Gender Differences in Yearly Changes in the Cross-sectional Areas and Dynamic Torques of Thigh Muscles in High School Volleyball Players

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This study aimed to investigate the gender differences in yearly changes in the cross-sectional areas (CSAs) and dynamic torques of thigh muscles in high school volleyball players. The CSAs of the quadriceps femoris (QF) and hamstrings (HAM) and dynamic torques during knee extension (KE) and flexion (KF) at a pre-set velocity of 1.05 rad·s⁻¹ were determined longitudinally with an interval of one year. Only the males showed significant increases in the CSAs of QF and HAM, without a significant change in the CSA ratio between the two muscle groups. The KF torque significantly increased in both genders, but KE torque did in the males only. Moreover, both genders showed significant increases in the ratio of KF torque to the product of HAM CSA and body height (T/CSA*h). The relative gains in KF torque and its T/CSA*h were significantly greater for the males than for the females. Additionally, only the males significantly increased the ratio of KF to KE in torque and T/CSA*h. The present results indicated that, at least in high school volleyball players, males compared to females showed greater increases in thigh muscle CSA and knee flexion torque.

Keywords: longitudinal study, isokinetic strength, thigh muscle, young athletes, knee flexion-to-extension torque ratio

1. Introduction

Profiles of muscle strength and/or body composition in young athletes have been extensively researched (Birrer & Levine 1987; Hansen, et al., 1999; Maffulli, et al., 1994; Thorland, et al., 1981; Wilmore, et al., 1989). For teenage athletes, however, less information about gender-related difference in muscle size is available from previous studies. To our knowledge, only one cross-sectional study has examined the subject in high school speed skaters (Kanehisa, et al., 2001).

On the basis of data obtained from the body composition and/or anthropometric measurements for young adults, it has been suggested that females are capable of significant strength gains with minimal or no increase in muscle mass (Brown, et al., 1974; Wilmore 1974). However, previous studies using imaging techniques have shown that resistance training produces almost the same changes in muscular hypertrophy relative to pre-training status for both genders (e.g. Holloway & Bachle 1990). According to the findings of a prior study on junior speed skaters, athletes achieved a greater quadriceps femoris cross-sectional area by 28% in males and 38% in females when compared to aged-matched untrained subjects (Kanehisa, et al., 2001). In addition, no significant effect of gender was found in knee extension torque normalized to the quadriceps femoris CSA (Kanehisa, et al., 2001). Considering these findings, it seems that the response of a muscle to athletic training is independent of gender, even in
an adolescent stage in which gender differences in muscle size and strength become evident as a result of normal growth (Kanehisa, et al., 1994, 1995; Tanner, et al., 1981).

In the present study, the cross-sectional area (CSA) of the quadriceps femoris (QF) and hamstring (HAM) were determined longitudinally with an interval of one year in high school volleyball players of both genders, using magnetic resonance imaging. In addition, dynamic torques during knee extension and flexion were also measured using an isokinetic dynamometer. We hypothesized that yearly changes in muscle CSAs and/or dynamic strength relative to muscle CSA would be similar between the male and female athletes. This study aimed to examine this hypothesis.

2. Methods

2.1. Subjects

Twenty-two high school volleyball players aged 15.6 to 16.2 years (11 males and 11 females) participated in this study. All the players were recruited as elite junior athletes to the training project by the Shizuoka Prefectural Government Department of Education in Japan. All had experience at regional and national junior competitive meets within the research period. The determinations of muscle CSA and dynamic strength were performed two times (T1 and T2) with an interval of almost one year. The average (± standard deviation) ages of the subjects were 16.0 (±0.2) years for the males and 15.8 (±0.2) years for the females in T1 and 17.0 (±0.2) years for the males and 16.9 (±0.2) years for the females in T2. These average values did not significantly differ between the males and females in either of the two cases. During the research period, all subjects participated in a volleyball training program, with almost the same schedule regardless of gender. They trained 18 to 24 hours per week. The training program was divided into four exercise sessions according to the type of exercise and movement pattern: 1) middle or long distance running, 2) circuit training using body weight- and/or light weight-resistance, 3) assistance exercises related to actual competitive games, and 4) practice games. The frequency and volume of each exercise session performed varied according to the type of training regimens and volume of work done in the preceding day. None of the subjects dropped out during the test period. All measurements were performed with intervals of more than 40 hours after completion of a training session. This study was approved by the Shizuoka Amateur Sports Association and the Office of the Sports Photonics Laboratory, Hamamatsu Photonics K. K. and was consistent with their requirements for experiments involving human subjects. The subjects and their parents were fully informed of the procedures to be used as well as the purpose of the study, and gave their informed written consent.

2.2. Measurements of muscle cross-sectional areas (CSAs)

Magnetic resonance images of the right thigh were obtained using a 0.2-T scanner (Signa Profile, General Electric Medical System) with a body coil to determine the CSAs of the QF and HAM. The subjects were scanned in a supine position with the knee and hip joints kept extended and the arms folded over their chest. Firstly, longitudinal images were obtained to identify the greater trochanter and the lower edge of the femur. Second, transverse scanning of T1-weighted images of 10mm thickness was performed from the greater trochanter to the lower edge with a 10mm gap (TR 350 ms, TE 21ms, matrix 256 x 256, FOV 40cm x 40cm, 2 NEX). The image located nearest to 50% of the length from the greater trochanter to the lower edge, where the CSA of the thigh is almost the maximum (Kanehisa, et al., 1994), was selected for determining the CSAs of QF and HAM. For each of the transverse images, a single experienced observer, who did not know the subject's characteristics, outlined the area of each of QF and HAM and calculated the CSA by summing the pixels surrounding those outlines using dedicated computer software. In addition, the total muscle CSA at the mid-thigh was also calculated. Inter-observer variation in the calculation of the cross-sectional area of muscles in the same magnetic resonance image was less than 1% in our laboratory testing.

2.3. Measurements of dynamic strength

Isokinetic torques during maximal concentric knee extension (KE) and flexion (KF) of the right lower limb were determined using a dynamometer (Biodex system 3, Biodex Co., U.S.A.). The pre-set angular velocity of the dynamometer was 1.05 rad·s⁻¹. For the torque measurements, subjects were seated in
an upright chair with arms folded over the chest and stabilized firmly at the shoulder, chest, hip, and mid-thigh via straps. The rotational axis of the dynamometer was visually aligned to the anatomical axis of the knee joint with the knee at 90° flexion, and the lower leg of the subject was attached to the lever arm of the dynamometer.

After a 10 minutes warm-up of light exercise and stretching, subjects were asked to take the prescribed position for the torque measurements and practice the task movement with submaximal effort in order to become familiar with the protocol. The standardized gravity correction procedure was performed before each trial. The subjects performed five maximal torque exertions at the pre-set velocity, with the highest torque value being used in later analyses.

Strength, measured as torque, is a function of muscular force (related to CSA) and muscle moment arm length considered to be proportional to body height (Sale, et al., 1987). In addition, muscle volume is a major determinant of joint torque in humans (Fukunaga, et al., 2001). In the present study, therefore, torque was correlated to the product of CSA and body height (CSA*ht). Moreover, the ratio of torque to CSA*ht (T/CSA*ht) was calculated as an index of strength relative to muscle volume.

2.4. Statistics

Descriptive data was presented as means and standard deviations (SDs). A simple linear regression analysis was used to calculate the correlation coefficients between the measured variables. The percentage of the difference between T1 and T2 (T2 minus T1) to T1 was calculated and expressed as a variable representing the relative change per one year. For each of the males and females, a Wilcoxon test was applied to locate significant differences across the measurement times for CSA, torque and T/CSA*ht values. In addition, a Mann-Whitney test was used to identify the effect of gender on the absolute value of every measured variable and its relative changes. Statistical significance was set at p≤0.05.

3. Results

Table 1 summarizes the results of the anthropometric and CSA measurements. Body height and mass for the males significantly increased, but those for the females did not change. Only the males showed significant gains in the muscle CSA values. On the other hand, the CSA ratio of HAM to QF was similar in both genders and did not change significantly between T1 and T2. For the males, the relative change in QF CSA was significantly correlated to that of body height (r=0.780, p<0.05). However, the corresponding correlations for HAM in the males and for both muscle groups in the females were not significant (r=-0.255 to 0.080, n.s.). In addition, there was no significant correlation between

### Table 1 Descriptive data of anthropometric and CSA measurements

<table>
<thead>
<tr>
<th></th>
<th>males, n=11</th>
<th>T1 mean±SD</th>
<th>T2 mean±SD</th>
<th>%△ mean±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>height, cm</td>
<td>181.1 ± 6.3#b</td>
<td>182.0 ± 6.6★b</td>
<td>167.2 ± 6.4</td>
<td>167.4 ± 6.5</td>
</tr>
<tr>
<td>body mass, kg</td>
<td>66.9 ± 5.9#b</td>
<td>68.7 ± 7.1#b</td>
<td>60.0 ± 7.3</td>
<td>60.5 ± 6.9</td>
</tr>
<tr>
<td>CSA, cm²</td>
<td>145.6 ± 12.5#b</td>
<td>153.8 ± 14.8★b</td>
<td>128.5 ± 18.0</td>
<td>129.6 ± 15.7</td>
</tr>
<tr>
<td>total muscle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HAM</td>
<td>33.0 ± 3.7#b</td>
<td>34.7 ± 4.1#b</td>
<td>28.0 ± 4.5</td>
<td>28.1 ± 4.2</td>
</tr>
<tr>
<td>QF</td>
<td>81.1 ± 7.2#b</td>
<td>85.2 ± 10.1#b</td>
<td>70.4 ± 9.8</td>
<td>71.2 ± 9.0</td>
</tr>
<tr>
<td>HAM/QF ratio</td>
<td>0.41 ± 0.05</td>
<td>0.41 ± 0.06</td>
<td>-0.1 ± 0.7</td>
<td>0.40 ± 0.03</td>
</tr>
</tbody>
</table>

### Notes:
- # denotes that the average value for the males is significantly different from that for the females at p≤0.05 in the comparison within the same measurement time.
- ★ denotes that the average value of the males is significantly different from that for the females at p≤0.05 in the comparison within the same gender.
- † denotes that the average value for the males is significantly different from that for the females at p≤0.05.

Gender differences in muscular development in young athletes
Table 2 Descriptive data on torque and the ratio of torque to the product of CSA and height (T/CSA*ht)

<table>
<thead>
<tr>
<th></th>
<th>males, n=11</th>
<th></th>
<th></th>
<th>females, n=11</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
<td>T2</td>
<td>%△</td>
<td>T1</td>
<td>T2</td>
</tr>
<tr>
<td>torque, Nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KE</td>
<td>199.7 ± 29.4</td>
<td>227.3 ± 40.4</td>
<td>13.5 ± 12.2</td>
<td>151.6 ± 21.5</td>
<td>160.1 ± 18.7</td>
</tr>
<tr>
<td>KF</td>
<td>97.9 ± 16.1</td>
<td>127.9 ± 18.8</td>
<td>31.5 ± 17.2</td>
<td>71.9 ± 13.0</td>
<td>77.8 ± 8.3</td>
</tr>
<tr>
<td>KF/KE ratio</td>
<td>0.49 ± 0.08</td>
<td>0.57 ± 0.08</td>
<td>16.6 ± 16.2</td>
<td>0.47 ± 0.05</td>
<td>0.49 ± 0.04</td>
</tr>
<tr>
<td>T/CSA*ht, kNm m⁻³</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KE</td>
<td>13.6 ± 1.6</td>
<td>14.7 ± 2.0</td>
<td>7.7 ± 12.6</td>
<td>13.0 ± 1.5</td>
<td>13.5 ± 1.4</td>
</tr>
<tr>
<td>KF</td>
<td>16.4 ± 2.6</td>
<td>20.4 ± 2.7</td>
<td>25.1 ± 15.7</td>
<td>15.4 ± 2.2</td>
<td>16.7 ± 1.9</td>
</tr>
<tr>
<td>KF/KE ratio</td>
<td>1.22 ± 0.22</td>
<td>1.41 ± 0.26</td>
<td>17.1 ± 17.8</td>
<td>1.19 ± 0.12</td>
<td>1.24 ± 0.12</td>
</tr>
</tbody>
</table>

mean±SD
KE, knee extension; KF, knee flexion; KF/KE ratio, the ratio of knee flexion to knee extension in each of torque and T/CSA*ht; %△, relative difference between T1 and T2, expressed as per one year
* denotes that the average value for the males is significantly different from that for the females at p ≤ 0.05 in the comparison within the same measurement time.
♭ denotes that the average value in T2 was significantly different from that in T1 at p ≤ 0.05 in the comparison within the same gender.
† denotes that the average value for the males is significantly different from that for the females at p ≤ 0.05.

the relative changes of CSAs for the two muscle groups in either the males (r=-0.171, n.s.) or the females (r=0.296, n.s.).

As a result of a regression analysis for the data pooled for all subjects, KE and KF torques were significantly correlated to the CSA*ht values of QF and HAM, respectively, with correlation coefficients of 0.740 to 0.811 (p<0.05) in T1 and 0.812 to 0.870 (p<0.05) in T2. The KF torque significantly increased for both males and females, but KE torque increased in the males only (Table 2). In T1, there were no significant differences between the males and females in T/CSA*ht values for the two motions (Table 2). T/CSA*ht for KE increased significantly for both males and females, but that for KE did not. The relative changes in torque and T/CSA*ht for KF were significantly higher for the males than for the females. Moreover, only the males showed significant gains in the ratio of KF to KE in torque and T/CSA*ht. No significant correlation was found between the relative change of body height and each of those in torque and T/CSA*ht for both genders (r=-0.509 to 0.336, n.s.).

4. Discussion

The main results obtained here were that 1) only the males significantly increased the CSAs of QF and HAM and 2) the males showed greater gains in KF torque and T/CSA*ht when compared to the females. At the start of the present study, we hypothesized that early changes in muscle CSAs and/or dynamic strength relative to muscle CSA would be similar between the male and female athletes. However, our results failed to match this hypothesis.

No measurements on the untrained and/or other athletic populations were performed in this study. Hence, we cannot directly refer to how the CSA and/or torque values observed in the volleyball players are characterized as their own event-related profiles. The average CSA values of QF for the male (81 cm²) and female (70 cm²) volleyball players in T1 were 14% and 24% greater as compared to the age-matched untrained males (74 cm²) and females (57 cm²), respectively, examined by previous studies (Kanehisa, et al., 1994, 1995). On the other hand, although the CSA values for both muscle groups significantly increased for the males, the CSA ratio of HAM to QF did not change and did not differ between males and females at either of the two measurement times. For young athletes, no information on the growth- and/or gender-related profiles in the CSA ratio between the two muscle groups is available from previous studies. In the reference data cited above, average values for the percentage of QF CSA to the thigh total muscle CSA at the mid-thigh was 56% for males and 54% for females. If one calculates the corresponding values for the subjects in the present study, a similar value is also observed in both genders regardless
For the males, however, the relative gain of HAM CSA was not significantly correlated to that of body height or QF CSA. This implies that factors explaining the gain in CSA determined at the mid-thigh differ between HAM and QF, although their relative gains were similar. Furthermore, the observed changes in torque also differed between the two motions and between the two genders. Namely, although KF torque significantly increased in both genders, the relative gains were significantly higher in the males than in the females. In addition, only the males showed significant increases in the torque ratio of KF to KE. These results were the same even in terms of T/CSA*ht. From the finding of a prior study on non-athletic males, the torque ratio of KF to KE, determined at 1.05 rad/s, is almost the constant in an age span between 7 and 18 years (Kanehisa, et al., 1995). Taking this point into account, together with the present results, it may be assumed that HAM compared to QF was more influenced by physical training performed during the research period, especially so for the males rather than for the females. However, the reasons remain unclear.

Volleyball places considerable demands on neuromuscular performance characteristics, especially during the various sprints and jumps that take place repeatedly during a competitive game (Hakkinen 1993). A prior study using a musculoskeletal model that utilized a total of eight musculotendinous units reported that the energy delivered to the skeleton during counter movement and squat jumps is dominated by the hips and knee extensors (Anderson & Pandy 1993). The hamstring acts not only at the knee joint but also the hip joint to perform functions such as hip extension. From the findings of Hewett, et al., (1996), plyometric training in female high school volleyball players produced significant gains for the knee flexion-to-extension torque ratios and vertical jump performances. In their results, the pre-training level for the knee flexion-to-extension torque ratio for female athletes was significantly lower than that for male athletes, but the ratio in post-training was similar in both genders. Unfortunately, we have no kinematic and/or kinetic data during the training exercises or volleyball games. However, the previous findings cited above tempt us to speculate that the observed gains in the KF torque for both genders can be considered to be an effect of jump-related exercises involved in their volleyball training.

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Only the T/CSA*ht for KF significantly increased in both genders, with a higher relative gain for the males than for the females. It is known that strength relative to muscle CSA increases as a result of the adaptations of neural factors to resistance training (Sale 1988). The training-induced gain in strength normalized to muscle CSA occurs regardless of gender (Cureton, et al., 1988). Hence, it seems that the neural adaptations to the use of HAM during the jump-related exercises, mentioned in the earlier paragraph, might be a reason for the significant gain in the T/CSA*ht for KF in both genders. On the other hand, Houston & Wojtys (1996) indicated that time-to-peak torque during dynamic knee flexion for female athletes was substantially slower than that for males and were similar to non-athletic populations, while the time-to-peak torque during dynamic knee extension was independent of gender. Again, Houston & Wojtys (1996) provided evidence suggesting that the use of HAM for stabilizing the knee joint during exercises differ between female and male athletes. In their results, females appeared to rely more on their QF in response to anterior tibial translation. In addition, Hewett, et al., (1996) reported that male athletes showed relatively high use of HAM as a knee flexor during landing in a simulated volleyball block jump over a standard height net. Considering these findings, it seems that the use of HAM during training exercises might have differed between the males and females, and so it would result in the gender-related differences in the gains of not only torque but also T/CSA*ht for the KF by producing different neural adaptations.

On the basis of a cross-sectional observation on resistance trained subjects, however, Alway, et al., (1990) provided negative evidence for an elevation of strength normalized to muscle CSA as a long term adaptation to resistance training. They have suggested that long term adaptations to resistance training include an initial elevation in strength normalized to muscle CSA and which then returns to pre-trained levels as muscle hypertrophy occurs and CSA increases. In addition, we should comment on limitations of the present study for discussing the observed changes in T/CSA*ht. Firstly, the CSA was determined at the mid-thigh. The anatomical CSA of the knee extensors becomes almost the maximum at the mid-thigh (Akima, et al., 2000). However, the corresponding site for the knee flexors is a more distal part of the thigh compared to the knee extensors (Akima, et al., 2000). Secondly, it is known that hypertrophic changes following resistance training do not occur uniformly along the muscle’s length (Narici, et al., 1996; Housh, et al., 1992). From the findings of Abe, et al., (2000), muscle thickness values of the HAM at 70% of thigh length were significantly increased by a 12-week resistance training program in both genders, but the significant increase at the mid-thigh was observed only in males. Hence, there is a possibility that the change in T/CSA*ht might be overestimated since the CSA was determined at the mid-thigh, notably in the males. If so, this point would be a reason for a significant gain in T/CSA*ht for KF in both genders with a greater magnitude for the males than for the females. Muscle volume is a major determinant of joint torque in humans (Fukunaga, et al., 2001). With regard to the observed changes in T/CSA*ht for KF, re-examination involving the measurements of muscle volume and/or CSA distribution along limb length is needed.

In summary, the present longitudinal observation of high school volleyball players of both genders indicated that 1) only males significantly increased the CSAs of QF and HAM, and 2) males showed greater gains in KF torque and T/CSA*ht, when compared to females. With regard to the observed change and gender difference in T/CSA*ht for KF, however, further investigation is needed to clarify the influences of the site selected for the CSA measurement of HAM.

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