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Efficacies of ultrasound and a handheld dynamometer to predict one-repetition maximum

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Abstract. [Purpose] It is important to accurately measure one-repetition maximum to determine the training load and number of repetitions. However, huge and expensive equipment, such as a torque machine and/or dynamometer, is needed to measure one-repetition maximum. Therefore, a more accessible and affordable method has been developed to predict one-repetition maximum. In this study, we aimed to investigate whether one-repetition maximum of the knee extensor could be predicted more accurately with a combination of muscle strength, measured using a handheld dynamometer, muscle thickness, and thigh circumference. [Participants and Methods] Participants were sixty-four non-athletic healthy adult volunteers (33 males and 31 females). Muscle strength of the knee extensor measured using one-repetition maximum, maximal voluntary isometric contraction measured using a handheld dynamometer, muscle thickness of the quadriceps and/or thigh circumference measured on ultrasonography. [Results] The stepwise regression analysis revealed that body mass, gender, muscle thickness at 15 cm above the patella, and maximal voluntary isometric contraction were the significant and independent determinants ($R^2=0.813$). [Conclusion] One-repetition maximum could be predicted more accurately with a combination of maximal voluntary isometric contraction measured using a handheld dynamometer and muscle thickness.
Key words: One-repetition maximum, Muscle thickness, Handheld dynamometer

INTRODUCTION

Skeletal muscle mass is an important factor that influences force capacity and muscle function, which declines with aging, the presence of disease, and disuse. Especially, sarcopenia, known as a decline in skeletal muscle mass and/or strength related to aging, is associated with the risk of falls, fracture, and mortality[1–3]. In general, high-intensity resistance training with at least 60–80% one-repetition maximum (1RM) has been prescribed to prevent atrophy and/or increase muscle mass[4, 5]. Interestingly, however, previous study showed that high-repetition and low-intensity resistance training (30% 1RM) resulted in increased muscle mass and strength[6]. Therefore, training load and the number of repetition should be taken into consideration when prescribing resistance training.

1RM is defined as the maximum load that can be moved throughout a full range of motion without deviating from proper form and can be measured using a torque machine or a dynamometer. It is important to measure 1RM accurately in order to determine the training load and the number of repetition[7–10]. In addition, there have been some studies on 1RM measurement

among the elderly and clinical population[11, 12]. However, 1RM measurement has led to an increased risk of musculoskeletal injury and elevated blood pressure among the elderly and clinical population with debility. Therefore, in estimating 1RM by submaximal effort, a method that predicts 1RM from multiple RM tests has been developed[13]. However, huge and expensive equipment, such as the torque machine and/or dynamometer, is needed to perform multiple RM tests. This equipment may be unavailable in hospitals and rehabilitation centers. Therefore, a more accessible and affordable method is developed to predict 1RM.

In previous studies, the handheld dynamometer (HDD) was reported to be an accessible and inexpensive instrument that is used to measure maximum voluntary isometric contraction (MVIC) strength for 1RM prediction. Specifically, Tan et al. reported that 1RM of knee extensors and elbow flexors were predicted more accurately by MVIC as measured using HHD[8]. In addition, Kanada et al. reported that 1RM was predicted more accurately by a combination of MVIC and body composition measurements than by MVIC measurement only[7]. Taken together, it is assumed that MVIC measured by HHD could provide an accurate 1RM prediction. However, although MVIC measurement is easy and inexpensive, participants still need to perform 1RM with maximum effort. Therefore, it is important for therapists and coaches to establish a 1RM prediction method that requires less effort and low muscle contraction.

In this study, we measured muscle thickness and/or thigh circumference through ultrasonography. These measurements were noninvasive and required minimal effort or cooperation from the participants. In previous studies, a significant relationship between MVIC and muscle thickness measured through ultrasonography was reported[14]. Therefore, 1RM could be predicted by muscle thickness and/or thigh circumference measurements. In addition, it was likely that 1RM can be predicted more accurately by a combination of muscle thickness and/or thigh circumference measurement and MVIC measurement by HHD than by MVIC only. Therefore, this study aimed to investigate (1) whether 1RM of knee extensor could be predicted by muscle thickness and thigh circumference and (2) whether 1RM could be predicted more accurately by a combination of MVIC and muscle thickness and thigh circumference. This study hypothesized that it was possible to predict 1RM through muscle thickness and thigh circumference and to predict 1RM more accurately by a combination of MVIC and muscle thickness and thigh circumference.

PARTICIPANTS AND METHODS

Sixty-four healthy adult volunteers who were non-athletes participated in this study [mean ± standard deviation [SD]: 33 males (age, 21.4 ± 1.8 years; height, 170.8 ± 6.3 cm; body mass, 64.5 ± 9.5 kg; body mass index [BMI], 21.1 ± 2.8) and 31 females (age, 20.7 ± 0.8 years; height, 158.4 ± 4.9 cm; body mass, 49.4 ± 5.0 kg; BMI, 19.6 ± 1.6)], all of whom volunteered to participate in this study. All participants were fully informed of the procedures and purpose of the study, and all provided written informed consent. This study was approved by the Ethics Committee at the Niigata University of Health and Welfare in Niigata, Japan (No.18104) and conducted in accordance with the Declaration of Helsinki.

1RM of knee extensor was measured using a leg-extension machine (Cybex VR1, Cybex International Inc., NY, USA). In this study, the participants were placed in a sitting position on a chair (70° hip angle) and were instructed to grasp the sitting board. Prior to 1RM measurement, each subject was instructed to perform a warm-up of five repetitions at 50% of the participant's predicted 1RM. After this warm-up, 1RM measurements were performed, and the initial load was selected by each subject. The load was increased until the participants could not lift the weight through a full range of motion (knee flexion from 90° to full extension), without deviating from proper form. 1RM measurements were performed with sufficient rest between trials to avoid fatigue. In this study, 1RM would be determined within 3–5 attempts.

After performing 1RM measurements, MVIC during a 3-sec voluntary contraction of the knee extensor was measured using HHD (µ-tas F1, ANIMA Co., Tokyo, Japan) in a sitting position with hip and knee flexion of 90°. The isometric strength (Newton, N) was measured three times for 3 seconds, separated by a sufficient rest period. A maximal value was obtained, and torque (Nm) was calculated by multiplying strength (N) by lever arm (m).

Transverse ultrasound images of the quadriceps femoris on the dominant leg were obtained with a B-mode ultrasound imaging device (LOGIQ e V2; GE Healthcare Japan, Tokyo, Japan) and an 8-MHz linear array probe. Participants were completely relaxed and in a supine position, with hip and knee angle extended. The transducer was positioned perpendicular to the longitudinal axis of the quadriceps femoris at 5, 10, and 15 cm above the patella and the midpoint between the anterior superior iliac spine and the proximal end of the patella[6, 15]. Muscle thickness of the quadriceps muscle was defined as the distance between the inner edges of the fascia and femoral bone. To ensure a minimum pressure of the transducer and lesser distortion of the skin and subcutaneous tissues caused by excess compression, a generous amount of contact gel was applied to the skin, and real-time ultrasonic images were observed. In addition, thigh circumference was measured in the same sites as that for muscle thickness measurement using a cloth tape to the nearest 0.1 cm. Muscle thickness and thigh circumference measurements were performed prior to muscle strength measurements.

SPSS (version 24.0; IBM Corp., Armonk, NY, USA) was used for statistical analysis. The Shapiro-Wilk test was used to evaluate the normality of all variables. Firstly, stepwise regression analysis was employed to investigate the associations between 1RM and independent variables, such as age, body mass, height, gender (male, 0; female, 1), muscle thickness, and thigh circumference, in order to clarify whether 1RM can be predicted with muscle thickness or thigh circumference. Secondly, stepwise regression analysis was employed to investigate the associations between 1RM and independent variables,

such as age, body mass, height, gender (male, 0; female, 1), muscle thickness, and thigh circumference, with the addition of MVIC, to establish a more accurate estimation. The variance inflation factor (VIF) was examined to monitor for a multicollinearity effect. The differences were considered statistically significant at an alpha level of 0.05. Finally, paired t-tests were used to compare the differences between measured and predicted 1RM. Descriptive data are shown as mean ± SD.

RESULTS

All variables were shown in Table 1. In addition, the result of stepwise regression analysis has shown that 1RM can be predicted with muscle thickness or thigh circumference, as shown in Table 2. It was also revealed that body mass, gender, and muscle thickness at 15 cm above the patella were significant and independent determinants. The following estimation formula was created: 1RM (kg)=0.548 × body mass (kg) −9.692 × gender (male=0, female=1) + 4.427 × muscle thickness at 15 cm above patella (cm) −6.79. The coefficient was R^2=0.777 (p<0.01). In addition, the predicted 1RM from this formula was 34.1 ± 11.7 (kg), and no significant difference was observed between measured and predicted 1RM (p=0.988).

The result of the stepwise regression analysis has shown that 1RM can be predicted with all variables, as shown in Table 3. It was revealed that body mass, gender, muscle thickness at 15 cm above the patella, and MVIC were significant and independent determinants. The following estimation formula was created: 1RM (kg)=0.337 × body mass (kg) −7.842 × gender (male=0, female=1) + 4.087 × muscle thickness at 15 cm above patella (cm) + 0.056 × MVIC (Nm) −4.627. The coefficient was R^2=0.813 (p<0.01). In addition, the predicted 1RM from this formula was 34.0 ± 12.0 (kg), and no significant difference was observed between measured and predicted 1RM (p=0.961).

Table 1. All variables for measurement

	Mean ± SD	Range
1RM (kg)	34.1 ± 13.2	12.5–74.0
MVIC (Nm)	179.7 ± 71.4	85.0–413.4
Muscle thickness (cm)		
5 cm above patella	1.74 ± 0.44	1.01–3.06
10 cm above patella	2.49 ± 0.54	1.33–4.04
15 cm above patella	3.19 ± 0.60	1.95–5.17
Midpoint	3.95 ± 0.66	2.61–5.74
Thigh circumference (cm)		
5 cm above patella	39.2 ± 3.2	32.5–48.5
10 cm above patella	43.6 ± 3.8	35.0–55.5
15 cm above patella	48.0 ± 4.1	38.5–61.0
Midpoint	52.2 ± 4.3	44.0–67.5

RM: repetition maximum; MVIC: maximum voluntary isometric contraction.

Table 2. Results of stepwise regression analysis showing that 1RM can be predicted with muscle thickness or thigh circumference

Dependent variables: 1RM (kg)	Independent variables	Partial regression coefficient (B)	Standard partial regression coefficient (β)	T value	p value	95% confidence interval Lower	95% confidence interval Upper	VIF
	Body mass (kg)	0.548	0.448	4.617	<0.01	0.311	0.786	2.486
	Gender (male, 0; female, 1)	−9.692	−0.393	−4.183	<0.01	−14.327	−5.056	1.992
R^2 = 0.777	Muscle thickness at 15 cm above patella (cm)	4.427	0.201	2.6	=0.012	1.019	7.834	1.577

RM: repetition maximum; VIF: variance inflation factor; R^2: coefficient of determination.

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Table 3. Results of stepwise regression analysis showing that 1RM can be predicted with all variables

Dependent variables: 1RM (kg)	Independent variables	Partial regression coefficient (B)	Standard partial regression coefficient (β)	T value	p value	95% confidence interval Lower	95% confidence interval Upper	VIF
	Body mass (kg)	0.337	0.275	2.663	<0.01	0.084	0.59	3.311
	Gender (male, 0; female, 1)	−7.842	−0.294	−3.548	<0.01	−12.266	−3.418	2.125
	MVIC (Nm)	0.056	0.303	3.343	0.001	0.023	0.09	2.548
$R^2 = 0.813$	Muscle thickness at 15 cm above patella (cm)	4.087	0.185	2.593	=0.012	0.932	7.241	1.584

RM: repetition maximum; MVIC: maximum voluntary isometric contraction; VIF: variance inflation factor; R^2: coefficient of determination.

DISCUSSION

After investigating the 1RM prediction method, the main findings of this study were as follows: Firstly, 1RM can be predicted by muscle thickness measurements through ultrasonography, which requires a lesser effort of muscle contraction among subjects. Secondly, 1RM can be predicted more accurately by a combination of MVIC measurement through HHD and muscle thickness measurement, which is more accessible and economical. The results suggested that when prescribing resistance training in hospitals and nursing homes, an easier method of predicting 1RM can be conducted using muscle thickness and MVIC measurement.

In previous studies, a significant relationship between muscle cross-sectional area and muscle thickness measurement through ultrasonography was reported[16–18], as well as between isometric or isokinetic muscle strength, and muscle thickness or muscle cross-sectional area[19–22]. Therefore, 1RM could be predicted by muscle thickness measurement as well as isometric and isokinetic muscle strength. The advantages of ultrasonic measurement included noninvasiveness and lesser effort or cooperation among the participants.

In addition, our results revealed that 1RM could be predicted more accurately by a combination of MVIC and muscle thickness than by MVIC only. These results supported the findings of Tan et al.[8] and Kanada et al.[7], which reported that MVIC measured by HHD was effective for 1RM prediction. In general, although there was a high reproducibility of MVIC measurement by HHD[23, 24], MVIC measurement was the isometric muscle contraction measurement. On the other hand, 1RM is a technique that measures the ability of muscle force to exercise throughout the full range of motion, and contraction mode is considered different between 1RM and MVIC measurements. Therefore, a poor relationship between 1RM and MVIC may be possible. However, our results showed that 1RM could be predicted by MVIC measurement, which has a different contraction mode, and it became evident that 1RM could be predicted more accurately with a combination of muscle thickness measured through ultrasonography and MVIC.

In prescribing resistance training, it is more preferred to set the training load from 1RM rather than MVIC measurements because a constant load is added to the entire range of training. However, a torque machine or dynamometer is necessary to perform 1RM measurement, which makes it difficult to measure 1RM in hospital or nursing home settings where therapists prescribe resistance training. For this reason, 1RM prediction by muscle thickness and MVIC is a more convenient method. Therefore, further studies need to be conducted to investigate the efficiency of 1RM prediction used to prescribe resistance training.

The following limitations were identified in this study. Since we investigated the relationship between 1RM and MVIC for healthy young adults, it is unclear whether the same regression equation is valid for the elderly or other clinical population. However, it is assumed that 1RM could be predicted by muscle thickness and MVIC in the elderly or clinical population. Therefore, further study is needed to investigate the relationship between 1RM and muscle thickness or MVIC in the elderly or clinical population.

RM measurement is a major component for the evaluation of muscle strength or resistance training prescription. Therefore, we have investigated the relationship between 1RM and muscle thickness, thigh circumference, and MVIC measured through HHD. Our results revealed that 1RM could be predicted accurately by measuring muscle thickness through ultrasonography; however, 1RM could be predicted more accurately by a combination of MVIC measured by HHD and muscle thickness. Future studies need to be conducted to investigate the effect of resistance training intervention using load setting through the regression equation established in this study.

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