The isokinetic strength profile of quadriceps and hamstrings in elite volleyball players

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Abstract. Knowledge of lower-extremity strength can be used in injury prevention, conditioning and rehabilitation of volleyball players. The goals were: (1) to describe the bilateral concentric and eccentric quadriceps (Q) and hamstrings (H) muscle function in volleyball players, (2) to evaluate the differences in Q and H strength, strength ratios and bilateral strength asymmetry among age groups, playing positions and playing levels, (3) to compare bilateral strength asymmetry in Q and H muscles in two different contraction modes. Ninety five professional male volleyball players were tested on an isokinetic machine at 60°/s to assess concentric and eccentric Q and H strength. We also calculated strength ratios and bilateral strength asymmetries. MANOVA's indicated significant main effect of playing level on relative PT \((p = 0.001)\) and strength ratios \((p < 0.05)\). International-level players had significantly \((p < 0.05)\) higher H strength and dynamic control ratio (DCR) of the right leg compared to the 1st and/or 2nd national division players. There were no signs of bilateral strength asymmetry regardless of muscle group tested and contraction mode. Our results suggest that right H strength and DCR could be important for successful volleyball performance. Descriptive data about Q and H muscle function can be used as guidelines for coaches and therapists during training and rehabilitation of male volleyball players.

Keywords: Volleyball, strength, isokinetics, strength ratios

1. Introduction

Volleyball is considered to be one of the most explosive and fast paced sports today [3,13,25] requiring highly developed qualities of muscular fitness such as strength, power, agility and speed. For elite male volleyball players, the studies reported 250–300 high-power activities of which 50% were jumps of various types that require hip extension, knee extension and ankle plantar flexion [14]. Knee extensors are maximally active during landing (deceleration and the control of knee flexion while working eccentrically) and during the take-off phase of the jump, while medium activity is observed during the amortization phase of the jump [11]. Apart from the jumps, the thigh muscles are also strongly involved during the step into dig/block activities. Finally, rapid changes of direction that commonly occur in volleyball require eccentric leg strength and a short amortization (plyometric) phase, i.e. rapid transition from eccentric to concentric muscle action.

Due to these sport-specific demands, volleyball players are at the greatest risk of acute ankle sprains and chronic knee conditions. Specifically, patellar tendinopathy (jumper’s knee) is the single most common overuse injury in volleyball, characterized by pain during tendon loading [21,22,24,27]. This finding is not surprising given the above-mentioned strong involvement of thigh muscles in specific volleyball activities. Richards et al. [27] suggested that, among other factors, high rate of knee extensor moment development is also related to patellar tendinopathy. It seems that young talented jumpers are more prone to patellar tendinopathy, and they usually have better jumping per-
formance than their healthy counterparts [22,24]. Apart from that, several studies have confirmed the positive effects of quadriceps eccentric training program in the treatment of patellar tendinopathy [9,18].

In the light of such findings, it is surprising that data regarding the quadriceps (Q) and hamstring (H) strength in volleyball players is poor. Specifically, to our best knowledge, only one study reported Q and H strength of volleyball players, focusing solely on concentric mode of contraction [23] Contrary to this, the strength of other muscle groups relevant for volleyball (i.e., internal and external shoulder rotators) is well described in the literature [8,26,30]. In addition to its importance in injury prevention and rehabilitation, an insight into the strength qualities of relevant muscle groups in sport is also relevant for predicting and enhancing performance. For instance, Forthomme et al. [8] reported that spike velocity in volleyball correlates significantly with strength performance of dominant shoulder (internal rotators) and dominant elbow (flexors and extensors) in the concentric mode of contraction. This study confirmed a positive correlation between strength and sport performance, so one could expect that the evaluation of Q and H strength can be equally interesting and revealing [31].

One of the most common methods of strength evaluation of knee muscles is isokinetic testing. Aside from its high reproducibility [19], isokinetic strength testing has several other important advantages including (1) quantification of muscle function in different contraction regimes and at different contraction velocities, (2) comparison of agonists and antagonists muscle function through various strength ratios, and (3) bilateral strength comparisons between the limbs (i.e., assessment of bilateral strength asymmetry).

The aims of this study were therefore (1) to establish the concentric and eccentric strength profile of Q and H in healthy male volleyball players varying in age, playing position and playing level; (2) to evaluate the differences in concentric and eccentric peak torques, various strength ratios and bilateral leg strength asymmetries among different playing positions, age groups and playing levels; and (3) to assess bilateral concentric and eccentric strength asymmetry of quadriceps and hamstrings.

2. Methods

2.1. Subjects

One hundred twenty seven male volleyball players from Slovenian national 1st and 2nd Division were tested following the end of 2006–2007 competitive season. The main inclusion criteria for further analysis were that players had to play in the 1st or 2nd National Volleyball Division and have at least three volleyball practice sessions per week. Prior to testing all players answered a questionnaire regarding injuries in the previous season. Injuries acquired during practice or competitive play that caused a player to miss the following match or and training sessions were reported. All the injuries were further divided into major, moderate, minor and slight injuries according to the time period a player was absent from practice/game as was suggested for other sports games [10] Those players who reported a major or moderate lower extremity injury or any injury to knee or thigh were excluded from further analysis. We also excluded players with any major injury to other body parts. Following these procedures, 95 players (mean (SD) age: 22.2 (5.7) yrs, body mass: 81.5 (9.2) kg, and body height: 188.0 (7.3) cm) met the criteria for further analysis and gave their written informed consent for participating in the study. The study was approved by Ethics Committee of the Faculty of Sport, University of Ljubljana.

2.2. Testing procedure

Testing was performed by the same experienced examiner in the Laboratory for isokinetic testing at the Faculty of Sport in Ljubljana, Slovenia. Laboratory was air-conditioned and room temperature was held between 22–24°C. Testing was performed between 10 AM and 4 PM over a period of three weeks. Players from the same volleyball club were tested on the same day. A day prior to testing no practice was allowed.

Each testing session started with a warm up consisting of cycling for 6 minutes at moderate pace (50–100 W), followed by a 15 second stretch of Q and H. All participants were given a detailed explanation about the testing procedure which was also demonstrated on an independent subject not participating in the study prior to testing.

2.3. Isokinetic strength testing

Testing was performed for quadriceps and hamstrings concentric and eccentric strength using TechnoGym REV 9000 isokinetic dynamometer (TehenoGym, SpA, Via G. Perticari 20, 47035 Gambet-Tola, ForlI, Italy). Players were tested in sitting position. Forward sliding on the seat was prevented with the use of proper belts that were pushing pelvis downward and back-
ward, but were not uncomfortable for the participants. Trunk movement was also prevented using comfortable strapping over the chest region. The thigh of the tested leg was secured using a special attachment. The subjects were instructed not to hold the handles and to keep hands folded across the chest during testing. The axis of rotation of knee joint was identified through the lateral femoral condyle and aligned with the motor axis using a laser beam preinstalled into the head of dynamometer. A range of motion of 60° was set from 30° to 90° knee flexion (full extension considered 0°). Testing was performed at 60°/s for both concentric and eccentric contraction modes for Q and H. Gravity error torque was recorded for every subject.

Prior to testing each participant performed 2 sub-maximal and 1 maximal repetition at a given velocity and mode of contraction. Those participants who experienced pain or discomfort during trial repetitions were not tested on that particular leg. Each participant performed 5 maximal contractions in the following order: (1) five consecutive concentric Q and H contractions followed by a 60 s pause, (2) five eccentric Q contractions followed by a 60 s pause, (3) five eccentric H contractions. When testing of one side was completed, a 3 minutes break followed during which the machine setting was changed to accommodate for the opposite leg. The first tested leg was assigned randomly for each subject. There was no verbal coaching during testing repetitions.

2.4. Data analysis

Data were processed and presented using the SPSS for Windows 15.0 statistical package. The main outcome measure was peak torque (PT) which was later normalized for body weight (BW) and expressed as PT/KgBW [17]. We also calculated the following strength ratios: the concentric H/Q ratio (HQR), Hecc/Qconc ratio – the dynamic control ratio – DCR [7], Qecce/Qconc ratio (QEC) and Hecc/Hconc ratio (HEC). Finally, we calculated the relative strength difference between left and right leg for all testing conditions – a neuromuscular measure known in literature as the bilateral strength asymmetry [1] using the following formula: [1 - (PT left/PT right)] · 100. The bilateral strength asymmetry expressed in percentages was used regardless of which leg was stronger. The results were further divided according to a player’s age, playing position and playing level. We divided players into three age groups according to the Fédération Internationale de Volleyball (FIVB) classification: youth 15–16 yrs, juniors 17–19 yrs and seniors > 19 yrs. Further, we divided players into groups according to five specific playing positions in volleyball: setting, receiving, blocking, correction and libero. Finally, we divided players according to their playing level: 1st Division players, 2nd Division players and International-level players. The distribution of all players according to their age, playing position and playing level is depicted in Table 1.

Three separate multivariate analyses of variance (MANOVA) with Bonferroni adjustments were used to examine any differences in (1) normalized Q and H peak torques, (2) strength ratios and (3) bilateral strength asymmetry indices according to playing position, age group and playing level. Both main effects and interactions among fixed factors were examined in all MANOVAs. Finally, repeated-measures analysis of variance (ANOVA) with Bonferroni adjustments was used to compare the bilateral strength asymmetry among all tested conditions, i.e., different muscle groups (Q and H) and muscle-contraction modes (concentric and eccentric). The level of significance was set to p < 0.05.

3. Results

Q and H peak torques (PT) and strength ratios for each level of play are depicted in Tables 2 and 3

3.1. Differences in age group, playing position and playing level

The first MANOVA revealed significant main effect of playing level on normalized (F = 2.76, p = 0.001) left and right Q and H PT in concentric and eccentric mode of contraction. No other significant main or interaction effects were observed among factors used (F = 0.72–1.32; all p > 0.05). Subsequent univariate ANOVAs revealed significant differences in normalized concentric and eccentric strength of the right H among three observed groups with International-level

<table>
<thead>
<tr>
<th>Playing position</th>
<th>Playing level</th>
<th>Age groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correction</td>
<td>21.1</td>
<td>Youth 7.4</td>
</tr>
<tr>
<td>Blocking</td>
<td>22.1</td>
<td>1st Division 35.2</td>
</tr>
<tr>
<td>Setting</td>
<td>21.1</td>
<td>Juniors 27.7</td>
</tr>
<tr>
<td>Receiving</td>
<td>24.2</td>
<td>Seniors 64.9</td>
</tr>
</tbody>
</table>

Table 1

The distribution of volleyball players according to their age, playing position and playing level

<table>
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</tr>
</tbody>
</table>
players having significantly higher ($p < 0.05$) eccentric strength of the right H compared to the remaining two groups, and having significantly higher ($p < 0.05$) concentric strength of the right H compared to the 2nd Division players (see Table 2).

The second MANOVA revealed significant main effect of playing level on calculated strength ratios ($F = 2.17, p = 0.01$). No other significant main or interaction effects were observed among factors used ($F = 0.49–1.32$; all $p > 0.05$). Subsequent univariate ANOVAs revealed significant differences in HQR of both legs and DCR of the right leg among the three groups, with International-level players having significantly higher ($p < 0.05$) DCR of the right leg compared to the 2nd Division players (Table 3).

Finally, the third MANOVA revealed no significant main or interaction effects ($F = 0.38–1.1$; all $p > 0.05$) for the calculated bilateral strength asymmetry measures.

### 3.2. Bilateral strength asymmetry

Bilateral symmetry indices for Q and H muscles of all volleyball players are shown in Table 4. Repeated-measures ANOVA showed no significant difference in bilateral strength asymmetry among the tested muscle groups and contraction modes ($F = 2.4; p = 0.07$).

### 4. Discussion

This is the first comprehensive description of Q and H muscle function of professional male volleyball players. Consequently our data can be considered as reference values for thigh muscle strength, strength ratios and bilateral strength asymmetries in male professional volleyball players. The reported normalized concentric and eccentric Q and H muscle torques of tested volleyball players are lower than the corresponding values observed in professional athletes from other sports games such as basketball [2,33], rugby [5] and soccer [4,20,33]. Moreover, the only previous study that described thigh muscle strength of male professional volleyball players also reported somewhat higher normalized concentric torques for both Q and H muscles than observed in this study [23]. These results of normalized strength values suggest that leg strength demands in volleyball seem generally lower compared to

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**Table 2**

Mean ($\pm$ SD) values for left and right quadriceps (Q) and hamstring (H) concentric and eccentric peak torques (PT) and peak torques per kg of weight (PT/KgBW) at 60°/s according to the playing level

<table>
<thead>
<tr>
<th></th>
<th>Overall PT</th>
<th>International-level PT</th>
<th>1st Division PT</th>
<th>2nd Division PT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Qcon</td>
<td>219.5 ± 35.8</td>
<td>232.3 ± 50.2</td>
<td>225.0 ± 34.2</td>
<td>215.2 ± 35.1</td>
</tr>
<tr>
<td>Right Qcon</td>
<td>220.8 ± 41.7</td>
<td>246.5 ± 68.5</td>
<td>219.3 ± 43.5</td>
<td>215.8 ± 34.4</td>
</tr>
<tr>
<td>Left Hcon</td>
<td>127.4 ± 22.7</td>
<td>146.0 ± 20.8</td>
<td>131.9 ± 23.2</td>
<td>122.4 ± 20.7</td>
</tr>
<tr>
<td>Right Hcon</td>
<td>131.8 ± 24.0</td>
<td>158.8 ± 32.2</td>
<td>134.6 ± 24.4</td>
<td>126.7 ± 19.1</td>
</tr>
</tbody>
</table>

**Table 3**

<table>
<thead>
<tr>
<th>Side</th>
<th>Overall</th>
<th>International-level</th>
<th>1st Division</th>
<th>2nd Division</th>
</tr>
</thead>
<tbody>
<tr>
<td>HQR</td>
<td>Left</td>
<td>0.58 ± 0.08</td>
<td>0.64 ± 0.10</td>
<td>0.63 ± 0.11</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>0.64 ± 0.12</td>
<td>0.73 ± 0.11*</td>
<td>0.66 ± 0.12</td>
</tr>
<tr>
<td>DCR</td>
<td>Left</td>
<td>0.64 ± 0.12</td>
<td>0.73 ± 0.11*</td>
<td>0.64 ± 0.13</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>0.64 ± 0.12</td>
<td>0.73 ± 0.11*</td>
<td>0.66 ± 0.12</td>
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</tbody>
</table>

**Legend:** HQR – Hconc/Qconc ratio; DCR – Hecc/Qconc ratio (dynamic control ratio); QEC – Qconc/Qconc ratio; HEC – Hconc/Hconc ratio; *Significantly higher strength ratio compared to the 2nd Division players.
other explosive-type sports games, and the possible explanation could be the non-contact nature of volleyball, while we must keep in mind that these difference could also arise from the fact that volleyball players have different bodyweight in comparison with the athletes from other sports.

Regarding the calculated thigh strength ratios, the observed values for HQR in both legs are within the proposed normative values for 60°/s [19] and in line with values observed in other athletes participating in sports games [4,5,12,20,23,32,33]. For DCR, the observed values in both legs are somewhat lower than those observed in soccer players [4,15] and sprinters [29]. These differences may reflect lower sprinting demands in volleyball compared to soccer and sprint events. Specifically, it has been demonstrated that during sprinting a significant role of H muscle is to eccentrically decelerate the forward swing of the lower leg [28] thereby accentuating its eccentric function. Finally, for QEC and HEC, we observed values of about 1.1, suggesting that the eccentric Q and H strength of tested volleyball players is only 10% higher than their concentric strength at 60°/s.

The major finding of this study is related to the significant effect of playing level, but not age and playing position, on the normalized concentric and eccentric Q and H muscle torques of tested volleyball players, as well as on the calculated thigh strength ratios. Specifically, international-level players have significantly higher eccentric strength of the right H compared to the remaining two groups, and they also have significantly higher concentric strength of the right H and DCR of the right knee compared to 2nd Division players. In order to explain this specific finding, we should look into the very nature of volleyball jumps. The players are usually performing a jump following a three step movement: left foot (short step) – right foot (long step) – left foot. At the second (right foot) long step, the player places the right foot on the ground and flexes his knees to about 30°. This long right-leg step requires high intensity activity of the right H muscles. The left foot than follows and at the time of contact of the left foot with the ground (third step) the push off phase of jump is initiated. The left foot ground contact time is, therefore, much shorter than for the right foot.

To keep the knee in semiflexion position the players need good Q and H control of right knee and they are using right Q and H contraction to produce sufficient strength for the execution of a vertical jump. It seems that international-level players use this advantage of stronger concentric and eccentric H to achieve their superiority over the 1st and/or 2nd Division players. This finding suggests that concentric and eccentric H strength of the right leg, as well as DCR of the thigh muscles of the right leg, are related to successful performance in volleyball. Further studies are needed to validate this conjecture, particularly if one takes into account the relatively small number of international-level players in the present study (see Table 1).

A lack of effect of playing position on thigh muscle strength and strength ratios suggest that volleyball generally does not require position-specific leg strength profile. This finding is further supported by the results of Duncan et al. [6], who also observed no significant position-specific differences in leg strength and vertical jump performance among elite junior volleyball players. No effect of playing position on leg muscle strength in volleyball considerably simplifies the design and implementation of lower-limb strength training into an overall training program. Finally, our finding that the thigh muscle strength and strength ratios of volleyball players are similar across age groups should be interpreted with caution due to the large differences in the number of players within a particular age group. Specifically, only 7.4% of all players in this study belonged to the youth group (Table 1).

This study also examined thigh muscles bilateral strength asymmetry in volleyball players. Bilateral strength asymmetry of Q and H is widely used in sports medicine to quantify the functional deficit consequent to knee injury, to monitor the effectiveness of sport rehabilitation programs, and to identify athletes at increasing risk of incurring lower-limb injuries during training and competition [16]. It has been suggested that bilateral strength asymmetry exceeding 15% can be considered clinically relevant with isokinetic, verti-
5. Conclusion

This is probably the first comprehensive description of Q and H muscle function in professional male volleyball players. Accordingly, the findings may be used by clinicians and coaches as reference values for knee extensor and flexor strength, strength ratios and bilateral strength asymmetries in male professional volleyball players. Further, we observed significant multivariate differences in Q and H muscle function with respect to playing level, with normalized concentric and eccentric strength of the right H and the right knee DCR as being important in discriminating players of varying quality level. Finally, we showed that Q and H muscle function of male professional players is independent of their age and playing position, a fact which could simplify the design and implementation of lower-limb strength training into a year-round volleyball training program.

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