Bioelectrical impedance analysis to estimate one-repetition maximum for leg press in healthy young adults

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Abstract

Skeletal muscle mass (SMM) obtained using bioelectrical impedance analysis (BIA) is often correlated with isometric muscle strength; furthermore, it might also have correlations with one-repetition maximum (1RM). Accurate prediction of 1RM is important because it is useful for determining progress in resistance training. This study examined the relationship between BIA measurements and 1RM and developed prediction models for 1RM using BIA measurements. Thirty-five healthy young Japanese adults were included in this cross-sectional observational study. The SMM of the dominant leg and the skeletal muscle mass index (SMI) were obtained using a BIA device. The 1RM for the dominant leg was measured using a unilateral leg-press (LP) machine. The correlations between BIA measurements and 1RM were calculated, and simple regression analyses were performed to predict 1RM from the BIA variables. The results showed significant correlations between 1RM and dominant-leg SMM (R=0.845, P=0.0001) and SMI (R=0.910, P=0.0001). The prediction models for 1RM for LP derived from SMM of the dominant leg and SMI were Y=8.21x + 8.77 (P=0.0001), R^2=0.73, and Y=15.53x − 36.33 (P=0.0001), R^2=0.83, respectively. Our results indicate that SMI may be used to accurately predict the 1RM for LP.

Introduction

Resistance training (RT) improves physical function and reduces the incidence of cardiovascular disease and all-cause mortality in adults [1]. Multiple types of exercise including RT have been reported to reduce fall risk in older adults [2]. Therefore, RT is an important physical activity for maintaining health [3]. Progression in RT is determined by one-repetition maximum (1RM) that is the maximum load a participant can lift at one repetition, number of repetitions and sets, and frequency [4]. In particular, the determination of the 1RM is essential for effectively gaining muscle strength and muscle mass. It is also useful for selecting strategies by either adopting heavier loads and fewer repetitions and sets [5] or adopting moderate loads and more repetitions and sets [6].

Despite the time-consuming process, direct measurement of 1RM is considered a reliable strength evaluation method [7]. In this step, however, safety considerations are necessary because joint injuries in older adults [8] and blood pressure elevations in young adults [9] have been reported with the use of loads close to 1RM during RT. Therefore, in prescribing RT, the development of safe 1RM measurement is an essential issue for all generations. Instead of direct 1RM measurements, estimations from several repetitions performed with submaximal loads [10–12] or maximal isometric muscle strength [13, 14] were reported as indirect 1RM measurements. Although these methods could shorten the time required to measure maximal loads, there are some concerns about cardiovascular safety [15] because nearly maximal effort is necessary for the estimation. Therefore, it is necessary to develop safer methods for predicting 1RM.

Muscle strength is determined by a combination of morphological and neural factors [16]. Morphological factors such as skeletal muscle mass (SMM) and cross-sectional skeletal muscle area have been well documented to have a moderate to strong correlation with muscle strength or power [17–19], and evaluating these morphological factors can be considered a viable option for the assessment of muscle strength. Several methods can be used to accurately assess SMM; the reliable measurement modalities for SMM includes magnetic resonance imaging, computed tomography, and dual-X-ray absorptiometry [20]. However, these modalities are not easy to utilize because of their cost and environmental restrictions. Further, radiation exposure in computed tomography and dual-X-ray absorptiometry limits their use. In recent years, bioelectrical impedance analysis (BIA) has been widely used in both clinical and research settings. The validity of BIA as an SMM measurement has been confirmed especially among Asian populations in previous studies [21–23], and the Asian Working Group for Sarcopenia recommends its use for diagnosing sarcopenia [24].

Some studies have reported moderate to strong correlations between muscle strength and BIA parameters [25–27]. However, most of the strength measurements used in previous studies involved isometric conditions [21, 25–27] and not dynamic muscle strength (e.g., 1RM, which is essential for prescribing RT). If the relationship between 1RM and parameters like SMM or skeletal mass index (SMI) obtained using BIA become clearer and 1RM can be accurately estimated using BIA parameters, it would provide a simple and safe method to prescribe RT without any concerns. This study aimed to examine the relationship between the measurements obtained using BIA and 1RM for leg-press (LP), a typical RT exercise of the lower extremities, and to develop prediction models for estimating 1RM for LP using BIA measurements. Subgroup analysis was also conducted to reveal sex differences in the correlation and accuracy of the estimation models to predict 1RM using BIA measurements.

Results

Forty applicants were enrolled in this study. Some applicants had a history of injury to the lower limbs (n = 1) or lumbar (n = 1), and some had low back pain (n = 3). Therefore, the abovementioned five applicants were excluded. Ultimately, 35 participants (18 men and 17 women) were included in this study. The participants’ characteristics are presented in Table 1.

Table 1
Participants' characteristics

	All participants (n = 35)	Men (n = 18)	Women (n = 17)
Age, years	28.3 ± 3.8	29.8 ± 3.1	26.7 ± 3.9
Height, cm	163.3 ± 8.8	170.3 ± 4.5	155.9 ± 5.4
Weight, kg	55.5 ± 8.7	61.8 ± 6.5	48.7 ± 4.6
BMI, kg/m^2	20.7 ± 2.1	21.3 ± 2.0	20.1 ± 2.1
Whole body FM, kg	10.9 ± 3.8	10.0 ± 4.0	11.8 ± 3.6
Dominant arm SMM, kg	2.2 ± 0.6	2.8 ± 0.3	1.6 ± 0.2
Non-dominant arm SMM, kg	2.2 ± 0.6	2.7 ± 0.3	1.6 ± 0.2
Dominant leg SMM, kg	7.2 ± 1.6	8.5 ± 0.9	5.7 ± 0.6
Non-dominant leg SMM, kg	7.2 ± 1.6	8.5 ± 0.9	5.7 ± 0.6
Trunk SMM, kg	19.5 ± 3.8	22.8 ± 1.8	15.9 ± 1.4
SMI, kg/m^2	6.9 ± 1.0	7.7 ± 0.5	6.1 ± 0.4
1RM for leg press, kg	71.0 ± 16.5	84.2 ± 8.4	57.1 ± 10.2

Data are presented as mean ± standard deviation.

BMI, body mass index; FM, fat mass, SMM: skeletal muscle mass, SMI: skeletal muscle mass index, 1RM: one-repetition maximum

In all participants, the correlation coefficients between 1RM for LP and dominant leg SMM and 1RM for LP and SMI as a BIA measurement were 0.845 (P = 0.0001) and 0.910 (P = 0.0001), respectively. In men, the correlation coefficients between 1RM and dominant leg SMM and 1RM and SMI were 0.527 (P = 0.025) and 0.752 (P = 0.0001), respectively. In women, the correlation coefficients between the 1RM and dominant leg SMM and 1RM and SMI were 0.310 (P = 0.225) and 0.613 (P = 0.009), respectively (Table 2).

Table 2

Correlation analyses between BIA measurements and 1RM for leg press

	1RM for leg press		
	All participants (n = 35)	**Men (n = 18)**	**Women (n = 17)**
Dominant leg SMM	0.845 (P = 0.0001)	0.527 (P = 0.025)	0.310 (P = 0.225)
SMI	0.910 (P = 0.0001)	0.752 (P = 0.0001)	0.613 (P = 0.009)
BIA, bioelectrical impedance analysis, 1RM, one-repetition maximum, SMM, skeletal muscle mass, SMI, skeletal muscle mass index			

Table 3

Prediction models of 1RM for leg press using BIA measurements

	Dependent variable	Prediction model	R^2	SEE	95% confidence interval		P-value
					Lower	Upper	
All participants (n=35)	Dominant leg SMM	Y=8.21X + 8.77	0.73	8.98	6.798	10.733	0.0001
	SMI	Y=15.53X − 36.33	0.83	6.96	13.022	18.040	0.0001
Men (n=18)	Dominant leg SMM	Y=5.23X +39.63	0.28	7.39	0.763	9.696	0.025
	SMI	Y=12.74X − 14.25	0.57	5.73	6.824	18.647	0.0001
Women (n=17)	Dominant leg SMM	Y=5.15X + 27.56	0.10	10.0	-3.553	13.831	0.225
	SMI	Y = 14.65X − 31.52	0.38	8.29	4.265	25.039	0.009
1RM, one-repetition maximum, BIA, bioelectrical impedance analysis, SEE, standard error of estimation, SMM, skeletal muscle mass, SMI, skeletal muscle mass index							

The results of the single linear regression analysis are presented in Table 3. Most of the prediction models for 1RM for LP using BIA measurements were statistically significant except for the model created using the dominant leg SMM as an independent variable in women. The R^2 values of the prediction model created from dominant leg SMM and SMI in all participants were 0.73 (standard error of estimation [SEE] 8.98 kg, P = 0.0001) and 0.83 (SEE 6.96 kg, P = 0.0001), respectively (Fig. 1). In the 1RM prediction model that analyzed sex, the models' R^2 values in men were 0.28 (SEE 7.39 kg, P = 0.025) in dominant leg SMM and 0.56 (SEE 5.73 kg, P = 0.0001) in SMI. In women, the R^2 value of the prediction model that used SMI as an independent variable was 0.38 (SEE 8.29 kg, P = 0.0001).

Discussion

This study aimed to determine the relationships between the 1RM for LP and measurements obtained using BIA and to develop a prediction model to estimate the 1RM for LP in healthy young adults. We also examined sex differences in the correlational analysis and the prediction models' accuracy. There were two important findings in the current study. First, there were strong correlations between the 1RM for LP and measurements obtained using BIA, and accurate prediction may be possible using BIA measurements, especially SMI that was used as the dependent variable. Second, there were stronger correlations in men than in women; therefore, accurate 1RM estimation using BIA measurements might be attainable for men.

Although previous studies have revealed that isometric knee extensor muscle strength and BIA measurements are strongly correlated [21, 25–27], few studies are available on the relationship between 1RM and dynamic muscle strength using BIA measurements. Kanada et al. [28] reported that there were strong relationships (Rho = 0.78, P < 0.01) between 1RM for the knee extensor and each appendicular limb's SMM or whole-body SMM obtained using BIA in young men. They also reported that 1RM could be accurately estimated by combining isometric muscle strength and SMM in healthy young men [28]. Our results showed stronger correlation coefficients with the 1RM for LP and measurements using BIA than those in their study; this may be because the required muscle activation in the adopted resistance exercise could influence the BIA measurements. Knee extension exercise mainly requires quadriceps muscle activity [29] whereas LP requires activities in most lower limb muscles [30]. Therefore, compared with the results of the previous study, our method showed better results because SMM or SMI that include most of the lower limb muscles might be strongly correlated with and could accurately estimate the 1RM for LP that is a multi-joint exercise.

In our study, an accurate prediction model could be developed when SMI, an index adjusted by height that includes both leg and arm muscle mass, was used as a dependent variable rather than the SMM of the dominant leg. This may be because each of the body parts affects strength measurements; not only the parts whose strength is directly measured but also those enabling bodily stabilization at the time of measurement. A previous study revealed that bodily stabilization by the hands influences isokinetic maximal torque production [31]. Because grasping handles is considered a body-stabilization strategy that is not involved in physiological processes associated with remote muscle contractions [32], the estimation accuracy of SMM and SMI as dependent variables to predict 1RM for LP might be influenced.

There were differences in the correlation coefficients and accuracy of the estimation model between men and women in this study, and the correlation between the 1RM for LP and BIA variables or the accuracy of the estimation model was higher in men than in women. A previous study reported a sex difference in the correlation between isometric knee muscle strength and SMM obtained using BIA in community-dwelling older adults [33]. Our study confirmed sex differences between dynamic muscle strength and BIA measurements in healthy young adults. A possible reason for these results may be the difference in neural factors that determine muscle strength between the sexes. Although it is well documented that men have generally greater muscle mass than women do[34, 35], few studies regarding sex differences in neural factors are available. However, some previous studies revealed that the firing rate of the vastus medialis differed between women and men [36], and less steady force production in women was caused by unstable modulation of the motor firing discharge rate [37]. BIA cannot evaluate such neural factors and only reflects morphological factors; that may explain the differences in the correlation and accuracy of the estimation model between the sexes in this study. Another possible reason that BIA could not evaluate may be the difference in the fiber characteristics of the lower limb muscles between men and women. A previous study revealed that type 2 fibers that could produce more force than type 1 fibers are larger in men than in women [38], and BIA could not distinguish the composed type of muscle fiber. This may also have influenced the correlation and accuracy of the estimation model between the sexes in this study.

Although our findings might help resolve safety concerns and time-consuming problems in measuring 1RM, we acknowledge some limitations regarding generalizability, and the interpretation of our results should be done carefully. First, we could not confirm the cross-validation of the estimation models developed in this study; therefore, the validity of these models needs to be confirmed in future studies. Second, our target population was relatively young and did not include older adults. Because a previous study revealed that SMM might not play crucial roles in muscle strength among healthy older adults [39], this study's correlations and estimation models could not be directly adapted to older populations. Multivariable estimation models that can be adapted to any age or sex should be developed in future studies. Finally, it was reported that the absolute SMM value differed among body composition analyzers [40]; therefore, the relationship and accuracy of the estimation models may differ from those of other BIA equipment. The correlation and accuracy of the estimation model using other equipment should be confirmed in future studies.

Methods

Study design and ethical approval

This cross-sectional study protocol was approved by the institutional ethics committee of Shinshu University (approval number: 3722). This study was conducted in accordance with the Declaration of Helsinki and was revised in 2013. All participants were informed of the study’s aim, procedures, and potential risks and signed informed consent forms before their participation.

Subjects

Healthy adults working as medical staff at Kakeyu-Misayama Rehabilitation Center, Kakeyu Hospital, Japan, were conveniently recruited via a displayed poster between July 2017 and November 2017. The inclusion criteria were as follows: 1) age ≥20 and <40 years; 2) no history of injury to the spine or lower limbs; 3) no history of neurological diseases; 4) no pain at rest or during exercise; 5) not pregnant or possibly pregnant; and 6) no cardiac pacemaker.

Procedure

First the body composition was measured using BIA, and then the 1RM was measured. Both the assessments were conducted at a fixed time on the same day. Participants were instructed to refrain from eating or drinking large amounts of water 4 h before the measurement and consuming alcohol 8 h before the measurement. Participants were also required to not undertake any intense exercise for 8 h before the measurements.

BIA measurements

BIA measurements were performed using a body composition analyzer (Inbody 430, Biospace, Korea) equipped with a terra-polar eight-point tactile electrode system. It used three multi-frequencies (5, 50, and 250 kHz) to measure the impedance of the subject's appendicular muscles and trunk. The measurement by multi-frequencies was considered a better method for assessing muscle function than single-frequency measurement [25]. After the participants wiped their soles off, they stood on the analyzer's platform grasping the handles with both hands according to the manufacturer's guidance. The measurements took approximately 40 s to complete. The analyzer calculated the values for absolute muscle and fat mass, body fat percentage, and segmental muscle mass (upper and lower limbs of both sides and trunk). We used dominant leg SMM and SMI that was the sum of appendicular SMM obtained by dividing the subjects' squared height (kg/m^2) for the analyses because SMI is reportedly correlated with muscle function in people with sarcopenia [41].

1RM measurement

1RM measurement was performed using the subject's dominant leg with an LP resistance training machine (HUR, Finland). This resistance training machine allowed the participants to lift the loads unilaterally. The 1RM procedure was performed according to the American College of Sports Medicine guidelines [42]. All participants underwent a 5 min warm-up session using an ergo cycle bike before the measurements. The participants sat on the LP machine with their hip and knee joints fixed at approximately 90 °, and the pelvis was stabilized by the belt. The participants were also required to hold handgrips placed on the side of the machine seat with each hand. The familiarization session with LP with light resistance for 8–10 repetitions was performed using perceived 50%1RM. The measurements were started at loads of 80%1RM. The load in the measurement was progressively changed by 3–10 kg until the participants could not lift the loads. The goal was to complete a maximal lift in five attempts, and 3–5 min of rest were provided between sets. All tests were performed by the same evaluator in the same order.

Statistical analysis

The sample size analysis was conducted using G* Power software 3.1.9.4 (Heinrich Heine University, Dusseldorf, Germany). Because moderate to strong correlations between measurements obtained using BIA and isometric muscle strength of the lower limbs have been previously reported [17-19], we set the alpha to 0.05, power to 0.8, and effect size to 0.5 and calculated the required minimum sample size to be n=26. The participants' characteristics are presented as mean ± standard deviation (SD). After confirming the normality of the obtained data using the Shapiro–Wilk test, we identified correlations between each of the variables obtained from the body composition analyzer and the 1RM for LP by calculating Pearson's product-moment correlation coefficients. To create the 1RM prediction models, a simple linear regression analysis was performed using the variables obtained using BIA as independent variables. To evaluate the models' accuracy, R^2 and SEE parameters were considered. All analyses were performed using SPSS version 25 (International Business Machine Corp., Armonk, NY, USA). Any P-values <0.05 were considered statistically significant.

Declarations

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Author contributions

KM, SK, and KS conceptualized this study. KS, YK, MI, MM, and SK contributed to data collection. KS and KM contributed to the data analysis. KS and KM wrote the initial draft, and all authors contributed to the interpretation of the data and critically reviewed the manuscript. All authors approved the final version of the manuscript.

Data availability

The datasets used in this study are available from the corresponding author upon reasonable request.

Competing interests

All authors declare no competing interests.

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Figures

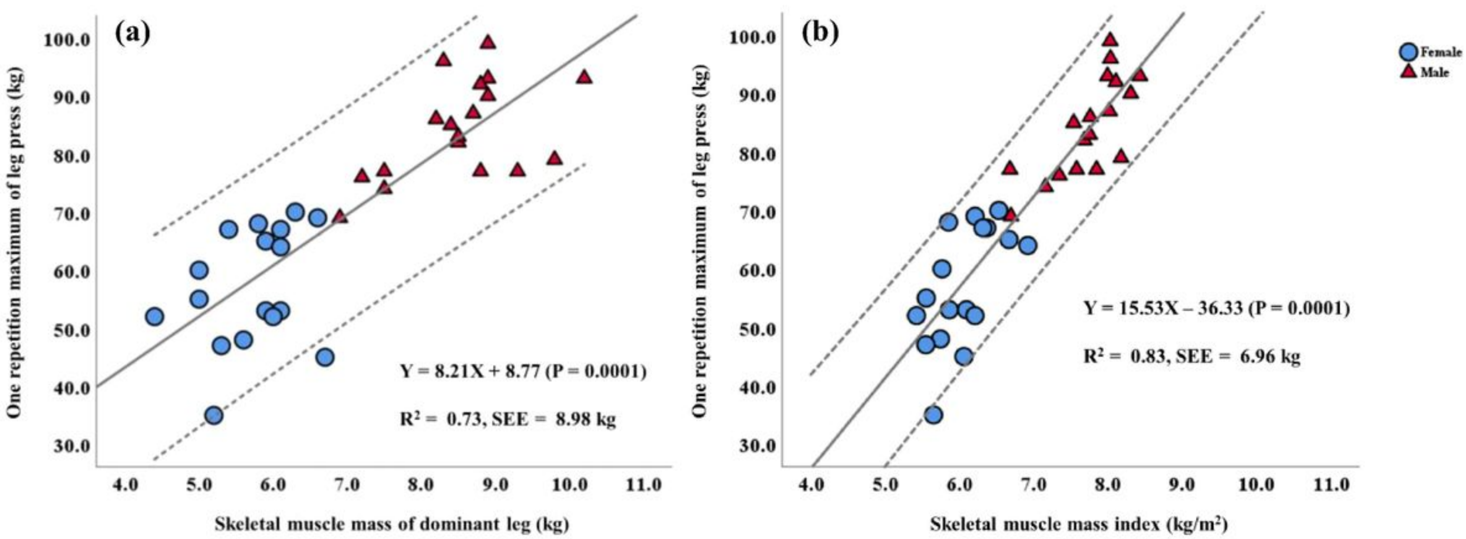

Figure 1

Regression models for one-repetition maximum for leg press from using BIA measurements. (a) skeletal muscle mass of the dominant leg, (b) skeletal muscle mass index. The dotted lines represent the 95% confidence interval.