

# Cross-Validation of Equations for Estimating Pre-Training, Post-Training, and Training-Induced Change in Bench Press One-Repetition Maximum

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## ABSTRACT

**PURPOSE:** Four published equations (EQs; Table 1) that estimate one-repetition maximum (1RM) from repetitions-to-failure (RTF) were cross-validated for estimating pre-training (PRE), post-training (POST), and training-induced change (POST – PRE) in bench press (BP) 1RM. **METHODS:** Twenty-seven recreationally active men (mean±SD: age = 20.7±1.5 yrs; body mass = 86.5±11.6 kg) trained the BP 3 d·wk<sup>-1</sup> for 8 weeks with 1 working set to failure at ~80% 1RM and completed BP 1RMs before and after training. The RTF for the first and last training visits were used to estimate PRE and POST 1RM, respectively, with 4 EQs (EQs 1-4; Table 1). Cross-validation analyses included constant error (CE = estimated mean – measured mean) using a paired t-test, correlation coefficient (*r*), standard error of the estimate (SEE), and total error (TE =  $\sqrt{[\text{Estimated value} - \text{measured value}]^2 / n}$ ). **RESULTS:** Training increased (*p* < 0.001) BP 1RM from PRE (95.4±15.3 kg) to POST (107.9±15.0 kg) by 12.5±5.9 kg and the working sets' weights from the first (78.7±12.3 kg) to last (91.7±12.4 kg) training visits by 13.0±4.0 kg. The RTF for the first and last training visits ranged from 3-10 and 3-8 repetitions, respectively. The results of the CE, *r*, SEE, and TE values for all EQs estimates of PRE, POST, and the change in BP 1RM are displayed in Table 1. Only EQ 3 exhibited non-significant (*p* > 0.05) CE values for estimating PRE, POST, and the change in 1RM. All EQs exhibited similarly high *r* values for estimating PRE (0.94-0.98), POST (0.96-0.98), and the change in 1RM (0.84-0.88). For estimating PRE 1RM, EQ 2 exhibited the lowest TE of 2.8 kg, and the TE for EQ 3 was 3.0 kg. These TE values represented 2.9% (EQ 2) to 3.1% (EQ 3) of the mean measured PRE 1RM. For estimating POST 1RM, EQ 3 exhibited the lowest TE of 3.3 kg, and the TE for EQ 2 was 3.8 kg. These TE values represented 3.1% (EQ 3) to 3.5% (EQ 2) of the mean measured POST 1RM. For estimating the change in 1RM, EQ 3 exhibited the lowest TE of 3.4 kg, and the TE values for EQ 4 and EQ 2 were 3.7 and 3.8 kg, respectively. These TE values represented 27.2% (EQ 3) to 30.4% (EQ 2) of the mean measured change in 1RM. **CONCLUSION:** Only EQ 3 exhibited non-significant CE values for estimating PRE and POST BP 1RM, however, EQ 2 and 3 exhibited similarly low TE values (Table 1) relative to the mean measured values for estimating PRE (2.9-3.1%) and POST (3.1-3.5%) BP 1RM. EQs 2-4 exhibited similar TE values for estimating the change in BP 1RM (Table 1), however, these TE values were high relative to the mean measured change in BP 1RM (27.2-30.4%). **PRACTICAL APPLICATION:** When 1RM testing may not be appropriate (e.g., lack of time or concerns of injury), EQ 2 or EQ 3 is recommended for estimating PRE and POST BP 1RM values in recreationally active men with weights resulting in 3-10 RTF, but none of the EQs are recommended for estimating the training-induced change in BP 1RM due to their high expected errors. **ACKNOWLEDGMENTS:** none.

**Table 1.** Results of the cross-validation analyses for estimating pre-training, post-training, and change in bench press one-repetition maximum values.

Equation Number	Pre-Training 1RM			Post-Training 1RM			Change in 1RM					
	CE (kg)	<i>r</i>	SEE (kg)	TE (kg)	CE (kg)	<i>r</i>	SEE (kg)	TE (kg)	CE (kg)	<i>r</i>	SEE (kg)	TE (kg)
#1 = $W / (1.0278 - 0.0278 \times \text{RTF})$	-0.4	0.94	5.1	5.4	-2.2*	0.96	4.2	4.7	-1.9	0.84	3.3	5.9
#2 = $-14 + (1.32 \times \text{RTF}) + (1.27 \times W)$	-0.1	0.98	2.8	2.8	2.1*	0.98	3.1	3.8	2.2*	0.88	2.9	3.8
#3 = $\text{RTF}^{0.1} \times W$	0.1	0.98	3.0	3.0	0.9	0.98	3.3	3.3	0.8	0.88	2.9	3.4
#4 = $W / [(52.2 + 41.9e^{-0.055 \times \text{RTF}}) / 100]$	2.3*	0.98	3.5	4.2	2.8*	0.98	3.3	4.3	0.5	0.88	2.9	3.7

1RM = one-repetition maximum; W = weight lifted; RTF = repetitions-to-failure; CE = constant error (estimated mean – measured mean); *r* = Pearson Correlation Coefficient; SEE = standard error of the estimate; TE = total error; \*Indicates a significant (*p* ≤ 0.05) difference between estimated and measured means.

## INTRODUCTION

- The 1-repetition maximum (1RM) is the most common test for assessing strength; however, it may not be warranted in certain situations (e.g., time-constraints or concerns for injury).<sup>1-3</sup> Thus, many equations (EQs) have been developed for estimating 1RM from performing repetitions-to-failure (RTF) with submaximal weights.<sup>1-4</sup>
- Several cross-validation studies have examined the accuracy of various EQs, yet there are a limited number of studies<sup>1,5,6</sup> that cross-validated EQs for estimating a bench press pre-training (PRE) 1RM, post-training (POST) 1RM, and the absolute change in 1RM values (estimated change in 1RM = estimated POST 1RM – estimated PRE 1RM).
  - These previous cross-validation studies<sup>1,5,6</sup> that examined estimates of the absolute change in 1RM, however, were limited to the examination of mean differences (i.e., constant error [CE] with paired *t*-tests) and correlation values. Cross-validation procedures should also include the examination of the standard error of the estimate (SEE) and total error (TE). TE combines the errors associated with the CE and SEE and is considered the single best criterion for determining the true difference between estimated and measured values.<sup>7</sup>
- Thus, the present study cross-validated four EQs (Table 1) that estimate 1RM from RTF for estimating PRE, POST, and the absolute training-induced change in bench press 1RM values.

## METHODS

- Subjects:** 27 healthy, recreationally active men (mean±SD: age = 20.7±1.5 years, height = 181.1±6.3 cm, body mass = 86.5±11.6 kg).
- 1RM Testing:** PRE and POST 1RM testing was performed on a flat bench with a rack, Olympic bar, and free weights. The present study followed the 1RM guidelines established by the National Strength and Conditioning Association for upper body exercises.<sup>4</sup>
- Resistance Training:** The bench press resistance training was 3 d·wk<sup>-1</sup> for 8 weeks. All training sessions included 2 warm-up sets of 8 repetitions at 50 and 70% 1RM, respectively, followed by 1 working set to failure at ~80% 1RM. Throughout the training, if subjects completed ≥8 repetitions during the working set, the weights for the subsequent training session were increased by 2.27 kg. In contrast, if subjects completed <8 repetitions during the working set, the weights for the subsequent training session were unchanged.
- Estimating 1RM:** The number of RTF and weight from the working set of the first and last training session were input into 4 EQs (Table 1) for estimating PRE and POST 1RM, respectively. Half of the EQs utilize a linear model to predict 1RM (EQ 1: Brzycki<sup>2</sup>; EQ 2: Julio et al.<sup>8</sup>), while the other half utilize an exponential model (EQ 3: Lombardi<sup>9</sup>; EQ 4: Mayhew et al.<sup>3</sup>). Absolute change in 1RM was estimated by subtracting the estimated PRE 1RM from the estimated POST 1RM.
- Statistical Analyses:** Changes in the measured 1RM, RTF weight, % 1RM of the RTF weight, and number of RTF from PRE to POST were analyzed with paired *t*-tests. The statistical procedures for the cross-validation of the estimated PRE 1RM, POST 1RM, and absolute change in 1RM values involved the examination of the following: CE using a paired *t*-test, Pearson Correlation Coefficient (*r*), SEE, and TE (TE =  $\sqrt{\sum[\text{Estimated Value} - \text{Measured Value}]^2 / \text{Sample Size}}$ ).
  - All criteria were considered, but primary consideration was given to TE since it represents the true difference between estimated and measured values.<sup>7</sup>

## RESULTS

- The performances of the PRE and POST 1RM and RTF from the working set of the first (i.e., PRE) and last (i.e., POST) training sessions are displayed in Table 2. Bench press 1RM and RTF weight increased (*p* ≤ 0.05) by 12.5 and 13.0 kg, respectively. The number of RTF decreased (*p* ≤ 0.05) by 1.4 repetitions, while the % 1RM of the RTF weight increased (*p* ≤ 0.05) by 2.5%.
- PRE 1RM (Table 3):** EQs 1-3 exhibited no significant (*p* > 0.05) mean differences between the estimated and measured PRE 1RM, whereas EQ 4 overestimated (*p* ≤ 0.05) PRE 1RM by 2.3 kg. All EQs exhibited excellent correlations (0.94-0.98) between estimated and measured PRE 1RM values. The SEE and TE values ranged from 2.8 (EQ 2) to 5.1 (EQ 1) kg and 2.8 (EQ 2) to 5.4 (EQ 1) kg, respectively. These TE values represented 2.9 to 5.7% of the mean measured PRE 1RM.
- POST 1RM (Table 4):** EQ 3 exhibited no significant (*p* > 0.05) mean difference between the estimated and measured POST 1RM. EQs 2 and 4 overestimated (*p* ≤ 0.05) POST 1RM by 2.1 and 2.8 kg, respectively, and EQ 1 underestimated (*p* ≤ 0.05) by 2.2 kg. All EQs exhibited excellent correlations (0.96-0.98) between estimated and measured POST 1RM values. The SEE and TE values ranged from 3.1 (EQ 2) to 4.2 (EQ 1) kg and 3.3 (EQ 3) to 4.7 (EQ 1) kg, respectively. These TE values represented 3.1 to 4.4% of the mean measured POST 1RM.
- Absolute Change in 1RM (Table 5):** EQs 1, 3, and 4 exhibited no significant (*p* > 0.05) mean differences between the estimated and measured change in 1RM, whereas EQ 2 overestimated (*p* ≤ 0.05) the change in 1RM by 2.2 kg. All EQs exhibited excellent correlations (0.84-0.88) between estimated and measured absolute change in 1RM values. The SEE and TE values ranged from 2.9 (EQs 2-4) to 3.3 (EQ 1) kg and 3.4 (EQ 3) to 5.9 (EQ 1) kg, respectively. These TE values represented 27.2 to 47.2% of the mean measured change in 1RM.

**Table 2.** Bench press performance characteristics of the subjects (*n* = 27).

Variable	Pre-Training		Post-Training		Change
	Mean±SD	Range	Mean±SD	Range	
1RM (kg)	95.4±15.3	65.8-127.0	107.9±15.0	79.4-136.1	12.5*
RTF weight (kg)	78.7±12.3	54.4-104.3	91.7±12.4	70.3-117.9	13.0*
% 1RM of the RTF weight	82.5±1.5	80.0-87.2	85.1±3.0	79.17-91.4	2.5*
Number of RTF	7.1±1.6	3-10	5.7±1.5	3-8	-1.4*

1RM = 1-repetition maximum; RTF = repetitions-to-failure

\*Indicates a significant change (*p* ≤ 0.05) change from pre-training to post-training.

**Table 3.** Results of the cross-validation analyses for estimating pre-training bench press 1-repetition maximum.

Equation Number	Measured Pre-Training 1RM	Estimated Pre-Training 1RM	CE (kg)	<i>r</i>	SEE (kg)	TE (kg)
	(mean±SD in kg)	(mean±SD in kg)				
1	95.4±15.3	95.1±16.6	-0.4	0.94	5.1	5.4
2	95.4±15.3	95.3±16.1	-0.1	0.98	2.8	2.8
3	95.4±15.3	95.5±15.5	0.1	0.98	3.0	3.0
4	95.4±15.3	97.7±16.1	2.3*	0.98	3.5	4.2

1RM = 1-repetition maximum; CE = constant error; *r* = Pearson Correlation Coefficient; SEE = standard error of the estimate; TE = total error. \*Indicates a significant difference (*p* ≤ 0.05) between estimated and measured values.

**Table 4.** Results of the cross-validation analyses for estimating post-training bench press 1-repetition maximum.

Equation Number	Measured Post-Training 1RM	Estimated Post-Training 1RM	CE (kg)	<i>r</i>	SEE (kg)	TE (kg)
	(mean±SD in kg)	(mean±SD in kg)				
1	107.9±15.0	105.7±15.0	-2.2*	0.96	4.2	4.7
2	107.9±15.0	110.0±18.9	2.1*	0.98	3.1	3.8
3	107.9±15.0	108.8±15.1	0.9	0.98	3.3	3.3
4	107.9±15.0	110.7±15.3	2.8*	0.98	3.3	4.3

1RM = 1-repetition maximum; CE = constant error; *r* = Pearson Correlation Coefficient; SEE = standard error of the estimate; TE = total error. \*Indicates a significant difference (*p* ≤ 0.05) between estimated and measured values.

**Table 5.** Results of the cross-validation analyses for estimating the absolute change in bench press 1-repetition maximum.

Equation Number	Measured Change in 1RM	Estimated Change in 1RM	CE (kg)	<i>r</i>	SEE (kg)	TE (kg)
	(mean±SD in kg)	(mean±SD in kg)				
1	12.5±5.9	10.7±9.7	-1.9	0.84	3.3	5.9
2	12.5±5.9	14.7±6.5	2.2*	0.88	2.9	3.8
3	12.5±5.9	13.3±7.1	0.8	0.88	2.9	3.4
4	12.5±5.9	13.0±7.6	0.5	0.88	2.9	3.7

1RM = 1-repetition maximum; CE = constant error; *r* = Pearson Correlation Coefficient; SEE = standard error of the estimate; TE = total error. \*Indicates a significant difference (*p* ≤ 0.05) between estimated and measured values.

## CONCLUSION

- For estimating a PRE bench press 1RM, EQ 2 and EQ 3 exhibited no systematic error (i.e., non-significant CE values) and similar, low TE values that represented 2.9-3.1% of the mean measured PRE 1RM of 95.4 kg.
- For estimating a POST bench press 1RM, although EQ 3 was the only EQ to exhibit no systematic error, EQs 2 and 3 demonstrated similar, low TE values that represented 3.1-3.5% of the mean measured POST 1RM of 107.9 kg.
- For estimating the absolute training-induced change in bench press 1RM, although EQs 2-4 exhibited similar TE values, these TE values were high relative to the mean measured change in bench press 1RM of 12.5 kg (27.2-30.4%).

## PRACTICAL APPLICATION

- When 1RM testing may not be appropriate (e.g., lack of time or concerns for injury), EQ 2 or EQ 3 (Table 1) are recommended for estimating a PRE and POST bench press 1RM in recreationally active men with submaximal weights resulting in 3-10 RTF.
- None of the EQs (Table 1) are recommended for estimating the absolute training-induced change in bench press 1RM.

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