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Validity of Formulas Used to Estimate One Repetition Maximum Strength of Upper and Lower Extremities

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ABSTRACT

This study aimed to assess the validity of 15 formulas used to estimate one repetition maximum (1RM) bench press and deep squat strength in male and female university students who are recreationally active in sports. Forty-eight students (age = 22.4 ± 2 years, height = 169.8 ± 10.2 cm, weight = 66.5 ± 17.6 kg, BMI = 22.8 ± 4.3 kg/m2) from the Faculty of Sport Sciences participated. The participants' 1RM values in the bench press and deep squat tests were compared with 15 different formulas. Levene's test was used to test the homogeneity of variance, and a paired t-test was employed to evaluate the agreement of repeated paired measurements. Additionally, Bland-Altman plots, Intraclass Correlation Coefficient (ICC), and Concordance Correlation Coefficient (CCC) were utilized to assess the agreement of measurements. Results indicated that some formulas provided predictions close to the measured 1RM values, while others showed deviations. Specifically, in the bench press test, the P2 (Berger) and P6 (Kemmler) formulas provided more accurate predictions for female participants, while P5 (Cummings & Finn) and P10 (Mayhew) were successful for males. In the deep squat test, P3 (Brown) and P4 (Brzycki) provided the best predictions for females, while P1 (Adams) and P12 (O'Connor) showed high agreement for males. The findings suggest that selecting suitable formulas for 1RM estimation by gender and exercise type is essential for enhancing the effectiveness of strength training in sports sciences.

INTRODUCTION

Strength training is a crucial factor in maintaining overall health and improving athletic performance (Naclerio et al., 2013). The need for strength development to maximize athlete performance is critical due to the demands of various sports. Athletes must produce force at the level required by their specific discipline. (Schoenfeld et al., 2015). Maksimal strength performance enables athletes to evaluate their athletic abilities objectively. Strength training has become one of the most frequently preferred methods for various purposes. It contributes to the improvement of many athletic performance characteristics, including motor performance and balance, while also enhancing muscle strength, power, speed, and hypertrophy (Kraemer & Ratamess, 2004).

Maximal muscle strength is an important determinant of performance in strength and power sports and in athletes requiring anaerobic work and explosive power. Maximal strength is commonly utilized in planning strength exercises to improve athletes' athletic performance, fitness, and health. In light of this information, strength output stands out as a determinant of performance and as an indicator of success in sports (Işık et al., 2020; Sarabia et al., 2017). One-repetition maximum (1RM) is defined as the highest weight individuals can lift at a single time (Grgic et al., 2020; Kraemer & Ratamess, 2004; McBurnie et al., 2019). Studies have indicated that the 1RM method is reliable for assessing muscle strength (Gordon et al., 1995; Seo et al., 2012; Shaw et al., 1995).

Although it is a reliable test, research shows that the direct application of the 1RM test may pose an injury risk for older adults, youth, individuals without prior resistance training experience, and those unfamiliar with proper lifting technique (Braith et al., 1993; Feigenbaum & Pollock, 1999; Levinger et al., 2009). Due to these risks, various estimation methods using submaximal loads and multiple repetitions have been developed to predict 1RM values (Adams, 1998; Berger, 1970; Brown, 1992; Brzycki, 1993; Cummings & Finn, 1998) and are frequently used by sports scientists (Aksakallı & Gelen, 2023; Balcı & Özdemir, 2020). While low-load tests may cause muscular fatigue and require more time due to higher repetition counts and necessary recovery between sets, they are preferred because they offer a safer, more accessible, and technically less demanding alternative to direct 1RM testing, especially for untrained individuals (Reynolds et al., 2006; Hackett et al., 2012). Using these formulas, 1RM can be estimated from the Fatigue Repetition Count (FRC), which typically ranges from 2 to 20, and the amount of weight lifted (Mayhew et al., 1995). Although prediction formulas generally yield accurate estimates, individual factors such as age, gender, sport discipline, and training history significantly affect their predictive accuracy (Mayhew et al., 1995), for instance, in a study conducted on young males, 10 out of 16 formulas provided valid and accurate predictions of 1RM. However, the applicability of such methods in different populations remains under debate (Hazır et al., 2019).

Although numerous studies have aimed to predict 1RM, few have simultaneously compared multiple formulas across both upper and lower body exercises in trained populations. Most existing research tends to focus on a limited number of formulas or evaluate only one extremity (e.g., either upper or lower body). In this study, 15 widely used prediction formulas for both upper and lower extremities were compared with directly measured 1RM values. In this regard, the study offers a systematic examination of the validity of different formulas across various movement patterns and thus makes a valuable contribution to the literature. Furthermore, we believe that the findings of this study will serve as a practical guide for coaches in selecting the most appropriate and reliable formula for their athletes, particularly in situations where direct 1RM testing is not feasible.

In addition to prediction formulas, standard strength testing equipment, such as the bench press (Lopes et al., 2017; Mitter et al., 2022; Pamart et al., 2023; Schoenfeld et al., 2019), leg extension (Pamart et al., 2023), deep squat (Schoenfeld et al., 2019), and shoulder press machines, are frequently used to evaluate dynamic strength. Moreover, perceived exertion is often used to guide training progression, although inconsistencies may arise depending on the training experience and subjective feedback of individuals (Hackett et al., 2012). Strength training is also known to support long-term athletic success by contributing to muscle hypertrophy, neuromuscular adaptations, and injury prevention (Haff & Triplett, 2015).

In light of the limitations identified in previous studies and the practical need for valid estimation methods, this study aims to determine the validity of commonly used formulas for estimating 1RM bench press and deep squat strength in male and female students studying in the department of sports sciences who maintain an active athletic lifestyle.

Hypothesis

In this study, it is hypothesized that there will be statistically significant differences between the predicted and directly measured one-repetition maximum (1RM) values in both the bench press and deep squat exercises. Furthermore, it is expected that the accuracy of the 1RM prediction formulas will vary according to gender, and that the differences between the estimated and measured 1RM values will also depend on the type of exercise performed. Additionally, a high level of agreement between the predicted and measured 1RM values is anticipated, as indicated by statistical metrics such as the intraclass correlation coefficient (ICC) and Lin's concordance correlation coefficient (CCC).

METHODS

Participants

This study was carried out with the participation of a total of 48 (24 female, 24 male) athletes aged an average of 22.4 years studying at Nevsehir Hacı Bektaş Veli University, Faculty of Sport Sciences. Statistical power was determined using G*Power version 3.1.9.2 for sample selection. Effect size (f) = 0.25; significance level (α error probability) = .05; statistical power (1 - β error probability) = .80; number of groups = 1; number of measures = 4; and correlation between repeated measures = 0.50, the required sample size for the study was determined as 44 participants. However, considering the possibility of missing participants for various reasons, an extra four people were included in the study. All participants were informed about the study's procedures, rules, advantages, and risks before giving their consent. The inclusion criteria were defined as having at least six months of strength training experience, not having any upper or lower extremity injuries in the past year, being medically cleared for participation in the study, and having no acute musculoskeletal injuries. Additionally, the participants stated that they were regularly engaged in sports and had participated in structured training programs at least twice a week over the past year. Among the study participants, one female and one male were found to have long-term lower and upper extremity disability in the last year. These participants were excluded from the study, and the study was finalized with 46 participants. Our study was approved by Nevsehir Hacı Bektaş Veli University Scientific Research Ethics Committee on 06/09/2024 with the number 2400081856. The study was conducted on the theoretical ethical requirements for human experimentation based on the principles of the Declaration of Helsinki.

Data Collection

This study was conducted using a cross-sectional and correlational experimental design. Before starting the measurements, participants attended a familiarisation session to familiarise themselves with the force procedure and equipment. The volunteers participating in the study were invited to the laboratory twice at 3-day intervals. The participants' height, body weight, and 1RM values in the bench press were taken after a dynamic warm-up protocol. After 72 hours, the 1RM values of the participants in the Deep Squat were taken. After resting for 72 hours, they were invited back to the laboratory, and bench press and deep squat movements were performed until fatigue at a weight corresponding to 75-90% of the measured 1RM values, and FRC was determined. To monitor perceived exertion, participants were also asked to rate their effort on a 10-point RPE (Rate of Perceived Exertion) scale after each set; however, these values were not included in the statistical analysis. All tests were performed at least 3-4 hours after the last meal between 13:00 and 17:00.

Table 1.
Descriptive characteristics of the participants

Variables	Male (n=23)	Female (n=23)
	X ± SD	X ± SD
Age (year)	22,4 ± 1,1	22,4 ± 2,5
Height (cm)	178,9 ± 6,2	161,7 ± 5,0
Body Weight (kg)	78,1 ± 17,6	56,2 ± 9,3
BMI (kg/m^2)	24,3 ± 4,9	21,4 ± 3,3
Bench press 1 RM	65,6 ± 16,4	31,0 ± 8,6
Deep squat 1 RM	96,3 ± 20,8	51,8 ± 17,4
Bench press RWL	55,0 ± 14,3	25,8 ± 7,9
Bench press FRC	5,2 ± 1,7	6,3 ± 2,6
Deep squat RWL	82,2 ± 19,0	45,9 ± 12,9
Deep squat FRC	5,5 ± 2,1	5,8 ± 2,0

RWL: Repetition Weight Load**, FRC**: Fatigue Repetition Count

Data Collection Tools

Anthropometric Measurements

Height and body weight were measured with a Seca (Seca, Hamburg, Germany) Brand height and weight measuring device with a precision of 0.01 kg-cm. Based on the height and body weight values obtained from the participants, the body mass index was determined using the formula (kg/m^2).

One Repetition Maximum Protocol (1RM)

A 20 kg Olympic bar (Eleiko AB, Halmstad, Sweden), Olympic plates (Eleiko AB, Halmstad, Sweden), and a standard bench were used to determine 1RM strength in bench press and deep squat movements. The standard 1RM test protocol was applied to the participants to determine 1 RM strength in all movements (Macht et al., 2016).

All participants were warmed up on the treadmill for 10 minutes, followed by 10 minutes of weight lifting exercises, with each repetition limited to 5–10 for the lower and upper extremities using low weights, and then rested passively for 2 minutes. This rest duration was selected based on prior findings indicating that 2 to 3 minutes of rest is sufficient to restore neuromuscular readiness before maximal strength attempts (Willardson, 2006; Ratamess et al., 2007). The protocol applied to determine the strength of the 1RM bench press and deep squat is shown in Figure 1 below. The protocol was applied until the participant could not perform one repetition lift, and the weight at which the participant achieved one repetition lift was recorded as 1RM force. At each test stage, the co-researcher was present to ensure the appropriate bar lifting and lowering motion angle and width, and the participants were verbally motivated during the lifting.

Figure 1.
Measurement Protocol Flowchart

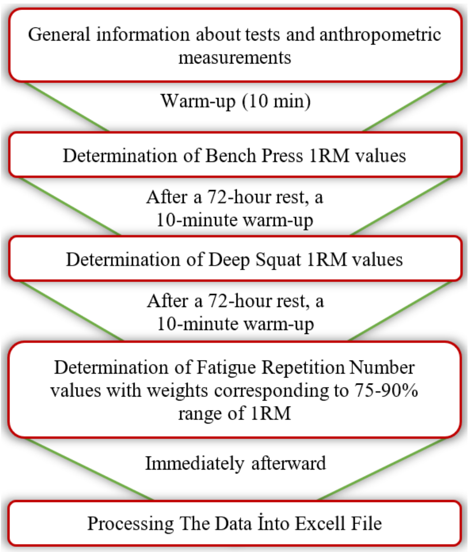
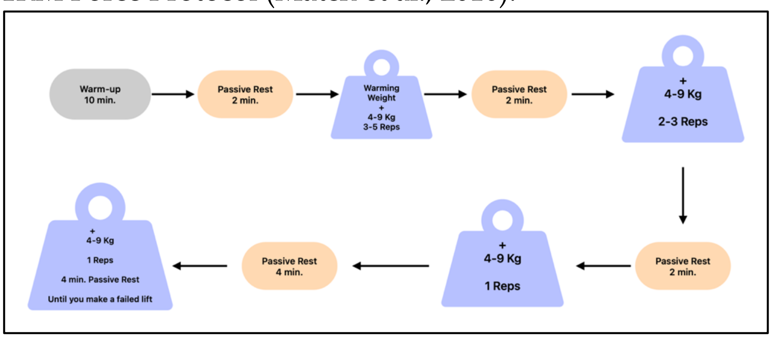


Figure 2.
1RM Force Protocol (Match et al., 2016).



Bench Press Protocol

After warming up, the participants lay on their backs on the bench with their knees in half flexion and their feet on the floor. They started with a pronation grip with the bar under the eyes at a broader range than shoulder level. After the bar was placed at the participant's chest level with the support of the assistant researcher, the participant lowered the bar with the wrists fixed and the forearms perpendicular to the floor until it touched the nipples. After that, he pushed the bar until his elbows were fully extended without arching his waist and bringing his chest closer to the bar.

Figure 3.
Bench Press Protocol

Deep Squat Protocol

To perform the deep squat, participants placed an Olympic barbell with plates horizontally on their shoulders. Feet were positioned shoulder-width apart and turned slightly outward (10–30°). The grip was adjusted so that the ring fingers aligned with the marked point on the bar. During the movement, the knees flexed to approximately 120–130° before returning to the starting position (Yüksel et al., 2019). A neutral spine posture was maintained, and the trunk remained upright with minimal forward lean. Participants inhaled during the descent and exhaled on the ascent to ensure proper breath control.

Fatigue Repetition Count Protocol (FRC)

The FRC protocol was performed 72 hours after the 1RM test in the same laboratory setting and using the same equipment. Before the FRC procedure, participants completed a 10-minute warm-up with light weightlifting exercises (5–10 repetitions) targeting both upper and lower extremities, followed by 2 minutes of passive rest (Willardson, 2006; Ratamess et al., 2007). They then assumed the starting position used in the 1RM test. Participants performed the movement repetitively using a load corresponding to 70–90% of their measured 1RM. The tempo of each repetition was controlled using a metronome (Wittner Taktell Piccolo, Germany), with 1-second eccentric and 1-second concentric phases (2 seconds per repetition). The exercise continued until volitional fatigue. Verbal encouragement was provided throughout. If a participant performed more than 10 repetitions at a given load, they rested for 5 minutes, and the test was repeated with an additional 4–9 kg until the number of repetitions was ≤10 (Macht et al., 2016).

Additionally, participants were asked to report their perceived exertion after each set using a 10-point RPE (Rate of Perceived Exertion) scale; however, these values were not included in the final analysis.

Figure 4.
Deep Squat Protocol

Predict a Repetition Maximal with Formulas

In the study, 15 different formulas selected from the literature were used. Eleven of these formulas are linear functions (formulas P1, P2, P3, P4, P5, P7, P8, P11, P12, P13 and P15) and four are exponential functions (formulas P6, P9, P10 and P14). The formulas are listed in Table 2 (Adams, 1998; Berger, 1970; Brown, 1992; Brzycki, 1993; Cummings & Finn, 1998; Kemmler et al., 2006; Kravitz et al., 2003; Lander, 1985; Macht et al., 2016; Mayhew et al., 1992; O’Connor et al., 1989; Tucker et al., 2006; Wathen, 1994; Welday, 1988).

Table 2.
Formulas for Estimating 1 Repetition Maximum (1RM) Strength Based on Fatigue Repetition Count (FRC) and Repetition Weight Load (RWL)

		Formulas to Predict 1 Repetition Maximum Strength
P1	Adams, 1998	RWL/(1-0,02xFRC)
P2	Berger, 1970	1RM (kg)= RWL / (1,0261- 0,00262 x FRC)
P3	Brown, 1992	1RM (kg)= 1RM (kg)= (FRC x 0,0338 + 0,9849) x RWL
P4	Brzycki, 993	1RM (kg)= RWL / (1,0278 - 0,0278 x FRC)
P5	Cummings & Finn, 1998	1RM (kg)= 1,175 x RWL + 0,839 x FRC - 4,29787
P6	Kemmler et al., 2006	1RM (kg)= RWL x (0,988 + 0,0104 x FRC + 0,0019* FRC2 - 0,0000584*FRC3)
P7	Kravitz et al., 2003	1RM= 90,66 + (0,085 x FRC x RWL) + (-5,306 x FRC)
P8	Lander, 1985	1RM (kg)= RWL / (1,013 - 0,0267 123 x FRC)
P9	Lombardi, 1989	1RM (kg)= FRC0,1 x RWL
P10	Mayhew et al., 1992a	1RM (kg)= RWL / (0,522 + 0,419xe-0,055* FRC)
P11	Macht et al., 2016	1RM (kg)= 1,17 x RWL + 2,15 x FRC + 12,31
P12	O'Connor et al., 1989	1RM (kg)= 0,025 x (RWL x FRC) + RWL
P13	Tucker et al., 2006	1RM (kg)= 1,139 x RWL + 0,352 x FRC + 0,243
P14	Wathen, 1994	1RM (kg)= RWL / (0,488 + 0,538 xe-0,075*FRC)
P15	Welday, 1988	1RM (kg)= (FRC x 0,0333) x RWL + RWL

Data Analysis

The conformity of the data to normal distribution was evaluated by histogram, Q-Q graphs, and the Shapiro-Wilk test. The homogeneity of variance was tested using Levene's test. An independent two-sample t-test was applied to quantitative variables in intergroup comparisons. A paired t-test was used to evaluate the agreement between repeated paired measurements. Bland-Altman plots, ICC (Intraclass correlation coefficient), and CCC (Concordance correlation coefficient) correlation coefficients were used to evaluate the agreement of the measurements. 0.00-0.50: poor, 0.51-0.75: moderate, 0.76-0.90: good, 0.91-1.00: excellent (Koo & Li, 2016). Data analysis was performed using R software (Version 4.4.1; R Core Team, www.r-project.org (Team, 2024)) and MedCalc software (Version 20; MedCalc Software Ltd., www.medcalc.org (Software, 2024)). The significance level was accepted as $p<0.05$.

RESULTS

According to the analyses given in Table 3, significant differences ($p<0.05$) were found between the measurements of the 1RM method and P1, P2, P3, P4, P6, P7, P8, P11, and P12 formulas in males. It was observed that the 1RM averages were higher than P1, P2, P3, P4, P5, P6, P8, P9, P12, P13, formulas and lower than P5, P7, P8, P10, P11, P13, P14, and P15 formulas. P14 and P15 formulas were lower than the averages of P7 and P11 formulas. In female participants, while 1RM method showed significant differences with P2, P6, P7 and P11 formulas (p<0.05), 1RM mean was higher than P1, P2, P4, P6, P9 and P12.

Table 3.
Repeated analysis results of 1 RM values of Bench press force measured and predicted by the formula

Variables	Gender	
	Male (*n*=23)	**Female (*n*=23)**
Measured 1 RM	65.65±16.40	31.09±8.65
Adams, 1998	61.43±15.73*	29.92±7.96
Berger, 1970	54.32±14.08*	25.63±7.71*
Brown, 1992	63.77±16.34*	31.09±8.06
Brzycki, 1993	62.39±16.00*	31.03±8.18
Cummings & Finn, 1998	64.70±16.69	31.86±8.55
Kemmler et al., 2006	59.80±15.31*	29.05±7.71*
Kravitz et al., 2003	87.13±6.20*	68.31±15.04*
Lander, 1985	63.03±16.16*	31.28±8.22
Lombardi, 1989	64.48±16.55	30.73±8.46
Mayhew et al., 1992a	65.65±16.82	31.61±8.55
Macht et al., 2016	87.88±16.70*	57.35±9.70*
O'Connor et al., 1989	62.10±15.91*	30.02±8.03
Tucker et al., 2006	64.72±16.23	32.13±8.57
Wathen, 1994	64.43±16.52	31.42±8.07
Welday, 1988	64.46±16.51	31.39±8.17

* p<0.005 is significantly different from the measured 1RM.

According to the intraclass correlation results in Table 4, ICC values were quite high (>0.75) in all formulas for both male and female participants, indicating that the reliability of the formulas was high. However, it has been observed that the ICC value of P7 for women (0.510) exhibits low agreement. In terms of CCC agreement values, the formulas P1, P3, P5, P9, P11, P12, P13, P14, and P15 exhibited high agreement in both male and female participants (>0.90). However, it is observed that the CCC values in the P7 and P10 formulas are particularly low in women (0.059 and 0.125, respectively), indicating that the validity of these formulas for female participants is low.

According to the analyses presented in Table 5, significant differences were found among the P1, P2, P3, P4, P6, P7, P8, P11, and P12 formulas using the 1RM method for male participants (p<0.05). Additionally, the 1RM average is higher for the formulas P1, P2, P3, P4, P5, P6, P8, P9, P12, P13, P14, and P15, while it is lower for the formulas P7 and P11. These results indicate that some formulas are inconsistent with the measured 1RM values. In female participants, significant differences were identified among the formulas P2, P6, P7, P11, and P12 using the 1RM method (p<0.05). It was observed that the 1RM average is higher for the formulas P1, P2, P4, P6, P9, and P12, while it is lower for the formulas P5, P7, P8, P10, P11, P13, P14, and P15.

Table 4.
Bench press compatibility analysis results (ICC and CCC)

Variables	1RM			
	ICC(%95 CI)		CCC(%95 CI)	
	Male (*n*=23)	Female (*n*=23)	Male (*n*=23)	Female (*n*=23)
Adams, 1998	0.987 (0.970-0.995)	0.954 (0.892-0.981)	0.941 (0.879-0.972)	0.903 (0.791-0.957)
Berger, 1970	0.984 (0.962-0.993)	0.962 (0.910-0.984)	0.752 (0.605-0.850)	0.752 (0.581-0.860)
Brown, 1992	0.985 (0.964-0.994)	0.959 (0.903-0.983)	0.964 (0.917-0.984)	0.921 (0.826-0.965)
Brzycki, 1993	0.983 (0.961-0.993)	0.912 (0.792-0.963)	0.947 (0.886-0.976)	0.838 (0.658-0.928)
Cummings & Finn, 1998	0.990 (0.977-0.996)	0.954 (0.891-0.980)	0.979 (0.951-0.991)	0.908 (0.797-0.960)
Kemmler et al., 2006	0.986 (0.968-0.994)	0.961 (0.907-0.983)	0.909 (0.825-0.953)	0.895 (0.783-0.951)
Kravitz et al., 2003	0.755 (0.423-0.896)	0.510 (0.156-0.792)	0.236 (0.118-0.347)	0.059 (0.008-0.126)
Lander, 1985	0.984 (0.963-0.993)	0.919 (0.809-0.966)	0.956 (0.902-0.980)	0.850 (0.680-0.933)
Lombardi, 1989	0.988 (0.972-0.995)	0.971 (0.932-0.988)	0.974 (0.939-0.989)	0.943 (0.871-0.975)
Mayhew et al., 1992a	0.988 (0.972-0.995)	0.969 (0.926-0.987)	0.499 (0.324-0.640)	0.125 (0.035-0.212)
Macht et al., 2016	0.984 (0.962-0.993)	0.792 (0.510-0.912)	0.976 (0.946-0.990)	0.937 (0.858-0.973)
O'Connor et al., 1989	0.988 (0.971-0.995)	0.965 (0.917-0.985)	0.952 (0.890-0.978)	0.924 (0.834-0.966)
Tucker et al., 2006	0.990 (0.977-0.996)	0.967 (0.923-0.986)	0.979 (0.951-0.991)	0.930 (0.843-0.969)
Wathen, 1994	0.983 (0.961-0.993)	0.961 (0.907-0.983)	0.964 (0.918-0.985)	0.923 (0.831-0.966)
Welday, 1988	0.985 (0.965-0.994)	0.960 (0.906-0.983)	0.968 (0.927-0.986)	0.923 (0.829-0.966)

ICC: Intraclass Correlation Coefficient, **CCC:** Concordance Correlation Coefficient, **CI:** Confidence Interval.

According to the intraclass correlation results in Table 6, it was observed that the formulas had high ICC values (>0.75) in both male and female groups, indicating that the formulas had good or excellent reliability. However, the P7 formula showed low ICC values in men (0.728) and women (0.737), indicating that this formula is less reliable than the others. In the CCC agreement assessment, formulas P1, P3, P5, P8, P9, P11, P12, P13, P14 and P15 showed good or excellent agreement in both gender(>0.75). Formulas P7 and P10 showed less reliability, especially for female participants (0.192 and 0.471, respectively), indicating that the validity of these formulas is low. The P7 and P10 formulas, particularly in female participants, demonstrated low conformity values (0.192 and 0.471, respectively), indicating that the validity of these formulas is low.

Table 5.
Results of repeated analyses of measured and formula-predicted Deep Squat strength 1RM values

Variables	Gender	
	Male (*n*=23)	Female (*n*=23)
1-RM	96.36±20.83	51.82±17.43
Adams, 1998	92.67±20.59*	47.12±15.49*
Berger, 1970	81.33±18.67*	41.14±13.81*
Brown, 1992	96.38±21.38	49.07±16.14
Brzycki, 1993	94.49±20.91	48.16±15.74
Cummings and Finn, 1998	97.06±22.13	49.53±16.19
Kemmler et al., 2006	90.27±20.04*	45.89±15.07*
Kravitz et al., 2003	99.59±7.67	79.69±9.77*
Lander, 1985	95.43±21.12	48.62±15.90
Lombardi, 1989	96.92±21.67	49.25±16.42
Mayhew et al., 1992a	98.91±22.05*	50.25±16.61
Macht et al., 2016	120.59±22.00*	73.68±16.17*
O'Connor et al., 1989	93.62±20.84*	47.59±15.70*
Tucker et al., 2006	95.92±21.55	49.70±15.81
Wathen, 1994	97.45±21.62	49.64±16.34
Welday, 1988	97.39±21.61	49.58±16.32

* p<0.005 significantly differs from the measured 1RM.

The Bland-Altman graphing method was restricted to formulae that provided predictions similar to the measured 1RM value. The bench press formulae for men were consistent with the measured 1RM bench press values, which were P5 (Bias:0.9, LoA;-5.5/7.3), P9 (Bias.1.2, LoA;-5.9/8.2), P10 (Bias;-0.0, LoA;-7.1/7.1), P13 (Bias;0.9, LoA;-5.4/7.2), P14 (Bias;1.2, LoA;-7.0/9.5) and P15 (Bias;1.2, LoA;-6.6/9.0), (Figure 5). Compatible bench press formulae for women are P1 (Bias;1.2, LoA;-5.7/8.0), P3 (Bias;0.0, LoA;-6.5/6.5), P4 (Bias;0.1, LoA;-9.4/9.3), P5 (Bias;-0.8, LoA;-7.9/6.3), P8 (Bias;-0.2, LoA;-9.3/8.9), P9 (Bias;0.4, LoA;-5.3/6.0), P10 (Bias;0.5, LoA;6.4/5.4), P12 (Bias;1.1, LoA;-5.0/7.1), P13 (Bias;-1.0, LoA;-7.0/5.0), P14 (Bias;-0.3, LoA;-6.7/6.1) and P15 (Bias;1.1, LoA;-5.0/7.1), (Figure 6). The male deep squat formulae that gave similar results with the measured 1RM deep squat value were P3 (Bias;-0.0, LoA;-11.6/11.6), P4 (Bias;1.9, LoA;-10.5/14.3), P5 (Bias;-0.7, LoA;-9.3/7.9), P8 (Bias;0.9, LoA;-11.2/13.1), P9 (Bias;-0.6, LoA;-10.4/9.3), P13 (Bias;0.4, LoA;-7.6/8.5), P14 (Bias;-1.1, LoA;-13.6/11.4) and P15 (Bias;-1.0, LoA;-12.6/10.5), (Figure 7). The female deep squat formulae were P3 (Bias;3.7, LoA;-10.8/18.1), P4 (Bias;2.8, LoA;-11.4/16.9), P5 (Bias;2.3, LoA;-11.5/16.1), P8 (Bias;3.2, LoA;-11.2/17.6), P9 (Bias;2.6, LoA;-11.3/16.4), P10 (Bias;1.6, LoA;-12.3/15.5), P13 (Bias;2.1, LoA;-11.6/15.8), P14 (Bias;2.2, LoA;-12.2/16.5) and P15 (Bias;2.2, LoA;-11.9/16.4),

(Figure 8). According to the results of the Bland-Altman graphs, a general agreement is observed between the measured 1RM values and the predicted 1RM values. Therefore, it is concluded that the measured 1RM values and the formulas provide compatible and reliable predictions.

Table 6.
Deep squad compatibility analysis results (ICC and CCC)

Variables	1RM			
	ICC(%95 CI)		CCC(%95 CI)	
	Male (n=23)	Female (n=23)	Male (n=23)	Female (n=23)
Adams, 1998	0.985 (0.965-0.994)	0.951 (0.882-0.980)	0.955 (0.900-0.981)	0.869 (0.729-0.940)
Berger, 1970	0.988 (0.971-0.995)	0.942 (0.861-0.976)	0.750 (0.598-0.849)	0.717 (0.527-0.839)
Brown, 1992	0.980 (0.952-0.992)	0.951 (0.883-0.980)	0.961 (0.908-0.983)	0.895 (0.769-0.954)
Brzycki, 1993	0.977 (0.943-0.990)	0.948 (0.875-0.978)	0.950 (0.885-0.979)	0.879 (0.742-0.945)
Cummings and Finn, 1998	0.989 (0.975-0.996)	0.954 (0.890-0.981)	0.979 (0.951-0.991)	0.904 (0.787-0.958)
Kemmler et al., 2006	0.985 (0.963-0.994)	0.949 (0.877-0.979)	0.927 (0.848-0.965)	0.844 (0.691-0.925)
Kravitz et al., 2003	0.728 (0.346-0.887)	0.737 (0.367-0.891)	0.560 (0.431-0.667)	0.192 (0.060-0.318)
Lander, 1985	0.978 (0.946-0.991)	0.949 (0.877-0.979)	0.955 (0.896-0.981)	0.886 (0.754-0.949)
Lombardi, 1989	0.986 (0.966-0.994)	0.955 (0.891-0.981)	0.972 (0.935-0.988)	0.902 (0.784-0.957)
Mayhew et al., 1992a	0.986 (0.967-0.994)	0.955 (0.891-0.981)	0.579 (0.397-0.717)	0.471 (0.273-0.630)
Macht et al., 2016	0.983 (0.959-0.993)	0.940 (0.856-0.975)	0.965 (0.922-0.985)	0.909 (0.796-0.961)
O'Connor et al., 1989	0.986 (0.966-0.994)	0.952 (0.884-0.980)	0.964 (0.916-0.984)	0.879 (0.744-0.945)
Tucker et al., 2006	0.991 (0.977-0.996)	0.954 (0.889-0.981)	0.981 (0.956-0.992)	0.904 (0.790-0.958)
Wathen, 1994	0.977 (0.944-0.990)	0.951 (0.882-0.980)	0.954 (0.893-0.980)	0.898 (0.775-0.956)
Welday, 1988	0.980 (0.953-0.992)	0.952 (0.884-0.980)	0.960 (0.908-0.983)	0.900 (0.779-0.956)

ICC: Intraclass Correlation Coefficient, **CCC:** Concordance Correlation Coefficient, **CI:** Confidence Interval.

Figure 5.
Bland-Altman plot for bench press measured and predicted 1RM (male)

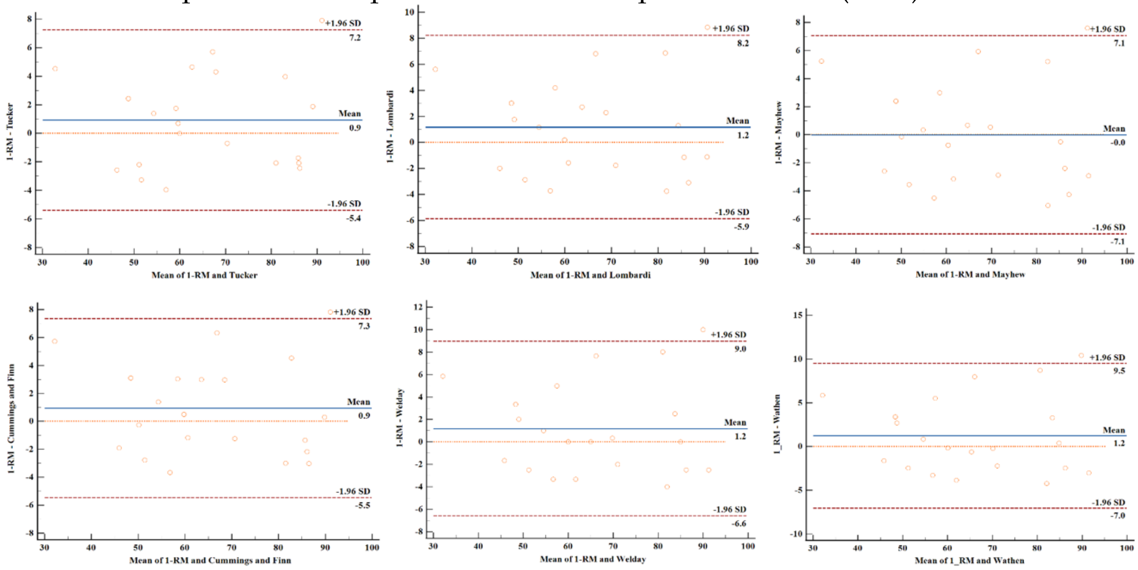


Figure 6.
Bland-Altman plot for bench press measured and predicted 1RM (female)

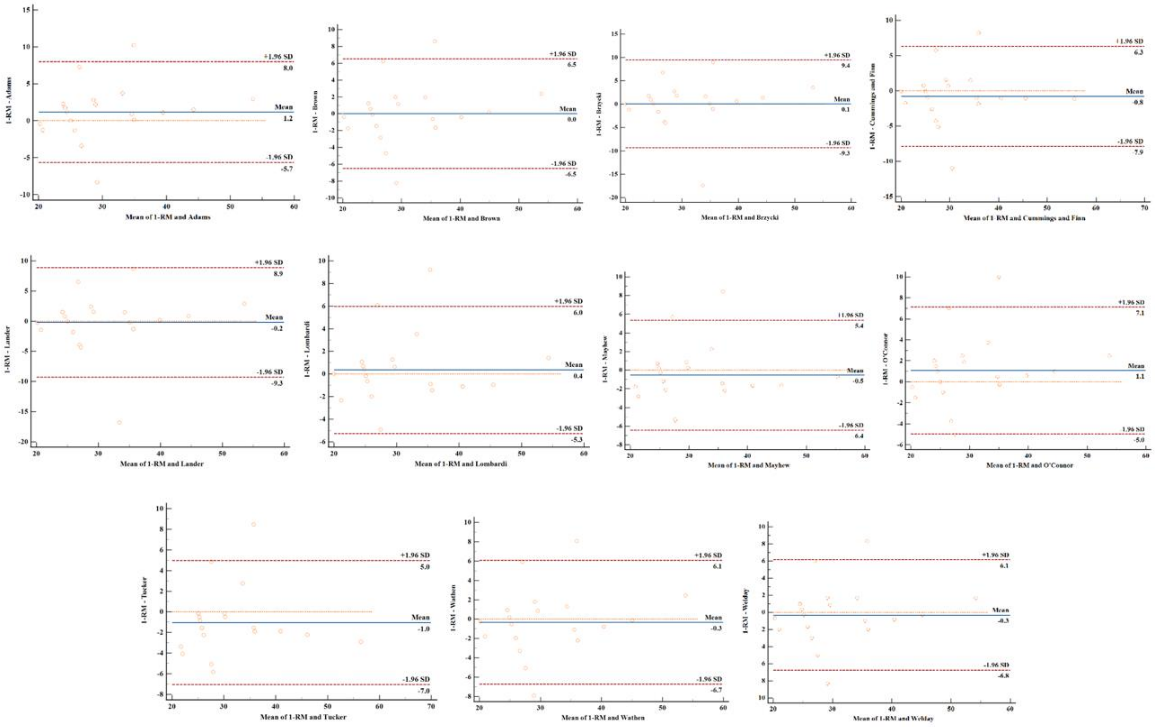


Figure 7.
Bland-Altman plot for deep squat measured and predicted 1RM (male)

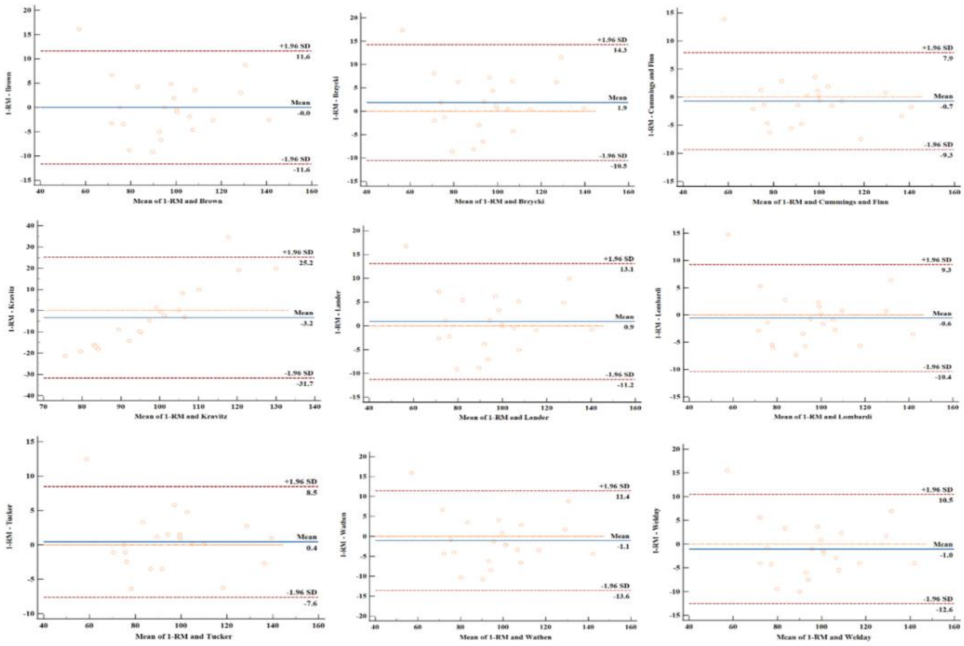
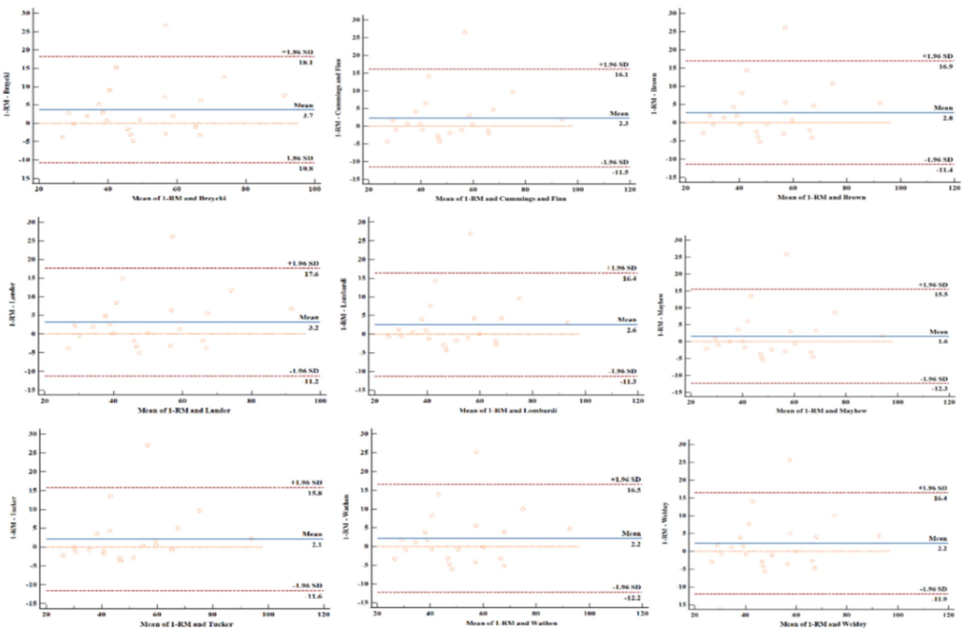


Figure 8.
Bland-Altman plot for deep squat measured and predicted 1RM (male)



Note: All Bland-Altman plots illustrate the agreement between measured and formula-predicted one-repetition maximum (1RM) values. The X-axis represents the mean of the measured and predicted values (kg), and the Y-axis represents the difference between them (kg). Solid lines indicate the mean bias, and dashed lines represent the 95% limits of agreement (±1.96 SD).

DISCUSSION

The aim of the study was to determine the validity of formulas predicting 1RM bench press force, which is widely used in the assessment of upper extremity dynamic strength, and deep squat force, which is widely used in the assessment of lower extremity dynamic strength, in recreationally active young male and female individuals. In the literature, many formulas estimate 1RM force from maximal FRC using submaximal weight. These formulas had higher predictive power, especially when FRC ≤10 (Hart et al., 1991; Mayhew et al., 1992b; Mayhew et al., 2008).

In this study, among the 15 formulas estimating 1RM, 9 formulas (P1, P2, P3, P4, P6, P7, P7, P8, P11, P12) estimating male bench press strength, and 4 formulas (P2, P6, P7, P11) in female participants were found to be different from the measured 1RM strength (Table 3), and the coefficient of concordance, in other words, the accuracy level was found to be low (Table 4). Predictive values of the formulas similar to the measured 1RM male bench press force (P5, P9, P10, P13, P14, P15) and the formulas similar to the female bench press force (P1, P3, P4, P5, P8, P9, P10, P12, P13, P14, P15) were also in the 'high' category (ICC=≥0.75), indicating that these formulas are valid for determining 1RM strength of recreationally active young female and male participants and can be used interchangeably.

These findings suggest that while several formulas are appropriate for estimating 1RM in both sexes, others demonstrate inconsistent results—particularly in females. These inconsistencies are in line with findings by Pioske et al. (2025), who reported that several commonly used equations over- or under-estimated 1RM in recreationally active men, further reinforcing the need for careful selection and validation of prediction models. Notably, formulas such as P2, P6, P7, and P11 showed significantly lower agreement with measured 1RM values in female participants. One possible explanation for this discrepancy is that many 1RM prediction formulas were originally developed and validated using predominantly male samples. As a result, these equations may not fully account for physiological and biomechanical differences observed in females, such as differences in muscle fiber composition, hormonal profiles, neuromuscular activation patterns, and fatigue resistance. Similarly, Tan et al. (2015) highlighted the need to develop population-specific prediction models, showing that age- and sex-based differences significantly influence 1RM estimations. In addition, formulas with complex interaction terms (e.g., combining repetition count and load, as in P7) may amplify predictive errors when applied to populations with different strength profiles and training histories. These factors may help explain why certain formulas underperformed in estimating 1RM in females, highlighting the need for sex-specific validation in predictive modeling.

Similar to the method of our study, Mayhew et al. (2004) reported that 10 of the 15 formulas (P1, P2, P3, P4, P8, P9, P10, P12, P14, and P15) showed a high correlation (r=0.96), but only P4 and P9 had similar predictions to the measured 1RM strength. These results show that some estimation methods have low agreement and do not give reliable results, while others give consistent and reliable results (Mayhew et al., 2004). In a study conducted by Hazır et al. in 2019 with young men, 16 formulas used in sports sciences were used. They reported that 10 of the 16 formulas used to predict 1RM were accurate and valid, and they also reported that Lombardi's 1RM strength was the best-predicting formula (Hazır et al., 2019). In another similar study conducted in female university students, it was reported that 9 out of 14 formulas (P3, P4, P5, P7, P8, P9, P11, P13 and P14) used for the prediction of 1RM strength before strength training applied 3 days a week for 12 weeks and 5 out of 14 formulas (P5, P9, P12, P13 and P14) after 12 weeks of strength training gave reliable results compatible with the measured 1 RM (Mayhew et al., 2008). In a study conducted by Knutzen et al. (199) with a group of elderly individuals, the validity of 6 1 RM prediction formulas with 11 machine lifts was examined. They concluded that there was a correlation (upper limb: r = 0.77-0.90; lower limb: r = 0.60-0.80) between measured and predicted 1 RM values in all exercises. The predicted mean 1RM value was lower than the actual 1RM value for all exercises and all prediction equations (p< 0.001). As a result, they concluded that the estimation equation underestimates the actual 1RM (Knutzen et al., 1999). Another study aimed to test the cross-validation of existing 1RM prediction equations in men with spinal cord injury. In the study of 45 28-year-old men, multiple regression analysis was used to create an equation to presdict 1RM. The result was that no significant difference was found between the 1RM test and the existing predictive equations. ICC values were also classified as significant and excellent for all available predictive equations. Lombardi's estimation method provided the best Bland-Altman results (Ribeiro Neto et al., 2017).

In our current study, it was found that 5 of the 15 formulas (P1, P6, P10, P11, P12) predicting 1RM male deep squat strength, and six formulas (P1, P2, P6, P7, P11, P12) in female participants were different from the measured 1RM strength (Table 5) and the coefficient of agreement was low (Table 6). Predictive values of the formulas similar to the measured 1RM male deep squat force (P2, P3, P4, P5, P7, P8, P9, P13, P14, P15) and the formulas similar to the female deep squat force (P3, P4, P5, P8, P9, P10, P13, P14, P15) were in the 'high' category

(ICC=≥0.75), indicating that these formulas are valid and can be used interchangeably to determine 1RM deep squat strength of recreationally active young male and female participants. In the literature, using estimation formulae is a common and accepted alternative when the 1RM value cannot be measured directly or when conditions are unsuitable. 1RM tests are recognized as a reliable and valid measure of strength in various populations, and predictions made by these methods are frequently preferred in sports sciences, especially in field studies and gymnasium settings. Most formulae provide force estimation by calculating according to a specific loading and number of repetitions. For example, maximum force can be reliably estimated in load-velocity tests using velocity data at submaximal loads for lower-limb exercises (squat) or upper-limb exercises (bench press). These methods can provide reliable results without requiring direct 1RM testing (Baker & Newton, 2008; Jaric, 2002; Mayhew et al., 2004). 1RM prediction formulae have been supported by studies in individuals of different age groups, gender, and fitness levels (Hazır et al., 2019; Knutzen et al., 1999; Mayhew et al., 2004; Mayhew et al., 2008). Prediction formulas, selected according to the type of loading in various strength tests, provide reliable and comparable measurements in strength training or rehabilitation, and some formulae can be used in place of a single repetition maximum test.

These findings are consistent with previous literature supporting the use of 1RM prediction formulas as practical tools when direct measurement is not feasible. Prediction formulas, selected according to the type of loading in various strength tests, provide reliable and comparable measurements in strength training or rehabilitation, and some formulae can be used in place of a single repetition maximum test.

In line with these conclusions, recent studies have further emphasized the reliability and validity of 1RM prediction equations across different populations and exercises. For instance, Ribeiro et al. (2024) assessed the accuracy of nine prediction equations for bench press, squat, and biceps curl exercises before and after a 16-week resistance training program. They found that certain formulas demonstrated greater accuracy, especially in female participants. Similarly, Picerno et al. (2016) introduced a novel method based on force–velocity and load–velocity relationships, which provided highly accurate estimates of 1RM in both upper- and lower-body exercises. Ruf et al. (2017) validated the use of load–velocity profiling in the deadlift, confirming its short-term reliability and validity. Additionally, Tan et al. (2015) developed specific equations for older adults and confirmed their predictive accuracy for 1RM estimation in exercises such as the bench press and squat. Collectively, these findings support the continued—but selective—use of prediction equations in various populations and reinforce the importance of contextual validation when applying such models in field or clinical settings.

Limitations

Limitations of this study include the fact that the participant group consists of only recreationally active young men and women. Furthermore, the findings of this study to assess the validity of the 1RM prediction formula used in a specific population have not been tested on individuals across different exercise types and a wider range of training levels. Finally, the estimation formula used may have limited sensitivity to individual differences as they do not consider body build and muscle mass characteristics. Considering these limitations, it is recommended that future studies be conducted with more diverse participant profiles and different exercise protocols.

CONCLUSION

As a result of the findings obtained in this study, it was concluded that 1RM force estimations in recreationally active young male and female individuals can be reliably applied with certain formulas. For the bench press, the P2 (Berger, 1970) and P6 (Kemmler et al., 2006) formulas provided the closest predictions to 1RM force in female participants, while the P5 (Cummings & Finn, 1998)) and P10 (Mayhew (Mayhew et al., 1992b) formulas were similarly successful in male participants. On the other hand, in the deep squat test, formulas P3 (Brown, 1992)) and P4 (Brzycki, 1993)) provided the best predictions for women, while formulas P1 (Adams, 1998) and P12 (O'Connor et al., 1989) showed high agreement for men. These findings indicate that the formula provided reliable alternatives for predicting 1RM strength in both genders and is considered an important basis for improving the effectiveness of strength training in sports sciences.

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Authors' Contribution

M.Y: The conception and design of the study and data collection contributed to the final approval of the published version. O.D: Conception and design of the study, data analysis, and interpretation contributed to the final approval of the version to be published. All authors have read and approved the published version of the article. All authors have read and approved the published version of the article. E.I: Conception and design of the study, article critical revision, and contributed to the final approval of the version to be published. All authors have read and approved the published version of the article. M.I.; Conception and design of the study, data collection, and contributed to the final approval of the version to be published. All authors have read and approved the published version of the article. H.C.: Conception and design of the study, data analysis and interpretation, article critical revision, and contributed to the final approval of the version to be published. All authors have read and approved the published version of the article.

Declaration of Conflict Interest

The authors declare no conflict of interest concerning this article's authorship and/or publication.

Ethics Statement

This study was approved by Nevsehir Hacı Bektaş Veli University Scientific Research Ethics Committee on 06/09/2024 with the number 240008185

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