Sex Differences in the Cross-sectional Areas of Psoas Major and Thigh Muscles in High School Track and Field Athletes and Nonathletes

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Abstract The present study aimed to examine the sex differences in the cross-sectional areas of the psoas major, quadriceps femoris, hamstrings, and adductors in high school track and field athletes and nonathletes. The cross-sectional areas of the psoas major at L4-L5 and three thigh muscles at the mid-thigh were determined in the right side of the body using magnetic resonance imaging in 61 sprinters (29 boys and 32 girls), 50 jumpers (28 boys and 22 girls), 33 throwers (18 boys and 15 girls), and 40 nonathletes (20 boys and 20 girls), aged from 16 to 18 yrs. On the whole, the cross-sectional area for every muscle group was greater in the athletes than in the nonathletes and in the boys than in the girls. The average value of the cross-sectional area for the girls as a percentage of that for the boys in every subject group was lower in the psoas major (57.6–64.7%) than in the thigh muscles (67.8–82.9%). Among the thigh muscles, the muscle group which showed significant sex differences in the ratio of cross-sectional area to the two-third power of lean body mass was limited to the quadriceps femoris in the sprinters and nonathletes and hamstrings in the throwers. However, the ratio for the psoas major was significantly higher in the boys than in the girls in all subject groups. The current results indicate that, although regular participation in sports training during adolescence promotes hypertrophy in the psoas major and thigh muscles in not only boys but also girls, a greater sex difference exists in the muscularity of the psoas major than of the thigh muscles, in athletes and nonathletes. J Physiol Anthropol 30(2): 47–53, 2011 http://www.jstage.jst.go.jp/browse/jpa2 [DOI: 10.2114/jpa2.30.47]

Keywords: sprinters, jumpers, throwers, lean body mass, psoas major, thigh muscles, CSA

Introduction

Sex differences in muscularity become apparent from 13 years of age, with a larger relative difference in the upper than in the lower body (Tanner et al., 1981; Kanehisa et al., 1994). For adolescent boys and girls, however, relatively little information on the extent of sex differences in the muscularity of the trunk is available. Trunk muscles have a critical role in the maintenance of stability and balance when performing movements with the extremities (Andersen et al., 1988), and a strong and stable trunk provides a solid foundation for the torques generated by the limbs (Behm and Anderson, 2006; Kibler et al., 2006). Among the muscle groups located in the trunk, the psoas major is the only muscle that connects the lumbar spine and lower limbs (Arbanas et al., 2009) and the largest in cross-section at L4-L5 (McGill et al., 1993; Santaguida and McGill, 1995). Hence, the psoas major is apparently an important muscle that has a role in the function of both the trunk and extremities (Hanson et al., 1999). Furthermore, it has been shown that, for women, there was a marked difference between the psoas major and quadriceps femoris in the pattern of decline in the cross-sectional area (CSA) owing to aging (Takahashi et al., 2006). The decline in psoas major CSA started in women in their 20s and continued until they were in their 70s, but quadriceps femoris CSA was maintained until the women reached their 60s. Takahashi et al. (2006) argued that a regular exercise program maintaining the muscularity of psoas major should be recommended to women earlier in life.

Many studies have provided substantial data on the size and anatomical variation of the psoas major (e.g. Gatton et al., 1999). However, most used adult populations. Much less information is available on the normal size of this muscle during growth. Peltonen et al. (1998) reported that the psoas major CSA of a group of adolescent female athletes (gymnasts, figure skaters, and ballet dancers) was greater than...
that of an age-matched control group, even when adjusted with body mass. This indicates that regular physical training in adolescence enhances the muscularity of the psoas major in girls. Boys, however, have not been tested. No study has examined the magnitude of the sex difference in muscularity of the psoas major during growth and whether it differs from that of lower limb muscles. In adult populations, the sex difference in skeletal muscle mass is more apparent in the trunk than in the extremities (Abe et al., 2003). Abe et al. (2003) reported that the muscle CSA at the iliac crest in women was only 61% of that in men. From the findings of Marras et al. (2001), the physiological CSA of the psoas major for women was about 54% of that for men. Taking these findings into account, it is reasonable to assume that, for boys and girls, the sex difference in the size of the psoas major will be greater than that in the size of limb muscles. However, it is unknown how the corresponding difference in athletic populations varies from that in nonathletic populations. Clarifying this will provide valuable information concerning the effect of regular physical training on the muscularity of the psoas major for women in the earlier stages of life.

In the present study, the CSAs of the psoas major (PM) at L4–L5 and three thigh muscle groups (quadriiceps femoris, QF; hamstrings, HAM; adductors, ADD) at the mid-thigh were determined using magnetic resonance imaging in track and field athletes and nonathletes of both sexes, aged from 16 to 18 yrs. The present study aimed to examine the sex difference in the CSAs of PM and the thigh muscles in high school track and field athletes and nonathletes.

**Methods**

**Subjects**

Sixty one sprinters (29 boys and 32 girls), 50 jumpers (28 boys and 22 girls), 33 throwers (18 boys and 15 girls), and 40 nonathletes (20 boys and 20 girls) voluntarily participated in this study. The physical characteristics of the subjects are summarized in Table 1. There was no significant difference in average age among the groups. All athletes had experienced regional and national junior competitive meets within the research period. They had engaged in organized training for their own events for at least 3 years and had recently undergone physical and technical training programs for 2–3 h per day, 5–6 days per week. For all athletes, work volume in the programs was greater in technical training, being specific to competitive movements and/or styles in their own events, as compared to physical training. As physical training programs, the athletes had regularly performed jump and sprint drills as well as circuit training, being specific to improve agility, balance, and muscular performance. For each event, the frequency and volume of each exercise session performed in the training programs varied according to work done the preceding day. All measurements were performed with intervals of more than 40 hours after completion of a training session. This study was approved by the ethics committee of the Japanese Society of Physical Fitness and Sports Medicine and was consistent with institutional ethical requirements for human experimentation in accordance with the Declaration of Helsinki. All subjects and their parents were fully informed of the procedures to be used as well as the purpose of the study, and gave their written informed consent.

**Measurements of muscle**

CSAs Magnetic resonance images for the right thigh and trunk were obtained using a 0.2-T scanner (Signa Profile, General Electric Medical System) with a body coil, in accordance with the method of an earlier study (Hoshikawa et al., 2006). The subjects were scanned while supine with the knee and hip joints extended and arms folded over the chest. For the thigh, longitudinal images were obtained to identify the greater trochanter and lower edge of the femur for the right side. Then, transverse scanning of T1-weighted images with a thickness of 10 mm was performed from the greater trochanter to the lower edge with a 10-mm gap (TR 350 ms, TE 21 ms, matrix 256×256, FOV 40 cm×40 cm, 2 NEX). Similar to the method of earlier studies (Kanehisa et al., 1994, 1995), the

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**Table 1 Physical characteristics of subjects**

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<th>Variables</th>
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<th>Th</th>
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B, boys; G, girls; Sp, sprinters (29 boys, 32 girls); Ju, jumpers (28 boys, 22 girls); Th, throwers (18 boys, 15 girls); Na, nonathletes (20 boys, 20 girls).

$^a$ indicates that the difference is significant at $p<$0.0018 as a result of the Bonferroni/Dunn test.
image located nearest to 50% of the femur’s length, from the lower edge of the femur to the greater trochanter, was selected for the determination of thigh muscle CSAs on the right side. For the trunk, after longitudinal scans to identify the portion of the lumbar vertebrae, transverse scanning of T1-weighted images (TR 250 ms, TE 20 ms, matrix 224×128, FOV 30×30 cm, 4 NEX) 10-mm thick was performed at the mid level of L4–L5, as described by Peltonen et al. (1998). For each transversal image, a single experienced observer, who did not know the subjects’ characteristics, outlined the areas of muscle compartments in the two body segments using a computer mouse. For the thigh, the areas of three muscle groups were analyzed: QF (rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius), HAM (biceps femoris, semitendinosus, and semimembranosus), and ADD (adductor brevis, adductor longus, adductor magnus, and adductor minimus). For the trunk, the area of PM in the right side was analyzed. The CSAs were then calculated by summing the pixels surrounded by the outlines. In a preliminary study of 16 young adult men, we examined the repeatability of CSA measurements. The subjects participated in the CSA measurements on two separate days. A paired Student’s t-test showed that there was no significant difference between the CSA values of the two measurements for any muscle. The mean of the coefficient of variation (%CV) and intra-correlation (ICC R) coefficient for the CSA measurement of each muscle were less than 2.0% and more than 0.977, respectively.

**Measurements of body composition**

Lean body mass (LBM) was determined using an air-displacement plethysmograph (Bodpod, model 2000A, Life Measurement Instrument, Concord, CA), with a protocol described previously (Dempster and Aitkens, 1995). Briefly, the subjects wore only a tight-fitting swimsuit and swim cap during this measurement. Following a body mass measurement to within an accuracy of 0.01 kg on a calibrated electronic scale, the subjects sat quietly in the fiberglass chamber with normal respiration while their body volume was determined. This measurement was performed twice and the average volume was adopted for the LBM calculation. To determine thoracic gas volume, the subjects were connected to a breathing circuit within the system via a breathing tube, fitted with a nose clip, and instructed to continue breathing normally. The subject’s tidal breathing was recorded and displayed on a computer monitor, and after two to three cycles of a pattern, the airway was occluded. Then the subjects were signaled by the investigator and puffed against the closed airway for about three seconds. Body density was calculated by dividing body mass (g) by body volume (cm³). Once body density was known, the percentage of fat mass (%fat) was calculated using the equation developed by Brožek et al. (1963): %fat = (4.570/ body density − 4.124)×100. LBM was obtained by subtracting fat mass from total body mass. The reliability of the body composition measurements was certified in a prior study (Ishiguro et al., 2005).

**Data analyses**

It has been shown that, in line with the dimensional relationship (Asmussen and Heebøll-Nielsen, 1954; Astrand and Rodahl, 1970), CSA is a function of length to the second power, and body mass is a function of length to the third power. Conversely, if body mass or LBM is determined, any CSA can be theoretically presented as a function of body mass or LBM to the two-third power (Jaric et al., 2005). In the present study, therefore, LBM was expressed as LBM²/³ to convert it into the same dimension as the CSA measurements. Using this index, we conducted a linear regression analysis with CSA measurements. Moreover, muscle CSA was expressed relative to LBM²/³ (CSA/LBM²/³) to reduce the

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B, boys; G, girls; Sp, sprinters (29 boys, 32 girls); Ju, jumpers (28 boys, 22 girls); Th, throwers (18 boys, 15 girls); Na, nonathletes (20 boys, 20 girls); QF, quadriceps femoris; Ham, hamstrings; Add, adductors; PM, psoas major; (G/B%), the percentage of the mean CSA in the girls to that in the boys; # indicates that the difference is significant at p<0.0018 as a result of the Bonferroni/Dunn test.
possible influence of the differences in total lean tissue mass on the comparisons between the boys and girls and among the subject groups.

Statistical analyses

Descriptive data were presented as means and standard deviations (SDs). A simple linear regression analysis was used to calculate the coefficients of the correlation between LBM2/3 and CSA. A Bonferroni/Dunn test was used to examine the significances of the subject group and sex differences in the measured variables. Significance levels for the results of the simple linear regression analysis and Bonferroni/Dunn test were set at $p<0.0125$ and $p<0.0018$, respectively.

Results

The boys were taller and heavier with a lower %fat as compared to the girls (Table 1). Among the subjects groups, the throwers showed the highest values in all measured variables listed in Table 1. On the other hand, there were no significant differences between the sprinters and jumpers in body mass, %fat, and LBM.

Table 2 summarizes descriptive data on the CSAs of the four muscle groups. In all subject groups, the boys showed significantly greater CSAs than the girls in all muscle groups. The mean CSA value for the girls as a percentage of that for the boys was lower in PM (57.6–64.7%) than in the three thigh muscle groups (67.8–82.9%). Among the girls, the athletes showed significantly greater CSAs than the nonathletes in all muscle groups. For the boys, HAM and PM CSAs were significantly greater for the athletes than for the nonathletes regardless of event, while QF CSAs for the jumpers and ADD CSAs for the sprinters and jumpers did not differ significantly from those for the nonathletes. In the comparison among the athletic groups, the QF CSAs for the throwers of both sexes were significantly greater than those for the sprinters and jumpers. For the CSAs of the other three muscles, the girls did not show a significant effect of event. Among the boys, however, the throwers had significantly greater CSAs than the sprinters and jumpers in HAM and ADD and than the jumpers in PM.

The result of a regression analysis for data of all subjects revealed the CSA of PM to be significantly correlated with LBM2/3 ($r=0.835$, $p<0.0001$, Fig. 1). The CSAs of the other three muscle groups were also significantly correlated to LBM2/3: $r=0.903$ ($p<0.0001$) for QF, $r=0.767$ ($p<0.0001$) for HAM, and $r=0.799$ ($p<0.0001$) for ADD. In terms of CSA/LBM2/3, the relative difference between the boys and girls was smaller than that for CSA (Table 3). Notably, the thigh muscles which showed a significant sex difference in CSA/LBM2/3 were limited to QF in the sprinters and nonathletes and HAM in the throwers. However, the sex difference in PM CSA/LBM2/3 was still significant in all subject groups. In the girls, the CSA/
LBM^{2/3} values of all muscle groups were significantly higher in the athletes than in the nonathletes, while the muscle groups which had significant event-related differences in CSA/LBM^{2/3} were limited to QF (throwers>sprinters and jumpers) and HAM (sprinters>throwers). In the boys, the only muscle group in which the athletes of all events showed significantly higher CSA/LBM^{2/3} values than the nonathletes was HAM. In the CSA/LBM^{2/3} values of the other muscle groups for the boys, QF and ADD for the throwers and PM for the sprinters were significantly higher than those for the other groups.

Discussion

For athletes and nonathletes, the relative difference between the boys and girls in CSA was greater in PM than in the thigh muscles. As a result of studies on nonathletic adult populations, it is known that the sex difference in muscularity is greater in the upper extremities and trunk than in the lower extremities (Abe et al., 2003; Janssen et al., 2000). Abe et al. (2003) reported that the muscle mass of the upper and lower legs for women was 63% and 75%, respectively, of that for men, whereas the corresponding values for the arms and trunk were about 50%. Notably, men compared to women had a greater muscle CSA at the gluteus as well as shoulder and chest. The current finding on the difference in the magnitude of the sex difference in CSA between PM and the thigh muscles agrees with the previous results cited here. At the same time, this indicates that the more apparent sex difference in the size of trunk muscles compared to limb muscles already exists in adolescence, regardless of whether the subjects are athletes or nonathletes.

The CSA of PM as well as of the thigh muscles was highly correlated to LBM^{2/3}, consistent with reports that the CSAs of muscles located in the limbs (Kaneshisa and Fukunaga, 1999) and trunk (Lee et al., 2004; Mannion et al., 2000) correlate directly with total lean body mass or muscle mass. The relationship between the LBM and CSA implies the observed differences in LBM between the two sexes and among the subject groups to be a factor in the differences in muscle CSA obtained here. In fact, the magnitude of the differences between the two sexes and between the athletes and nonathletes was reduced in terms of the CSA/LBM^{2/3} compared to CSA. However, the CSA/LBM^{2/3} of not only the thigh muscles but also PM for the girls was significantly higher in the athletes than in the nonathletes, consistent with a previous report (Peltonen et al., 1998) indicating a trainability during adolescence in the muscularity of PM in girls. In addition, the relative differences between the boys and girls in both CSA and CSA/LBM^{2/3} for every muscle group tended to be smaller in the athletes than in the nonathletes. Bishop et al. (1987) suggested behaviorally linked differences in the amount of participation in strength-developing activities as a reason for sex differences in muscle strength for the nonathletic population. This may be applied to explain the greater sex differences in muscle CSA for the nonathletes compared to the athletes. In the athletic groups of boys and girls with similar long-term participation in sports activities such as sprinting, jumping, or throwing, however, the influence of behaviorally linked sex differences in muscle CSA might be assumed to be minimized, and it would be a reason for the smaller sex differences in muscle CSA as compared to the nonathletes.

Even in terms of CSA/LBM^{2/3}, however, the sex difference in PM was still significant in all subject groups, while the corresponding differences observed in the thigh muscles were limited to QF in the sprinters and nonathletes and HAM in the throwers. Reasons for the greater sex difference in PM than in thigh muscles are unknown but might involve three possibilities. First, the functional significance of PM for performing various physical activities should be considered. The sex difference in not only muscle mass but also strength capability is more apparent in the upper than in the lower extremity (Bishop et al., 1987). As described earlier, trunk muscles have a critical role in the maintenance of stability and balance when performing movements with the extremities (Andersen et al., 1988), and a strong and stable trunk provides a solid foundation for the torques generated by the limbs (Behm and Anderson, 2006; Kibler et al., 2006). Among the muscle groups located in the trunk, PM is the only muscle that connects the lumber spine and lower limbs (Arbanas et al., 2009). Taking this into account together with previous findings on sex differences in muscular distribution (Abe et al., 2003; Janssen et al., 2000) and strength (Bishop et al., 1987), therefore, the greater PM CSA in the boys compared to the girls might be assumed to be a functional requirement associated with greater development in the muscle mass and strength capability of the upper extremity and trunk. The second is the possible influence of the sex differences in the size and/or shape of body. The boys were significantly taller than the girls. This difference might produce a sex difference in muscle CSA, being related to that in muscle length. However, a prior study has shown that an individual difference in PM CSA is independent of that in its length (Hanson et al., 1999). On the other hand, body shape apparently differs between men and women, notably in the breast, waist, and hips. During growth, while waist circumference increases with age in both sexes, with a higher mean value in boys, the changes after 13–15 years are less in girls compared to boys (Galcheva et al., 2009; Katzmeryk, 2005; Kelishadi et al., 2007; McCarthy et al., 2001; Sung et al., 2008). This morphological difference in the abdominal region might be associated with the observed sex difference in PM CSA. The third explanation is the possible difference in size of muscle fibers between boys and girls, in relation to muscle fiber type. Thorstensson and Carlson (1987) observed smaller type II fibers in lumber back muscles for women than for men, in spite of a similar relative occurrence of type I fibers between the sexes. Larger type II fibers in men than in women have also been observed in limb muscles (Staron et al., 2000; Alway et al., 1989). However, Alway et al. (1989) reported that, for biceps brachii, the ratio of type II fiber area to LBM was...
higher in male bodybuilders than in female bodybuilders, but the corresponding ratio for type I fibers was similar between the two groups. Arbanas et al. (2009) indicated that the human psoas major muscle has a predominance of type IIA fibers. Considering these findings, therefore, the possible difference in the size of type II fibers between the boys and girls might also be a reason for the sex difference observed in PM CSA/LBM^{2/3}. In any case, the three possibilities described here are speculation. Further study is needed to clarify the physiological reasons for the greater sex differences in PM CSA.

In the comparisons among the three events within the same sex, the CSA/LBM^{2/3} values of QF and ADD for the throwers were the highest, although that of ADD for the girls did not show a significant event-related difference. On the other hand, the CSA/LBM^{2/3} values of PM and HAM tended to be higher in the sprinters of both genders as compared to the other athletic groups. For adult populations, it has been shown that athletes exhibit specific adaptations to their own competitive styles and/or training regimens in the size of muscles located in the limbs (Kanehisa et al., 1998, 1999) and trunk (Engstrom et al., 2007; Hides et al., 2008; Kubo et al., 2007). This is true for adolescent athletes (Hoshikawa et al., 2010). However, most previous studies have examined male athletes, and less information on the event-related difference in muscularity for female athletes is available. In terms of the relative distribution of muscle tissue throughout the body, the current results regarding the event-related differences in CSA/LBM^{2/3} suggest that, even in adolescence, participation in regular sports training produces a specific adaptation in the muscularity of given muscle groups in not only boys but also girls.

From the findings of Terzis et al. (2007), shot-put performance in track and field athletes is significantly correlated to one repetition maximum load in a squat task and the level of electromyographic activity during the shot-put. This finding indicates the importance of the muscularity of the quadriceps femoris and its activation during shot-put movement. Similarly, electromyographic studies on sprint running have shown that the biceps femoris as well as the gastrocnemius muscles play an important role in the population phase (Mero et al., 1992). In addition, Nilsson et al. (1985) and Mann et al. (1986) suggested that, during maximal sprint running, a larger hip flexor torque is needed to reserve the hip extension with a larger angular momentum due to a higher angular velocity and to accelerate the leg forward within the shorter swing time available. Considering these findings, the high CSA/LBM^{2/3} values of PM and HAM in the sprinters may be explained as a profile linked to the requirements for high performance in maximal sprint running.

In summary, the current results indicate that 1) regular participation in sports training during adolescence promotes hypertrophy in PM and thigh muscles in not only boys but also girls, and 2) the gender difference in muscularity is more apparent in PM than in thigh muscles, in athletes and nonathletes.

### References


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