Cross-Validation of Original and Modified Equations for Estimating Bench Press One-Repetition Maximum from Repetitions to Failure

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Introduction

An athlete's ability to improve their relative and absolute muscular strength can be enhanced by regular participation in resistance training (5,111). Muscular strength is commonly assessed with the one-repetition maximum (1RM), which is defined as the maximal amount of weight that can be lifted against gravity in a single repetition (11). Regular testing of 1RM is an effective way to prescribe and adjust training intensity, which is often expressed as a percentage of 1RM, to optimize muscular strength development. (10,11). However, regular 1RM testing can consume a large amount of time, accumulate unwanted fatigue (10,11) and, as a result, reduce the number of training sessions that can be completed and potentially hinder an athlete's ability to improve their performance (1,11). Thus, an alternative to 1RM testing is to utilize equations (EQs) to estimate 1RM from repetitions to failure (RTF) performed at submaximal weights (2,4,7-11).

Recently, Roberts et al. (9) investigated the accuracy of sixteen EQs for estimating bench press (BP) 1RM from RTF and reported that the EQs of Lombardi (6) and Mayhew et al. (7) provided the most accurate estimations. Roberts et al. (9) further improved the accuracy of these EQs from by adjusting the y-intercept of each EQ to eliminate the systematic error (5). The modified versions of the EQs of Lombardi (8) and Mayhew et al. (7) proposed by Roberts et al. (9), however, have not been cross-validated on an independent sample of recreationally active men. Therefore, the purpose of this study was to cross-validate the original EQs of Lombardi (6) and Mayhew et al. (7), and their modified versions proposed by Roberts et al. (9) to estimate BP 1RM from RTF at ~80% of 1RM. It was hypothesized that the modified EQs of Roberts et al. (9) would provide more accurate estimates of BP 1RM than the original EQs of Lombardi (6) and Mayhew et al. (7).

Methods

Thirty-five recreationally active men (mean ± SD: age: 20.5 ± 1.4 yrs; height: 181.3 ± 6.4 cm; body mass: 84.8 ± 12.5 kg) with previous resistance training experience (5.0 ± 2.9 yrs) volunteered to participate in this study. Each participant completed BP 1RM testing followed by a single set of RTF at ~80% 1RM. The 1RM testing procedure was consistent with the protocol established by the National Strength and Conditioning Association. Repetitions were considered successful if the participants maintained 5-points of contact (head, shoulders, buttocks, left foot, and right foot) throughout the repetition; the bar was lowered in a controlled manner to lightly touch the mid-chest region; and the elbows reached full extension at the end of the concentric phase. For the RTF at ~80% 1RM, participants were instructed to avoid resting between repetitions at the starting position, and the test was terminated when participants rested for more than 1-2 seconds or could not complete a repetition with proper technique.

The EQs cross-validated in the present stud are exhibited in Table 1. EQ 3 and EQ 4 were derived using a previously determined constant error (CE) value (CE = estimated mean – measured mean) to adjust the y-intercepts of the original EQ 1 and EQ 2. The cross-validation analyses in the present study consisted of examining the CE values using paired *t*-tests, Pearson Correlation Coefficients (*r*), standard error of estimate (SEE), and total error (TE = √[∑estimated value – measured value]^2/*n*) values.

Table 1. Estimation Equations (EQ) used in the Cross-Validation Analysis for the Bench Press

EQ no.		Source	EQ	*r*	SEE (kg)	TE (kg)	Derivation of Sample*	Repetition Limitation**
ORG EQ	1	Lombardi (8)	$RTF^{0.1} \cdot W$	N.A.	N.A.	N.A.	"Intermediate and advance trainees" (*n* = N.A.)	≤10 RTF
	2	Mayhew (9)	$W/([52.2 + 41.9e^{-0.055 \cdot RTF}]/100)$	0.98	4.8	N.A.	Recreationally trained, men and women (*n* = 435)	≤15 RTF
MOD EQ	3	Roberts (11)	$(RTF^{0.1} \cdot W) + 1.49$	0.99	2.03	1.98	Recreationally active, men (*n* = 39)	4-10 RTF
	4	Roberts (11)	$(W/([52.2 + 41.9e^{-0.055 \cdot RTF}]/100)) - 0.43$	0.99	2.56	2.52	Recreationally active, men (*n* = 39)	4-10 RTF

EQ = equation; ORG = original; MOD = modified; N.A. = not available (from source); W = weight in kg; RTF = repetitions to failure.
SEE = standard error of estimation; TE = total error.
*Derivation Sample = the characteristics and size of the sample in which the EQ was derived.
**Repetition Limitation = the number of RTF intended for the EQ based on the derivation methodology.

Equations derived from training weight and repetitions to failure can **accurately predict** bench press 1RM. The **Lombardi Equation** provided the most accurate estimate of **bench press 1RM** with weights that result in 4-11 repetitions to failure.

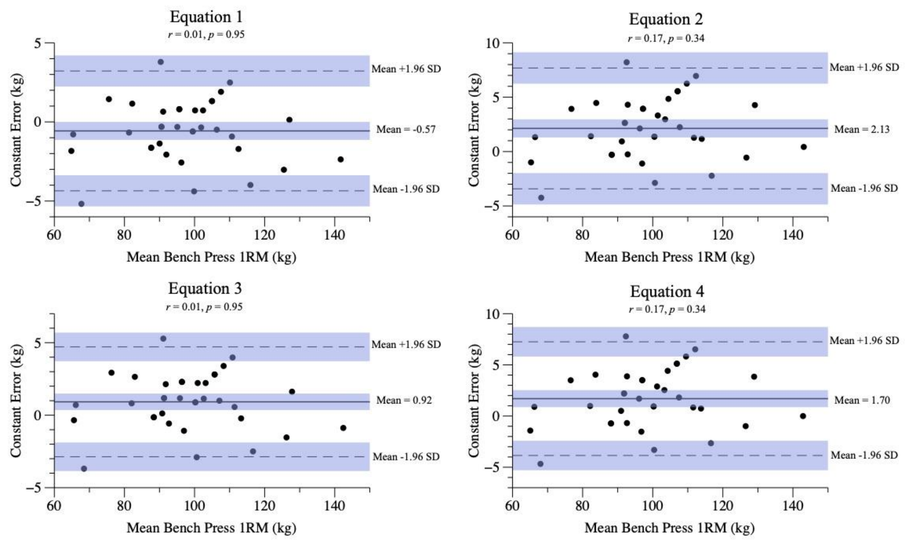

Figure 1. Bland-Altman plots of the relationships between constant error (CE) and mean 1 repetition maximum (1RM) for the bench press expressed in kg. The mean 1RM was calculated as follows: (estimated 1RM + measured 1RM) / 2. The shaded regions represent the 95% confidence intervals (CI) for the upper limit of agreement, lower limit of agreement, and bias. SD = standard deviation.

Practical Application

The use of EQ to estimate 1RM values from RTF and training weight is a valid alterative to 1RM testing. This method allows practitioners to avoid the use of multiple near maximal, maximal, and supramaximal (i.e. failed attempts) weights that can cause accumulation of unwanted fatigue. In addition, athletes can minimize the number of training sessions missed due to 1RM testing and, therefore, devote more time towards improving their muscular strength. Based on these cross-validation analyses, the original EQ of Lombardi (EQ 1 = $RTF^{0.1}$ x weight) is recommended for estimating BP 1RM when directly testing 1RM is not feasible (e.g. lack of time, concern for injury) or to assist in training intensity prescription. Practitioners should use a weight heavy enough to result in 4-11 RTF for accurate 1RM predictions.

Results

The participants' RTF at 80% 1RM ranged from 4-11 repetitions. The results of the cross-validation analyses are exhibited in Table 2. Equations 2, 3, and 4 significantly ($p < 0.05$) overestimated BP 1RM with CE values of 2.13 kg (EQ 2), 0.92 kg (EQ 3), and 1.70 kg (EQ 4), while EQ 1 did not differ ($p = 0.091$) from the measured 1RM values (CE = -0.57 kg). All four EQs exhibited *r* values of 0.99. The SEE values for the four EQ were 1.96 kg (EQ 1 and EQ 3) and 2.79 kg (EQ 2 and EQ 4). The TE values for the four EQ were 1.99 kg (EQ 1), 2.12 kg (EQ 3), 3.27 kg (EQ 4), and 3.51 kg (EQ 2).

The Bland-Altman plots demonstrated no correlation between the CE and mean BP 1RM values, which indicated consistent agreement between estimated and measured 1RM values regardless of the magnitude of the mean 1RM values. In addition, most data points fell within the limits of agreement for all equations, with EQ 1 having the smallest limits of agreement (Figure 1).

Table 2. Results of the Bench Press Cross-Validation Analysis

EQ no.		Measured 1RM (mean ± SD)	Estimated 1RM (mean ± SD)	CE (kg)	*p*	*r*	SEE (kg)	TE (kg)
ORG EQ	1	97.72 ± 16.59	97.15 ± 16.57	-0.57	0.091	0.99	1.96	1.99
	2	97.72 ± 16.59	99.85 ± 17.06	2.13	< 0.001	0.99	2.79	3.51
MOD EQ	3	97.72 ± 16.59	98.64 ± 16.57	0.92	0.008	0.99	1.96	2.12
	4	97.72 ± 16.59	99.42 ± 17.06	1.70	0.001	0.99	2.79	3.27

EQ = equation; ORG = original; MOD = modified; 1RM = one repetition maximum.
SD = standard deviation; CE = constant error; *r* = correlation coefficient; SEE = standard error of estimate; and TE = total error.

Conclusion

The findings of the present study did not support our hypothesis that the modified EQs of Roberts et al. (9) would provide more accurate estimations for BP 1RM than the original EQs of Lombardi (6) and Mayhew et al. (7) in recreationally active men. The modified version of EQ 1 (EQ 3) did not improve the accuracy of BP 1RM estimations compared to the original EQ 1. The estimations of EQ 4, however, exhibited slightly more accurate BP 1RM values than EQ 2. Although, all EQs displayed acceptable agreement for the Bland-Altman plots, EQ 1 provided the lowest TE and CE values, the smallest difference between the SEE and TE values, and the smallest limits of agreement for the Bland-Altman plots.

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