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Original Article

New ultrasonography-based method for predicting total skeletal muscle mass in male athletes

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Abstract. [Purpose] This study aimed 1) to assess whether a prediction model for whole body skeletal muscle mass that is based on a sedentary population is applicable to young male athletes, and 2) to develop a new skeletal muscle mass prediction model for young male athletes. [Subjects and Methods] The skeletal muscle mass of 61 male athletes was measured using magnetic resonance imaging (MRI) and estimated using a previous prediction model (Sanada et al., 2006) with B-mode ultrasonography. The prediction model was not suitable for young male athletes, as a significant difference was observed between the means of the estimated and MRI-measured skeletal muscle mass. Next, the same subjects were randomly assigned to a development or validation group, and a new model specifically relevant to young male athletes was developed based on MRI and ultrasound data obtained from the development group. [Results] A strong correlation was observed between the skeletal muscle mass estimated by the new model and the MRI-measured skeletal muscle mass (r=0.96) in the validation group, without significant difference between their means. No bias was found in the new model using Bland-Altman analysis (r=−0.25). [Conclusion] These results validate the new model and suggest that ultrasonography is a reliable method for measuring skeletal muscle mass in young male athletes.

Key words: Muscle thickness, B-mode ultrasonography, Magnetic resonance imaging

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INTRODUCTION

In the field of competitive sports, athletes need to be able to regularly evaluate their whole body skeletal muscle mass (SMM) using a simple method. Some athletes, particularly those engaged in intense contact sports like rugby and American football, must gain weight and build a large SMM, which can be achieved through long-term nutritional support and resistance training. The net effect of nutrition management and training on SMM gain should be successively evaluated for these athletes as a source of continuous feedback. Thus, a convenient and reliable method for assessing the SMM of athletes would be useful for both nutritionists and athletic trainers. There are currently no established methods for measuring SMM in this manner, although a number of general methods do exist, such as magnetic resonance imaging (MRI), computed tomography (CT)[1)], and anthropometry[2)]. Although MRIs and CTs are able to scan the entire body and are considered the gold standard for imaging, they are quite expensive to perform and involve extensive measurements. Another modality is ultrasonography, which has been used for the accurate measurement of skeletal muscle size in vivo[3–8)]. A compact ultrasound system, which

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can quantify muscle thickness (MTH), requires very little time to perform the measurements and would seem optimal for use in the field.

Previous studies[9–11] led us to hypothesize that an ultrasound-based prediction model for SMM could be applied to competitive athletes, and our first objective was to determine whether the existing prediction model[9] was relevant young male athletes (Study I). Based on the results of Study I, we developed a new prediction model for estimating SMM using ultrasonography that specifically targets young male athletes, and verified its validity (Study II).

SUBJECTS AND METHODS

The subjects were 61 healthy Japanese young male athletes engaged in contact sports (rugby, 20; American football, 23; lacrosse, 18; mean age (SD), 20.4 (0.9) years; height, 175.0 (6.4) cm; body mass, 82.5 (15.0) kg). None of the subjects had neurological disorders. This study was approved by the Ethics Review Board of Ritsumeikan University Biwako-Kusatsu Campus (BKC-IRB-2012-031). Each subject received an explanation of the nature and purpose of the study, and provided written informed consent.

All subjects participated in both Study I and Study II. In Study II, subjects were randomly assigned to two groups: 40 were involved in tests for developing the new prediction model for SMM (development group), and 21 were involved in model validation (validation group).

All measurements for both studies were completed in one or two visits to the laboratory and were performed on the same day, except for the dual-energy X-ray absorptiometry. Body mass and height were measured with a digital weight scale (0.1 kg resolution) and a standard height scale, respectively. Percent body fat and fat-free mass were determined by dual-energy X-ray absorptiometry (Lunar Prodigy, GE, Tokyo). SMM measurements were conducted by MRI and ultrasonography.

SMM was directly measured by MRI (Signa HDxt 1.5T, GE) using the following parameters: repetition time of 600 ms, echo time of 10 ms, slice thickness of 1.0 cm, and inter-slice gap of 0. During the measurements, the subjects were in the prone position with their hands placed on their abdomen. Approximately 200 consecutive scanned images were obtained from the first cervical vertebra to the lateral malleolus. The scanned images were stored on a hard disk, and the anatomical cross-sectional area was determined using image analysis software (Slice Omatic Ver.4.3, Tomovision, Inc., Montreal, Canada). Total body skeletal muscle volume (L) was calculated from the sum of successive anatomical cross-sectional areas and converted to mass (kg) (i.e., SMM) by multiplying the total skeletal muscle volume (L) by the assumed constant density for adipose tissue-free skeletal muscle (1.04 $kg \cdot L^{-1}$)[9].

MTH was measured by B-mode ultrasound at nine sites on the anterior and posterior surfaces of the body. The location of the probe was determined according to a previous study[3], as follows:

(1) Forearm lateral: on the anterior surface at 30% proximal between the styloid process and the head of the radius;

(2, 3) Biceps and triceps brachii: on the anterior and posterior surfaces at 60% distal between the lateral epicondyle of the humerus and the acromial process of the scapula;

(4) Abdomen: at a distance of 2–3 cm to the right of the umbilicus;

(5) Subscapula: at a distance of 5 cm directly below the inferior angle of the scapula;

(6, 7) Quadriceps and hamstrings: on the anterior and posterior surfaces at midway between the lateral condyle of the femur and the greater trochanter;

(8, 9) Gastrocnemius and tibialis anterior: on the anterior and posterior surfaces at 30% proximal between the lateral malleolus of the fibula and the lateral condyle of the tibia.

MTH was visually determined by ultrasonography using on-screen digital calipers. MTH was defined as the distance between the adipose tissue-muscle interface and the muscle-bone interface[9], and MTH9 was calculated from measurements at the nine sites described above. Body height was adopted as a measure with which to estimate skeletal muscle length and was one of the independent variables used for SMM estimation[9]. The ultrasound measurements and determinations of muscle thicknesses for all subjects were conducted by a single observer who was very familiar with these procedures.

In Study I, since our objective was to determine whether a previously developed prediction model for SMM[9], which uses ultrasound MTH9 as an independent variable, can be applied to the estimation of SMM in young male athletes, the MTH9 values of the young male athletes were entered into the previous prediction model. This allowed for a simultaneous comparison of the SMM values calculated using the model with the SMM values directly measured by MRI. Differences between the MRI-measured and ultrasound-predicted SMM values were assessed using a paired t-test. Descriptive statistics are expressed as means (SD), and $p<0.05$ was considered statistically significant.

In Study II, further analyses were performed using data obtained in Study I to formulate a new prediction model specific to young male athletes and to verify its efficacy, using the method described previously[9]. Briefly, the new prediction model was a first-order (i.e., linear) function: ($SMM(x) = ax + b$), wherein MTH9 (cm) multiplied by body height (m) was used as the explanatory variable x. In order to determine the proportional constant (a) and intercept (b), a simple linear regression analysis between the explanatory variable (x) and MRI-measured SMM was performed for the measured data in the development group (n=40). The validity of the new model was confirmed in the validation group (n=21) using the measured data (i.e., MRI data and MTH9 × body height). Linear regression analysis was performed between the MRI-measured SMM value and the SMM value predicted by the new model. A paired t-test was also performed between the MRI-measured and predicted

SMM values. The validity of the new model was further assessed using the method suggested by Bland and Altman[12]. In this approach, the differences between the MRI-measured and predicted SMM values were plotted against the means of the MRI-measured and predicted SMM values.

RESULTS

The subject characteristics and ultrasound-measured MTH values are shown in Table 1. No significant difference was found in any parameter between the development and validation groups. In Study I, the mean SMM measured by MRI was 35.9 (5.3) kg, which substantially differed from that predicted by the initial model (31.2 (5.0) kg; $p<0.001$). On average, the percent difference between directly measured and estimated SMM values was 13.1% (4.4%). These results suggest that the previously developed prediction model cannot be applied to young male athletes.

In Study II, there was a strong correlation between MRI-measured SMM (kg) and the product of MTH9 (cm) and body height (m) ($r=0.94$, $p<0.001$) in the development group (n=40), as indicated by the following equation (Eq. (1)):

$$\text{SMM (kg)} = 0.645 \times (\text{MTH9 (cm)} \times \text{Body height (m)}) - 7.821 \quad (1)$$

Eq. (1) is the new prediction model specific to young male athletes. In order to assess the reliability of the new model, we applied it to the validation group, which consisted of different subjects than those in the development group. A strong correlation was observed between the MRI-measured SMM and the SMM values predicted by Eq. (1) ($r=0.96$, $p<0.001$). The mean predicted SMM in the validation group was 38.5 (5.7) kg, which was equal to the MRI-measured SMM (38.5 (5.8) kg) ($p=0.98$, paired t-test). Furthermore, the new prediction model was not biased, as confirmed by Bland-Altman analysis ($r=-0.25$, $p=0.23$).

DISCUSSION

Sanada et al.[9] developed and validated an equation for estimating SMM using ultrasound parameters based on data from a sedentary Japanese adult population (72 sedentary men and women; age range, 18–61 years) [SMM (kg) = 0.687 × (sum of MTHs at nine body sites (MTH9) (cm)) × (body height (m)) − 15.122]. That prediction model allowed for the estimation of total and regional skeletal muscle mass in field measurements for a large subject group, and was a portable and timesaving method. Midorikawa et al. then verified the reliability of that SMM prediction model in Japanese pre-pubertal children and adolescents, suggesting that it could also be used for that population. More recently, Abe et al. reported on the utility of the model for estimating SMM in Caucasian adults aged 50–78 years. However, no studies to date have determined whether the model could be used to estimate SMM in young athletes.

Table 1. Subject characteristics and ultrasound-measured muscle thickness (MTH)

		All	Lacrosse	Rugby	American football	Development group	Validation group
		(n=61)	(n=18)	(n=20)	(n=23)	(n=40)	(n=21)
Age	(years)	20.4 (0.9)	20.7 (0.8)	19.7 (0.7)†	20.8 (0.8)§	20.4 (0.9)	20.5 (0.9)
Body height	(cm)	175.1 (6.4)	170.8 (5.8)	176.9 (6.7)†	177.0 (4.8)‡	173.9 (6.2)	176.5 (5.4)
Body mass	(kg)	82.5 (15.0)	67.7 (5.9)	87.0 (10.3)†	90.2 (15.2)‡	82.5 (15.3)	82.5 (14.9)
%Fat	(%)	16.1 (7.0)	11.0 (3.7)	16.6 (6.1)†	19.7 (7.4)‡	16.1 (7.1)	16.2 (7.0)
FFM	(kg)	65.4 (7.5)	57.5 (4.2)	69.0 (4.9)†	68.4 (6.8)‡	65.5 (7.6)	65.1 (7.4)
SMMw	(kg)	35.9 (5.3)	29.8 (2.7)	38.2 (3.1)†	38.8 (4.4)‡	35.9 (5.4)	36.1 (5.4)
Lateral forearm MTH	(cm)	2.63 (0.31)	2.31 (0.20)	2.79 (0.16)†	2.75 (0.30)‡	2.65 (0.27)	2.61 (0.38)
Anterior upper arm MTH	(cm)	3.52 (0.67)	3.10 (0.31)	3.62 (0.86)†	3.74 (0.55)‡	3.61 (0.54)	3.33 (0.85)
Posterior upper arm MTH	(cm)	4.15 (0.78)	3.35 (0.58)	4.55 (0.52)†	4.43 (0.65)‡	4.17 (0.73)	4.13 (0.89)
Abdomen MTH	(cm)	1.74 (0.26)	1.52 (0.14)	1.76 (0.25)†	1.90 (0.21)‡	1.73 (0.25)	1.76 (0.28)
Subscapula MTH	(cm)	3.30 (0.94)	2.52 (0.32)	3.47 (1.14)†	3.77 (0.67)‡	3.35 (0.99)	3.22 (0.85)
Anterior thigh MTH	(cm)	6.19 (0.71)	5.80 (0.62)	6.30 (0.58)†	6.38 (0.77)‡	6.15 (0.70)	6.25 (0.73)
Posterior thigh MTH	(cm)	6.66 (0.85)	6.27 (0.62)	6.68 (1.05)	6.96 (0.71)‡	6.61 (0.84)	6.76 (0.88)
Anterior lower leg MTH	(cm)	2.97 (0.48)	2.62 (0.25)	3.39 (0.52)†	2.87 (0.27)‡§	2.98 (0.50)	2.94 (0.45)
Posterior lower leg MTH	(cm)	7.31 (1.01)	6.71 (1.57)	7.51 (0.42)	7.60 (0.56)‡	7.41 (0.50)	7.41 (0.61)

FFM: fat free mass, SMMw: whole body skeletal muscle mass, MTH: muscle thickness.
Data are presented as mean (SD). †$p<0.05$ Lacrosse vs. Rugby, ‡ $p<0.05$ Lacrosse vs. American football, §$p<0.05$ Rugby vs. American football

The first goal of this study was therefore to determine whether that existing model could be applied to young male athletes. We found that the SMM values predicted using the previous model were significantly lower than those directly measured by MRI, suggesting that the model underestimates SMM and cannot be applied to this population.

In a previous study, the muscularity of elite junior weight lifters was compared with that of non-trained subjects by measuring MTH at 10 sites (anterior forearm, anterior upper arm, posterior upper arm, chest, abdomen, back, anterior thigh, posterior thigh, anterior lower leg, and posterior lower leg) using B-mode ultrasonography[13]. At six sites (anterior forearm, anterior upper arm, posterior upper arm, chest, back, and anterior thigh), the weight lifters showed significantly greater MTH (9–24%) than the non-trained subjects, even when MTH was corrected for body mass. The difference in MTH between groups was largest at the chest. In contrast to that study, we did not measure chest MTH in Study 1, and the large potential difference in pectoralis major muscle mass between young male athletes and sedentary individuals may account for the substantial error in the SMM estimated for young male athletes using the previously developed model. To address this, we developed a new prediction model specific to young male athletes. The correlation coefficient (r=0.96) between MRI-measured SMM values and those predicted using the new model in the validation group was as high as that reported for the previous prediction model (r=0.97)[9]. This suggests that the new prediction model is highly accurate and thus a possible alternative to MRI.

In summary, the existing skeletal muscle mass prediction model[9] was found to underestimate the SMM of young male athletes. This prompted us to develop and validate a more accurate model specific to this population that would be convenient for field measurements due to its portability and efficiency.

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