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Establishment of the Prediction Equations of 1RM Skeletal Muscle Strength in 60- to 75-Year-Old Chinese Men and Women

Sijie Tan, Jianxiong Wang, and Shanshan Liu

The purpose of this study was to establish the one-repetition maximum (1RM) prediction equations of a biceps curl, bench press, and squat from the submaximal skeletal muscle strength of 4–10RM or 11–15RM in older adults. The first group of 109 participants aged 60–75 years was recruited to measure their 1RM, 4–10RM, and 11–15RM of the three exercises. The 1RM prediction equations were developed by multiple regression analyses. A second group of participants with similar physical characteristics to the first group was used to evaluate the equations. The actual measured 1RM of the second group correlated significantly to the predicted 1RM obtained from the equations (r values were from .633–.985), and standard error of estimate ranged from 1.08–5.88. Therefore, the equations can be used to predict 1RM from submaximal skeletal muscle strength accurately for older adults.

Keywords*:* muscle strength, one repetition maximum, submaximal strength, prediction equation, older adults.

Skeletal muscle strength is very important to the well-being of older adults. Previous studies have reported that skeletal muscle strength and mass gradually decline during the aging process (Delmonico et al., 2009; Frontera, Hughes, Lutz, & Evans, 1991; Gallagher et al., 1997; Janssen, Heymsfield, Wang, & Ross, 2000; Lindle et al., 1997). This geriatric syndrome has been defined as sarcopenia, which may increase the risks of falls, fractures, disabilities, and loss of independence in older adults (Cruz-Jentoft et al., 2010). Furthermore, low skeletal muscle strength is considered as one of the major factors of poor quality of life as people get older (Imagama et al., 2011; Samuel, Rowe, Hood, & Nicol, 2012). To manage this geriatric health problem, resistance exercise has been applied to maintain or improve skeletal muscle strength for older adults (Peterson, Rhea, Sen, & Gordon, 2010). However, to design the most effective resistance training program and achieve the most benefits from this intervention, we need to measure the skeletal muscle strength accurately at baseline to clarify the initial situation of the skeletal muscles, determine the suitable resistance training intensity, and evaluate the potential effects following resistance training.

One-repetition maximum (1RM) is the standard for dynamic skeletal muscle strength assessment (American College of Sports Medicine, 2006, pp. 80–83). As it is defined, 1RM tests require participants to perform with maximum effort during testing, and it usually takes many trials and a long time to reach the 1RM. Even though this test has been reported as an acceptable tool to apply to older adults (Barnard, Adams, Swank, Mann, & Marty, 1999; Shaw, McCully, & Posner, 1995), the high physical stress during the test may still pose a risk for the participants, such as incurring muscle or bone injuries, particularly for those who have low physical fitness and are physically inactive. Therefore, prediction of 1RM from submaximal efforts would be an alternative test which is safer and time efficient. In the literature, there are some prediction equations of 1RM from the submaximal muscle strength (i.e., a multiple RM test), but most of these studies were performed in young people (Dohoney, Chromiak, Lemire, Abadie, & Kovacs, 2002; Kravitz, Akalan, Nowicko, & Kinzey, 2003; LeSuer, McCormick, Mayhew, Wasserstein, & Arnold, 1997; Whisenant, Panton, East, & Broeder, 2003). There are few studies about the prediction equation of 1RM for older adults (Knutzen, Brilla, & Caine, 1999). With the purpose of establishing the prediction equations of 1RM for older adults, we investigated the hypothesis in which the 1RM would be predicted accurately from the results of 4–10RM (the resistance that can be moved through the full range of motion within 4–10 repetitions) and 11–15RM (the resistance that can be moved through the full range of motion for 11–15 repetitions) tests in a group of older Chinese people.

Methods

Participants

There were two groups of participants in the current study. The first group consisted of 109 older adults (60–75 years old, 48 men and 61 women) who were recruited to establish the prediction equations of 1RM, while the second group of 31 older adults (60–75 years old, 15 men and 16 women) evaluated the accuracy of the 1RM equations obtained from the first group. The inclusion criteria were healthy, community-dwelling older people without any serious medical conditions that might impede the performance of muscular function tests. Individuals with cardiovascular disease, hypertension, asthma, chronic obstructive pulmonary disease, chronic liver or kidney disease, neurological limitations, and musculoskeletal conditions were not enrolled. None of them had undergone any supervised resistance training program over the past five years. Before the tests, the details of the study were described to the participants and a written informed consent form for the study was obtained from each participant. All methods and procedures of this study were approved by the ethics committee of Tianjin University of Sport, China.

Study Design

The present study comprised of two parts. Part I was intended for establishing the prediction equations for the 1RM, 4–10RM, and 11–15RM of a biceps curl, bench press, and squat, in which the first group of participants were measured. The prediction equations of 1RM from the results of 4–10RM and 11–15RM tests were established. The reliability of 1RM tests was then tested by 30 participants (15 men and 15 women from the first group), who repeated the 1RM test two weeks after the original test. For Part II, the evaluation of the prediction equations, the second group of participants whose physical attributes did not differ significantly from those of the first group were recruited. Their 1RM of the three exercises were measured directly and also predicted using the equations obtained from the first group. Correlation analyses between the directly measured and the predicted 1RMs were performed to evaluate the accuracy of the equations.

Measurements

Each participant of the first group visited the Exercise Physiology Laboratory at Tianjin University of Sport four to six times. The first session was a familiarization session which included study introduction, medical history check, ethics issues, and signing the informed consent form. Each participant's body mass and height were measured. Body mass index (BMI) was calculated by dividing body mass (kg) by height in meters squared (m^2). During the second session, the participants learned how to perform a biceps curl, bench press, and squat with a light weight. The purpose of this session was to teach the participants the correct techniques to perform these exercises. At the third session, 1RM, 4–10RM, and 11–15RM of a biceps curl, bench press, and squat were measured in a random order. Based on the unpublished results of a pilot trial in our laboratory, the starting weights of the 1RM biceps curl test were 20% body mass in men and 15% in women; 1RM bench press tests were 50% body mass in men and 35% in women; and 1RM squat tests were 70% body mass in men and 55% in women. The 1RM was usually achieved within five increases in weight, and 3–5 min of rest was given between the trials. The resistance that can be moved through the full range of motion in a controlled manner with good posture within 4–10 or 11–15 repetitions were measured and defined as 4–10RM and 11–15RM, respectively. Participants were required to refrain from any strenuous physical activities 24 hr before each testing session. At least 48 hr of rest was allowed between the sessions. Before each test, participants warmed up on a cycle ergometer or by walking for 5 min. Two researchers and one laboratory technician supervised each participant's tests.

Thirty participants of the first group who did the test–retest of 1RM reliability had an additional one to two visits to the laboratory, two weeks after the original test. They were asked to maintain their normal physical activity level and not to take part in any muscle training program during that time.

The second group of participants did the same tests; in addition, their results of 4–10RM and 11–15RM were used to predict 1RM through the prediction equations obtained from the first group of participants.

Data Analyses

The prediction equations of 1RM were established through multiple regression analyses, with two predictor variables (4–10RM or 11–15RM and their number of repetition). Reliability of 1RM measurements was assessed by the intraclass correlation coefficient (ICC) analyses; while the standard error of measurement (*SEM*) and minimal difference (MD) were also calculated (Weir, 2005). Pearson correlation coefficient analyses between the directly measured and the predicted 1RMs were used to evaluate the accuracy of the prediction equations. Total error was calculated to evaluate the regression equations (Housh et al., 1989). A t-test compared the means of the estimated versus measured 1RM scores in the second group. Furthermore, the differences between directly measured and predicted 1RMs from all 12 prediction equations were visualized using the Bland-Altman plots (Rankin & Stokes, 1998). Data were expressed as group mean ± *SD*. A p value of $< .05$ was regarded as statistically significant. All analyses were performed using the SPSS Version 21 for Windows (IBM, Inc., Chicago, IL, USA).

Results

No muscle injuries were incurred during the experiments. The physical characteristics of the first group of participants are presented in Table 1. The 1RM test–retest for the three exercises showed high reliability (Table 2). The results of 4–10RM and 11–15RM tests are reported in Table 3. The prediction equations of 1RM from the 4–10RM or 11–15RM results are shown in Table 4. The R^2 values indicated that higher than 78% of variance in 1RM for men and 55% for women can be predicted by the 4–10RM strength and its repetitions; while up to 68% of variance in 1RM for both men and women can be predicted from the 11–15RM tests. The standard error of estimate (SEE) of the 11–15RM equations was usually higher than those of the 4–10RM ones in men but not in women. The predictive index (% variability accounted for by the dependent variable) of the bench press was usually higher than those of the biceps curl and squat (Table 4). The results of analysis of variance (ANOVA) suggested that all of 4–10RM and 11–15RM prediction equations reached statistical significance (Sig = .000, means $p < .0001$), which meant that the equation with variables X_1 (4–10RM or 11–15RM strength) and X_2 (number of repetitions) can significantly predict Y (1RM strength).

\insert Table 1
\insert Table 2
\insert Table 3
\insert Table 4

The physical characteristics of the second group of participants are presented in Table 5. There were no differences in age, body mass, height, and BMI between the two groups. The results of correlation analyses are reported in Table 6. There were significant correlations between the predicted and directly measured 1RM. *T*-test results showed no significant differences between the estimated versus measured 1RM scores ($p > .05$). The Bland-Altman plots of all 12 prediction equations are given in Figures 1 and 2.

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\insert Figure 1a
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\insert Figure 2c

Discussion

Evaluating skeletal muscle strength accurately is the first step to design effective resistance training programs for older adults to help them maintain or improve their muscle function (American College of Sports Medicine, 2006, pp. 80–83). 1RM can be measured directly or predicted from submaximal efforts. We believe that it may be much safer to predict 1RM from submaximal efforts for older adults who are physically inactive. There was a study on the validity of 1RM prediction for older adults, however, significant differences were found between the actual 1RM and the predicted one (Knutzen et al., 1999). A likely reason for this discrepancy may be that the equations applied were mostly developed from young participants. Therefore, the special 1RM prediction equations for older adults are needed.

In the current study, we have established the 1RM prediction equations of three exercises from the results of 4–10RM and 11–15RM tests in older adults. The equations showed the R^2 from .546 for the women's bench press to .937 for the men's biceps curl. Men's results were higher than women's. The R^2 for the bench press was usually lower than those of the biceps curl and squat, which may be caused by the unfamiliar body movement of the bench press. The SEE of the bench press was higher than those of the biceps curl and squat in men but not in women. SEE values of the current study range from 1.05–6.33, and they are comparable to the SEEs from a study of young men (Dohoney et al., 2002). However, we found higher SEE from men's bench press equations compared with those of the biceps curl and squat (see Table 4). For example, the 11–15RM equation had an SEE of 6.33, which means that the 95% confidence intervals for the 1RM measurement would be ± 12.39 kg. Caution should be used when applying this equation. This outcome suggests that the bench press is not a familiar exercise for older adults; much practice should be done to achieve correct technique to perform this exercise before the tests. Using the 4–10RM equation may result in better predicted 1RM of the bench press for men. The ANOVA results of all prediction equations demonstrated statistical significance in estimating 1RM from the independent variables. This outcome supports the hypothesis of this study. Furthermore, we had the second group of participants to evaluate the accuracy of the equations. Correlation analyses showed significant *r* values between the directly measured 1RM and the predicted 1RM. Men's SEE was from 1.49–4.34; while women showed a higher SEE of 5.10 (11–15RM equation) and 5.88 (11–15RM equation) in their squat tests, which may reflect a possible difference in skeletal muscle controlling between men and women. The Bland-Altman plots of the prediction equations showed that most differences between directly measured 1RM and predicted 1RM were near the line of the mean of differences, though with few outliers. Several patterns were evident from the Bland-Altman plots. The 4–10RM biceps curl prediction equation tended to underestimate the true 1RM for weaker participants and overestimate the true 1RM for stronger participants. The bench press prediction equations for men and women, and the 4–10RM squat prediction equation for women, tended to overestimate the true 1RM for weak participants and underestimated true 1RM for stronger participants. In summary, these outcomes indicate that submaximal muscle strength tests can be used to predict 1RM values in older adults accurately. According to Knutzen and colleagues' study (1999), age-specific equations should be used when predicting 1RM of older adults.

The equations developed in the current study have the practical value to be used in clinical settings and public health evaluations. For each exercise (i.e., biceps curl, bench press, and squat), we have established two 1RM prediction equations either from 4–10RM or 11–15RM measurements. In reality, if we want to know the 1RM for a person aged 60–75 years, we can measure submaximal muscle strength within the range of 4–15RM and then predict his or her 1RM by the appropriate equation. One measurement should be enough, only if the repetitions fall in the 4–15RM range. The potential risk of 1RM tests for sedentary older adults could be avoided by taking safer submaximal muscle strength tests. However, it is noteworthy that the SEE values of the 11–15RM prediction equations are usually higher than those of the 4–10RM equations. This finding suggests that an increased number of repetitions can decrease the accuracy of the prediction, in accordance with a previous study (Whisenant et al., 2003).

There are limitations in our study. The prediction equations were developed from the experimental results of older Chinese participants. These equations may not be suitable or accurate to other ethnicities in different age groups (younger than 60 and older than 75). In addition, in this particular study, only three exercises were chosen for the experiment. However, the study design can be used to develop unique equations for other groups of people and other exercises to be studied.

Conclusion

The prediction equations of the current study may provide an accurate, safe, and convenient way to estimate 1RM of the biceps curl, bench press, and squat from submaximal effort in older Chinese people. Predicted 1RM from submaximal efforts is a useful additional method to the direct 1RM measurement in older adults.

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Figure 1 — The Bland-Altman plots of the equations for men.

Figure 2 — The Bland-Altman plots of the equations for women.

Table 1 Physical Characteristics and the Directly Measured 1RM Values of the First Group of Participants

Variables	Men (*n* = 48)	Women (*n* = 61)
Age (years)	63.6 ± 6.9	62.5 ± 7.2
Body mass (kg)	74.2 ± 11.6	66.1 ± 9.9
Height (cm)	170.2 ± 5.7	157.8 ± 4.9
BMI (kg/m^2)	25.6 ± 5.6	26.6 ± 3.9
1RM biceps curl (kg)	27.4 ± 5.3	18.2 ± 2.6
1RM bench press (kg)	49.5 ± 11.0	36.4 ± 6.1
1RM squat (kg)	78.0 ± 15.4	55.4 ± 12.9

Note. All data are presented as mean ± *SD*. BMI = body mass index.

Table 2 Reliability Analyses of the Directly Measured 1RM Values

	Men (*n* = 15)					Women (*n* = 15)				
Exercise	First 1RM	Second 1RM	ICC	*SEM*	MD	First 1RM	Second 1RM	ICC	*SEM*	MD
Biceps curl (kg)	25.2 ± 4.4	25.2 ± 4.6	.993	0.376	1.042	18.2 ± 2.9	18.1 ± 2.4	.960	0.520	1.441
Bench press (kg)	51.9 ± 12.1	51.7 ± 11.7	.989	1.248	3.459	36.4 ± 6.2	36.6 ± 5.5	.979	0.840	2.328
Squat (kg)	72.9 ± 10.7	73.1 ± 9.4	.978	1.48	4.102	53.2 ± 10.6	53.3 ± 9.8	.992	0.903	2.503

Note. All data are presented as mean ± *SD*. ICC = intraclass correlation coefficient; *SEM* = standard error of measurement; MD = minimum difference.

Table 3 Results of 4–10RM and 11–15RM Tests

Exercise		Men (n = 48)	Women (n = 61)
Biceps curl	4–10RM (kg)	22.8 ± 5.3	14.8 ± 2.3
	# of repetition	6.4 ± 2.2	6.4 ± 1.8
	11–15RM (kg)	17.8 ± 3.8	12.6 ± 2.3
	# of repetition	13.3 ± 1.7	13.2 ± 1.9
Bench press	4–10RM (kg)	42.4 ± 11.8	28.3 ± 6.7
	# of repetition	6.3 ± 2.0	7.2 ± 2.1
	11–15RM (kg)	33.9 ± 9.2	23.8 ± 4.0
	# of repetition	12.8 ± 1.4	13.1 ± 2.3
Squat	4–10RM (kg)	65.6 ± 12.8	45.3 ± 8.8
	# of repetition	6.6 ± 2.1	7.1 ± 2.3
	11–15RM (kg)	50.2 ± 10.0	38.4 ± 8.8
	# of repetition	12.9 ± 1.6	12.5 ± 1.2

Note. All data are presented as mean ± *SD*.

Table 4 Regression Equations for Predicting 1RM From 4–10RM and 11–15RM Tests

	Men (n = 48)					Women (n = 61)				
Exercise	4–10RM Equation	r value	R^2	SEE	Predictive Index	Equation	r value	R^2	SEE	Predictive Index
Biceps curl	$Y = 1.03\times_1 + 0.55\times_2 + 0.35$	.968	.937	1.37	4.99%	$Y = 1.01\times_1 + 0.42\times_2 + 0.59$	.918	.842	1.05	5.77%
Bench press	$Y = 0.79\times_1 + 0.74\times_2 + 11.56$	.880	.775	5.38	10.86%	$Y = 0.67\times_1 + 0.81\times_2 + 11.74$	.739	.546	4.18	11.49%
Squat	$Y = 1.15\times_1 + 1.37\times_2 - 6.39$	.970	.940	3.85	4.93%	$Y = 1.18\times_1 + 1.20\times_2 - 6.57$	.928	.861	4.88	8.81%
	11–15RM Equation	r value	R^2	SEE	Predictive Index	Equation	r value	R^2	SEE	Predictive Index
Biceps curl	$Y = 1.32\times_1 + 0.58\times_2 - 3.77$	.944	.892	1.79	6.56%	$Y = 0.90\times_1 + 0.30\times_2 + 2.94$	.823	.678	1.50	8.25%
Bench press	$Y = 1.01\times_1 + 1.21\times_2 - 0.14$	.826	.682	6.33	12.78%	$Y = 1.40\times_1 + 0.48\times_2 - 3.27$	.900	.810	2.71	7.44%
Squat	$Y = 1.38\times_1 + 3.53\times_2 - 36.80$	.966	.933	4.06	5.21%	$Y = 1.28\times_1 + 3.09\times_2 - 32.30$	.936	.877	4.59	8.29%

Note. Y = predicted 1RM; X_1 = 4–10RM or 11–15RM value; X_2 = number of repetition; R^2 = multiple correlation coefficient squared; SEE = standard error of estimate; predictive index = SEE/1RM (%).

Table 5 Physical Characteristics of the Second Group of Participants

Variables	Men (n = 15)	Women (n = 16)
Age (years)	61.5 ± 5.1	63.8 ± 7.1
Body mass (kg)	77.1 ± 9.8	66.7 ± 8.2
Height (cm)	170.6 ± 5.7	158.8 ± 3.1
BMI	26.3 ± 3.5	26.5 ± 3.5

Note. All data are presented as mean ± *SD*. BMI = body mass index.

Table 6 Evaluation of the Regression Equations From 4–10 RM and 11–15 RM Tests

Exercise	Men (n = 15)							Women (n = 16)						
4–10 RM	Directed 1RM (kg)	Predicted 1RM (kg)	r value	R^2	SEE	Predictive Index	Total Error	Directed 1RM (kg)	Predicted 1RM (kg)	r value	R^2	SEE	Predictive Index	Total Error
Biceps curl	28.6 ± 3.0	28.9 ± 3.9	.985**	.970	3.57	12.48%	0.26	18.5 ± 2.1	18.5 ± 1.9	.785**	.616	1.24	6.70%	0.31
Bench press	48.7 ± 6.7	48.7 ± 4.9	.940**	.880	1.91	3.92%	0.68	39.1 ± 5.3	37.3 ± 2.5	.777**	.604	2.45	6.26%	1.00
Squat	75.5 ± 8.3	76.7 ± 8.6	.911**	.830	3.46	4.58%	0.94	57.3 ± 14.3	59.4 ± 11.4	.894**	.779	5.88	10.26%	1.69
11–15 RM	Directed 1RM (kg)	Predicted 1RM (kg)	r value	R^2	SEE	Predictive Index	Total Error	Directed 1RM (kg)	Predicted 1RM (kg)	r value	R^2	SEE	Predictive Index	Total Error
Biceps curl	28.6 ± 3.0	28.5 ± 3.8	.899**	.808	1.49	5.21%	0.43	18.5 ± 2.1	18.3 ± 1.2	.633*	.401	1.08	5.84%	0.39
Bench press	48.7 ± 6.7	48.8 ± 7.3	.784**	.615	4.34	8.91%	1.16	39.1 ± 5.3	38.5 ± 4.0	.871**	.759	2.21	5.65%	0.66
Squat	75.5 ± 8.3	76.0 ± 8.1	.981**	.962	1.60	2.11%	0.42	57.3 ± 14.3	59.2 ± 12.1	.920**	.846	5.10	8.90%	1.47

Note. All data are presented as mean ± *SD*. R^2 = multiple correlation coefficient squared; SEE = standard error of estimate; predictive index = SEE/1RM (%).

*$p < .05$; **$p < .01$.

Author Queries

[AUQ1] Ensure author bios area accurate. Also ensure names are correct under the manuscript title.