Strength Values of Shoulder Internal and External Rotators in Elite Volleyball Players

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Objective: To determine concentric shoulder external-internal rotator strength, dominant and non-dominant shoulder differences and agonist/antagonist ratios.

Design: A transversal study of isokinetic dynamometry of healthy shoulders, 95% confidence intervals are presented. Participants: 35 asymptomatic elite, male volleyball players. Measurements: Peak torque normalized for body weight was recorded at 60, 180, and 300°/sec. with a Cybex 6000 dynamometer. Results: (1) internal rotators were significantly stronger than external rotators of the same shoulder; (2) internal rotators of the dominant arm were significantly stronger than of the non-dominant arm; (3) no difference existed between external rotators of the dominant and the non-dominant arm; (4) external–internal rotator ratios of the dominant arm were significantly lower than of the non-dominant arm; and (5) no differences were found between the ratios of each arm separately. Conclusions: Data presented are important for interpreting isokinetic shoulder rotator strength tests in elite volleyball players and could be relevant in rehabilitation and prevention of shoulder injuries.

The shoulder is a complex joint, characterized by a high degree of mobility combined with a significant need for dynamic stability. It has previously been reported that muscles, comprising the rotator cuff, serve as dynamic stabilizers of the shoulder.1,17 This neuromuscular aspect is especially important in athletes who perform activities requiring repeated overhead arm positions (eg, volleyball players, baseball pitchers, tennis players) in order to provide the optimal stabilization required during the immense forces that are produced at the shoulder girdle complex.
In the modern volleyball game, the main form of attack is the smash or “spike”.4 A highly skilled volleyball player spikes about 40,000 times a year. The impact occurs in an anteverision position of about 170°-140° with neutral rotation. The speed of the hand is approximately 13.1 m s⁻¹ accelerating the ball to velocities of up to 120 km h⁻¹.²² During the spike, quick reactions to changes in ball position, direction, and spin placed on the ball involves added stress on the dynamic stabilizers of the shoulder.²¹ Although each sport requires specific techniques and kinematics, the arm motions needed to perform a volleyball serve or spike resemble, to some extent, those of other overhead sport activities.⁸,¹⁵,²¹,²⁹,³⁰ Rokito et al²⁹ described EMG patterns of the rotator cuff, anterior deltoid, teres major, latissimus dorsi, and pectoralis major muscles during the volleyball serve and spike. They showed that during the volleyball spike and serve, muscle activity patterns were comparable to the baseball pitch and the tennis serve.

Comparable to baseball pitchers and tennis players, elite volleyball players frequently suffer from shoulder injuries.²,¹⁹,²²,⁴⁰ Holzgraefe et al¹⁹ demonstrated that suprascapular neuropathy is a frequent finding in the dominant arm of elite volleyball players, resulting in a loss of recruitable motor unit potentials during EMG examination, combined with infraspinatus and supraspinatus atrophy. Wang and Cochrane³⁵ identified rotator cuff muscle and tendon injuries or involved lesions as the main shoulder injuries in top level English male volleyball athletes in the UK. Factors such as rotator cuff, lower trapezius, and serratus anterior muscle weakness and muscle imbalance have been suggested as intrinsic factors contributing to such injuries.³⁴,³⁵ In addition, the duration of the motion combined with the peak force might play an important role as demonstrated in the volleyball spike. For most muscles, Rokito et al²⁹ showed that EMG activity is greater during each phase of the spike because the range of motion takes place in less time compared with the corresponding phase of the serve. This factor allows the athlete to spike in a shorter time but may place the shoulder at more risk for injuries.

Considering the important role active stabilizers play in shoulder biomechanics, it seems imperative to evaluate the shoulder muscle performance of volleyball players that is required during overhead arm activities. Collecting reference values in asymptomatic athletes involved in activities requiring overhead arm positions using isokinetic dynamometry is a well documented and clinically accepted method in studying baseball players.³,¹³,²⁵,³¹,³⁹ and tennis players.³,¹¹,¹²,¹₄,₂₄ However, literature is very limited with respect to shoulder strength values of asymptomatic male volleyball players.³₃,₃₄ Reference values are important for interpreting isokinetic shoulder rotator strength tests and could be relevant in rehabilitation and prevention of shoulder injuries. Therefore, the purposes of this study were (1) to determine whether differences exist between the dominant and non-dominant arm in concentric shoulder external and internal rotation strength and (2) to determine external–internal strength ratios in asymptomatic male elite volleyball players.

**Methods**

**Subjects**

Thirty-five asymptomatic male elite volleyball players were included in the study. All subjects were competing in the highest division of the Dutch volleyball league.
for at least two years and selected for the Dutch National team. Subjects practiced 4-6 hours per day, 5 days a week. Prior to the start of the competition, all players performed the same preseason strengthening program (ie, dumbbell training) as described by Pappas et al.,27 with the emphasis on the external rotators and scapular stabilizers. The program was performed 5 days a week over a period of 3 months. Data collection was performed at the end of the preseason.

The physical characteristics of the subjects are displayed in Table 1. All players were right dominant. Subjects were included by the team physician after orthopedic examination. Exclusion criteria were shoulder pain, excessive shoulder laxity (using the apprehension-, relocation- and release test, based on the criteria as described by Tennent et al32), signs of neuropathy, a history of operation to either shoulder or injury in the previous three months requiring cessation of volleyball practice, including the preseason strengthening program. Subjects had previous experience in isokinetic testing, were familiar with the procedures, and were free of pain during actual measurements. All subjects voluntarily participated and gave their written informed consent.

**Interventions**

All tests were performed on a CYBEX 6000 dynamometer, calibrated according to the operating manual.6 Testing was performed in supine position with 90° abduction and 90°-elbow flexion; 0° of shoulder rotation was defined with the forearm in the neutral position.4,7,15,29,33,34,38 Hellwig and Perrin18 reported for this position a high test-retest reproducibility ($r = .90 – .93$) for concentric internal-external rotation muscle strength. Testing was conducted with subjects on the Upper Body Extremity Table (UBXT) allowing for muscle isolation and maximal trunk stability. Each subject performed 5 minutes of warm-up stretch and active exercise to the upper limb before testing. The warm-up exercises were standard activities that they would normally perform before a volleyball match. After warm-up, the shoulder joint was placed in line with the dynamometer axis of rotation. The pelvis and trunk were secured with stabilizing straps and the feet were supported. Subjects performed 4 sub maximal and 1 maximal trial prior to the assessment for the purpose of warm-up and familiarization.7,33,34 Actual measurement was performed with 3 maximum repetitions at 60°/sec. and 5 at 180 and 300°/sec. First, the dominant arm was tested. The range of test was between 50° external rotation and 50° internal rotation.33,34 Subjects were asked to move as fast and as powerful as possible throughout the preset range of motion of internal and external rotation. The rest period between each set was 30 seconds. Gravity correction was not used for this testing position.

| Table 1 Physical Characteristics of Subjects ($n = 35$) |
|----------------|----------------|----------------|---------------|----------------|
|                | N   | Minimum | Maximum | Mean | Std. Deviation |
| Age (yr)       | 35  | 18      | 33      | 24,6 | 3, 9           |
| Weight (kg)    | 35  | 74      | 106     | 90   | 7, 4           |
| Length (cm)    | 35  | 181     | 214     | 199,2| 6, 2           |
because both the internal and external rotator muscles moved with and against gravity as they applied force.\textsuperscript{13,14,33,34} The highest peak torque value of the three to five repetitions was used for subsequent data analysis. To ensure uniformity in testing procedures the same investigators performed all tests.

### Data Reduction and Statistical Analysis

Presentation of isokinetic data is expressed as peak torque related to body weight (PT/BW). This enables clinicians to compare and interpret test data from individuals with different anthropometric values.\textsuperscript{7,10} All PT/BW values were tested for normality via One-sample Kolmogorov-Smirnov test. All data were distributed normally; mean and 95\% confidence intervals were determined at all 3 test velocities. Internal and external rotation strength and strength ratios were examined for significant differences by using a two-tailed paired t-test. Level of significance was set at 0.05. Statistical analysis was performed in SPSS, version 8.0.

### Results

Mean PT/BW values and 95\% confidence intervals are presented in Table 2. Table 3 presents the external–internal ratios of the shoulder.

#### Test Velocity

At all test velocities, the internal rotators were significantly stronger ($P < 0.0001$) than the external rotators for both shoulders. With increasing test velocity, the mean PT/BW values of the external and internal rotators decreased significantly ($P < 0.0001$) for both arms (Table 2).

#### Dominant Versus Non-Dominant Arm

No significant differences were found between the external rotators of the dominant arm versus the non-dominant arm. The internal rotators of the dominant arm were significantly stronger ($P < 0.0001$) than of the non-dominant arm (Table 2).

#### Ratios

At all test velocities, the external–internal rotator ratios of the dominant arm were significantly lower ($P < 0.01$) than of the non-dominant arm. No significant differences were found between the ratios of each arm separately. There was no significant influence of the test velocity (eg, 60 versus 180°/sec) on the ratio values (Table 3).

### Comments

The present study yielded concentric isokinetic shoulder internal and external reference values for asymptomatic elite volleyball players. The results showed that at three different test velocities, the internal rotators were significantly stronger than the external rotators, and the internal rotators of the dominant arm were
Table 2  Mean and 95% Confidence Interval (CI) of PT/BW in Newton Meter per Kg for Shoulder Internal and External Rotators per Test Velocity

<table>
<thead>
<tr>
<th>Test velocity in °/sec</th>
<th>Muscle group</th>
<th>Mean and 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>IRD</td>
<td>0.67 (0.63 – 0.71)*</td>
</tr>
<tr>
<td></td>
<td>IRND</td>
<td>0.58 (0.54 – 0.62)</td>
</tr>
<tr>
<td></td>
<td>ERD</td>
<td>0.45 (0.42 – 0.48)</td>
</tr>
<tr>
<td></td>
<td>ERND</td>
<td>0.45 (0.42 – 0.48)</td>
</tr>
<tr>
<td>180</td>
<td>IRD</td>
<td>0.56 (0.51 – 0.60)*</td>
</tr>
<tr>
<td></td>
<td>IRND</td>
<td>0.49 (0.44 – 0.53)</td>
</tr>
<tr>
<td></td>
<td>ERD</td>
<td>0.38 (0.35 – 0.41)</td>
</tr>
<tr>
<td></td>
<td>ERND</td>
<td>0.38 (0.35 – 0.41)</td>
</tr>
<tr>
<td>300</td>
<td>IRD</td>
<td>0.48 (0.44 – 0.52)*</td>
</tr>
<tr>
<td></td>
<td>IRND</td>
<td>0.43 (0.40 – 0.47)</td>
</tr>
<tr>
<td></td>
<td>ERD</td>
<td>0.33 (0.30 – 0.36)</td>
</tr>
<tr>
<td></td>
<td>ERND</td>
<td>0.34 (0.31 – 0.36)</td>
</tr>
</tbody>
</table>

IRD = internal rotators dominant arm, IRND = internal rotators non-dominant arm, ERD = external rotators dominant arm, ERND = external rotators non-dominant arm. * = significant difference ($P < 0.01$) between dominant and non-dominant arm.

Table 3  Mean and 95% Confidence Interval (CI) for the Shoulder External - Internal Rotator Ratios in Percentage per Test Velocity

<table>
<thead>
<tr>
<th>Test velocity in °/sec.</th>
<th>Arm</th>
<th>Mean and 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>D</td>
<td>68.1 (64.2 – 72)</td>
</tr>
<tr>
<td></td>
<td>ND</td>
<td>77.1 (73.1 – 81.1)*</td>
</tr>
<tr>
<td>180</td>
<td>D</td>
<td>69.3 (65.5 – 73.1)</td>
</tr>
<tr>
<td></td>
<td>ND</td>
<td>79.4 (74.4 – 84.4)*</td>
</tr>
<tr>
<td>300</td>
<td>D</td>
<td>70.7 (67.4 – 74)</td>
</tr>
<tr>
<td></td>
<td>ND</td>
<td>79.7 (74 – 85.5)*</td>
</tr>
</tbody>
</table>

D = dominant arm, ND = non-dominant arm. * = significant difference ($P < 0.01$) between dominant and non-dominant arm.
significantly stronger than of the non-dominant arm. The most striking finding of the study was that no significant differences were found between extremities in external rotation strength. Ratios of the dominant arm were significantly lower than of the non-dominant arm.

When comparing our data with other studies, we limited ourselves to studies dealing with (1) elite athletes using specific overhead motions, (2) measurements in the same test position, and (3) similar test protocols (eg, test velocities, randomization). In view of the arm positions common in volleyball, we used the supine test position with 90° abduction and 90°- elbow flexion.\textsuperscript{4,7,15,29,33,34,38} Comparing our results with other elite volleyball players, we only found two studies.\textsuperscript{33,34} Therefore, with some restrictions, we also want to compare the results with elite tennis players and baseball pitchers.

The difference between sides in shoulder internal rotators may result from regular training.\textsuperscript{3} Similar to baseball and tennis, volleyball players use one arm as the dominant arm to practice a large number of forceful spikes and overhead serves. These movements consist predominantly of concentric internal rotation and eccentric external rotation.

This is the first study in which we found no significant differences between extremities in concentric external rotation strength in elite volleyball players. These findings are in contrast with those reported by Wang and Cochrane.\textsuperscript{33,34} They found that the external rotators were significantly weaker in the dominant arm during concentric measurements. This is an important finding since the external rotators play an important role in decelerating the arm rotation during spiking and serving actions. As the external rotator muscles slow down (eccentric), the overhead arm activity high shoulder distraction forces occur. Eccentric contraction of the external rotators generates higher tension in controlling concentric muscle contraction of the internal rotators during the deceleration period of the spike or serve action.\textsuperscript{21} Training of these activities increases the risk of muscle damage or degeneration from eccentric overload.\textsuperscript{23} For this reason, the volleyball players in this study especially performed a preseason strengthening program, with the emphasis on the external rotators and scapular stabilizers. The strengthening program consisted of concentric exercises. Concentric training has been shown to increase the concentric and eccentric strength, but eccentric training does not increase concentric strength.\textsuperscript{24} We postulate that this preseason strengthening program could be the reason why we found no differences in concentric external rotation strength in this study. Wang and Cochrane\textsuperscript{33,34} found that the external rotators were significantly weaker in the dominant arm, which could be because they did not perform any preseason strengthening program. Comparisons with elite tennis players and baseball pitchers also show that there were no significant differences in concentric external rotation strength, the internal rotators were stronger than the external rotators, and the internal rotators of the dominant arm were stronger than the internal rotators of the non-dominant arm.\textsuperscript{11,12,13}

In the shoulder, rotator cuff muscle balance is essential to maintain stability and ensure permanent centering of the humeral head.\textsuperscript{13} Previous studies on untrained, asymptomatic subjects noted a concentric external–internal strength ratio of 64–79%, at various test velocities (60 – 300°/sec.) with minor differences between both shoulders.\textsuperscript{3,20,28} The present study shows that the external–internal ratio for the dominant arm is 68,1 to 70,7% and 77,1 to 79,7% for the non-dominant arm. The
significant differences in internal rotation strength, combined with no differences in external rotation strength, explains why the ratios of the dominant arm are significantly lower than of the non-dominant arm. As these ratios are comparable to those in a normal population, we found no significant shoulder muscle imbalance in our elite volleyball players.

In their volleyball study, Wang and Cochrane found a muscle ratio of 67 to 69% for the dominant arm and 97 to 98% for the non-dominant arm. Their second study revealed a muscle ratio of 70 to 73% for the dominant arm and 104 to 106% for the non-dominant arm. In both studies, the concentric external rotator strength of the dominant arm was significantly lower than of the non-dominant arm. Other studies on elite tennis players and baseball pitchers showed that the muscle ratio in the dominant arm is also significantly lower compared to the non-dominant arm but the concentric external rotation strength in the dominant arm is not different from the non-dominant arm.

Muscle balance between shoulder rotation force couples and functional strength of the external rotators are important in normal shoulder function, including overhead athletes. As a result from the present study, we hypothesize that not only the muscle ratios are important but also the presence of significant differences in concentric external rotation strength between the dominant and non-dominant arm. Future studies should focus on the effects of external rotation strength training in the prevention of shoulder injuries in elite volleyball players.

References