Prediction model of a maximal repetition (1RM) based on male and female anthropometrical characteristics*

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ABSTRACT

The goal of the present study was to develop an equation for predicting the workload of one maximal repetition (1RM) in women and men, based exclusively on anthropometrical characteristics. Forty-four low-risk and experienced in strength training young subjects, being 22 male (23 ± 4 years, 76.6 ± 12.7 kg, 173.9 ± 5.5 cm, 11 ± 4.5% of body fat) and 22 female (22 ± 4 years, 54 ± 6.0 kg, 161 ± 5.8 cm, 18 ± 2.2% of body fat) volunteered for this study. All subjects were submitted to an anthropometrical evaluation followed by a 1RM familiarization test (shoulder press), which was repeated after 48 h. The repeatability was tested using Wilcoxon Matched paired test. Finally, the 1RM workload was modeled in relation to the anthropometrical variables through multiple linear regression (forward stepwise) using as cutoff criteria for the independent variables $\Delta r^2 < 0.01$. The models reliability was expressed by the Bland and Altman analysis. All tests assumed $\alpha = 0.05$. No significant differences were recorded between the two tests, resulting 44.6 ± 13.2 kg and 12.2 ± 3.2 kg, for male (MS) and female (FS) subjects respectively. The time of practice in strength training was also included in the models. The model resulted in 84% of explained variance and a standard error of 12% for the MS. On the other hand, for the FS the predictive capacity was weaker than for = the MS, resulting in 56% of the explained variance and a standard error of 20%. In conclusion, the obtained models showed acceptable reliability so that they can be currently used as a tool for predicting the 1RM workload.

Keywords: Strength training. Muscular strength. Exercise. Prediction equation.

INTRODUCTION

The one maximal repetition test (1RM) is frequently used as measurement of muscular strength in physical preparation, sports training, physical rehabilitation or simply in the scientific research viewpoint. Within this context, it is a consensus that the grounding for the exercise prescription in counter-resistance training (CRT) is established through the relation between the 1RM percentage and the number of repetitions[1]. On the other hand, previous studies have shown that several factors – such as: physical conditioning level[2]; muscular group[3]; sleep routine[4]; diet[5]; chronobiological rhythm[6]; motivation[7]; menstrual cycle[8] and muscular fatigue[9] – effectively interfere in such relation, resulting in distinct intensities for a given number of repetitions.

In addition, long time required for the performance of a 1RM test, muscular discomfort[10], as well as possible risks of injury[11], have determined the development of more simple and less injury-prone methods which are still capable of accurately estimating the maximal strength. Thus, with the purpose to predict the maximal strength without maximal physical and emotional stress, several studies have used the validation of submaximal tests based on the maximal number of repetitions for each workload[12-13]; on the 1RM percentage[4,15]; on the maximal workload for a given number of repetitions[16-20], or simply on anthropometric characteristics such as height, segmental area, muscular area[21-26], or body mass[10,27]. Conversely, although the literature is rich in work involving the 1RM estimate, few studies have focused on anthropometric characteristics of the Brazilian population. Therefore, the aim of the present study was to develop a model for predicting the 1RM workload exclusively based on male and female anthropometric characteristics.

METHODS

Experimental procedures

Forty-four volunteers (22 male and 22 female) randomly selected in a health club of Rio de Janeiro participated in this study. The inclusion criteria considered were: that the volunteers had at least six months of experience in CRT; that they did not use any ergogenic device and that they did not present any previous osteomioarticular injury. These were considered low risk individuals since they presented up to a risk factor for arterial coronary disease and did not present any sign or symptom suggestive of cardiopulmonary or metabolic disease.

All volunteers were previously instructed not to perform physical exercise in the 24 h prior to the tests, not to ingest alcoholic beverages and to remain hydrated throughout the tests. The experimental procedures took place only after the verbal consent and the signature of the free and clarified form, according to the Research Ethics Committee of the Estácio de Sá University. The volunteers were initially submitted to an anthropometric evaluation followed by a familiarization 1RM test[28], and in a 48 h minimum interval, 1RM retest was performed. All 1RM tests were performed between 5:00 and 7:00 p.m.

Anthropometric evaluation

It consisted of body mass (BM) and height measurement (H), performed with a mechanical scale with stadiometers (Filizola, Brazil). For the calculation of the area of the transversal section of the segment, it was necessary to measure the circumference of the right arm relaxed (AC) as a standard using an anthropometric tape (Sanny, Brazil), as well as the skinfold (S) of the brachial triceps with scientific dividers (Cescorf, Brazil). From these measurements, the fat percentage (F) and the fat-free mass (FFM) were calculated using the Jackson and Pollock equations[29], Jackson *et al.*[30] for the estimation of the body density on men and women, respectively, combined with the Siri's equation[31].

From the SC measurement, the arm transversal area section was calculated (As):

$$As = \frac{SC^2}{4.\pi} \quad (1)$$

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Thus, the muscular area (Ma) was calculated in relation to the As and the tricipital D:

$$Ma = \pi \cdot \left(\frac{SC}{2\pi} - \frac{CD}{2}\right)^2 \quad (2)$$

and finally the fat area (Fa) was calculated by the difference between As and Ma:

$$Fa = As - Ma \quad (3)$$

1RM test protocol

The development exercise on the machine was selected due to its multi-articular nature, besides offering low injury risk. Moreover, although there are several studies dealing with exercises such as supine, leg press and bench press among others, until the present study there is no register of results dealing with the 1RM workload prediction for this kind of exercise. The test started from the initial seated position with back against the bench, flexed knees with feet on the bench, flexed elbows, abducted shoulders and bar grip relatively wider than the shoulders aligning. In the concentric phase, the shoulders abduction and elbows extension were simultaneously performed from the initial position, and sequentially, the eccentric phase consisted of the return to the initial position.

The 1RM tests were conducted according to the protocol proposed by Brown and Weir[28]: 3-5 min of light activity which involved the tested muscular group were performed; after one minute of light stretching, warming-up of eight repetitions at 50% of perceived 1RM, followed by three repetitions at 70% of perceived 1RM. After 5 min interval, the 1RM test was performed, adding when needed, 0.4 to 5 Kg, with a total of 3 to 5 trials. The registered maximal workload was that one lifted in a single movement.

Statistical treatment

The 1RM test repeatability was confirmed by the non-parametric test of ordered pairs by Wilcoxon. The 1RM workload was modeled by multiple linear regression through quadratic error minimization (forward stepwise method), using as independent variables: age; H; BM; FFM; RF; SC; SA; MA and FA, besides the experience time in strength training. A variation in the r^2 smaller than 0.01, as well as its – p value was adopted as slicing criteria of the independent variables. The regression models reliability was expressed by the estimate standard error (SEE) and studied through the method by Bland and Altman[32], in which the measured value of the 1RM workload was applied in the horizontal axis, and the difference between the measured values and those obtained by the method in the vertical axis. In addition, 95% of the limit of agreement (LOA) was presented, being expressed as the interval between two standard deviations (± 2SD). In all applied tests, $\alpha = 0,05$ was adopted. All statistical procedures were performed in Matlab v6.2 (Mathworks, EUA).

RESULTS

No osteomioarticular problem was registered during or immediately after any test; therefore, all volunteers have reached the maximal workload in the 1RM tests in the development exercise. In table 1 the physical and anthropometric characteristics are presented, as well as the experience time in CRT of the volunteers. As one can notice, except for the experience time – which varied from 6 months to 5 years – the data low dispersion points to an experimental group fairly homogeneous.

In table 2 the 1RM workloads and the number of trials obtained in the test and retest of 1RM of the volunteers are presented. Although the 1RM workload obtained in the retest is averagely higher than the one in the familiarization test, no significant differences were registered, which led to a high correlation between the tests (SM, r = 0.99; SF, r = 0.94). Thus, the results of the familiarization test were discarded, being the second measurement (retest) adopted as reference for independent variable in the prediction of the 1RM workload.

TABLE 1
Physical and anthropometric characteristics of the volunteers

Variables	Men	Women
Age, years	23 ± 4	22 ± 4
Height, cm	173 ± 5.5	161 ± 5.8
BM, kg	76.6 ± 12.7	54 ± 6
FFM, kg	68.1 ± 8.6	44.2 ± 4.9
RF, %	11 ± 4.5	18 ± 2.2
AC, cm	35.7 ± 3.2	25.8 ± 1.7
Experience, months	38.8 ± 34.9	19.7 ± 19.5
AS, cm²	102.3 ± 18.5	53.5 ± 7.2
MA, cm²	77.5 ± 24.3	35.8 ± 5.9
FA, cm²	24.8 ± 22.2	17.6 ± 2.8

Where BM represents body mass; FFM fat-free mass; RF relative fat; AC relaxed arm circumference; Experience experience time in counter-resistance training; AS arm segmental area; MA arm muscular area; and FA arm fat area.

TABLE 2
Performance in the 1RM tests in the development exercise of men and women

Sex	Male	Female
1RM Test, kg	43.2 ± 13.4	11.6 ± 3.1
1RM Retest, kg	44.7 ± 13.1	12.2 ± 3.2
N_{trial} test	4.7 ± 0.6	4 ± 0.8
N_{trial} retest	3 ± 1.2	2.6 ± 0.9

Where N_{trial} test is the number of trials in the test and N_{trial} retest is the number of trials in the retest.

Table 3 presents the coefficients of partial correlation between the anthropometric variables (independent) and the 1RM workload (dependent variable). The experience in CRT resulted in 31% of the variance explained of the 1RM workload. Moreover, the anthropometric variables presented the highest correlations with the 1RM workload in the SM. The BM contributed with 28% ($p = 0.01$) and the FFM with 31% ($p < 0.01$); nonetheless, the highest correlations were obtained by the SC and the AS ($r^2 = 0.73$, $p < 0.01$). In the SF, the correlations were lower, reaching determination coefficients of 0.23 (age) and 0.18 FFM ($p < 0.05$).

TABLE 3
Determination coefficient and the significance level between the anthropometric variables and performance in the 1RM test in the development exercise

Variables	Men		Women	
	R²	Value-p	R²	Value-p
Age	0.01	0.569	0.23	0.023
Height	0.09	0.158	0.09	0.173
Weight	0.28	0.012	0.16	0.059
FFM	0.31	0.007	0.19	0.038
RF	0.04	0.345	0.04	0.361
AC	0.73	0.000	0.10	0.143
Experience	0.31	0.008	0.07	0.207
SA	0.73	0.000	0.10	0.134
MA	0.13	0.106	0.12	0.101
FA	0.11	0.139	0.00	0.693

Where FFM is fat-free mass; RG is relative fat; AC is arm circumference; experience is experience time in counter-resistance training; AS is segmental area; MA is muscular area and FA is fat area.

Table 4 summarizes the prediction models of 1RM using from two to six independent variables. All extracted models were significant; however, it is possible to notice that, although there is a tendency to increase the explanation coefficient as the independent variables are added, the SEE tends to be stable, which seems

TABLE 4
Determination coefficient; standard error of the estimation and the significance level of the anthropometric variables and the experience time in counter-resistance training, when added to the male and female models

Prediction equation of male 1RM	r^2	SEE	p
1RM = –13.64 + 0.60 · SA	0.73	6.99	< 0.001
1RM = –15.23 + 0.72 · SA – 0.89 · RF	0.80	6.17	< 0.001
1RM = –24.03 + 0.65 · SA – 1.26 · RF + 0.25 · BM	0.83	5.94	< 0.001
1RM = –19.82 + 0.65 · SA – 1.15 · RF + 0.27 · BM – 0.32 · age	0.84	5.94	< 0.001
Prediction equation of female 1RM	r^2	**SEE**	**p**
1RM = 20.41 – 0.36 · age	0.23	2.89	0.023
1RM = 20.50 – 0.42 · age + 0.06 · E	0.39	2.65	0.009
1RM = 13 – 0.38 · age + 0.05 · E + 0.12 · BM	0.44	2.61	0.014
1RM = 33.56 – 0.41 · age + 0.04 · E + 0.27 · BM – 0.17 · H	0.46	2.62	0.025
1RM = 40.92 – 0.38 · age + 0.04 · E – 0.06 · BM – 0.24 · H + 0.49 · FFM	0.49	2.63	0.039
1RM = 82.17 – 0.42 · age + 0.03 · E + 3.5 · BM – 0.22 · H – 3.87 · FFM – 2.32 · RF	0.56	2.52	0.031

Where E represents the experience time in counter-resistance training; BM the body mass; AS segmental area; RF relative fat; H, height and FFM fat-free mass.

that no information is added to the prediction capacity of the models. Therefore, the best model for the estimation of 1RM was given to the equation which presented the highest determination coefficient and lowest standard error of the statistics. The models resulted in $r^2 = 0.84$ with error equivalent to 12% (SEE = 5.94 kg, $p < 0.001$) in the SM. In the SF though, the predictive capacity of the model obtained was weaker, resulting in $r^2 = 0.56$ and standard error of 20% (SEE = 2.52 kg, $p < 0.05$).

The reliability of the regression models was studied through the Bland and Altman method[32], in which the measured 1RM workload was applied on the horizontal axis and the difference between the measured values and those obtained by the model were applied on the vertical axis. Figure 1 illustrates the ratio between the measured and expected 1RM values in both sexes, as well as the Bland and Altman analysis. The obtained models showed reliability of 95% of the limit of agreement, being expressed as the interval between two standard deviations (± 2SD). The SM model presented a steady error behavior, being independent from the load, despite having presented two volunteers outside the limit of agreement, that is, 9.09% of the group. The SF model presented its data within the 95% of the limit of agreement; however, the error tends to increase as the workload is increased. When observing the Bland and Altman table[32] applied to the SF (figure 1), one can notice a tendency in workloads lighter than 12 kg, to overestimate the results, while in workloads heavier than 12 kg, the result is underestimated. Therefore, higher reliability and boldness can be given to the SM model when compared with the SF model.

DISCUSSION

The 1RM test is usually used for the evaluation of the maximal strength in a single repetition; nevertheless, massive discussion has been raised concerning its risk of injury[11], as well as its duration and intensity of muscular discomfort[10] generated from a 1RM test. Massive previous research has proposed estimations of 1RM workload from submaximal tests, based on the maximum number

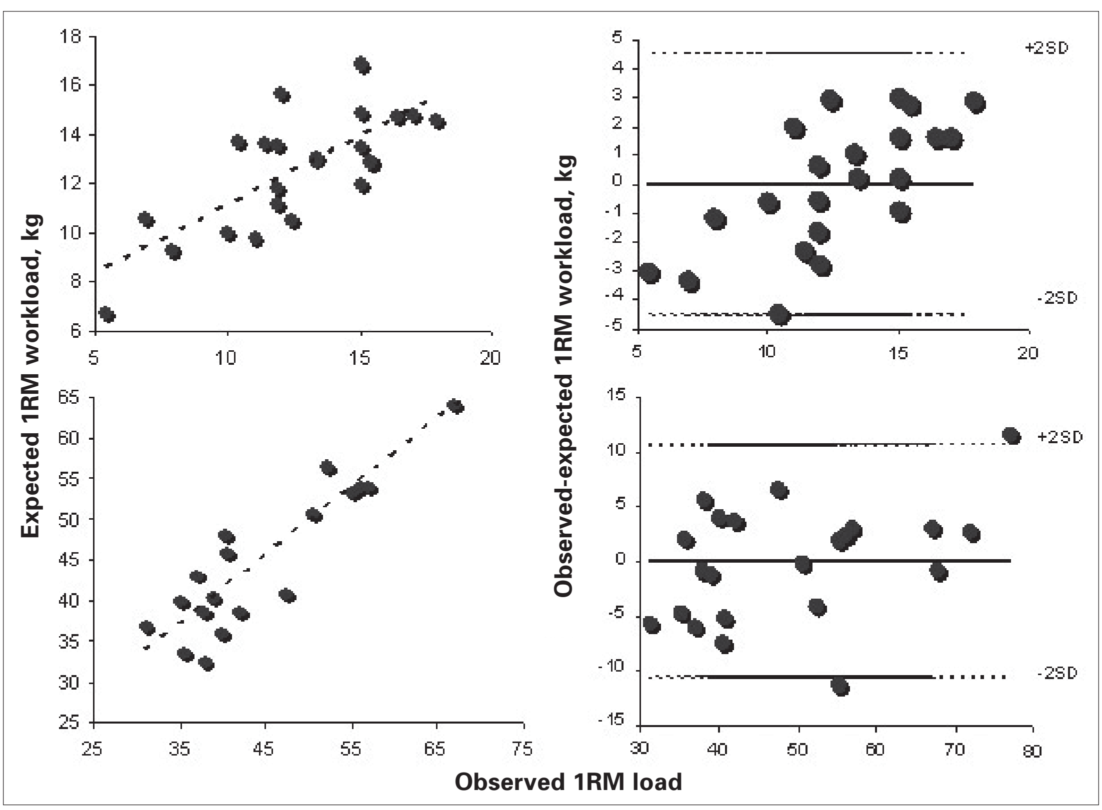

Figure 1 *– Bland and Altman analysis for the prediction of 1RM workload and prediction of the 1RM equation between the observed load over the load expected in men (lower figures) and women (upper figures). In the Bland and Altman analysis the dots represent the coordinates between the axis of the ordinates (the difference of the observed load over the expected load) and the abscises (the observed load), the continuous line represents the mean difference of the ordinates and the dotted line represents the limits (L) of reliability, where the* L_{upper} *is the mean difference added by 2SD of the difference of the ordinate and the* L_{lower} *is the mean difference decreased by 2SD of the difference of the ordinate.*

of repetitions for a given workload[12-13], on the 1RM percentage[14-15]; on the maximal workload for a given number of repetitions[16-20]; on the body mass percentage[10,27]; or simply on the anthropometric characteristics[20-25]. The present study follows such panorama, since few studies have been dedicated to the anthropometric characteristics of the Brazilian population. In our study, a 1RM workload prediction model was developed in the exercise in development, exclusively based on the anthropometric variables and the experience on CRT.

According to the procedures pointed by the literature, all volunteers performed a previous familiarization test. Contrary to previous studies[20,33], it did not result in significant differences when comparing test and retest, so that the repeatability of the measures was guaranteed. Possibly, the experience time of at least six months in CRT has influenced in this result. In a recent study[14] with young weightlifting athletes, the experience time was much more correlated to a 1RM than any other anthropometric variable, resulting in 49% of the explained variance. In the present study, the experience resulted in 31% of the 1 RM explained variance.

Very low correlations between the 1RM workload and anthropometric variables have been shown[13,21-22,24-25]; consequently, the prediction power of 1RM from these variables tends to be fairly weak. However, in the present study, the arm circumference and the transversal section area (in the SM group) resulted in 73% of the explained variance, respectively. The same variables (in the SF group) obtained weaker results, contributing with 10% of the explained variance, respectively. Conversely, the MA presented low correlations ($r = 0.35$ SM and $r = 0.37$ SF) with the 1RM workload. Such finding clashes with a recent study[34], in which a correlation of 0.81 between the MA and the 1RM load performed in the straight free supine exercise was found. In a very interesting study[35], such difference was given to the large number of muscles and joints involved during the performance of the straight supine when compared with the exercise of the present study, which according to the same authors[35], may lead to misinterpretation of results.

The prediction models of 1RM found here were based on the variables that presented the highest partial correlation coefficients with the 1RM load. Later, polynomial models from the first to sixth order were found, that is, with 1-6 independent variables. The models results were significant, presenting an increase in the explanation coefficient as independent variables are added. Conversely, the SEE tends to stabilize, which gives the impression that no information is added to the prediction capacity of the models. The equation which presented the highest determination coefficient and the lowest standard error of the statistics was used as prediction model for the estimative of 1RM.

In the male individuals, the prediction model of 1RM resulted in 84% of the explained variance, with standard error equivalent to 12% (SEE = 6.06 Kg, $p < 0.001$). On the other hand, in the SF, the prediction capacity of the obtained model was weaker, resulting in 56% of the explained variance (SEE = 2.61 kg, $p < 0.05$) and standard error equivalent to 20%. Considering that the sample group[36], the selected exercise[36], the age[37], the physical conditioning level[14], among other factors may interfere in the boldness of the model, one could expect distinct results between SF and SM. Although previous work has found error in the 1-10% order with models based on tests of 7-10RM[17-20], considering that in this work only anthropometric measurements without any physical stress were used, the results obtained show suitable consistency so that the models can be considered as an alternative tool for the estimation of the maximal strength. Moreover, despite of the prediction model of 1RM obtained in the SF group being more modest than that of the SM, it can be, with some reserve, taken as acceptable.

The difference in the prediction capacity in the male model in comparison with the female one was very remarkable, which can be associated with the differences in the male and female performances[38], or with distinct types of strength training[39-40]. In addition to that, men present more muscular mass[38], which tends to result in higher absolute strength than in women[38]. As seen in table 1, the segmental and muscular areas were respectively 96.7% and 116.5% higher in men than in women. While in exercises for lower limbs such difference tends to be lower or inexistent[38-39], anthropometric differences with magnitude similar to those found here corroborate the expectation that great differences are found in muscular strength. In a previous study[21] where the 1RM workload was estimated in the *leg press* in women using the anthropometric characteristics, a model explaining 67% of the variance of 1RM (SEE = 20.2 Kg) was presented, which corroborates the fact that the model is sensitive to the followed training patterns. Alternatively, one may hypothesize that the higher experience level in men (38.9 ± 34.9 SM and 19.7 ± 19.5 SF), as well as the motivation in the exercise, may have influenced in the results.

It is worth mentioning that the present study is restricted to strength measurement of upper limbs, whose extrapolation for endurance measurements, despite commonly mentioned in the literature, and deserves more detailed study, since the prediction of loads equivalent to a higher number of repetitions would imply in error propagation. Additionally, the group of volunteers is restricted to young individuals with experience in CRT, so that, *a priori*, the obtained equations here are limited to application in groups with such characteristic.

It is explicit that the obtained models may be used as potential tools for the prediction of the 1RM workload in individuals with physical and anthropometric characteristics similar to those described here. Finally, based on the results found, it was possible to develop prediction models for 1RM workload in men and women using exclusively anthropometric variables, resulting in acceptable errors and suitable reliability.

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