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Original Article

Estimation of 1RM for knee extension based on the maximal isometric muscle strength and body composition

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Abstract. [Purpose] To create a regression formula in order to estimate 1RM for knee extensors, based on the maximal isometric muscle strength measured using a hand-held dynamometer and data regarding the body composition. [Subjects and Methods] Measurement was performed in 21 healthy males in their twenties to thirties. Single regression analysis was performed, with measurement values representing 1RM and the maximal isometric muscle strength as dependent and independent variables, respectively. Furthermore, multiple regression analysis was performed, with data regarding the body composition incorporated as another independent variable, in addition to the maximal isometric muscle strength. [Results] Through single regression analysis with the maximal isometric muscle strength as an independent variable, the following regression formula was created: 1RM (kg)=0.714 + 0.783 × maximal isometric muscle strength (kgf). On multiple regression analysis, only the total muscle mass was extracted. [Conclusion] A highly accurate regression formula to estimate 1RM was created based on both the maximal isometric muscle strength and body composition. Using a hand-held dynamometer and body composition analyzer, it was possible to measure these items in a short time, and obtain clinically useful results.

Key words: 1RM, Maximal isometric muscle strength, Knee extension

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INTRODUCTION

Ikezoe et al.[1)] noted that a reduction in the muscle strength frequently interferes with activities of daily living, and resistance training is performed as a method of exercise therapy in such cases. Resistance training refers to exercise to increase the muscle mass and strength by applying loads on target skeletal muscles. It aims to promote muscle activity at or above a certain level of resistance. In resistance training, the maximal weight a subject can lift with 1 repetition (1 repetition maximum: 1RM) is initially calculated to use a relative rate of this value, %1RM, in general[2)]. 1RM is used for such setting, as it facilitates optimal and reliable loading in each case. As a criterion to determine the loading level, it is most frequently used in exercise therapy, and a large number of studies have been conducted to date to examine the effects of exercise-based intervention using %1RM for loading[3–6)]. On the other hand, 1RM measurement requires considerable time and labor, and loads stress on muscles and tendons, consequently increasing the risk of injury, as some researchers warn[7)]. In most studies estimating 1RM for knee extension, the estimation was based on the relationship between the percentage of 1RM and the number of repetitions[8)]. In addition to these, there have been multiple studies on this issue. For example, Okada et al.[9)] and

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Kravitz et al.[10] focused on the maximum number of repetitions to estimate 1RM, while Sugiura et al.[11] and Jidovtseff et al.[12] based such an estimation on the movement velocity. Takeichi et al.[13] used measurement values obtained with hand-held dynamometers. The subjects of previous studies estimating 1RM based on the number of repetitions were students studying sports sciences and weightlifters; therefore, it remains unclear whether this method is also usable for adults of the general public. Furthermore, requiring maximum efforts, these methods are unlikely to be usable for patients with orthopedic or circulatory impairment, in whom priority should be given to ensuring safety. In short, methods to estimate 1RM may be classified into 2 categories: direct: examining the capacity to lift a certain weight with 1RM; and indirect or presumptive: measuring numbers of repetitions with maximum efforts and loading to estimate 1RM[14]. However, the usability varies among the methods.

Based on these findings, the establishment of measurement techniques to safely and simply estimate 1RM for single-joint movements may be considerably important in the clinical setting. As a method to evaluate the muscle strength, measurement of the maximal isometric muscle strength using hand-held dynamometers (HHD) that facilitate convenient and objective muscle strength evaluation is being disseminated, in addition to the Manual Muscle Testing (MMT)[10].

Under these circumstances, body composition analyzers to conveniently analyze the body composition using bio-electrical impedance analysis (BIA) are increasingly drawing attention[15]. As for the applicability of skeletal muscle mass measurement using BIA, values obtained through such measurement have been reported to be correlated with the skeletal muscle mass measured using ultrasonography[16]. BIA makes it feasible to simultaneously measure the somatic fat volume and bone mass, in addition to the skeletal muscle strength. Being portable and facilitating noninvasive measurement, body composition analyzers using BIA may be highly useful in clinical environments.

Considering these points, the present study aimed to create a regression formula to estimate 1RM for knee extensors that also represent the lower-limb muscle strength, using the maximal isometric muscle strength measured with HHD and data regarding the body composition. The estimation of 1RM using a regression formula may provide useful findings for the implementation of appropriate resistance training.

SUBJECTS AND METHODS

The study involved 21 healthy males in their twenties to thirties (age: 27.7 ± 5.4; height: 170.5 ± 5.6 cm; and weight: 66.8 ± 13.8 kg). The exclusion criteria were as follows: 1) the restriction of motor activity by the doctor in charge; 2) difficulty in understanding explanations of motor tasks; and 3) the presence of pain, possibly requiring the discontinuation of motor tasks; 4) an acutely progressive, acute, or unstable chronic disease; 5) a history of hypertension or tachycardia; or 6) an orthopedic disease of the knee.

The subjects were provided with an explanation of the study objective and procedure to obtain their consent before initiating the experiment. The approval of the Ethics Committee of the Incorporated Medical Institution Howa Group (approval number: 16-005) and the Medical Research Ethics Committee of Fujita Health University (HM16-087) was also obtained prior to the study.

Motor tasks to measure 1RM and the maximal isometric muscle strength were limited to the maximum-effort concentric contraction of left knee extensors. 1RM was measured using a leg extension device (NR-S: Senoh Corporation, Japan). The measurement was performed at a knee extension angle of 90 degrees to the final point of lifting. The initial position was adopted at a hip flexion angle of 70 degrees and a knee flexion angle of 100 degrees. Both upper limbs were kept crossed in front of the chest. The trunk and pelvis were immobilized with a belt to prevent them from moving during measurement. For warm-up, a 10-minute ergometer workout was previously executed at an intensity level corresponding to the Borg Scale: <Somewhat hard>. On measurement, maximal voluntary knee extension without loading was repeated 5 times to adopt a mean (unit: cm; the values were rounded down to 1 decimal place) as the final point of lifting. Subsequently, to predict the weight to be initially lifted, knee extension was executed to the final point of lifting at a loading level corresponding to the Borg Scale: <Somewhat hard>. The loading level was adjusted at intervals of 0.5 kg until the maximum weight each subject could lift was determined. The value obtained at the final point of lifting the maximum weight was adopted as 1RM in each case. Between measurements and load adjustments, 30-second and 3-minute rests were inserted, respectively, and the value was determined, not repeating the procedure more than 5 times. The measurement method reported by Sugiura et al.[17, 18] was adopted.

The maximal isometric muscle strength was measured using a HHD (microFET2: HOGGAN Scientific, LLC, USA) at a hip flexion angle of 70 degrees and a knee flexion angle of 90 degrees. Both upper limbs were kept crossed in front of the chest. Similarly to the case of 1RM measurement, immobilization using a belt was performed. On measurement, maximum-effort isometric knee extension was executed for 5 seconds, and it was repeated 3 times to adopt the highest value.

Body composition analysis was performed using a body composition analyzer (InBody 230: InBody Co., Ltd., South Korea). On measurement, the weight, total muscle mass, somatic fat volume, body mass index (BMI), muscle mass and fat volume of each part of the body (the four limbs and trunk), moisture level, bone mass, and basal metabolism rate were measured. Among these items, the weight, total muscle mass, and muscle mass of each part of the body (the four limbs and trunk) were used to analyze the body composition.

To create a regression formula to estimate 1RM, single regression analysis was performed, with measurement values

Table 1. Result of body compositions

Characteristic	Age (yrs)	27.7 ± 5.4
	Height (cm)	170.5 ± 5.6
	Weight (kg)	66.8 ± 13.8
Whole	Muscle mass (kg)	29.2 ± 4.5
	Fat mass (kg)	14.8 ± 7.5
Obesity evaluation	BMI (kg/m^2)	22.9 ± 4.0
	Body fat percentage (%)	21.2 ± 6.4
Muscle mass by site	Left U/E (kg)	2.8 ± 0.6
	Right U/E (kg)	2.8 ± 0.5
	Left L/E (kg)	8.5 ± 1.3
	Right L/E (kg)	8.6 ± 1.2
	Trunk (kg)	23.1 ± 3.2
Fat mass by site	Left U/E (kg)	0.9 ± 0.6
	Right U/E (kg)	0.8 ± 0.6
	Left L/E (kg)	2.4 ± 1.0
	Right L/E (kg)	2.4 ± 1.0
	Trunk (kg)	7.3 ± 4.2
Other information	Body water contect (kg)	38.2 ± 5.4
	Bone mass (kg)	2.8 ± 0.5
	Basal metabolic rate (kcal)	1,493.9 ± 162.1

(average ± SD)

Table 2. Relationship between 1RM and body composition

	Weight	Whole muscle mass	Muscle mass by site				
			Left U/E	Right U/E	Left L/E	Right L/E	Trunk
1RM	0.679*	0.780*	0.710*	0.734*	0.700*	0.707*	0.761*

Spearman's rank correlation coefficient *p<0.01

representing 1RM and the maximal isometric muscle strength as dependent and independent variables, respectively. This was followed by the calculation of Spearman's rank correlation coefficient to examine the relationship between 1RM and data regarding the body composition. Furthermore, multiple regression analysis adopting the stepwise method was performed, with data regarding the body composition incorporated as another independent variable, in addition to the maximal isometric muscle strength. For statistical analysis, the software IBM SPSS Statistics Ver. 21 was used. The significance level was set at 5% in all cases.

RESULTS

The subjects' mean ± SD 1RM was 35.0 ± 7.0 kg. Their mean maximal isometric muscle strength measured using a HHD was 43.8 ± 8.2 kgf. Table 1 outlines their body compositions. Based on the results of single regression analysis with measurement values representing 1RM and the maximal isometric muscle strength as dependent and independent variables, respectively, the following estimation formula was created: 1RM (kg)=0.714 + 0.783 × maximal isometric muscle strength (kgf). The coefficient was R^2=0.849. On examining the relationship between a measured 1RM and data regarding the body composition, significant correlations among the maximal isometric muscle strength, weight, and total, left and right upper- and lower-limb, and trunk muscle mass (Table 2). On multiple regression analysis with the maximal isometric muscle strength and data regarding the body composition as independent variables, only the total muscle mass was extracted from the latter. Furthermore, through multiple regression analysis with the maximal isometric muscle strength and total muscle mass as independent variables, the following estimation formula was created: 1RM (kg)= −5.282 + 0.569 × maximal isometric muscle strength (kgf) + 0.526 × total muscle mass (kg). The coefficient was R^2=0.902.

DISCUSSION

Measurement using HHD has shown sufficient reliability and validity[19]. The authors also examined measurement values obtained using such a device in a pilot study by calculating the intraclass correlation coefficient (ICC), and obtained ICC (1, 1)=0.855 (p<0.01), confirming their high reproducibility.

Takeichi et al.[13] conducted a study involving inpatients, and estimated their 1RM based on their maximal isometric muscle strength, creating the following formula: 1RM (kg)=0.188 + 0.187 × maximal isometric muscle strength. As they examined elderly inpatients, the values they obtained tended to be lower than those in the present study. They measured 1RM, with loads applied, rather than using a leg extension device. In the case of knee extension with loading, the loading level depends on the knee angle, making it difficult to maintain the same loading level throughout the range of motion. Such a variation in the loading level, depending on the joint angle, may be a demerit of their method.

Kai et al.[15] reported a positive correlation between the systemic skeleton and knee extensor strength. Similarly, in the present study, the total muscle mass was extracted from data regarding the body composition as a factor estimating 1RM. In contrast, the lower-limb muscle mass on the measurement side was not extracted. The muscle strength varies depending on the frequency of firing motor units (temporal factor), their number (spatial factor), and timing of such firing (synchronization). The number and thickness of muscle fibers determine the maximum effort level. Thus, the muscle strength has been reported to require nerves, neuromuscular junctions, and muscle fibers as its components[20]. The results of the present study support the finding that the relationship between the muscle mass and strength is not simply proportional. When focusing on the relationship between the trunk and lower limbs, there is a close association in terms of sequential movements. It has been reported that trunk symptoms are frequently associated with lower-limb impairments[21], and gait and other ADL are also markedly influenced by not only lower-limb functions, but also those of the trunk[22].

According to Sugiura et al.[11], knee extension is an angular movement of a single joint, and it may be possible to create more accurate regression formulas using the joint torque and angular velocity. However, considering the structure of leg extension devices, it is noted that the lower limb is pushed back in the direction toward knee flexion in response to the free fall of a weight after maximal knee extension. This may lead to difficulty in making the most of concentric contraction, reflecting the intention emerged during knee extension to support the weight even after the movement. As a future challenge, it may be necessary to develop measures in order to avoid the reverse turn of knee rotation axes, and prevent weights from freely falling when using leg extension devices. It should also be noted that the estimation of 1RM based on the joint torque and angular velocity is difficult in the clinical setting, as such measurement takes time, while loading mental/physical stress on patients due to immobilization using belts.

Therefore, in the present study, a regression formula to estimate 1RM based on the maximal isometric muscle strength and body composition was created, using an HHD that involves less mental/physical stress. To enhance the clinical usability of this method, both the maximal isometric muscle strength and body composition were incorporated into the formula. Concerning body composition analyzers, they are increasingly used in various fields, considering their merit of facilitating the simultaneous objective evaluation of multiple items, as well as their portability. Using such devices, the relationships between elderly community residents' body compositions and physical functions and among the total skeletal muscle mass, strength, and circumference[15] have already been clarified. In this respect, HHD and body composition analyzers, such as those used in the present study, are likely to facilitate measurement in a short time, and be easily used in the actual clinical setting. Present study has a limitation that the present mathematical formula might not be suitable for every individual because of small sample size and limited diversity of participants.

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