drive provided by the action of the agonist muscles.¹⁷⁻¹⁹ In this study, we found that the average eccentric external strength was weaker in the dominant arm, compared to the concentric internal strength and this was associated with shoulder injury or pain. This finding could be used to support the above belief and could be applied in a sports injury prevention context. To increase eccentric strength and possibly prevent shoulder injury, external rotators' eccentric strength needs to be

strengthened by concentric exercises.²⁹ Since concentric exercises demonstrate an overflow phenomenon and a more significant increase than eccentric exercise, they may be a better choice to prevent injury. The effects of prevention exercises still need to be assessed in further studies.

Muscle weakness

The term muscle imbalance, in this study, was used to describe an unbalanced force couple that occurs between agonist and antagonist muscles around the play arm's shoulder joint.⁶ It has also been used to

describe the relative weakness of a specific muscle group when there is a comparison of strength values between the dominant and non-dominant sides.¹⁴ Both imbalance and relative weakness have been found in elite volleyball athletes' dominant arms in this and in one of the author's preliminary studies.¹³ This study showed there is a significant association between muscle imbalance and shoulder injury or pain. However, this relative muscle weakness of external rotator muscles seems widely distributed in these elite athletes' dominant arm and it may be more likely to be involved in the early stages of shoulder maladaptation than directly related to the occurrence of shoulder injury.

The decrease in concentric external rotation strength may be caused by repetitive eccentric overload which leads to musculotendinous microtrauma or suprascapular nerve injury. Research is needed to study the relative contribution of musculotendinous microtrauma and nerve entrapment to eccentric overload induced muscle weakness.

Mobility impairment

As shown in Figure 1, the shoulder rotation range of motion of the dominant arm in highly skilled volleyball athletes is shifted toward a relatively more external and less internal rotation position, than that of the non-dominant arms.^{6,12,30} Furthermore, the results of Kibler's studies on young tennis and baseball players indicate that the first alteration that occurs in an athlete's dominant arm is inflexibility in internal rotation (Kibler, W. B., 1999 personal communication). Mobility impairment, like relative muscle weakness, may be an early shoulder maladaptation for these athletes.

It has not been confirmed that this altered range of shoulder rotation is caused by pathological tightness of shoulder posterior capsule (through repetitive microtrauma), physiological adaptation to training or progression of pre-existing inherent glenohumeral laxity.³⁰ Posterior capsule tightness and relatively weak external rotators have been found to be associated with shoulder impingement syndrome, but it is not clear whether these findings represent causes or effects.⁸ If these phenomena are the causes of impingement, we would recommend shoulder external rotator strengthening exercises combined with a controlled stretching programme for these volleyball players to prevent injury. However, it should be noted that stretching

exercises should be given with care to prevent further injuries or hyperlaxity as these can often be caused by unsupervised or aimless stretch programmes.

Scapular asymmetry

The results of scapula lateral slide tests showed a higher baseline and a larger displacement in different positions, when compared to Davies and Dickoff-Hoffman²⁸ (Fig. 3). This could be explained by the body height of these volleyball players which was greater than general populations (Table 1). However, there was no statistically significant association between mobility impairment and scapular asymmetry, and shoulder injury or pain. A similar finding regarding shoulder flexibility has been reported in swimmers.^{6,31} Greipp has successfully used a modified method to measure the flexibility of supraspinatus and biceps, and used the results to predict, with 93% accuracy, shoulder pain in swimmers.³² It has to be pointed out that it is unknown whether the changes in shoulder ranges of rotation, which are measured by a standard goniometer technique, are indicative of a painful shoulder. There is a possibility that the methods of shoulder mobility and scapular symmetry measurement, in this study, may have lacked the precision to detect the conditions of glenohumeral or scapulothoracic joint motion in a spiking or forceful internal rotation movement. In addition, only 16 subjects participated in this study and different prevalences of mobility impairment, muscle imbalance and scapular asymmetry could be a weakness of this study and may affect our results.

Side to side difference

Many researchers have focused on the differences of shoulder strength and mobility between the dominant and the non-dominant sides.^{6 11 13 15 20 27 33 34} In this present study, stronger shoulder internal rotators, weaker external rotators and reduced mobility were found in the dominant arm when compared to the non-dominant arm (Figs. 1, 2). Furthermore, the dominant arm exhibited decreased concentric external/internal and eccentric external/concentric internal strength ratios (Table II). The low concentric external/internal strength ratio may lead to or allow excessive humeral head anterior displacement and increase the load of the biceps long head tendon during spiking or throwing movements.¹⁶ These side-to-side dif-

ferences may have been caused by physiological training adaptation or cuff muscle degeneration.^{20 33} Research regarding non-injured swimmers shows there is no significant difference in shoulder flexibility, strength or ratio between the two sides.^{6 27} Swimmers are trained bilaterally and this is a possible reason why the strengths in both sides are similar and are much stronger than in a matched general population.²⁷ However, an imbalance between shoulder rotator force couples has been observed by some researchers.^{6 27} In baseball pitchers, the side-to-side differences of shoulder girdle muscles seem controversial. Both positive and negative results have been found in high school, college level and professional players.^{11 15 33 34} Beside the intrinsic sources of isokinetic measurement, this inconsistent phenomenon could also be caused by some extrinsic sources, such as whether the athletes were highly developed, participating in in-season bilateral strength exercises or performing isokinetic tests immediately after the training season. This is because the muscle strength between the two sides may be affected by the skill of athletes, stage of season and exercise programmes for prevention. We believe that athletes with relatively weak muscles in the dominant arm should be monitored and should consult with medical staff, coaches and trainers to decrease the potential for soft tissue over-use and consequent degenerative change which are common in elite or highly skilled overhead athletes.

Sport populations may have particular profiles of strength and mobility in the playing and non-playing arms. Normative shoulder concentric external/internal strength ratios for athletes, such as tennis players, swimmers and baseball pitchers, have been reported by many researchers.^{12 15 27} In our study, ratios of 0.75 and 1.0 were observed for the dominant and non-dominant side at 60/sec test, respectively (Table II). The use of the profiles of strength and mobility of non-injured contralateral extremity in rehabilitation may not satisfy the need of injured professional athletes to return to their sport. Establishing descriptive normative ranges of motion and strength values and ratios for the dominant and non-dominant upper extremities in different sports are important because such information can enable medical staff and coaches to assist injured athletes in setting goals for rehabilitation, or uninjured but at risk athletes in taking appropriate preventive action.

Conclusions

Mobility impairment, muscle imbalance, relative muscle weakness and scapular asymmetry have been found in these elite volleyball players' dominant arm. Athletes with muscle strength imbalance, where the dominant arm average external rotation eccentric torque was less than that in concentric internal rotation, were more likely to have an injured or painful shoulder. If muscle balance about the shoulder joint is needed to preserve normal function and concentric internal rotation strength is important for the serving and spiking actions, the implication of this finding is that eccentric external rotator strength may need to be developed as an integral part of the training programme of these athletes.

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