วารสารวิทยาศาสตร์และเทคโนโลยีการกีฬา ปีที่ 21 ฉบับที่ 1, กรกฎาคม 2564

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PREDICTION OF BENCH PRESS ONE REPETITION MAXIMUM USING AN ACCELEROMETER

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ABSTRACT

The purpose of this study was 1) to develop a predictive equation for calculating bench press one repetition maximum (1RM) via measurement of lifting velocity using accelerometry, and 2) subsequently test the validity of the predictive equation. A total of 31 healthy males (age ranged 18-35 years) who regularly performed resistance training and bench press exercise for at least 6 months were recruited. The anthropometric data of each participant were collected prior to the participants having their 1RM of a bench press assessed using both direct (NSCA protocol) and indirect (load-velocity relationship using accelerometer) methods. Linear regression was performed to establish the relationship between barbell velocities and the distinct 1RM percentages. To validate the actual 1RM (direct method) and predicted 1RM (indirect method) methods, a paired *t*-test was employed to compare the two methods. Pearson's correlation coefficients and the Coefficients of determination (R^2) between the actual 1RM and predicted 1RM were calculated. Bland-Altman's method was used to evaluate the agreement between the actual 1RM and the predicted 1RM estimated. The obtained equation from the load-velocity relationship was: $y = -80.53x + 113.35$; $R^2 = 0.869$; where y represents the percentage of RM and x represents the measured velocity during the 1RM attempt. This relationship was used to formulate a predictive 1RM equation as follows: 1RM = 100 x (load /% RM); where load is defined as weight used during the concentric contraction phase by using an average of 3 repetitions. The predictive equation was found to have high validity ($R^2 = 0.89$) compared to the direct method. The agreement between the different measurement methods was assessed using a Bland-Altman plot, and demonstrated the obtained 1RM values of the predictive equation to be within the upper and lower limits of agreement (LOA). Therefore, it is concluded that the predictive equation possessed high validity and can be used to accurately calculate 1RM. It is expected that the predictive equation may be used to assist sport practitioners and clinicians in the design and monitoring of resistance training programs.

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การคาดการณ์ของน้ำหนักสูงสุดที่สามารถยกได้เพียงหนึ่งครั้งในท่านอนดันด้วยการใช้อุปกรณ์วัดความเร่ง

ขวัญ ศรีจันทร์ทับ, วีรวัฒน์ ลิ้มรุ่งเรืองรัตน์, คริสโตเฟอร์ โมวินนีย์, สายฝน กองคำ*

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บทคัดย่อ

วัตถุประสงค์ของการศึกษาครั้งนี้คือ 1) เพื่อพัฒนาสมการทำนายน้ำหนักสูงสุดที่สามารถยกได้เพียงหนึ่งครั้งด้วยอุปกรณ์วัดความเร่งในท่านอนดัน 2) เพื่อทดสอบความเที่ยงตรงของสมการทำนายน้ำหนักสูงสุดที่สามารถยกได้เพียงหนึ่งครั้งที่ได้จากการศึกษา อาสาสมัครเพศผู้ชาย 31 คน อายุระหว่าง 18-35 ปี เข้าร่วมการศึกษาในครั้งนี้ โดยอาสาสมัครมีประวัติการฝึกด้วยแรงต้านและเทคนิคการยกท่านอนดันที่ถูกต้องเป็นเวลาอย่างน้อย 6 เดือน ในวันทดสอบข้อมูลทางกายภาพของอาสาสมัครจะถูกวัด หลังจากนั้นอาสาสมัครทุกคนจะได้รับการทดสอบเพื่อหาค่าน้ำหนักสูงสุดที่สามารถยกได้เพียงหนึ่งครั้งในท่านอนดันโดยใช้วิธีวัดทางตรง (วิธีการของ NSCA) และทางอ้อม (หาความสัมพันธ์ของน้ำหนักและความเร็วด้วยอุปกรณ์วัดความเร่ง) ใช้การถดถอยเชิงเส้นเพื่อสร้างความสัมพันธ์ระหว่างความเร็วของบาร์เบลล์และเปอร์เซ็นต์ 1RM เพื่อตรวจสอบความถูกต้องของ 1RM ที่แท้จริง (การวัดโดยตรง) และจากการคำนวณ 1RM (วิธีทางอ้อม) ใช้การทดสอบด้วย paired t-test เพื่อเปรียบเทียบค่าที่ได้จากทั้งสองวิธี จากนั้นคำนวณหาค่าสัมประสิทธิ์สหสัมพันธ์ของเพียร์สัน และค่าสัมประสิทธิ์แสดงการตัดสินใจ (R^2) ระหว่าง 1RM ที่แท้จริงและ 1RM จากการคำนวณ ใช้ Bland-Altman ในการหา agreement ระหว่าง 1RM ที่แท้จริงและ 1RM จากการคำนวณ

จากผลลัพธ์ที่ได้ สมการความสัมพันธ์ของน้ำหนักและความเร็ว คือ $y = -80.53x + 113.35$ ($R^2 = 0.869$) ในขณะที่ y คือเปอร์เซ็นต์น้ำหนักสูงสุดที่สามารถยกได้เพียงหนึ่งครั้ง และ x คือความเร็วที่วัดได้ในการยกน้ำหนักที่ใช้ในการทดสอบนั้นๆ สมการจากความสัมพันธ์นี้ถูกนำมาใช้เพื่อสร้างสมการทำนายน้ำหนักสูงสุดที่สามารถยกได้เพียงหนึ่งครั้งในท่านอนดันคือ 1RM = 100 x (load /% RM) ในขณะที่ load เป็นน้ำหนักที่ใช้ในช่วงการยกที่กล้ามหดตัวแบบสั้นลง โดยใช้ค่าเฉลี่ยที่ยกได้ 3 ครั้ง ความเที่ยงตรงของสมการทำนายเมื่อเปรียบเทียบกับวิธีวัดทางตรงพบว่า มีความเที่ยงตรงสูงโดยมีค่าสัมประสิทธิ์สหสัมพันธ์เท่ากับ 0.89 นอกจากนั้นผลจากกราฟ Bland-Altman ยังแสดงให้เห็นว่าค่าน้ำหนักสูงสุดที่สามารถยกได้เพียงหนึ่งครั้ง ที่ได้จากสมการทำนายนั้นอยู่ในขอบเขตบนและล่างของข้อตกลง ดังนั้นจึงสรุปได้ว่าสมการที่ได้จากการศึกษานี้มีความเที่ยงตรงในการทำนายน้ำหนักสูงสุดที่สามารถยกได้เพียงหนึ่งครั้ง และสามารถนำมาใช้เพื่อช่วยโค้ชหรือผู้ฝึกสอนส่วนบุคคลในการประเมินและออกแบบโปรแกรมการฝึกด้วยแรงต้านตามน้ำหนักสูงสุดที่สามารถยกได้เพียงหนึ่งครั้ง

(วารสารวิทยาศาสตร์และเทคโนโลยีการกีฬา 2564; 21(1)34-44)

คำสำคัญ : น้ำหนักสูงสุดที่สามารถยกได้เพียงหนึ่งครั้ง/ ท่านอนดัน/ ความแข็งแรงของกล้ามเนื้อ/ การฝึกด้วยพื้นฐานความเร็ว

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INTRODUCTION

The maximum weight that can be lifted in a single effort, on a selected exercise, is typically referred to as an individual's repetition maximum (1RM). The 1RM is extensively used in the prescription of resistance training to determine the relevant workload to improve muscular strength in athletes and the general population[1]. The assessment of 1RM can either be measured directly or indirectly using a maximal or submaximal effort, respectively[2]. In the direct 1RM assessment, progressively more weight is added over several attempts, starting from a light resistance, which permits a high number of repetitions to be achieved, up to the point where the subject can only complete a single repetition. Each attempt is separated by a rest period ranging between 2 to 4 minutes and requires a number of different weight plates to allow resistance increments of between 5 to 90 pounds to correctly identify the subject's true 1RM. Consequently, the direct 1RM method is time-consuming, with a spotter required during lifting attempts. Importantly, improper technique with the maximum (or near maximum) weight may lead to muscle injury[3-6]. Therefore, the direct method may not be suitable for untrained subjects due to the high loads increasing the potential for injury during testing[2].

The indirect 1RM method uses a submaximal load alongside the number of repetitions to calculate 1RM using an equation, thus, a maximal effort is not required. The equation used to calculate the 1RM is predicted either via number of repetitions performed until a failed attempt is attained using a higher submaximal load[7-9], or alternatively, a lower load that allows a higher number of repetitions until a failed attempt. Since the estimation error for predicting 1RM is greater in the latter method[8], higher submaximal loads that permit a lower number of performed repetitions are typically preferred in order to minimize calculation error.

Recently, 1RM measurement has been predicted using the relationship between bar speed and the load during a bench press test. The load-velocity relationship produces a linear pattern since when weight increases and approaches maximum weight, the bar's movement speed reduces to as low as zero[10]. This has led to previous investigations using linear position transducers and accelerometers to predict 1RM in bench press and squat exercises in well-trained athletes. The results showed a small coefficient of variation, making it possible to use these methods to predict 1 RM[11-13]. Furthermore, these studies have shown that the inclusion of velocity training, using different bar lifting speeds, results in specific muscle force velocity adaptations.

Predictive equations have been developed and used for 1RM determination across different exercises and muscle groups due to its benefits in lowering risk of injury and convenience. While the bench press is a common weight training exercise, it has a higher injury incidence rate than other exercises[15]. Despite this, to our knowledge, a 1RM prediction equation has not yet been developed and validated in Thai male subjects. Most of the previous studies were performed in different population (top-level athletes VS recreational weight trainers) who exhibited different anthropometric characteristics and employed different protocol (Free weight VS Smitch machine) and different measured device (a linear position transducer VS accelerometer) [11-13, 15]. Therefore, the purpose of this study was to determine the predictive equation of the 1RM bench press test using

the relationship between percent of RM and bar speed, and subsequently validate the predictive equations to using the direct 1 RM bench press method. We hypothesized that the predictive equation would be valid when compared to the direct 1RM bench press method.

MATERIALS AND METHODS

Thirty-one healthy males (age range 18-35 years old) volunteered to take part in this study. Sample size in this study has been prior calculated using the study of Loturco et al., 2017. Sample size was calculated using the G-Power program with R^2 value was 0.95 and the minimum number of data was 180 points. Each participant was able to provide at least 6 values per person. Therefore, 31 participants were use in this study. Participants who performed regular resistance training (>6 months) and demonstrated correct bench press technique were recruited. Participants who presented with a history of cardiovascular disease and/or major orthopedic conditions were excluded from the study. The participants completed a Physical Activity Readiness Questionnaire (PAR-Q) and their written informed consent to participate was attained after describing all test procedures and associated benefits and risks. This study was approved by the Ethical Committee of Mahidol University Institutional Review Board (MU-CIRB 2018/153.0608)

Experimental procedure

Participants were asked to attend the laboratory on a single occasion. Anthropometric data and history of musculoskeletal system injury and exercise training were recorded and a familiarization session was completed. The experimental testing consisted of 1RM determination using direct and indirect methods, with a predictive equation formulated using the obtained data. Participants were asked to refrain from alcohol and vigorous exercise for at least 48 hours prior to testing. The National Strength and Conditioning Association (NSCA) protocol was used as a gold standard to define 1RM, whereas an accelerometer attached to the forearm during the direct method was used to monitor bar velocity. The data was subsequently used to formulate the predictive equation.

1RM Conventional Testing

A Hammer Strength Olympic Flat Bench (Life Fitness, USA) was used for all 1RM testing. During the test, the accelerometer was attached to the forearm for bar velocity monitoring. On the test day, participants were required to perform a set of standardized stretching exercises, which included stretching and holding the arms behind the neck, followed by arms crossed in front of chest (15-30 s) at the range were little discomfort was perceived. The 1RM bench press testing protocol was performed according to the NSCA protocol[2] using the Hammer Strength Olympic Flat Bench (Life Fitness, USA). Briefly, testing started with a warm-up session using a light resistance that easily allowed 5 to 10 repetitions, and was followed by a 1-minute rest period. The load was increased with 10 to 20 pounds (4-9 kg) or 5-10%, which allowed the participant to complete 2 to 3 repetitions. After a 2-to 4-minute rest period, this step was repeated until 1 RM was achieved. If the participant

failed the 1RM attempt, the load was decreased by removing 5 to 10 pounds (2.3 to 4.5 kg), or 2.5 to 5%, for the participant to re-attempt a 1RM. During the test, the speed of barbell was monitored by an accelerometer (PUSH Band 2.0, Canada) by attaching the device to the forearm. The data obtained was used to determine the relationship between the load and velocity during the 1RM test.

STATISTICAL ANALYSIS

All data are presented as mean ± SD. The normality of data distribution was tested using a Shapiro-Wilk test. Linear regression was performed to establish the relationship between barbell velocities and the distinct 1RM percentages (i.e., predictive equation). To validate the actual 1RM (direct method) and predicted 1RM (indirect method) methods, a paired *t*-test was employed to compare the two methods. Pearson's correlation coefficients and the Coefficients of determination (R^2) between the actual 1RM and predicted 1RM were calculated. Bland-Altman's method was used to evaluate the agreement between the actual 1RM and the predicted 1RM estimated. This was achieved by plotting the distribution of the differences between the actual 1RM and predicted 1RM (Mean bias) against their respective average values. The level of significance was set at $P \leq 0.05$. All statistical analyses were performed using SPSS (version 23, SPSS Inc, Chicago, IL) and GraphPad Prism software (version 8.0, GraphPad Software, Inc. San Diego CA).

RESULTS

Participant characteristics

The participant characteristics are shown in Table 1.

Table 1. Physical characteristics of the participants. Data are presented as mean ± SD

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Characteristics	Mean ± SD
Age (year)	21.4 ± 2.58
Body weight (kg.)	77.79 ± 13.04
Height (cm.)	176.05 ± 5.78
% BF	12.10 ± 4.54

1RM measurement Relationship between %RM and velocity

The velocity and %RM recorded using the accelerometer during the 1RM bench press test is shown in Figure 1. The linear regression between velocity and %RM demonstrated a strong negative relationship with $r = -0.93$ ($R^2 = 0.87$) with higher loads decreasing the speed of barbell velocity.

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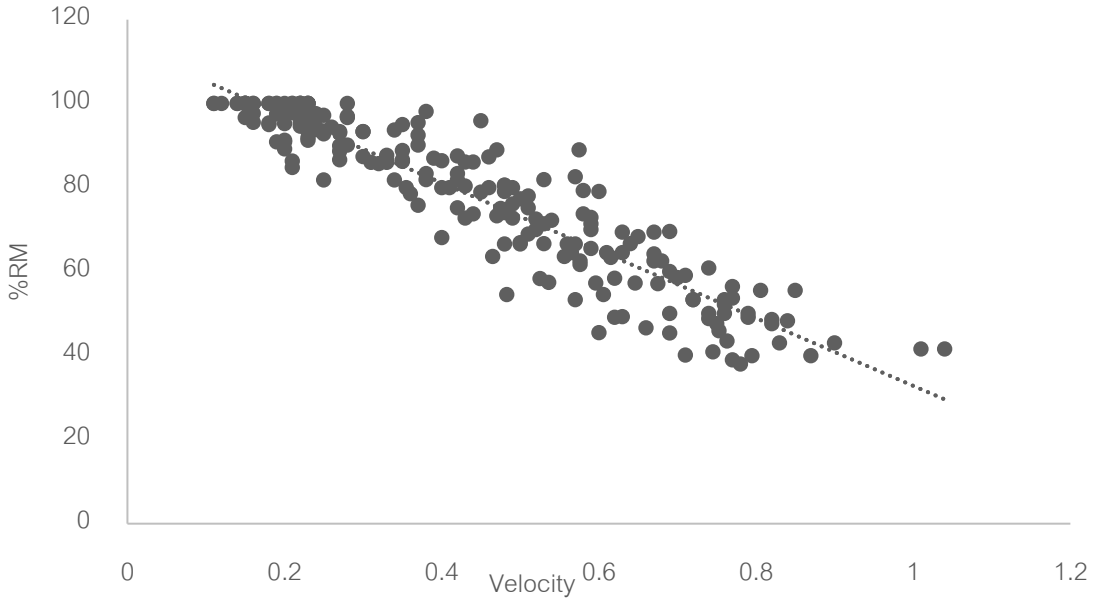

Figure 1. Linear relationship between percent RM & velocity

The linear regression equation between percent RM and velocity was; **y = -80.53x + 113.35**, where **x** represents the velocity and **y** represents the %RM. The aforementioned equation was used to formulate the predicted equation for 1RM as follows; **1RM = (100 x load) / % RM**, with the load being the weight used during the concentric contraction phase (an average 3 reps is recommended).

Validity of 1RM measurment

There was no significant difference in 1 RM found between the direct (81.72 ±18.54) and predicted (81.41 ± 16.56) 1 RM methods (P=0.793). The relationship between actual 1RM and predicted 1RM is shown in Figure 2. A significantly strong positive relationship existed between predicted 1 RM and actual 1 RM with r = 0.94 (R^2 = 0.89, P<0.001).

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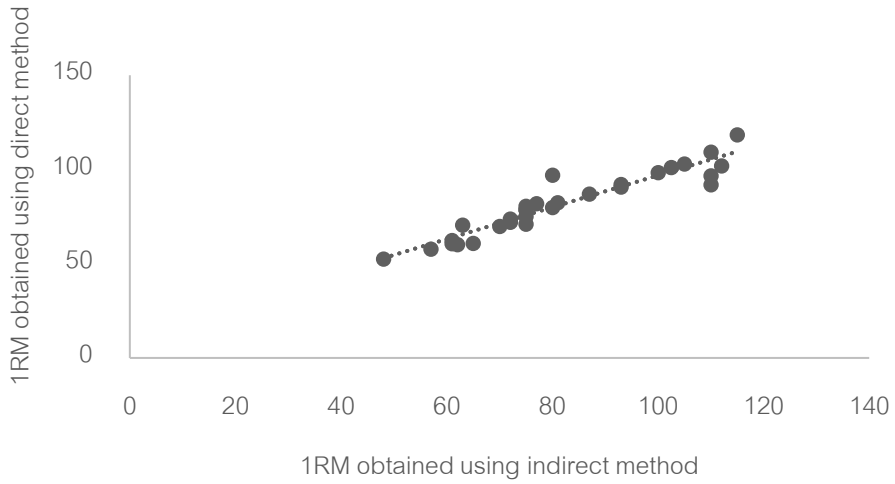

Figure 2. Linear regression of 1RM between the 1RM obtained from two methods.

The bias (difference) between the direct and indirect methods and the 95% limits of agreement (LOA) were performed to assess the degree of agreement between the two methods. The mean difference between the two methods in 1RM was 0.31 kg (±6.12). Therefore, the expected difference would be below (0.306 + [1.96 x 6.121]) and above (0.306 – [1.96 x 6.121]) the obtained upper (12.303) and lower LOA (-11.690); Figure 3.

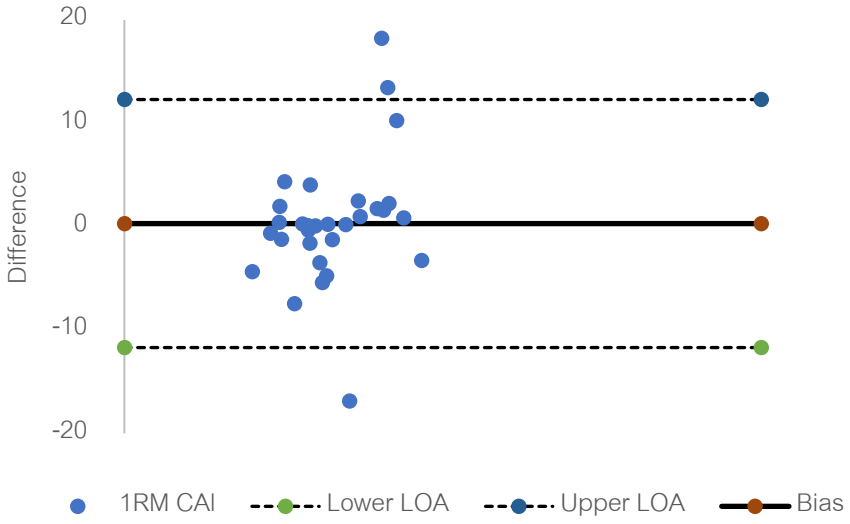

Figure 3. Bland-Altman plot of 1RM derived from the predictive equation

DISCUSSION

This study firstly aimed to formulate a predictive 1RM bench press equation using the relationship between % RM and barbell velocity. Secondly, we aimed to validate the predictive equation with the direct 1RM

bench press method. The results showed that the 1 RM obtained from the predictive equation did not differ from the actual 1RM obtained from direct method, with the predictive equation demonstrating a significantly strong relationship compared to the direct method.

1 RM measurement

The bench press exercise is one of the most popular exercises among athletes and recreational weight lifters, and is used as an indicator of upper body strength. The 1 RM is defined as the maximum weight that can be lifted in a single effort on a selected exercise[1]. The 1 RM can be measured using various methods, including the direct method and by indirectly estimating 1 RM using predictive equations[2]. However, the direct method is time consuming and exposes the athlete/individual to a higher risk of injury. Moreover, it can lead to a relatively large variation in the estimated 1 RM, especially when estimation is taken from a higher number of repetitions; as is the case with less experienced individuals[3-6]. Consequently, a predictive equation based on the load-velocity relationship has recently been developed and has gained increasing popularity[2].

In this study, an accelerometer was used to determine the bar velocity and formulate the predictive equation to determine the 1RM. The actual 1 RM and predicted 1 RM was not significantly different, with a trivial difference of 0.37% found between methods. Similar to the present study, Loturco *et al* [11] developed a predictive equation for the 1RM bench press from the load-velocity relationship using a liner transducer in a rugby player cohort. The results showed that 1RM calculated from predictive equation was within 0.59% and 1.02% of actual 1RM in the bench press test when using a Smith machine and free weights, respectively. The difference in the obtained 1RM value from both studies were within ±10% of coefficient variation, indicating that the predictive equation was acceptable for prediction of 1 RM.

In another study conducted by Roland and Nick[16], the validity and reliability of bench press was investigated using an accelerometer (PUSH band) and linear encoder in resistance trained subjects. The results revealed that the 1RM calculated from the accelerometer underestimated 1RM by 14 kg, with less reliability compared to the linear encoder. This contrasts with our present findings, which showed a difference of only 0.3 kg between direct and indirect methods. The difference between the present study and Roland's study is likely related to the different protocols employed, with Roland's study commencing at an initial load of 50% of estimated 1RM, before incrementally adding 10 kg (equated 50-82% of individual 1 RM). This which may have led to earlier fatigue and an underestimation of achieved 1 RM. In the present study the load applied followed the well documented NSCA protocol, which recommends the initial use of light loads (3-5 sets) as a part of the warm-up protocol, before increasing the load up to the maximum weight (1 RM).

Validity test

In order to identify tests that possess the best measurement properties, assessment of test validity is required. Importantly, test validity represents the degree to which a test measures what it purports to measure.

The present study aimed to validate a predictive 1RM equation compared to a traditional method using the bench press exercise. Pearson's Coefficients of determination (R^2) and a Bland-Altman plot (with 95% LOA) were employed. The results revealed that the correlation coefficient between the predictive 1 RM and actual 1 RM had a significantly strong positive relationship of $R^2 = 0.89$, with the Bland-Altman plot demonstrating good agreement between the two methods.

Jidovtseff *et al.*[17] previously examined the relationship between the bench press 1RM and maximal isometric force in recreational weight lifters, using bench press force and velocity profiles via linear encoder. The results showed a high correlation between the actual and predictive bench press 1RM ($r = 0.98$), thus confirming the validity of their approach. The accuracy of their predictive 1RM using the 95% LOA revealed bias of ±13.7% compared with the actual 1 RM (60 ± 19 kg), which was less than reported in our present study.

In other previous studies of recreational trained individuals, mean velocity, mean propulsive and peak velocity were measured in the concentric phase of the deadlift exercise using a linear encoder. The results demonstrated that in individuals who possessed a 1RM strength / body mass ratio > 1.5 demonstrated a high relationship in calculating 1 RM (0.91-0.93). The high correlations obtained from these previous studies, may be due to the application of different devices used to assess the load-velocity relationship. For example, a linear encoder measures force produced by muscles directly, whereas accelerometer device measures rate of change of velocity of the part body. In addition, the different characteristics of the subject and experience of the participants may partly explain the difference in the load-velocity relationship; alternatively, it may be explained by the magnitude of load increase to the bar.

In this study, the accelerometer (Push band) was selected as a velocity testing device because it was affordable is easier to use than a linear position transducer[11, 17, 18]. The main limitation of the present study was the predictive equation is specific in this population. In addition, the inability to assess the complete muscle activation of the subjects' during the 1RM. It is therefore recommended that future studies consider using electromyography on the muscles of interest to determine the full muscle activation and true achievement of 1RM. Furthermore, the validity of a predictive equation in different populations are required to verify that our equation is reliable and valid to implement across various cohort groups. Finally, as this study only focused on upper body exercise, a predictive equation for 1RM of lower body exercise (i.e., squat) should be performed develop lower body strength and power among athletes and recreation weight trainers.

CONCLUSION

This was the first study to formulate a predictive equation for the 1 RM bench press in a Thai healthy male age ranged 18-35 years. The load-velocity relationship using accelerometer (PUSH band) produced a valid predictive equation, as shown via high correlation coefficient and agreement between the direct and indirect 1 RM methods.

REFERENCES

1. Scienceforsport. 1RM Testing [Available from: https://www.scienceforsport.com/1rm-testing/#toggle-id-1.
2. Miller T. NSCA's Guide to Tests and Assessments 2012.
3. Mazur LJ, Yetman RJ, Risser WL. Weight-training injuries. Common injuries and preventative methods. Sports Med. 1993;16(1):57-63.
4. Risser WL, Risser JM, Preston D. Weight-training injuries in adolescents. Am J Dis Child.1990;144(9): 1015-7.
5. Risser WL. Weight-training injuries in children and adolescents. Am Fam Physician. 1991;44(6): 2104-8.
6. Risser WL. Musculoskeletal injuries caused by weight training. Guidelines for prevention. Clin Pediatr (Phila). 1990;29(6):305-10.
7. Brzycki.M. Strength testing. Predicting a one-rep max from rep-to-fatigue. J Phys Educ Recr Dance 64. 1993:88-90.
8. Dohoney J, Chromiak, D., Lemire, B.R., Kovacs, A., & Kovacs, C. Prediction of one repetition maximum (1-RM) strength from a 4-6 RM and a 7-10 RM submaximal strength test in healthy young adult males. J Exerc Physiol 5(3). 2002: 54-9.
9. Reynolds JM, Gordon TJ, Robergs RA. Prediction of one repetition maximum strength from multiple repetition maximum testing and anthropometry. J Strength Cond Res. 2006;20(3):584-92.
10. CSCS OWM. Velocity Based Training. [Available from: https://www.scienceforsport.com/velocity-based-training/#toggle-id-1.
11. Loturco I, Kobal R, Moraes JE, Kitamura K, Cal Abad CC, Pereira LA, et al. Predicting the maximum dynamic Strength in Bench Press: The High Precision of the Bar Velocity Approach. J Strength Cond Res. 2017;31(4):1127-31.
12. Macht JW, Abel MG, Mullineaux DR, Yates JW. Development of 1RM Prediction Equations for Bench Press in moderately trained Men. J Strength Cond Res. 2016;30(10):2901-6.
13. Jidovtseff B, Harris NK, Crielaard JM, Cronin JB. Using the load-velocity relationship for 1RM prediction. J Strength Cond Res. 2011;25(1):267-70.
14. Dohoney J C, D., Lemire, B.R., Kovacs, A., & Kovacs, C. Prediction of one repetition maximum (1- RM) strength from a 4-6 RM and a 7-10 RM submaximal strength test in healthy young adult males. J Exerc Physiol. 2002:54-9.
15. Krol H, Golas A. Effect of barbell weight on the structure of the flat bench press. J Strength Cond Res. 2017;31(5):1321-37.
16. Van den Tillaar R, Ball N. Validity and reliability of kinematics measured with PUSH band vs. linear encoder in bench press and push-ups. Sports (Basel). 2019;7(9).

17. Jidovtseff B, Harris NK, Crielaard JM, Cronin JB. Using the Load-Velocity Relationship for 1 RM Prediction. J Strength Cond Res. 2011;25(1):267-70.

18. Bazuelo-Ruiz B, Padial P, Garcia-Ramos A, Morales-Artacho AJ, Miranda MT, Feriche B. Predicting maximal dynamic strength from the load-velocity relationship in squat exercise. J Strength Cond Res. 2015;29(7):1999-2005.