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Original Article

Relationship between 10 repetition maximum for chest press, leg press, and muscle mass measured using bioelectrical impedance analysis in healthy young adults

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Abstract. [Purpose] This study aimed to examine the relationship between bioelectrical impedance analysis measurements and 10 repetition maximum for chest press and leg press, and to develop a regression model to determine if bioelectrical impedance analysis can predict 10 repetition maximum in healthy young adults. [Participants and Methods] Ninety-four healthy adults participated in the study. Correlations between 10 repetition maximum and bioelectrical impedance analysis measurements were calculated, and simple linear regression was performed using bioelectrical impedance analysis measurements as independent variables to develop 10 repetition maximum prediction models. [Results] Significant correlations were found between 10 repetition maximum and bioelectrical impedance analysis measurements. The regression models for 10 repetition maximum for chest press based on upper limb muscle mass, skeletal muscle mass, and skeletal muscle mass index were Y=16.40X−13.27, Y=3.81X−36.78, and Y=20.51X−81.27, respectively. The regression models for 10 repetition maximum for leg press based on lower limb muscle mass, skeletal muscle mass, and skeletal muscle mass index were Y=12.60X−3.21, Y=8.09X−24.39, and Y=43.68X−119.60, respectively. [Conclusion] These findings may contribute to developing a safe and efficient method for measuring 10 repetition maximum, which can be useful in resistance training prescriptions.
Key words: Muscle strength assessment, 10 repetition maximum, Bioelectrical impedance analysis

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INTRODUCTION

Ten repetition maximum weight (10RM) is defined as the maximum weight that can be lifted in ten repetitions and is a loading intensity commonly used in clinical practice. In contrast, one-repetition maximum weight (1RM) is the most widely used strength index. When prescribing resistance training, load intensity is typically determined based on the expected number of repetitions at a given percentage of 1RM (%1RM)[1)]. However, previous research has shown variability in the number of repetitions performed at load intensities derived from %1RM[2)]. For example, the estimated number of repetitions at 85%

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1RM in the leg press is 10.69, with a 95% confidence interval ranging from 6.98 to 16.37, indicating that overestimation or underestimation may occur when load intensity is indirectly determined from %1RM. Directly measuring load intensity with the 10RM test may provide a more accurate load than indirect estimation from %1RM. Furthermore, 1RM tests are time-consuming and involve heavy weights, which can place significant strain on muscles and joints, increasing the risk of injury for beginners, older adults, and patients. This has led to discussions on methodologies for indirectly estimating 1RM using alternative assessment measures[3–7]. However, estimated 1RM values naturally contain some degree of error, and furthermore, as mentioned above, using these estimates to determine loading intensity in %1RM can lead to large variations depending on the actual number of repetitions performed. Consequently, developing methodologies to estimate 10RM through other means could be clinically beneficial.

Bioelectrical impedance analysis (BIA) is a method for estimating muscle mass by applying a weak current through electrodes on the body and has gained wide usage in clinical and research settings. Since muscle strength is influenced by both morphological and neural factors[8], evaluating morphological factors may be an effective means of assessing muscle function. BIA provides a safe and relatively low-cost estimation of muscle mass, offering a valid assessment compared to magnetic resonance imaging (MRI), computed tomography (CT), and dual-energy X-ray absorptiometry (DEXA). While MRI[9–11], CT[12], and DEXA[13–15] can also estimate muscle mass with high accuracy, their clinical use is limited by time and equipment costs[16, 17]. Additionally, CT and DEXA pose restrictions due to radiation exposure[16, 17]. Therefore, it is necessary to clarify the relationship between BIA measurements and 10RM in order to develop a methodology for indirectly estimating 10RM using BIA.

Previous studies have reported significant relationships between BIA-measured values and muscle strength[18–20]. Sue et al. found significant positive correlations between dominant-leg skeletal muscle mass (SMM) and skeletal muscle index (SMI) measured by BIA and 1RM in the leg press (LP), suggesting the potential for predicting 1RM in the LP from BIA measurements[7]. However, no studies to date have investigated the relationship between BIA-measured values and 10RM. Thus, the aim of this study was to investigate the relationship between BIA measurements and 10RM for the chest press (CP) and LP in untrained, healthy young adults and to develop a regression model to determine whether BIA measurements can explain 10RM for CP and LP. Subgroup analyses were also conducted to examine correlations and assess the accuracy of sex differences in the BIA-based 10RM regression models.

PARTICIPANTS AND METHODS

Ninety-four healthy adults (43 males and 51 females) volunteered for this study. All participants were between 18 and 29 years of age and had not regularly performed resistance training in the past year. All participants were checked to ensure that they were not using performance-enhancing drugs or other medications that could affect the study and were not injured. This study (Approval No: 5556) was approved by the Ethics Committee, including approval for the use of data from a previous study that had been reviewed and approved by the Shinshu University Ethics Committee (Approval No: 4896). Written informed consent was obtained from all participants.

The test sessions lasted three days, with muscle mass measurement and familiarization on day 1, and 10RM testing on days 2 and 3[21]. All tests were conducted by the same investigators.

All 10RM tests were first performed CP, and then for LP. In this study, a seated, weight-stacked chest press machine (TD-AR14, Hitachi Capital Corporation, Tokyo, Japan) was used for chest press exercises (Fig. 1), and a 45° leg press machine (LPM5-2, Super Sports Company, Osaka, Japan), with adjustable weight using detachable Olympic plates, was used for leg press exercises (Fig. 2). The participants completed familiarization sessions to receive instructions on proper techniques for CP and LP exercises[22]. The two exercises required the participants' shoulders and buttocks to remain in contact with the bench during the exercise. The participants were instructed to start the CP with the elbows fully extended and move the handles until the elbows reached 90° before returning them to the original position. Similarly, the participants were instructed to start the LP with the knee fully extended and move the foot platform until the knees were at 90° before returning them to the original position. During the LP, the participants were instructed to keep their thighs parallel to each other. After a 5-minute warm-up on the ergometer and stretching of the major muscle groups, the participants performed three warm-up sets of 10 repetitions at approximately 50%, 70%, and 90% of the assumed 10RM. The load was then gradually increased until the participants could no longer lift in the correct form, allowing the participants to complete the 10RM test within five sets. Rest periods between the warm-up sets were 1 minute after the first set, 2 minutes after the second set, and 3 minutes after the third set, with a 3-minute rest between the main sets[23]. At least 48 h were left between the first and second 10RM tests, and the time periods were fixed as much as possible to minimize time zone effects. The representative value of the 10RM test was the largest of the two measurements.

Muscle mass was assessed using segmental multifrequency bioimpedance analysis (InBody 430; Biospace, Seoul, South Korea). The participants were instructed to refrain from eating and drinking for 4 h before the measurement and to avoid alcohol and strenuous exercise for 8 h prior to the measurement. Before the measurement, the participant's palms and soles were wiped with alcohol cotton. Age, height, and sex, which were previously measured, were entered into the instrument. The participants then took a standing position on the platform of the instrument with bare feet and held the hand grips to perform the measurements. We used the upper limb muscle mass (ULMM), lower limb muscle mass (LLMM), SMM, and skeletal muscle mass index (SMI). ULMM was defined as the total muscle mass of the left and right upper limbs, and LLMM was defined as the total muscle mass of the left and right lower limbs. The SMI was calculated by dividing the SMM by the squared height.

Descriptive data were presented medians and interquartile ranges. As most measurement variables were not normally distributed (confirmed by the Shapiro–Wilk test), non-parametric statistical procedures were performed. Spearman's rank correlation coefficient was used to analyze the relationship between the 10RM for CP and ULMM, SMM, and SMI, as well as the relationship between the 10RM for LP and LLMM, SMM, and SMI. Simple linear regression analysis was performed with BIA measurements as independent variables to create a 10RM regression model. The R2 and standard error (SE) parameters were used to assess the accuracy of the model. The significance level for all analyses was set at $p<0.05$. Statistical calculations were performed using R version 4.2.3.

RESULTS

One participant dropped out during the test sessions, leaving 93 participants for the analysis. The physical characteristics of the participants are listed in Table 1. There were significant differences in the physical characteristics other than age by sex.

The relationships between the 10RM for CP, LP, and muscle mass are shown in Table 2. Significant correlation coefficients were found between the 10RM for CP and BIA measurements in all the participants. Significant correlation coefficients were also observed between the 10RM for LP and LLMM, SMM, and SMI in all the participants.

Fig. 1. Chest press machine.

Fig. 2. Leg press machine.

Table 1. Participants' characteristics

Characteristic	All participants (n=93)	Male (n=42)	Female (n=51)
Age, years	21.0 (20.0, 22.0)	21.0 (20.0, 22.8)	20.0 (20.0, 22.0)
Height, cm	165.0 (157.8, 169.4)	170.4 (166.2, 173.3)*	158.7 (155.1, 162.1)
Weight, kg	54.6 (50.3, 59.3)	59.0 (55.3, 61.6)*	51.3 (47.1, 54.9)
10RM for chest press, kg	55.0 (40.0, 70.0)	70.0 (66.2, 80.0)*	40.0 (35.0, 50.0)
10RM for leg press, kg	170.0 (145.0, 205.0)	205.0 (181.2, 228.8)*	145.0 (120.0, 167.5)
ULMM, kg	4.1 (3.4, 5.0)	5.1 (4.8, 5.5)*	3.5 (3.0, 3.8)
LLMM, kg	18.2 (15.3, 20.9)	16.1 (15.1, 17.4)*	11.9 (10.9, 12.9)
SMM, kg	23.9 (20.8, 27.7)	28.1 (27.0, 30.1)*	21.1 (19.0, 22.6)
SMI, kg/m^2	6.7 (6.1, 7.4)	7.4 (7.1, 7.7)*	6.1 (5.7, 6.4)
Whole body fat mass, kg	11.1 (8.3, 13.0)	8.4 (5.9, 11.1)*	12.3 (10.6, 15.1)

Data are presented as median (inter-quartile range). *$p<0.001$ statistically significant difference from female values. 10RM: 10 repetition maximum; ULMM: upper limb muscle mass; LLMM: lower limb muscle mass; SMM: skeletal muscle mass; SMI: skeletal muscle mass index.

Table 3 presents the results of the simple linear regression analysis. The R^2 values of the regression model for 10RM for CP using ULMM, SMM, and SMI in all participants were 0.80 (SE: 0.86, p<0.001), 0.77 (SE: 0.22, p<0.001) and 0.79 (SE: 1.11, p<0.001), respectively. In the 10RM regression model that analyzed sex, the R^2 values for males were 0.44 (SE: 2.39, p<0.001) for ULMM, 0.33 (SE: 0.63, p<0.001) for SMM and 0.45 (SE: 3.04, p<0.001) for SMI. In females, the R^2 values were 0.52 (SE: 1.80, p<0.001) for ULMM, 0.48 (SE: 0.47, p<0.001) for SMM and 0.48 (SE: 2.18, p<0.001) for SMI. Next, the R^2 values of the regression model for 10RM for LP using LLMM, SMM, and SMI in all participants were 0.55 (SE: 1.20, p<0.001), 0.64 (SE: 0.63, p<0.001) and 0.66 (SE: 3.27, p<0.001), respectively. In the 10RM regression model that analyzed sex, the R^2 values for males were 0.29 (SE: 3.10, p<0.001) for ULMM, 0.51 (SE: 1.51, p<0.001) for SMM and 0.55 (SE: 7.66, p<0.001) for SMI. In females, the R^2 values were 0.18 (SE: 3.02, p=0.002) for ULMM, 0.29 (SE: 1.79, p<0.001) for SMM and 0.32 (SE: 8.11, p<0.001) for SMI.

Table 2. Correlation analyses between BIA measurements and the 10RM for chest press and leg press

	All participants (n=93)	Male (n=42)	Female (n=51)
10RM for chest press			
ULMM	0.90**	0.61**	0.71**
SMM	0.89**	0.56**	0.69**
SMI	0.90**	0.67**	0.69**
10RM for leg press			
LLMM	0.75**	0.53**	0.43*
SMM	0.81**	0.72**	0.56**
SMI	0.83**	0.80**	0.56**

*p<0.01, **p<0.001. 10RM: 10 repetition maximum; ULMM: upper limb muscle mass; LLMM: lower limb muscle mass; SMM: skeletal muscle mass; SMI: skeletal muscle mass index.

Table 3. Regression models of the 10RM for chest press and leg press using bioelectrical impedance analysis (BIA) measurements

	Dependent variable	Regression model	R^2	SE	95% CI		p-value
					Lower	Upper	
The 10RM for chest press							
All participants (n=93)	ULMM	Y=16.40X−13.27	0.80	0.86	14.68	18.11	**
	SMM	Y=3.81X−36.78	0.77	0.22	3.38	4.24	**
	SMI	Y=20.51X−81.27	0.79	1.11	18.31	22.70	**
Male (n=42)	ULMM	Y=13.27X+4.42	0.44	2.39	8.45	18.09	**
	SMM	Y=2.82X−7.21	0.33	0.63	1.54	4.10	**
	SMI	Y=17.40X−56.39	0.45	3.04	11.26	23.54	**
Female (n=51)	ULMM	Y=13.02X−2.90	0.52	1.80	9.40	16.64	**
	SMM	Y=3.18X−24.76	0.48	0.47	2.23	4.13	**
	SMI	Y=14.78X−47.94	0.48	2.18	10.40	19.16	**
The 10RM for leg press							
All participants (n=93)	LLMM	Y=12.60X−3.21	0.55	1.20	10.22	14.98	**
	SMM	Y=8.09X−24.39	0.64	0.63	6.84	9.35	**
	SMI	Y=43.68X−119.60	0.66	3.27	37.18	50.18	**
Male (n=42)	LLMM	Y=12.50X−0.020	0.29	3.10	6.23	18.77	**
	SMM	Y=9.75X−73.09	0.51	1.51	6.69	12.81	**
	SMI	Y=53.55X−193.82	0.55	7.66	38.07	69.02	**
Female (n=51)	LLMM	Y=9.89X+27.90	0.18	3.02	3.82	15.96	*
	SMM	Y=7.99X−21.08	0.29	1.79	4.39	11.59	**
	SMI	Y=38.86X−89.73	0.32	8.11	22.57	55.16	**

*p<0.01, **p<0.001. 10RM: 10 repetition maximum; ULMM: upper limb muscle mass; LLMM: lower limb muscle mass; SMM: skeletal muscle mass; SMI: skeletal muscle mass index; SE: standard error; CI: confidence interval.

DISCUSSION

The purpose of this study was to investigate the relationship between BIA measurements and the 10RM for CP and LP, and to further develop a regression model to determine whether BIA measurements can describe the 10RM for CP and LP in young healthy adults. This study had two main findings. First, a significant correlation was found between BIA measurements and the 10RM for CP and LP. Second, the 10RM for CP and LP can be described using BIA measurements.

When examining the relationship between BIA measurements and 10RM, it is essential to consider the distinct differences in energy supply and muscle fiber activation that differentiate between 1RM and 10RM[24]. As the 1RM test involves a single maximum force exertion, it primarily relies on the ATP-CP system for energy and is largely influenced by fast-twitch muscle fibers, according to the size principle. In contrast, the 10RM test, due to the prolonged exercise duration, depends mainly on the glycolytic system and engages both fast- and slow-twitch muscle fibers. The 10RM requires not only high-force exertion but also the endurance to sustain 10 consecutive repetitions. Thus, it is crucial to note that 10RM may be affected by endurance-related factors such as energy supply and muscle fiber activation patterns that cannot be fully captured through BIA alone.

The findings of the present study demonstrated significant correlations between BIA measurements and 10RM for CP and LP in healthy adults. Alizadehkhaiyat et al. found significant correlations between SMM using BIA and shoulder joint strength[18], Sue et al. reported significant correlations between 1RM and both dominant-leg SMM and SMI for single-leg LP[7], and Cataidi et al. reported a significant correlation between BIA measurements and isokinetic muscle strength[20]. Unlike isometric muscle strength, 1RM, and other strength indices used in previous studies, the 10RM in the current study is influenced by endurance-related factors, such as energy supply and muscle fiber type, which BIA cannot directly assess. Nevertheless, consistent with prior studies, our results showed a significant correlation between BIA measurements and muscle strength, making this, to our knowledge, the first study to specifically examine the correlation between BIA measurements and 10RM.

In this study, regression models were constructed to explain 10RM in CP and LP exercises. The coefficients of determination (R^2) for the models describing 10RM in CP were 0.80 ($p<0.001$) using ULMM, 0.77 ($p<0.001$) using SMM, and 0.79 ($p<0.001$) using SMI. For the LP, the R^2 values were 0.55 ($p<0.001$) using LLMM, 0.64 ($p<0.001$) using SMM, and 0.66 ($p<0.001$) using SMI. These results indicate that BIA measurements significantly contribute to the regression models explaining 10RM in both CP and LP, despite the possible influence of endurance factors that cannot be assessed by BIA. Previous studies primarily focused on developing regression models for 1RM using BIA measurements[7]. Our findings suggest that BIA measurements can also effectively describe muscle strength for 10RM. Furthermore, the differences in R^2 values between the exercises highlight that the descriptive accuracy of BIA-based models may vary depending on the muscle group involved. This is in line with previous studies that reported different R^2 values in regression models between different muscle groups, particularly between lower limb and trunk exercises[20]. Differences in R^2 values between exercises may be attributed to factors that BIA cannot assess, such as the distribution of muscle fiber types[25–27]. Given these findings, further research is warranted to explore the reasons for these differences in the coefficients of determination between exercises. Such research could help refine the regression models and improve their applicability to different types of strength exercises.

The present study examined the relationship between BIA measurements and muscle strength according to sex and founding significant correlations in both males and females. However, previous studies have yielded inconsistent results on this topic[7, 19, 20]. Cataldi et al. reported significant correlations between free fat mass measured using BIA and isokinetic lower limb muscle strength in both male and female athletes[20]. Conversely, Hayashida et al. found a significant correlation between BIA measurements and muscle strength in older men, but not in older women, as a function of age[19]. Sue et al. observed a strong correlation between BIA measurements and 1RM of the unilateral LP in healthy adult men, but no significant correlation in women[7]. These inconsistencies can be attributed to several factors. First, several studies have reported sex differences in firing rate[28] and variability in motor units[29]. BIA can assess morphological factors but not neurological factors, which could explain the varying results across sexes. Additionally, differences in target populations, age groups, and methods of muscle strength measurement among the studies may contribute to inconsistent findings. The relationship between BIA measurements and muscle strength by sex is complex and requires further investigation. Future studies should standardize the measurement methods and control for factors such as age and population characteristics to provide more conclusive results.

These results may assist athletic trainers, fitness professionals, and rehabilitation clinicians in developing indirect methods for estimating appropriate weights in resistance training. While this study indicates that BIA measurements can explain 10RM, it remains unclear whether estimating 10RM directly from BIA measurements may actually reduce variability in the number of repetitions performed compared to estimating 10RM using %1RM based on 1RM values indirectly derived from BIA measurements. Future research should focus on expanding the sample size, incorporating additional variables, further improving the model's predictive accuracy, and exploring optimal methodologies for the indirect estimation of 10RM.

This study had several limitations. First, the participants were healthy young adults with no training experience, and the correlation and regression models used in this study may not be directly applicable if the individual are older or have training experience. To address this issue, a multivariate regression model adaptable to any population must be developed. Second, because absolute SMM values have been reported to vary across BIA, the correlation and accuracy of the regression models may differ from those of other BIA instruments[16]. Therefore, new regression models should be developed by using other types of equipment. Finally, the regression model used in this study cannot be directly adapted to the same training category because the absolute value of the muscle force varies depending on the machine used. For example, in a horizontal LP machine that uses cables and pulleys to lift a weight stack, the force to push the platform and the weight of the weight stack are almost the same; however, in the 45° LP machine that uses barbell plates, the force to push the platform and the weight of the barbell plates are different. Therefore, it is necessary to develop a regression model for each machine.

In conclusion, BIA measurements were significantly correlated with 10RM for CP and LP in young healthy the participants with no training experience, suggesting that 10RM can be explained by BIA measurements. These results may help in the development of a methodology to safely and efficiently measure 10RM when prescribing resistance training.

Conflicts of interest

None.

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