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SHORT REPORT

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# Skeletal muscle size distribution in large-sized male and female athletes

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## Abstract

**Objective:** In healthy adults, it is generally accepted that women have less upper body muscle mass compared to men. However, it is unknown whether there are sex differences in skeletal muscle distribution in highly trained large-sized athletes. Our aim was to compare the skeletal muscle size distribution between large-sized male and female athletes.

**Methods:** Ten female athletes (>80 kg body mass) and twenty-one male athletes (>100 kg body mass) had muscle thickness (MT) and subcutaneous adipose tissue thickness measured by ultrasound at nine sites on the anterior and posterior aspects of the body. Total muscle mass (SM) was estimated from an ultrasound-derived prediction equation. Body fat percentage and fat-free mass were calculated from ultrasound measured subcutaneous fat thickness.

**Results:** The average SM in female athletes (30.0 kg) was approximately 70% of the mean value of the male athletes (45.3 kg).With respect to MT, the relative values of femaleto male athletes were 68% to 78% in the upper body and 85% to 92% in the lower body. Similar results were observed when analyzing data for male and female athletes (n = 5 each) who were pair matched for height.

**Conclusion:** The relative values of MT for female/male athletes were higher in the lower body compared to the upper body. This is similar to that observed in healthy non-athletes indicating that this difference is not due to resistance training. The lower muscle mass in the arms and trunk of females appears to be a true sex difference but the cause of this difference is unknown.

## 1 | INTRODUCTION

The process of body growth is influenced, both independently and collectively, by genetic, nutritional, environmental, and hormonal factors (Lui, Garrison, & Baron, 2015). Many athletes actively seek to manipulate their body size (ie, skeletal muscle mass or lean tissue mass) via environmental factors such as structured resistance-training, in combination with a generous nutritional intake (Abe, Bell, Wong, Spitz, & Loenneke, 2020). A simple model for the determination of body composition is the separation of body mass into fat mass and fat-free mass (FFM), with FFM often being used as a surrogate for whole body muscle mass. Several studies that used underwater weighing techniques reported levels of FFM over 60 kg for female athletes and over 100 kg for male athletes (Abe, Brechue, Fujita, & Brown, 1998; Kondo, Abe, Ikegawa, Kawakami, & Fukunaga, 1994; Wilmore & Haskell, 1972), with the largest female athlete having 82.1 kg FFM (Abe

  

et al., 1998) and the largest male athlete having 121.3 kg FFM (Kondo et al., 1994). However, since the amount of adipose tissue (ie, body fat) is likely to change in the body of athletes (as it pertains to their specific sporting event), the amount of FFM will likely change in the same direction (Abe, Dankel, & Loenneke, 2019). This is mainly due to the fat-free component of adipose tissue being included in the measurement of FFM when estimated by underwater weighing methods. The large-sized (>100 kg body mass) female athletes had approximately 10 kg fat-free adipose tissue (50-60 kg fat mass), which corresponds to about 10% to 15% of FFM (Abe, Wong, et al., 2020). It is desirable to eliminate the influence of the fat-free component of adipose tissue to remove these effects from FFM or is desirable to estimate SM of the body in athletes. Thus, it is necessary to actually compare the total amount of skeletal muscle mass (SM), not the lean tissue mass, between male and female athletes.

Recent projects from our lab (Abe, Buckner, Dankel, et al., 2018; Abe, Buckner, Mattocks, et al., 2018; Abe, Wong, et al., 2020) estimated total SM in large-sized athletes and found that four of the female athletes had more than 30 kg SM. In addition, eight of the male athletes had more than 50 kg SM. The largest value of SM index (divided by height square) in female athletes (13.2 kg/m$^2$) was approximately 77% of the largest value of the male athletes (17.2 kg/m$^2$). The magnitude of this difference in SM index observed between large-sized female and male athletes was similar to that of healthy young adults, which measured SM index using magnetic resonance imaging (Abe, Kearns, & Fukunaga, 2003). It was in this same study where the researchers found that healthy females had less upper body muscle mass compared to healthy males (Abe et al., 2003). However, to the best of our knowledge, it is unknown whether these sex-differences in SM distribution exist among large-sized athletes. Thus, the aim of this study was to compare the skeletal muscle size and distribution between large-sized male and female athletes.

## 2 | MATERIAL AND METHODS

We analyzed datafrom 10 female athletes and 21 male athletes that incorporated identical study designs from our previous research (Abe, Buckner, Dankel, et al., 2018; Abe, Buckner, Mattocks, et al., 2018; Abe, Wong, et al., 2020). To be included in the comparative analysis between male and female athletes, each athlete had to meet the following criteria: (a) highly trained athletes who participated in the International competitions (eg, the World Championships and the Olympics) and/or competed at the NCAA Division I level; (b) involved large-sized athletes, that is, >80 kg body mass in females and >100 kg body mass in males; (c) in order to exclude the influence of the dimension of muscle length, the height of athletes was less than 190 cm; and (d) not taking anabolic hormones. The sports events of the female athletes analyzed in this study were shot put (n = 4), powerlifting (n = 5), and pentathlon (n = 1). For the male athletes, sporting events included shot put (n = 2), powerlifting (n = 8), and American football (n = 11). Each athlete read and signed an informed consent document that was approved by the Institutional Review Board. The most recent approval was protocol #19-049.

Muscle thickness (MT) and subcutaneous adipose tissue thickness (SAT) were measured by B-mode ultrasound (Logiq e, GE, Firfield, CT and SSD-500, Aloka, Tokyo, Japan) at nine sites on the right side of the body as described previously (Abe, Buckner, Dankel, et al., 2018; Abe, Wong, et al., 2020). This measurement was carried out at least 24 hours after the last their training session. Body density was estimated from SAT using an ultrasound-derived prediction equation (Abe, Kondo, Kawakami, & Fukunaga, 1994). We have reported previously that the SE of the estimate of body density using ultrasound equations is approximately 0.006 g/mL (~2.5% body fat) for men and women (Abe et al., 1994). Percent body fat was calculated from body density using Brozek et al's equation (Brozek, Grande, Anderson, & Keys, 1963) and was used to calculate total fat mass and FFM. SM was estimated using a prediction equation (Sanada, Kearns, Midorikawa, & Abe, 2006). Test-retest reliability of SAT and MT measurements were determined as described previously (Abe, Buckner, Dankel, et al., 2018; Abe, Wong, et al., 2020).

Given the nature of the manuscript, we chose to visually compare the athletes using violin plots. Although we did not find it appropriate, the means and standard deviations are found in Table 1 for those interested in running inferential statistics. The violin plot is a combination of a box plot and a density plot. The width of the violin, at a given *y* value, represents the point density at that *y* value. In other words, x would represent "Group" and "*y*" represents the muscle variable in question. The violins begin and end at the minimum and maximum data values, respectively. The thickest part of the violin corresponds to the highest point density in the dataset. To account for height, we pair matched five women and men [Average 179.6 cm, difference of −0.22 (1.08) cm between pairs] but saw similar differences (Figure S1).

## 3 | RESULTS

In the present study, the average total SM in female athletes (30.0 kg) was approximately 70% of the mean value of the male athletes (45.3 kg) (Table 1). When observing

the relative value of female to male athletes, female athletes had lower arm and trunk MT compared to male athletes. More specifically, the relative values of female to male athletes were 68% to 78% in the upper body and 85% to 92% in the lower body (Figure 1). Similar results were observed when analyzing the data for male and female athletes (n = 5 each), who were pair matched for height (Figure S1).

**TABLE 1** Body composition and muscle thickness in large-sized male and female athletes

| | Female | Male |
|---|---|---|
| n | 10 | 21 |
| Age (y) | 31 (9) | 24 (5) |
| Height (m) | 1.74 (0.08) | 1.84 (0.05) |
| Body mass (kg) | 104.2 (21.5) | 121.4 (24.2) |
| Body mass index (kg/m$^2$) | 35.1 (9.5) | 35.8 (7.3) |
| Body fat (%) | 31.1 (11.1) | 20.9 (6.5) |
| Fat-free mass (kg) | 70.0 (7.3) | 94.9 (12.5) |
| Muscle mass (kg) | 30.0 (4.0) | 45.3 (6.0) |
| Muscle thickness (cm) | | |
| Anterior forearm | 2.78 (0.50) | 3.52 (0.47) |
| Anterior upper arm | 3.35 (0.48) | 4.72 (0.61) |
| Posterior upper arm | 4.23 (0.69) | 5.85 (0.78) |
| Anterior thigh | 6.46 (0.68) | 7.53 (0.80) |
| Posterior thigh | 7.60 (0.81) | 8.47 (1.09) |
| Anterior lower leg | 3.26 (0.33) | 3.52 (0.32) |
| Posterior lower leg | 7.82 (0.69) | 8.40 (0.75) |
| Anterior trunk | 1.60 (0.19) | 2.17 (0.38) |
| Posterior trunk | 3.05 (0.64) | 4.46 (1.23) |

*Note:* Values are expressed as means and SD.

## 4 | DISCUSSION

The main finding of this study was that the difference in muscle size between males and females was larger in the upper body (females were 68%-78% of males) than in the lower body (females were 85%-92% of males).Interestingly, the relative differences between large-sized male and female athletes are similar to what would be expected in healthy non-athletes (Abe et al., 2003). It is unknown how much muscle is gained through resistance training, but our data included both male and female world champion powerlifters, who have the largest estimated SM indexes ever recorded (Abe, Buckner, Dankel, et al., 2018; Abe, Buckner, Mattocks, et al., 2018; Abe, Wong, et al., 2020). Therefore, ourresults would suggest that sex differences in the size and distribution of skeletal muscle persist even among those who are highly resistance-trained.

Despite being highly resistance-trained, it is unclear why large differences between males and females for muscle size in the upper body were still observed. Previous research has found there to be sex differences in average muscle fiber cross-sectional area (CSA) of the limb muscles in healthy adults (Holmback, Porter, Downham,

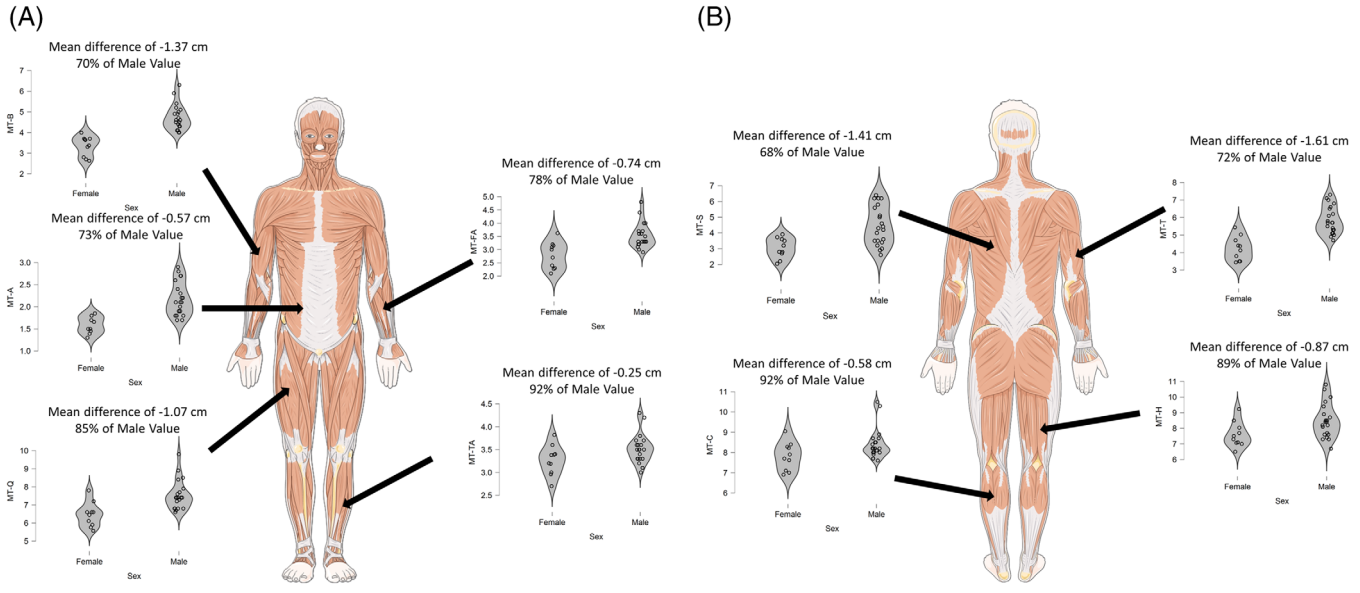


**FIGURE 1** Sex comparison of muscle thickness measured at 9 sites of the body in large-sized athletes. MT-B, anterior upper arm; MT-A, anterior trunk; MT-Q, anterior thigh; MT-FA, anterior forearm; MT-TA, anterior lower leg; MT-S, posterior trunk; MT-C, posterior lower leg; MT-T, posterior upper arm; MT-H, posterior thigh. Image for Part A taken from: https://smart.servier.com/smart_image/musculature-2/; image for Part B taken from: https://smart.servier.com/smart_image/musculature/

Andersen, & Lexell, 2003) and bodybuilders (Alway, Grumbt, Stray-Gundersen, & Gonyea, 1992). However, there has been less work comparing the sex differences in muscle fiber CSA between the upper and lower extremity muscles (Miller, MacDougall, Tarnopolsky, & Sale, 1993). To our knowledge, there is no study comparing large-sized male and female athletes. Future work could consider comparing whole muscle estimates, directed to measures as the fiber level, in order to provide rough estimates of "hypertrophy vs. hyperplasia."

In conclusion, the relative values of MT for female to male athletes were much less for the upper body (68%-78%) compared to relative values within the lower body (85%-92%). This is similar to that observed in healthy non-athletes, and would indicate that factors outside of resistance training are causally contributing to this difference. The lower muscle mass in the arms and trunk of females appears to represent a true sex difference. However, the cause of this difference remains to be elucidated.

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## AUTHOR CONTRIBUTIONS

**Takashi Abe:** Conceptualization; data curation; formal analysis; writing-original draft. **Zachary Bell:** Conceptualization; writing-review and editing. **Vickie Wong:** Conceptualization; writing-review and editing. **Robert Spitz:** Conceptualization; writing-review and editing. **Yujiro Yamada:** Conceptualization; writing-review and editing. **Jun Seob Song:** Conceptualization; writing-review and editing. **Jeremy Loenneke:** Conceptualization; data curation; formal analysis; writing-review and editing.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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