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# Predicting Chest Press Strength from a 4RM Triceps Brachii Exercise in Trained Women

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# PREDICTING CHEST PRESS STRENGTH FROM A 4RM TRICEPS BRACHII EXERCISE IN TRAINED WOMEN

by

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ABSTRACT

**Predicting Chest Press Strength from a 4RM Triceps Brachii Exercise in Trained Women**

by

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Determining maximal strength is important when developing a resistance exercise program for trained athletes. The most frequent strength procedure used to evaluate maximum strength is the 1RM test. However, risk of injury from a 1RM test increases for the athletes, therefore a 4RM test is used in the following study. The purpose of the study is to test whether there is a linear relationship between the bench press and the triceps rope extension exercise. A secondary purpose is the development of a prediction equation for the purpose of prescribing bench press exercise loads from triceps brachii loads using a 4RM submaximal load. Participants included 50 trained women. The following variables were measured: 4RM triceps brachii extension, chest circumference, arm circumference, limb lengths, grip width, shoulder width, and RPE. Data were evaluated using stepwise multiple regression to predict 4RM chest loads from the variables listed above. Analysis of data revealed that the 4RM triceps extension exercise ($p<0.001$), chest circumference ($p<0.001$), and percent body fat ($p<0.006$) were significant predictors of the 4RM chest press. Three regression equations were developed using the three significant variables. Equation 1

consisted of only the 4RM triceps brachii extension ($R^2$=0.62). Equation 2 consisted of the 4RM triceps brachii extension and chest circumference ($R^2$-0.74). Equation 3 consisted of all three variables ($R^2$=0.78). Based on the analysis, chest press strength was predicted from three variables in order to help reduce risk of injury by using the 1RM. Finally, suggestions for future research are considered.

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# CHAPTER 1

# INTRODUCTION

Determining maximal strength is important when developing a resistance exercise program for trained athletes. Ascertaining maximal strength helps strength and conditioning specialists better determine appropriate fitness programs that match the athlete's goals. Coaches, health and fitness specialists, physical therapists, and athletic trainers use the measurement of maximal strength as a guide to quantify the level of strength, assess the severity of injury or strength imbalance, and to evaluate the effectiveness of a training program (Kravtiz, Akalan, Nowicki, & Kinzey, 2003).

The most frequent strength procedure used to evaluate maximum strength is the 1RM test. The aim of the 1RM test is to determine the weight an individual can lift once through the complete movement of an exercise. Percentages of the 1 repetition maximum (RM) are used to calculate and prescribe the intensity for resistance exercise training (Ebben et al., 2008). The 1RM has been shown to be a reliable testing tool and, when properly conducted, 1RM tests are safe for most subjects (Braith, Graves, Leggett, & Pollock, 1993). However, the risk of injury from a 1RM test increases for the athlete, particularly the shoulder/arm and back regions. Research has shown that rotator cuff and pectoralis muscle strains or tendon impingements are the most likely injuries to occur in specific upper body 1RM tests (Baker & Newton, 2004).

The bench press is one of the most frequently prescribed exercises in high performance weight training (75-95% 1RM) (Ebben et al., 2008; Madsen &

McLaughlin, 1984; Jerry L. Mayhew, Ball, Arnold, & Bowen, 1992). Attempting the 1RM lift requires great concentration and considerable mental preparation by the lifter. For the novice lifter, attempts to handle heavy loads may be limited. More recent prediction equations appear to use a ‘repetition-maximum’ principle. In this regard, a weight that can be lifted maximally to fatigue after 6 – 10 repetitions has been used to calculate 1-RM. Dohoney et al.(2002) reported that a 4-6 RM had a higher predictive accuracy compared to a more commonly used 7-10 RM testing range. Eston et al. (2009) expanded this idea by expressing the validity of using sub-maximal ratings of perceived exertion to predict the 1 RM from the Borg 6-20 scale.

Even though the 1RM is the most widely used testing tool for strength, it is not the safest way to determine one’s intensity level. Limited data on injury is available concerning the use of 1RM lifts. The potential for rotator cuff and pectoralis major rupture or strain may be magnified with the use of heavier loads (Baker & Newton, 2004), implying that submaximal lifts may be a safer approach. For this reason, several researchers have developed prediction charts and regression equations from performance in submaximal strength tests (Abadie, Altorfer, & Schuler, 1999; Abadie & Wentworth, 2000; Braith et al., 1993; Dohoney, Chromiak, Lemire, Abadie, & Kovacs, 2002; Jidovtseff, Harris, Crielaard, & Cronin, 2011; Kemmler, Lauber, Wassermann, & Mayhew, 2006; Jerry L. Mayhew et al., 1992; Rose & Ball, 1992; Willardson & Bressel, 2004).

Although training loads are often based on testing data, it is impractical for practitioners to test numerous exercises due to the increased risk of injury

(Ebben et al., 2008). A 1RM demands individuals to undertake maximal efforts with weights they may never have attempted. Therefore, regression analyses and prediction equations offer a safer method of prescribing exercise loads through a submaximal test without having to analyze numerous exercises or rely on trial and error. In addition, 1 RM testing can stress the muscle to the point of fatigue and prevent the individual from attaining a true maximum (Morales & Sobonya, 1996). Many studies have been conducted in men to produce regression equations for predicting 1 RM strength through submaximal testing (Dohoney et al., 2002).

Regression analysis has been used to predict training loads for the deadlift, lunge, step-up, and leg extension exercises based on a squat load (Ebben et al., 2008; Ebben et al., 2010; Wong et al., 2010). Only one study conducted by Ebben et al. (2010) created a regression equation in which a small number of athletic women (N=13) were incorporated, along with men. They created a regression equation from a 6 RM squat load to predict hamstring loads. While the 6RM squat successfully predicted hamstring loads in men, the relationship was not significant in the female participants. This study concluded that for women, regression analysis could not predict any of the dependent variables. The squat was a significant predictor for the hamstring loads in men, possibly due to the small number of women participants.

Up to this point, there is a limited body of research focused on whether regression analyses are as useful for women athletes as compared with males. To the authors' knowledge, previous literature has analyzed only the lower body region in women with no studies determining upper body prediction analyses. Therefore, the purpose of this study is to test whether there is a linear relationship between the bench press and the lying triceps brachii extension exercise. A secondary purpose is the development of a prediction equation for the purpose of prescribing bench press exercise loads from triceps loads using a 4RM submaximal load (90% of 1RM).

## Hypothesis

Do any of the following variables: chest circumference, upper arm circumference, grip width, limb length, and the 4RM triceps brachii extension combine to allow us to predict the 4RM chest press?

## Significance of the Study

To provide a safe method to predict chest press strength, limiting injury risk. To develop to a regression equation for women athletes.

## Definition of Terms

Repetition Maximum - the most weight that can be lifted for complete exercise movements.

Regression Analysis- Statistical analysis that allows quantitative predictions of one variable from the values of another.

# CHAPTER 2

# REVIEW OF RELATED LITERATURE

## 70-90% of 1 Repetition Maximum

Submaximal loads have been shown to be most effective when trying to predict the 1RM. The greatest significance found was with loads between 70 and 90% of 1RM. The studies below use loads between 70 and 90% of a particular exercise to predict the 1RM.

In a study conducted by Kravitz et al. (2003), eighteen male power lifters aged 15-18 were recruited. The purpose was to create prediction equations from submaximal repetitions that best predict the 1RM in the squat (SQ), bench press (BP), and dead lift (DL) exercises, as well as which structural dimension variables best predict the 1RM strength for this population. Chest and bicep circumference was measured using a cloth tape measure with metric divisions. For the 1RM tests, each participant attempted a weight that he thought could only be lifted once using maximum effort. Weight was incrementally added until the subject preformed a 1RM of the squat, bench press, and deadlift. For the maximum number of repetitions at 70, 80, and 90% of 1RM, each lifter was instructed to perform as many repetitions as possible, to failure, at the percentage selected for a particular lift. Regression equations were then created using submaximal percentage of 1RM, number of repetitions (REP), REP X REPWT, age, height, body weight, years in power lifting, chest and bicep circumference, and bench drop distance. The results showed that the estimated 1RM derived from the regression equations were highly correlated with the actual

SQ, BP, and DL performances. The best predictors for SQ and BP were the REPS and REPS X REPWT performed at 70% 1RM. For the DL, the best predictors were REPS X REPWT and REPS performed at 80% 1RM. The study demonstrated the estimated 1RM derived from the regression equations using REPS and REPS X REPWT as variables was adequate for estimating 1RM. The best predictors were 70% and 80% of 1RM for the exercises (Kravtiz et al., 2003), enabling lower weights to be used and theoretically decreasing the risk of injury.

Rontu et al. (2010) examined if the 1RM bench press performance could be reliably predicted with accelerometer data from submaximal lifts of 50,60,70,80, and 90 % of 1RM. Twenty-two Finnish male, competitive flootball players participated. The experimental study was based on acceleration measurements from a 3-axis accelerometer. This method was based on the assumption that the estimation of 1RM can be calculated from submaximal weight and maximal acceleration of the submaximal weight during the lift. Prediction estimation equations were created. Olympic bars and plates were used for the lifts. The participants made two bench press series of 10 lifts with 50% 1RM load of estimated 1RM result and one series of four repetitions with 60% 1RM load and one series of four repetitions with 80% 1RM load, the first test was a traditional 1RM test, with the target to make a 90% load for estimated the 1RM. The participant then executed five single separate submaximal bench press lifts after the 1RM test. The load levels used were 50,60,70,80, and 90% of the 1RM. The correlations between measured and estimated 1RM were 0.89-

0.97 ($p<0.001$). The measurements indicated that the estimation was improved with higher loads. The correlations varied between 0.89 and 0.97. Five estimated equations were developed based on each load. The equations of 70 and 80% were very similar. The results showed promising prediction accuracy for estimating bench press performance by performing just a single submaximal bench press lift. The study showed that the higher the percentage of the submaximal lift, the more accurate the equation (Rontu, Hannula, Leskinen, Linnamo, & Salami, 2010).

Desgorces et al. (2010) identified the pattern of strength evolution according to training induced physical capabilities to propose prediction equations of the 1RM specific to certain populations using loads of 20, 40, 60, 75 and 85% of their 1RM. A total of 110 male athletes aged 21-28 participated in the study. The athletes comprised of four groups, power lifters, racket ball games, swimmers, and rowers. The 1RM strength for the bench press was measured using a free weight Olympic bar and plates for all groups. Before the test, the participants performed several warm-up sets using light weights of their choice. The maximum number of repetitions (MNR) was then determined using the same technique of the 1RM. The bar was required to touch the chest and then be returned to a full arms' length away from the body, was a maximum pause of 2 seconds between each repetitions. The participants carried out the MNR test at 20, 40, 60, 75 and 85% of their 1RM. Newly created prediction equations and those of Epley (1985) and Mayhew (1993) were used. A Significant difference between the high endurance and high strength groups were found for MNR performed at 20%-75% of 1RM ($p<0.05$ at 75%, $p<0.01$ at 60%, $p<0.001$ at 40%, and 20% of 1RM). Epley's (1985) linear equations resulted in significant $r^2$, but SEE remained high. Mayhew's equation provided accurate predictions, but remained lower than those calculated from the equations computed in the study. Each equation developed allowed to accurately determine the maximal number of repetitions that could be performed at any strength level. Few differences were shown in high strength levels (75-100% of 1RM) in equations (Francois D. Desgorces, Geoffroy Berthelot, Gilles Dietrich, & Marc S.A. Testa, 2010). The equations appear to be relevant when determining one's fitness program, thus making it easier for athletes to predict their 1RM for the bench press and potentially lowering their risk of injury from using higher loads.

In a study conducted by Cummings et al. (1998) they made a comparison between estimated strength from 3 commonly used linear equations (Brzycki (1993), Epley (1985), and Landers (1985) for the bench press and the 1 RM for untrained women. In addition, measurements were taken to establish a separate regression equation for the 1RM bench press from performance measures and structural dimensions related to the bench press strength for untrained women. Fifty-seven female volunteers aged 18-50yr who had not undergone any muscular training for at least three months participated. Structural dimensions measured were height, body mass, arm length, upper arm circumference, biacromial breadth, and triceps skinfold. Four sessions were scheduled to familiarize the participants with the testing procedures before the study began. After this period, repetitions to fatigue were assessed using the submaximal bench press test, attempting a 4-8RM (85% of 1RM). Within 24-48 hours of the rep-to-fatigue testing, the bench press 1RM was measured. Results showed significant underestimations of the 1RM by the Bryzcki and Lander equations. Three estimation equations were developed from the analysis using three variables, submaximal weight, repetitions, biacromial breadth. The results suggested that the estimated 1RM derived from the regression equations using the number of reps-to-fatigue with a submaximal weight may be highly correlated with actual bench press performance(Cummings & Finn, 1998) and therefore by creating a regression equation with a high load of 1RM will help predict the 1RM of athletes.

Morales et al. (1996) tried to determine the best predictors of 1RM strength for the bench press, squat, and power clean. The best predictor for each lift was defined as the maximal number of repetitions performed at a given intensity (70-95% of 1RM). Participants were 16 varsity football players and 7 track and field throwers competing in NCAA Div. 1-A. The variables measured were the squat, bench press, and power clean lifts; and maximal number of repetitions the participants could perform at 70, 75, 80, 85, 90, and 95% of 1RM for each lift. Data collection took approximately two weeks, with different 1RM and submaximal tests each day and different percentages selected. Results showed that for the squat and power clean, the best predictors corresponded to the number of repetitions performed at 80 and 90% respectively. The squat had the highest prediction power; the $R^2$ value accounted for 26.9% of the variance. The bench press best predictor was 95% of 1RM. Using the percentages of 80-

95% of 1RM will give us the best predictor of 1RM (Morales & Sobonya, 1996) and therefore implying that higher submaximal loads better help predict the individuals 1RM.

In a study done by Shimano et al. (2006) the number of repetitions that trained and untrained men could perform at 60, 80, and 90% of 1RM in three different exercises: back squat, bench press, and arm curl was evaluated. By doing this, the approach was used to demonstrate, using free weight exercises the relationship between exercise intensity and the number of repetitions allowed. Participants for the study were 8 trained and 8 untrained men aged 25.3±3.7yr. Trained men had undergone continual heavy resistance weight training program at least twice a week for more than six months. The participants performed four testing sessions. On day 1, a one repetition maximum testing was performed on each exercise. The next three sessions consisted of one set to failure for each of the three exercises performed at different percentages of 1RM. Results showed a significant interaction ($p>0.05$) found between exercise and intensity. For all exercises, subjects could perform significantly more repetitions at 60% of 1RM compared with 80 and 90% of 1RM. At 90% 1RM, both groups performed the back squat with greater mean power than the bench press. The primary findings were that more repetitions could be performed in the back squat than the bench press or arm curl and there were no significant differences in the number of repetitions between both groups. These results explain that the untrained and trained can perform ≤6 repetitions at

90%1RM.  Therefore, loads of at least 90% 1RM may be optimal for strength gains in both groups (Shimano et al., 2006) and better predict 1RM loads.

Submaximal testing between 70-90% of 1RM has been shown to in the literature to be significant when trying to predict 1RM.  The studies mentioned have had success with different exercises and higher loads to predict the 1RM in subjects.  The higher the submaximal load, without testing for 1RM, the closer the predicted 1RM maybe to the actual 1RM.

<u>6RM to Predict Lower Body Exercises</u>

In order to better design a program, researchers use large lower body muscle exercises to predict smaller muscle exercises with the use of submaximal loads. The studies below used a 6RM load for one exercise to create equations that predict the 1RM for other exercises.

Ebben et al. (2008) hypothesized whether there is a linear relationship between squat loads and loads used for a variety of lower-body resistance training exercises which have been thought to activate the quadriceps muscle group as a prime mover.  This study also created prediction equations for the determination of the exercise loads for the deadllift, lunge, step-up, and leg extension, based on the squat load.  Twenty one collegiate students aged 20.86±1.85yr, who participated regularly in lower-body resistance training volunteered for the study.  On the day of testing, 6RMs were determined for each exercise (squat, deadlift, lunge, stepup, and leg extension).  The participants performed the 6RM in a randomized order with 4 minutes of recovery between each test exercise.  Analysis of the data revealed that the squat was a significant predictor of the load for the deadlift, lunge, step-up, and leg extension, with $R^2$ values ranging from 0.67 to 0.81. Based on the data collected, prediction equations were devised and can be used to calculate training loads for each exercise. Results of the cross-validation procedure using the equation indicated that the predicted and actual loads were similar, thus demonstrating prediction equations can be used to determine lower-body resistance exercise loads for training (Ebben et al., 2008), allowing 6RM prediction equations or lower to be significant when predicting 1RM.

In 2010, Ebben et al. tested the hypothesis that a linear relationship exists between the squat 6RM and the 6RMs of a variety of lower-body hamstring exercises in order to create a prediction equation for the purpose of prescribing hamstring exercise loads from squat testing data. Twenty-one men and 13 women NCAA D-I and NCAA D-III aged 20.38± 1.77yr participated in the study. On the day of testing the participants were instructed to perform each exercise at maximal volitional velocity and reach a 6RM of each exercise during the testing sessions. Participants performed the 6RM test for the squat, seated leg curl, stiff leg dead lift, single leg stiff leg dead lift, and good morning exercises in randomized order, with 5 minutes of recovery between each test exercise. The results showed significant differences in strength and body mass because men were stronger, larger, and had a higher strength to mass ratio than women. Regression analysis revealed using sex and squat load predictors indicated that sex was not a significant predictor when all the participants were analyzed. For women, regression analysis could not predict any of the dependent variables.

When only males were assessed, squat load was a significant predictor of the seated leg curl, stiff leg dead lift, and good morning exercise loads. On the basis of the analysis for the men, prediction equations were developed. When cross-validation of the equations was competed, the correlations of predicted and actual loads were similar to the developmental equations. Thus, the equations developed provide values that are similar when different participants are used (Ebben et al., 2010).

Wong et al. (2010) determined the relationship between the 6RM loads of bilateral and unilateral exercises such as the bilateral squat, deadllift, and leg press vs. the unilateral stepping actions of lunges and step-ups. They then aimed to create prediction equations based on squat loads to determine the loads for lower body exercises. Fourteen male elite karate athletes aged 22.6±1.2yr participated in the study during the precompetition phase. Before any exercise, body density was determined by a skinfold caliper (7 site). At the start of testing, all athletes performed a 10 minute warm up of static and dynamic exercises. After the warm-up, athletes performed one warm up set of 6 repetitions at 65-75% of their perceived maximal load of each exercise. Loads were assessed by having the athletes perform the 6RM test for the back half squat, bent-knee deadlift, lunge, step-up on a box, and a 45 degree inclined leg press. All athletes attained at least 6 repetitions of the 6RM loads, and 4 minutes of recovery was given between exercises. Testing was performed over 3 days with 48 hours of recovery between tests. Results showed that the 6RM squat load was significantly correlated with the 4 lower body exercises; deadlift (r=0.86, p<0.001), leg press (r=0.76, p<0.001, lunge (r=0.86, p<0.001, and step-up (r= 0.92, p<0.001). In addition, linear regression showed that the 6RM squat load was a significant predictor for the deadlift, leg press, lunge, and step-up. These results compared with those of Ebben et al. (2008;2010) signify that 6RM loads can predict close to accurate values for the purpose of training (Wong et al., 2010).

All of the aforementioned studies used lower body exercises to develop equations that help minimize loads for athletes without a large risk of injury. The 6RM loads for the regression equations created were shown to be a significant predictor of the 1RM, thus making an effective protocol for some athletes to follow.

## Injury relating to the Bench press 1RM

Injuries related to any 1RM test can be increased without proper training or placing high of a load on the working muscle. Specific injuries can be developed when performing the most popular 1RM test, the bench press. The studies below identify these specific injuries and how they can be avoided.

Green and Comfort (2007) studied the acute and chronic over-use injuries in regard to the bench press. The risk of both acute and chronic shoulder injury may be increased by repetitive movements performed with the shoulder close to 90 degrees of abduction, as seen during the bench press. Different techniques used increase the risk of anterior instability, atraumatic osteolysis of the distal clavicle and pectoralis major rupture. The volume, repetitions, and sets performed in weight lifting encourage over-use injuries as athletes will perform 1-

12 repetitions with loads of 80-100% of the 1RM. Green and Comfort highlighted some common injuries which include anterior glenohumeral instability (inability to maintain the humeral head centered in the glenoid fossa), atraumatic osteolysis of the distal clavicle (a stress failure syndrome of the distal clavicle), and pecotralis major rupture. The proper grip for the bench press is a grip ≤1.5 x biacromial width. Research has demonstrated a nonsignificant difference of ±5% in 1RM with a grip width of 100% and 200% biacromial width. To potentially minimize the risk of injury (Green & Comfort, 2007) mentioned that the bench press should be performed with a grip ≤1.5 x biacromial width to maintain shoulder abduction within 45 degrees. The adjustments of the grip width will decrease the angle of abduction and possibly external rotation at the shoulder, in turn potentially reducing the risk of shoulder injury without altering performance during the bench press (Green & Comfort, 2007).

Baker et al. (2004) determined whether two popular field tests of strength could be used to determine the existence of a concise strength ratio in the roughly opposing muscle actions of pressing away from and pulling in towards the shoulder girdle. The relationship between pressing and pulling strength was also investigated and analyzed according to the training status of athletes and whether or not injury risk could increase or decrease. Forty-two rugby league players aged 22.0±3.8yr participated in the study. All athletes were current resistance trained individuals. They were divided into two groups: national rugby league competitors (NRL) and second division competition (SRL). The exercises chosen were the bench press (BP) and pull-up (PU). The tests were conducted on separate days, with the 1RM BP performed first and 72 hours later the 1RM PU was performed.  After a generalized warm-up, the athletes' commenced the testing procedure by performing three repetitions in the PU with their own body mass and gradually increased in weight until a 1RM was attained.  A 1RM was also performed for the bench press.  Thus the tests incorporated roughly opposing muscle actions in fairly simple and universal popular resistance training exercises.  The results showed significant differences in 1RM BP and PU strength in the NRL and SRL groups.  The relationship between BO and PU was much lower in the stronger and more experienced in the NRL group (27%) than the SRL group (86%).  Both upper body pressing and pulling strength are vital in sports . Large discrepancies in strength in either movement action could limit the success of the athlete in these sports or could increase the likelihood of shoulder injuries, such as muscle strains or tendon impingements.  The balance of these muscle groups would then lead to an equivalent strength ratio and theoretically develop a more balanced and stable shoulder complex.  Although, at all times coaches need to consider whether weak antagonist muscles may limit limb speed and accuracy during rapid movements, which can then lead to muscle strains or tendon impingements (Baker & Newton, 2004).

In a study conducted by Madsen and McLaughlin (1984) the bench press was examined.  To do this, a study of the kinematics and kinetics of the bar was performed to see which kinematic factors might be relevant to performance and injury risk in the bench press. Clearly, all subjects exhibit a motion pattern of first lowering and then raising the bar.  Of greater interest is the possible existence of bar movements, bar velocities, bar accelerations, and /or force patterns appearing across subjects that are not implied by the requirement that the bar be lowered and then raised. The bench press techniques of 36 male subjects who comprise of two groups (Expert and Novice weightlifters) participated. All the 1RM lifts were recorded with a motor-driven, 16-mm LoCam camera. The bench press was recorded nine times throughout the lift, identifying different factors. Results showed all subjects exhibited a distinct minimum of vertical acceleration while raising the bar, and 34 of the subjects exhibited a distinct minimal of vertical velocity while raising the bar. The bar path used by the expert group was much closer to the shoulder, the sequence of movements used by the expert group was different, and the expert group required more time to complete the lift. The expert lifter exerted a much more uniform force on the bar. The differences in force exerted between the expert and novice were more pronounced at their positions of minimum force exertion. The kinematic factors that have been identified at potentially important to the bench press are: the possible existence of a sticking point, the position of the bar movements used in raising the bar, the degree of control maintained in lowering the bar, and the role of grip spacing. All of these factors determine the risk of injury to the athlete while performing the bench press (Madsen & McLaughlin, 1984).

Pollock et al. (1991) determined the adherence and injury rate of 70yr old men and women while participating in walking, walking-jogging, or strength training programs. Seventy participants volunteered. Their $VO_2$ maximum was first tested before any training. Based on their $VO_2$ max, they were divided into two groups: the walk/ jog exercise training program or strength exercise training program. Training consisted of 3 times a week for 26 weeks. During this time, injury data was recorded and to be considered to have an injury, if training had been significantly altered or stopped for 1 week. A total of nine subjects were eliminated from the final strength analyses due to the orthopedic limitations resulting from injuries due to a restricted range of motion. During the testing, there were no injuries sustained during the treadmill VO2 max test. However, during the 1RM strength testing, 11 of 57 subjects (19.3%) incurred an injury. Five of the injuries were knee injuries related to leg extension testing, while five shoulder/arm injuries and one back injury were related to the chest press testing. During training only two of the 23 subjects in the strength group sustained an injury (8.6%). Thirty six percent of injuries were related to previous orthopedic problems. The results from this study underline the importance of modification of exercise prescription based on the individual needs to limit the amount of injuries (Pollock, Carroll, Braith, Limacher, & Hagberg, 1991).

Injuries are prevalent with resistance training. By limiting the use of 1RM testing, injuries from this test can be reduced. With the use of submaximal testing and prediction equations, these exercises may be potentially safer for athletes.

## Underestimated Prediction Equations

Numerous prediction equations have been developed to help predict the 1RM. These equations have used different exercises to see which are effective and which are not.  The studies below represent the prediction equations that underestimate the 1RM in various exercises.

Hutchins and Gearhart (2010) examined the validity of the Berger (1970) and O'Connor et al. (1989) non-exercise specific 1RM prediction methods for the bench press and biceps curl when compared to the determined 1RM. Twenty-seven men aged 23.6±3.5 yr, who participated in regular recreational activity, volunteered in the study.  Participants' resistance trained on average of 3.56±1.11 days per week.  On day one of testing, the 1RM was determined for both the bench press and biceps curl exercises.  The protocol used was developed by the American College of Sports Medicine.  The second day of testing consisted of an experimental trial at 85% of the previously measured 1RM.  A weight load equal to 85 ± 1.3% of the previously obtained 1RM was loaded onto the bar.  The subject was asked to complete one set of repetitions to concentric failure.  The number of repetitions was recorded and used in the Berger 1RM (1970) and O'Conner et al. (1989) equation.  Results concluded that the estimate was lower for the O'Conner et al. equation than the Berger equation. The total equation with the lowest total error of estimation for both the bench press and the biceps curl (7.2% error for Berger and 5.7% error for O'Connor et al.).  The Berger equation 1RM underestimated the 1RM 1.5% more, but both equations underestimated the 1RM obtained (Hutchins & Gearhart, 2010).

Knutzen et al. (1999) studied the validity of six prediction equations that use repetition-to-fatigue regression formulas.  Fifty-one participants (21 male, 30 female) volunteered for the study.  All participants were enrolled in an 8 week high resistance training program (80% of 1RM). Participants completed 2 experimental sessions, 5 to 8 days apart, on 11 machine exercises. Over days 1 and 2, actual and predicted 1RM measurements were made on 11 machine lifts: triceps press, biceps curl, lateral row, bench press, supine leg press, hip flexion, hip extension, hip abduction, hip adduction, plantarflexion, and dorsiflexion. A three trial protocol to reach maximum weight was used for each lift. To obtain a predicted 1RM, subjects selected a weight they could lift 7-10 times and completed the trial sequence up through 10 trials. Weight and trial data were entered into the following six prediction equations: Brzycki (1993), Epley (1985), Lander (1985), Mayhew et.al (1995), O'Connor et.al (1989), and Wathan (1994). Correlations between actual and predicted 1RM scores demonstrated a moderate to strong relationship for all exercises. In all of the exercises, the average predicted 1RM value was lower than the actual 1RM ($p \leq 0.001$). Between all of these equations, the O'Connor et al. equation consistently predicted the lowest value of all of the predicted equations across all of the exercises (Knutzen, Brilla, & Caine, 1999), making the O'Connor et al. equation the least applicable when predicting 1RM from a submaximal test.

Ware et al. (1995) tried to determine the accuracy of using relative muscular endurance performance to estimate 1RM bench press and squat strength in college football players. Forty-five division II college football players participated in the study. These players had undergone an extensive modified periodized resistance training program during the previous 12 weeks. On the day of testing, 1RM bench press and 1RM squat strength was measured. During the week prior to 1RM testing, each subject performed repetitions to fatigue in both the bench press and squat. The players used loads approximately 70% of their probable 1RM. Predicted bench press and squat 1RMs were estimated from the methods of Brzycki (1993), Lander (1985), Mayhew et al. (1992), and Epley (1985). Results showed that in the bench press the Mayhew et al. (1992) equation significantly underestimated the 1RM by an average of -3.1kg (±7.7kg) while the other equations overestimated. In the squat, all four equations significantly overestimated 1RM (Ware, Clemens, Mayhew, & Johnston, 1995). This study demonstrates that the Mayhew et al. (1992) equation significantly underestimated the bench press, leading researches to believe this is not an accurate equation to use for predicting bench press 1RM from submaximal repetition testing.

Reynolds et al. (2006) examined the relationship of decreases in the load lifted and increases in repetitions to fatigue, determine if there are gender differences in the decrease loads lifted, assess which of loads accurately predicts 1RM strength, and identify if the addition of anthropometry, age, gender, and training history data increases the accuracy of 1RM strength prediction in a large, diverse population. The leg press (LP) and chest press (CP) were the exercises studied. Seventy subjects, 34 men and 36 women; (18-69 years of age) of varied resistance training experience were recruited for the study. Two 1 hour testing sessions consisting of four maximum resistance bouts were conducted on each subject. During the first testing session, each subject completed a 20 RM and a 10RM for the LP and CP. Subsequent loads were based on the following estimations obtained from a collection of past research. The second session consisted of a 5RM and a 1RM for the same 2 exercises, and these loads were again based on their 20RM and 10RM loads. The values obtained were placed in 6 different linear equations (Reynolds (2006), Abadie (2000), Brzycki (1993), Epley (1985), Lander (1985), O'Connor (1989)) and 2 nonlinear equations (Lombardi (1989), Mayhew (1992)). All of the linear prediction equations using the 5RM data functioned with similar accuracy for the LP and CP. The equations of Brzycki (1993), Lander (1985), and O'Connor (1989) all underestimated LP strength. All equations were less accurate when the 10RM rather than the 5RM was used. The nonlinear equations of Lombardi (1989) and Mayhew (1992) were less accurate than all the linear equations (Reynolds, Gordon, & Robergs, 2006). The Brzycki (1993), Lander (1985), and O'Connor (1989) equations significantly underestimated the leg press, signifying these equations to be less accurate when compared to a 1RM leg press.

LeSuer et al. (1997) examined seven prediction equations using repetitions to fatigue in estimating the 1RM for the bench press, squat, and deadlift using a common data set. Subjects were 67 untrained college students (40 males, 27 female) enrolled in weight training classes. On day one of testing, subjects performed 1RM tests for all three lifts performed according to the guidelines established by the National Strength and Conditioning Association. On day two of testing, subjects were to perform repetitions to fatigue for each lift. Subjects were randomly assigned to 1 of 2 groups. Those in group 1 were tested for the 1RM for a given lift first then allowed 10 minutes of rest before testing repetitions to fatigue. Those in group 2 tested repetitions to fatigue first then rested for 10 minutes before the 1RM was completed. Seven formulas were used to predict 1RM in each lift: Brzycki (1993), Lander (1985), Epley (1985), Lombardi (1989), Mayhew (1992), O'Connor (1989), and Wathan (1994). Results showed that Brzycki, Lander, Epley, Lombardi, and O'Connor significantly underestimated all lifts by an average of 1 to 2.5kg (0.8-6%). The greatest underestimation was in the dead lift, by an average of 10 to 15.3kg (9-14%). The study showed the deadlift being the most difficult to estimate and only the Mayhew and Wathan equations to being close to predicting the RM (LeSuer, McCormick, L.Mayhew, Wassertein, & Arnold, 1997).

In a study previously mentioned, Cumming et al. (1998) used three common prediction equations: Brzycki (1993), Landers (1985), and Epley (1985) to estimate the 1RM bench press in untrained women. The two equations that significantly underestimated the bench press were Brzycki (r=0.941, SEE=±1.79kg) and Landers (0.942, SEE=±1.78kg). The percentage declines for the equations were 2.78% for Brzycki and 2.67% for Landers. These results reiterated the inaccuracy of the Brzycki and Landers equations for the bench press indicating these equations to unable to predict the 1RM bench press from a submaximal lift.

The most underestimated equation was shown to be Brzycki (1993) for the bench press, as well as the O'Connor et al. (1989). A few others showed underestimations, but were not significant as were the Brzycki and O'Connor studied when predicting the 1RM.

## Overestimated Equations

In addition to prediction equations underestimating 1RM, many equations have overestimated 1RM. These overestimations have depended on repetitions, loads, and exercises.

Mayhew et al. (1995) conducted a study to determine the accuracy of using relative muscular endurance performance to estimate 1RM strength in the bench press. A total of 220 men participated in the study. The composite sample was made up of seven groups of various ages and training backgrounds. The groups consisted on untrained college men, college men, NCAA DII college wrestlers, NCAA DII college soccer players, NCAA DII college football players, high school boys, and middle aged men. A 1RM was determined for each athlete and then within 48 hours, a repetitions to fatigue was performed, at least 10-20 repetitions. Predicted 1RM values were estimated from the methods developed by Brzycki (1993), Landers (1985), Mayhew et al. (1992), Epley (1985), Lombardi (1989), and O'Connor et.al (1989). Results concluded that the Epley, Lander, and Bzycki equations significantly overpredicted by 2.7, 13.7, and 14.3 kg respectively. The study indicated that the predicted bench press derived from the number of repetitions to failure with a < 1RM load may be highly correlated with actual bench press performance but can exhibit varying degrees of under and overestimation of the actual performance (J.L. Mayhew et al., 1995).

Mayhew et al. (2004) evaluated the effectiveness of existing repetitions to fatigue (RTF) equations for predicting 1RM bench press performance in male high school athletes. Male members of high school athletic teams (n=213) from four states were tested for 1RM bench press and RTF.  On day one of testing, participants were instructed to used a <1RM load to perform RTF that would fall in the range of 2 to 10 repetitions.  Within a week after RTF was established, 1RM for the bench press was conducted.  Ten RTF prediction equations identified from the literature were evaluated: Adams (1998), Berger (1961), Brown (1992), Brzycki (1993), Lander (1985), Lombardi (1989), Mayhew et.al (1991), O'Connor et.al (1989), Wathan (1994), and Welday (1988).  Results showed that the Brzycki and Lombardi equations over predicted, by an average of 0.8% (SD=6.7%) and 0.6% (SD=6.4%).  In an attempt to identify factors that might lead to under or overproduction, the sample was divided into three groups relative to prediction accuracy: underprediction (4.5kg less than actual), accurate (within ±4.5kg of actual), and overprediction (4.5kg greater than actual).  The major outcome of the study was the suggestion that RTF can be used to accurately estimate 1RM bench press performance in the majority of male high school athletes when dealing with only one equation and not comparing it to multiple equations (J. L. Mayhew, Kerksick, Lentz, Ware, & Mayhew, 2004), therefore certain equations maybe suitable for certain populations in order to predict 1RM.

Wood et al. (2002) examined the accuracy of seven existing prediction equations for estimating 1RM performance from RTF in apparently healthy, older, sedentary adults using resistance exercise machines.  Participants were apparently healthy, untrained, nonexercising volunteer adult males (n=26) and females (n=23) aged 53.55±3.34 years.  Prior to the study, all participants attended six instructional sessions that focused on proper lifting technique, safety, and weight room etiquette. During the first testing sessions, 1RM values were obtained for the following exercises: chest press, high lat pull, and leg curl. In session 2, leg press, shoulder press, and low lat pull down 1RM were determines. In session 3, incline chest press, leg extension, biceps curl, and triceps extension 1RM were conducted. Repetitions to fatigue (RTF) were determines over the course of three testing sessions. Participants were randomly assigned to 1 or 10 groups, and each group completed RTF of the 10 exercises. Three exercises were tested during session 4 and 5, and four were tested on session 6 of the study. Each of the 10 exercises was randomly assigned one of the following percentages of the 1RM: 50, 55, 60, 65, 70, 75, 80, 95, and 90. Results showed the Lombardi (1989) and O'Connor (1989) formulas a lack of similarity with large and statically significant mean differences over all exercises. The Mayhew (1992) formula had a lack of similarly for all but the low lat pull down. Across genders over the full range of RTF trials, males evidenced larger mean differences than females. No single formula showed similarity across all exercises for males; however the Brzycki (1993) and Lander (1985) formulas exhibited smaller mean differences and similarity over more exercises for females. The Brzycki and Lander formulas tended to overestimate the 1RM for triceps extension, high lat pull down, and leg press(Wood, Maddalozzo, & Harter, 2002) and therefore may not be suitable for these exercises.

In Ware et al.'s (1995) study of determining the accuracy of using relative muscular endurance performance to estimate 1RM bench press and squat strength in college football players, four prediction equations were used: Brzycki (1993), Lander (1985), Mayhew et al. (1992), and Epley (1985). A 70% of 1RM load was used. Results showed for the squat that the Epley, Lander, and Brzycki equations significantly overestimated the 1RM by averages of 4.8±8.2kg, 14.1±12.0kg, and 14.2±14.4kg. For the squat, all four equations significantly overestimated the 1RM squat as follows: Epley by 11.6±11.5kg, Lander by 45.7±31.2kg, Mayhew et.al by 48.5±14.4kg, and Brzycki by 47.9 ±33.6kg. These numbers signify that higher repetitions to fatigue do not provide an accurate basis for judging strength levels in the bench press or squat among resistance-trained athletes(Ware et al., 1995).

Whisenant et al. (2003) also validated submaximal prediction equations for the 1RM for the bench press. As previously mentioned they compared 11 equations to see which was the most accurate. The Lander (1985) and Brzycki (1993) equations significantly overestimated the actual 1RM by averages of 14.5± 28.6kg and 15± 31.3kg. In addition, the Mayhew et al. (1993) equation significantly overestimating the actual 1RM by an average of 2.2± 5kg. The data in this study also suggests that the validity of prediction equations varies with the number of repetitions performed. When 1-10 repetitions were performed, the Lander (1985) and Brzycki (1993) equations were the most accurate. When 11-20 repetitions were performed, the Lombardi (1989) and Wathan (1994) equations were the most accurate. Accuracy of these equations depends on the repetitions performed, although Lander, Brzycki, and Mayhew significantly overestimated the bench press (Whisenant, Panton, East, & Broeder, 2003).

The equations shown to significantly overpredict the 1RM were the Lander and Brzycki equations for the bench press. The Lander and Lombardi equations over predicted as well, but not as significantly as the Lander and Brzycki. Also, depending on the number of repetitions, this signified if the equation overestimated, underestimated, or was accurate to predicting 1RM.

## Prediction Equations Created to Predict 1RM

In addition to prediction equations being created and used over time for a number of exercises and populations, many researchers have developed their own equations. The prediction equations created, are more focused on a specific population, 1RM load, and exercise.

The objective of Abadie et al. (1999) was to determine if proper lifting technique is responsible for altering the relationship between maximal and submaximal strength in trained participants by creating a regression equation to predict maximal strength. Thirty men ages 18-26yr, who had not weight trained for 6 months, volunteered for the study. On day 1, participants were instructed on proper lifting technique for performing the bench press. During the second and third testing sessions, participants were assessed for 1RM or submaximal 7-10RM bench press strength. After these assessments, the men were randomly assigned to either the experimental group or a control group. The experimental group was required to practice proper lifting technique by participating in four training sessions during a two week period. During the first week, the men took part in two training sessions, where they were required to lift 2 sets of 7-10 RM repetitions at 50% 1RM. During the second week, participants took part in 2 training sessions and were required to lift 2 sets of 7-10RM repetitions at 60% 1RM. The control group was told to refrain from any weight training. Following the 2 week training period, participants were reassessed for post training 1RM ad 7-10 RM bench press strength. Based on the results, regression analysis created the following formula to predict 1RM bench press strength from the weight lifted during the 7-10RM bench press strength test: 1RM=8.8147+1.1828(7-10RM). Using the formula, predicted 1RM was calculated for each participant. The measured and predicted bench press strength values were 74.3±17.1kg and 73.0± 12.1kg. The correlation between measured and predicted 1RM was significant (r = +969), SEE was 3.1kg or 4.2% of the mean 1RM. The correlation between experimental and subjects' measured and predicted 1RM was significant (r = +983), SEE was 2.5kg or 8.8% of the mean 1RM. The results demonstrated that the initial regression equation to predict 1RM bench press strength produced a positive correlation between predicted and measured 1RM in 30 untrained men (r = 0.97; SEE = 4.2kg); therefore displaying significant results when a regression equation is developed (Abadie et al., 1999).

Jidovtseff et al. (2011) examined the relationship between 1RM and the lead-velocity profile and subsequently determine 1RM prediction equations from that profile. A total of 112 men and women participated in the study. On day 1, participants were familiarized with the bench press when shown, the standardized position was determination and the 1RM assessment was made. During the second session, all participants were tested at 3 or 4 increasing bench press loads. The number of trails performed at each load was as follows: 4 trails at 30, 35, and 40% 1RM; 3 trials at 50, 60, and 70% 1RM; and 2 trails at 80, 90, and 95% 1RM. The best trial was selected for analysis in terms of highest velocity value. Results showed theoretical load corresponded to 116±8% of the 1RM. Average velocity at 1RM was 0.23± 0.09ms$^{-1}$. The results confirmed that the load velocity relationship can be used to estimate maximal strength performance. A practically perfect correlation between theoretical load and 1RM (r = 0.98) was found, providing evidence that the load velocity relationship may be used to estimate 1RM using he following equation developed: 1RM= (0.871LD0) – 0.624. The formula offers a reasonable prediction of the 1RM with a standard error of estimate of 4kg (7%), therefore predicting close to the 1RM from a regression equation created (Jidovtseff et al., 2011).

Kemmler et al. (2006) developed an equation to estimate the 1RM performance from repetitions to failure (RTF) tests over a wide range of repetitions in trained postmenopausal women and to compare the results with other equations to predict 1RM performance. Seventy postmenopausal women aged 57.4±3.1 yr participated in the study. All data was collected within a 6 month period of 25 month of high intensity training. Four pairs of 1RMs and corresponding RTF tests were performed for the leg press, bench press, rowing, and leg adduction, carried out on resistance machines. To determine RTF at different intestines, participants were asked to select loads that permitted repetitions in the 3-5, 6-10, 11-15, and 16-20 ranges. From these results, 2 equations were developed: $w\ (0.988-0.0000584r^3 + 0.00190\ r^2 +0.0104\ r)$,

$|(a,b,c,d)$ in $R^4$ | $\sum(w\ (ar^3 + br^2 + cr + d) - R)^2$ | (w= load of measurement I and r.

The equation presented, adequately estimates 1RM from RTF in trained postmenopausal women over wide range of repetitions (3-20 = 55 to 95% 1RM), with an average error within the range of reproducibility (CV<4%) of the 1RM, indicated by a coefficient of variance <3.3%. Consequently, a significant prediction equation can be developed with a wide repetition range to predict 1RM (Kemmler et al., 2006).

Willardson et al. (2004) devised prediction equations for novice and advanced lifters whereby the 10RM for the 45 degree angled leg press may be used to predict to predict the 10RM for the free weight parallel squat, while also including body mass and limb length as predictor variables. Two groups of sixty men volunteered for the study. One group consisted of advanced strength trainers and the other of novice strength trainers. Each subject performed 10RM for both the squat and the leg press on three separate occasions. During session 1, participants were tested for their 10RM in the free weight parallel squat and 45 degree angled leg press, along with body mass and limb length determined. During session 2 and 3, participants were tested again for their 10RM in the squat and leg press. Results indicated that body mass and limb length were not significant predictors of squat mass. Leg press mass contributed significantly to predicting squat mass ($p<0.05$). The leg press accounted for approximately 25% of the variance in squat mass lifted. Body mass was approaching significance as a predictor for the advance group. The following prediction equations were devised (a) novice group squat mass- leg press mass(0.210) + 36.244kg, (b) advanced group squat mass = leg press mass(0.310) + 19.438kg, and (c) subject pool squat mass= leg press mass (0.354) + 2.235kg. These prediction equations may save time and reduce risk of injury when switching from the leg press to the squat exercise (Willardson & Bressel, 2004).

Braith et al. (1993) evaluated the validity of a dynamic knee extension test, consisting of 7-10 repetitions (7-10RM) performed to exhaustion, to estimate bilateral knee extension 1RM strength in untrained and trained participants. In addition, they wanted to determine whether resistance training would influence the relationship between 1RM strength and submaximal strength and thereby affect the prediction accuracy of a multiple repetition test. Thirty three men aged 25±4.6 yr and 25 women aged 23±5.8 yr participated in the study. During sessions 1 and 2, two 1RM tests were completed for the bilateral knee extension. During session 3, each participant completed a dynamic strength test consisting of a single set of bilateral knee extensions performed to volitional fatigue with a weight that permitted 7-10RM. After completion of the pre-training 1RM and 7-10 RM tests, participants were ranked according to 1RM strength, forty seven of the participants became the trained group and 11 the control group. The participants in the trained group completed two to three training sessions per week for 18 weeks. The following prediction equation was used: 1RM= 1.554(7-10RM weight) – 5.181. This equation over predicted for the trained participants, so this following second equation was developed: 1RM= 1.172 (7-10RM weight) + 7.704. The relationship between 1RM strength and 7-10RM weight was linear. The standard error of estimate indicated that pre training 1RM strength could be predicted with an accuracy of ± 9.3kg. The accuracy of predicting 1RM strength from 7-10RM strength values was high both before (SEE-9.3kg; 10.6% of group mean) and after training (SEE= 9.9kg; 8.9% of mean group). This equations developed demonstrate that 1RM strength can be predicted from a 7-10RM test with a moderate amount of accuracy (SEE-10% of group mean), therefore displaying the accuracy of prediction equations based on a specific population (Braith et al., 1993).

Abadie and Wentworth (2000) developed three regression equations to predict 1RM chest press strength (CPS), shoulder press strength (SPS), and knee extension strength (KES) from a 5-10RM CPS, SPS< and KES test in females. Thirty females 19-26 years of age, who have not participated in a strength training program, volunteered for the study. During session 1, all participants underwent an orientation session to familiarize themselves with the lifts. During the second and third testing sessions, participants were assessed for 1RM or submaximal 5-10RM. Simple regression analysis produced the following equation to predict 1RM CP strength from submaximal 5-10RM CPS tesing : [1RM (Ryan et al.)= 7.24 + (1.05 CPS)]. The correlation between predicted and measured 1RM chest press was r=0.91. The SEE was 5.5lb or 7.8% of measured 1RM CPS. The following equation was produced to predict 1RM KES from 5-10RM knee extension testing: [KES1RM (Ryan et al.) = 4.67 + (1.14 KES). The correlation between predicted and measured 1RM KES was r= 0.94 and SEE was 2.3kg. The regression equation produced to predict 1RM SPS from 5-10RM SPS was [1RM (Ryan et al.) = 1.43 + (1.20)]. The correlation between predicted and measured 1RM SPS was r-0.92 and SEE 1.6kg. The results demonstrated significant positive correlation between predicted and measured 1RM CPS, SPS, and KES in 30 untrained female subjects, therefore demonstrating that prediction equations can be a significant predictor of 1RM in untrained women.

Mayhew et al. (1992) determined the accuracy of using relative muscular endurance performance to estimate 1RM bench press lifting strength in various groups. Male (n=184) and female (n=251), who were members of a college fitness class, participated in the study. The participants were tested at the conclusion of a 14 week three day per week fitness course. The program consisted of 20 minutes of aerobic exercise and 20 minutes of resistance training during each session. Resistance exercise for the arms, chest, shoulders, back, abdomen, hips, thighs and calves were performed as one circuit. A 10-12 RM was used and when more than 12 repetitions could be performed. The resistance was increased at the next session to maintain 10-12 repetitions. During session 1, the 1RM bench press strength was measured. Within three to five days after the 1RM test, a specially designed computer program randomly assigned a relative endurance load for each participant from 55 to 95 percent of the 1RM. The relationship between percent 1RM and reps was exponential for both men and women. Since the curves were not significantly different ($p>0.05$) in slope or intercept, the data for men and women were combined to produce the following exponential regression equation: Percent 1RM= $52.2 + 41.9e^{-0.955reps.}$ The equation had a correlation coefficient of $r = 0.80$ and a standard error of estimate of ± 6.4 percent. This equation allowed the percent 1RM to be reasonably estimated from the number of reps completed in one minute. Some subjects completes more than 15 repetitions during a one minute time, therefore an additional regression equation was computed: 1RM bench press (kg) = rep weight (kg)/ (predicted percent 1RM/100). When the above equations were applied to a cross validation group, the correlations between predicted and actual 1Rm for both men and women were high (r= 0.96 and 0.90). The procedure overpredicted the 1RM of the men by an average of 1.2 ±9.6kg and the women 0.2±13.2kg. The standard errors of estimate for the men and women were ±5.7kg and ±3.6kg. The study indicated that the number of repetitions completed in one minute with a <1RM load can be used to estimate accurately the 1RM bench press in a wide variety of subjects, therefore demonstrating the validity of creating the prediction equation .

Dohoney et al. (2002) hypothesized whether 1RM strength could be predicted from 4-6RM sub maximal strength tests for both large and small muscle mass exercises with greater accuracy than the commonly used 7-10RM sub maximal strength test. Thirty four healthy males between the ages of 19and 32 years, who had not participated in strength training with the last year, participated in the study. Participants completed 1RM, 4-6RM, and 7-10RM strength assessments in random order with a minimum of 48 hours between strength assessments. During each session, participants performed strength assessments for the bench press, incline press, leg extension, biceps curl, and triceps extension in random order. Stepwise regression analysis was used to generate ten regression equations for predicting 1RM strength from the 4-6RM and 7-10 sub maximal strength tests for each exercise. For each exercise, the prediction based on a 4-6 RM set was a better predictor of 1RM strength than the prediction equation based on a 7-10RM set. The results also suggest that the predictive accuracy of the prediction equations is greatest for the upper body exercises, such as the bench press and incline press, compared to lower body exercises. No participants reported that either the 4-6RM or the 7-10RM test limited their ability to exercise or cause noticeable muscle soreness, therefore using a 4-6 RM is valid measure to predict 1RM from a regression equation without causing muscle soreness.

All of the regression equations created showed significant correlations between the predicted and actual 1RM measured. Creating these equations helped to minimize the risk of strength assessment and reduce soreness in participants, therefore allowing prediction equations to be valid and reliable when established for a specific population and exercise.

(See Appendix III for equations)

## Anthropometric Measurements Relating to 1RM

The extent to which anthropometric dimensions relate to and dictate strength performance has been receiving increasing attention. In the literature, circumference measurements, limb lengths, body mass, and body composition to be significant when predicting 1RM in the trained athlete.

Mayhew et al. (1993) examined the relationship between anthropometric dimensions and strength performance in the bench press, squat, and dead lift in a group of resistance trained athletes. Fifty-eight college football players aged 20.1± 1.2yr were measured for anthropometric measurements following their winter conditioning program. The program consisted of 10 weeks of heavy resistance, low repetitions weight training on three days of the week and agility drills on the other two days. Anthropometric dimensions included standing height, seated height, body mass, three muscle circumferences, and six skinfolds. Circumferences were taken on the right side of the flexed muscle (arm, thigh, and calf). Muscle cross sectional areas (CSA) for the arm and thigh were estimated from the formula given by Gurney and Jelliffe (1973). Each participant has trained extensively using free weights and was well acquainted with proper lifting techniques. During the same day as the measurements, bench press, squat, and deadlift 1RM strength was determined. Once all measurements and lifts were recorded, multiple regression analysis was used to select the significant variables which provided the best prediction of each weighing maneuver. Without correction for body mass, most of the body dimensions were related significantly to the strength performances. Arm CSA explained more of the variance in bench press strength (Coefficient of Determination (CD) =62%) than thigh CSA did in either the squat (CD=38%) and deadlift (CD=34%) performance. Body mass was significantly related to circumferences of the arm (r=0.91), thigh (r=0.87), and calf (r=0.82). LBM had a slightly higher relationship for the bench press (r=0.68) than the squat (r=0.60) and deadlift (0.54). Arm circumference correlated best with the bench press (r=0.71), as well as arm CSA (r=0.79). Multiple regression analysis developed three separate equations for the squat, bench press, and deadlift. In the bench press equation, arm CSA contributed 47.2% of the explained variance, while percent fat contribute 33.6%, and BMI added 19.2%. The results of the study point to significant relationships between body structural dimensions and strength performance in resistance trained athletes (J.L. Mayhew, Piper, & Ware, 1993).

Ballman et al. (1999) determined the relationships of selected anthropometric dimensions and psychological perceptions of the appropriateness of strength with the 1RM bench press in untrained college females. One hundred and twenty four untrained college females aged 18.7 ±1.7yr volunteered for the study. Anthropometric procedures included a 3 site skinfold measurement, circumferences taken around the flexed right arm, flexed forearm, chest, hip and calf. Arm CSA was calculated from the flexed arm circumference. Skeletal dimensions were also taken for shoulder width, hip width, arm length, forearm length, elbow width and knee width. Following these measurements a 1RM bench press was measured using a free weight bar and plates. Then the perceptions and attitudes of the subjects toward strength activities were evaluated using the Physical Activity Assessment Scale (PAAS). Pearson product moment correlations were used to evaluate relationships among selected variables and multiple regression analysis was used to estimate the1RM bench press from measured and derived anthropometric variables. Of the 13 anthropometric variables, seven were moderately but significantly related to the 1RM bench press, accounting for 7.3% to 15.2% of the total variance. Of the nine derived anthropometric variables, six were significantly correlated with the

1RM bench press accounting for 7.3% to 16.8% of the common variance. Correlations with the bench press performance included weight (62.6±10.3 kg), fat free mass (48.5±6.1kg), arm circumference (27.6±3.1cm), chest circumference (86.8±6.5cm), hip circumference (96.2± 9.7cm), shoulder width (38.1±1.9cm), arm length (33.6±2.5cm), and forearm length (25.9 ±1.4cm). When developing the regression equation, arm circumference made the largest contributions to the known variance (69.0%). A second multiple regression analysis was performed and five principal factors explained the variance: body fatness, muscle size, limb length, shoulder and hip diameters, and age. Three more regression equations were developed (5 in total) using different variables. The highest zero-order correlations with the bench press strength were the arm CSA (r-0.41), flexed arm circumference (r=0.39), chest circumference (r=0.41), fat free mass (r=0.38), and mesomorphy (r=0.38). The five equations were cross validated on the current sample and four of the equations under predicted the 1RM bench press by 10.8% and the remaining over predicted by 7.9%. Results demonstrate the difficulty of estimating upper body strength in untrained females using anthropometric dimensions (Ballmann, Scanlan, Mayhew, & Lantz, 1999). The use of fat free mass, arm circumference, chest circumference, and arm length helped to predict strength in untrained female partcipants.

Willardson and Bressel (2004) devised prediction equations for novice and advanced lifters whereby the 10RM for the 45$^{o}$ angled leg press maybe used to predict the 10RM for the free weight parallel squat. In addition, they compared body mass, and limb length to see if they were significant predictors. It was shown that body mass and limb length were not significant predictors of squat mass ($p>0.05$). Although, body mass was approaching significance as a predictor for the advance group ($p=0.07$). When stepwise regression was used to create the equation for the subject pool, leg press mass was still the only significant predictor of squat mass. The independent t-tests indicated that the novice and advanced groups were significantly different in terms of body mass, leg press mass lifted, and squat mass lifted. Considering these findings, the advanced individuals may have a better chance of producing significance with body mass and limb length.

Mayhew et al. (1993) determined the relationships between structural dimensions and strength performance among novice male high school athletes during a power lifting competition. Muscle circumferences were taken around the arm, chest, thigh, hips, and calf. Skeletal dimensions included standing and sitting height, body mass, percent body fat, arm and forearm lengths, bench press drop distance, and deadlift pull distance. Body mass was the only dimensional variable to account for more than 50% of the explained variance in strength (70.7%). Arm and chest circumferences were the next highest correlates with strength performance. All of the muscle circumference measurements ($r>0.69$) and skeletal lengths ($r>0.55$) were significantly interrelated. The skinfold (14.4%), forearm length (6.3%), arm CSA (5.1%), and age (3.5%) accounted for less of the explained variance. Four of the variables were significant and were selected to estimate the bench press, arm circumference (36.1%), skinfold (33.5%), forearm length (16.9%), and age

(13.55). Results concluded that structural dimensions could account for 68.9% of the known variance in the bench press, with body size being the major determinant.

Body mass, limb length, and arm circumferences have been shown to be a significant predictor in strength training. For the untrained individual these variables do not seem to be significant, whereas with the trained participants the opposite was observed. This may be to due to adaptations (increased lean body mass and muscular hypertrophy) that have come about with strength training over the years.

<u>Rating of Perceived Exertion on 1RM</u>

Ratings of perceived exertion (RPE) are compared during exercise programs to see how hard we are working when it comes any type of exercise depending on our heart rate. RPE can be evaluated with many different scales, the Borg 6-20 being the most popular. RPE and comparison to 1RM should be able to show a similar correlation, thus helping us to predict 1RM.

Eston et al. (2009) assessed the efficacy of predicting 1RM using ratings of perceived exertion (RPE) from three submaximal loads. Twenty undergraduate students aged 20.8±0.6 yr volunteered for the study. The study consisted on two experimental sessions separated by 48 hours of rest. The orientation trial was conducted on day 1. The main purpose of this was to establish each individual participants' 1RM on two separate bilateral exercises; the biceps curl (BC) and knee extension (KE). Once the 1RM was established, the individuals were given instructions for the Borg 6-20 RPE scale. On day 2, participants performed three sets of two repetitions on each exercises, with each set performed at an unknown pre-determined intensity (20, 49 or 60% of 1RM). The RPE was recorded following each set at the three prescribed intensities. Results reveled no significant difference between the measured 1RM (35.9±12.8kg) and predicted 1RM (34.3±12.4kg) for the knee extension and similar analysis of the biceps curl. There was a positive linear relationship between the measured 1RM and the predicted 1RM (extrapolated from the RPE scores at the three submaximal intensities). All of the participants were able to perceive differences in loads lifted for the knee extension, relating heavier loads with higher RPE scores. Similarly, for the biceps curl, 19 out of 20 participants were able to perceptually differentiate between 20, 40, and 60 percent of their 1RM loads. A two factor ANOVA revealed significant main effects between the RPE at each of the three intensities for both the biceps curl ($F=173.6$, $p<0.001$) and the knee extension ($F=232.9$, $P<0.001$). This study showed the Borg 6-20 to be a significant predictor of 1RM (Eston & Evans, 2009).

Pincivero et al. (2004) examined gender differences in the perceived exertion response, and strength, during a single set of continuous dynamic knee extensor contractions and two different approaches of modeling the perceived exertion response during fatiguing knee extension exercise. Participants consisted of 15 healthy men aged 25.7±3.9yr and 15 healthy women aged 22.4±2.4yr. All testing procedures were performed on the same day. The participants were evaluated for their 1RM during inertial knee extension exercise. After a 2 to 3 minute rest period, the participant was asked to perform a single set of continuous knee extensions with a load equivalent to 50% of their 1RM to the point of failure. Perceived exertion was measured with a modified version of the original category ratio scale (CR-10) developed by Borg. The modified CR-10 scale used presently eliminated the numerical rating of 0.5 and changed the verbal descriptors from weak and strong to light and hard. The results showed a significant increase in perceived exertion across the duration of the knee extension repetitions to fatigue ($F=583.17$, $P<0.001$, $n^2=0.95$) with no significant gender main effect observed ($F= 1.27$, $P=0.27$, $n^2=0.04$). The results concluded that there was no significant difference between men and women when using RPE and RPE showed to be effective when correlating it with 1RM (Pincivero, Coelho, & Campy, 2004).

Focht (2007) examined differences in RPE and training load during self-selected and imposed intensity bouts of resistance exercise in a sample of untrained women. Nineteen female undergraduate students aged 20.6±3.1yr participated in the study. On day 1 of testing, each participant 1RM for the leg extension, chest press, torso arm pull down, and overhead press extension exercises were determined. Once the 1RM's were complete, participants completed self selected and imposed intensity bouts of resistance exercise as well as a quiet rest control condition. Assessments of RPE using the Borg 15 category scale and training load were obtained only during the resistance exercise sessions. RPE was obtained following each set during the resistance exercise session. Results showed RPE yielded significant main effects for intensity ($p<0.003$). Post hoc analyses demonstrated that RPE were significantly higher during imposed intensity exercise. Additionally, RPE increased significantly across sets for all exercise during both resistance exercise sessions. RPE was found to increase across sets, whereas the number of repetitions completed decreased across sets. When the women selected their own load, RPE was equal to 56% of the individuals 1RM, showing that the untrained women did not choose high intensity loads therefore demonstrating RPE to be effective when determining how hard a person is working (Focht, 2007).

Tomporowski (2001) evaluated untrained adult men's and women's ratings of perceived effort obtained during a 25 week strength development program. Participants aged 25-50 volunterred for the study. Each sessions of the exercise program consisted of 5 minutes of stretching, a 7 station circuit resistance training regimen, and a cool down period. Participants assigned to the low volume exercise condition performed 1 set of each exercise for 8 to 12 repetitions to volitional fatigue. Those assigned to the high volume exercise condition increased from one set to three sets over a two week period. Training weight loads for each participant were increased by 5% when the participant was able to complete 12 or more repetitions of each exercise. Training continued for 25 weeks; sessions three times a week, as well as to complete the Borg scale immediately following the completion of the chest press and the leg extension exercise. The analysis of participants' ratings of perceived effort during the chest press exercise and during the leg extension exercise gave significant main effects for the time factor ( $F=14.41$, $p<0.001$ and $F= 5.96$, $p<.01$). The physical demands of performing one set of exercise or three sets of exercise did not differentially influence participant's ratings of perceived exertion. Men's and women's RPE effort did not differ significantly at any point during the 25 week training program; yielding no sex differences. There was a significant increase in participants RPE effort over the course of the training program, therefore demonstrating the higher one works, the higher the RPE number chosen (Tomporowski, 2001).

Egan (2003) evaluated the overall effectiveness of using the current Borg RPE scale (CR-10) to measure physical effort during bouts of resistance training exercise, as well as to examine the validity of this scale in rating the entire resistance training sessions. The study used a randomized, crossover design, in which participants completed two experimental trials twice. Participants performed sets of a low intensity protocol (LIP) and a high intensity protocol (HIP) for the bench press and squat. The study lasted a total of 5 days, day one consisting of a familiarization session, and the other four days of two HIP working of 75% 1RM ( 6 sets of 10 repetitions) and two LIP workouts at 30% 1RM (3 sets of 10 repetitions) . The study consisted of seventeen participants, male and female between the ages of 18-25 years. Each participant had their 1RM evaluated 1 week prior to training. Thirty minutes following each of the exercise sessions, RPE was measured using the Borg CR-10 scale. Results showed a significant different between the mean RPE values for each intensity (RPE at 30% 1, RPE at 75% 7, $p<0.05$) and a significant difference between the session RPE values for each intensity of lifting ($p<0.05$). The study demonstrated that the CR-10 scale is a reliable and useful tool of measuring a resistance training session.

RPE has been shown to be effective tool when experimenting with different strength loads. The Borg 6-20 Scale has been the most widely used RPE scale to help predict aerobic intensity, but has also been used when predicting the 1RM. In addition, the Borg CR-10 scale is another effective and reliable scale when measuring resistance training. A RPE scale is a reliable testing tool when determining how hard someone is working in comparison with 1RM prediction.

# CHAPTER 3

# METHODS

## Subject Characteristics

Institutional Review Board (IRB) approval for testing with human participants was obtained from the protection of human subjects committee at the University of Nevada, Las Vegas prior to any testing. Fifty apparently healthy trained women athletes, aged 18-45y, from the University of Nevada, Las Vegas and the Las Vegas community were recruited to volunteer for this study by word of mouth. Women were considered a trained athlete if they regularly resistance train 2-3 days a week and have been doing so for the last 3 months. Participants performed upper-body resistance training as a normal part of their usual training program. Participant inclusion criteria included the requirements of being apparently healthy as determined by the American College of Sports Medicine health and fitness facility preparticipation screening questionnaire and be free of any cardiovascular, metabolic, and/or pulmonary diseases (Thompson, Gordon, & Pescatello, 2010). Participants will be recruited for the study from the members of the research team and a designated time will be established to collect data. Exclusion criteria consisted of injuries which would interfere with resistance training, women who are pregnant or think they are pregnant, and those who are obese (>30% body fat).

## Procedures

On the day of testing, participants arrived at the University of Nevada, Las Vegas and proceeded to the Exercise Physiology laboratory. An informed consent was explained to each participant and the form was completed once all questions and concerns have been addressed. First the athlete's the athlete's height, weight, chest circumference, upper arm circumference, arm limb lengths, lean body mass of the arm and chest circumference was measured. Upper chest measurements were taken around the upper latissimi dorsi muscle, directly below the armpits. Upper arm circumference was measured on the right arm midway between the olecranon process and acromion process with the arm in the anatomical, flexed position (Thompson et al., 2010). Arm limb lengths were measured from the olecranon process to the styloid process on both the right and left limbs. Shoulder distance was measured from one acromion process to the other on the distal side of the body. Then, percent body fat was obtained by the DEXA. The participant completed a DEXA scan. Body composition and lean body mass of the arms and chest were obtained by dual-energy X-ray absorptiometry. To establish an accurate regression equation, a four repetition maximum bench press and a barbell lying triceps extension.

After these measurements were taken, the athletes participated in a general and dynamic warm up with an 18.18kg straight bar. According to previous studies (Cummings & Finn, 1998; Francois D. Desgorces, Geofffroy Berthelot, Gilles Dietrich, & Marc S.A. Testa, 2010; Jerry L. Mayhew, John, & Jessica, 1993; J.L. Mayhew et al., 1995), each athlete was allowed to warm up according to personal preferences using light weights before the test. After the warm up was complete a one minute rest period was provided. The participant then grasped the bar, with the elbow at 90 degrees of abduction and feet flat on the ground with the knees bent. A spotter assisted the athlete in lifting the bar from the support rack; Grip distance was self selected and measured from thumb to thumb on the bench press exercise. The participant then lowered the bar slowly to touch the chest and then fully extended their arms. Next, an estimated load was determined to ensure that the athlete was within her perceived capacity (50-70% of 1RM). Participants then rested for a period of three to five minutes. Resistance was then progressively increased by 5 to 20 kg until the athlete could only complete 4 repetitions (Thompson et al., 2010). A 4RM was ideally determined within two to three attempts. If the athlete failed to hit the 4RM load on the second attempt, the athlete rested another three to five minutes and weight was added or subtracted from the bar (Baechle & Earle, 2008) . The triceps 4RM followed the same protocol as the chest press. The exercise used for the triceps extension repetition maximum was the barbell lying triceps brachii extension, a 7.27kg straight bar was used. The participant laid on bench with a narrow overhand grip on barbell and position the barbell over her shoulders with arms extended. The bar was lowered to the forehead by the bending elbows; arms were then extended back up to starting position.

Immediately after each 4RM attempt in both the triceps rope extension and bench press, each participant was asked to “associate the feelings in the active muscles with maximal exertion” evaluated by the original Borg 6-20 scale (Eston & Evans, 2009) and Borg CR-10 scale . A 4RM was chosen because assistance exercises are not usually performed at fewer than four repetitions according to published descriptions of periodized programs(Baechle & Earle, 2008).

After data was recorded, Pearson's *r* correlation statistics was used to find the linear relationship between the bench press and triceps rope extension exercises. A simple linear regression analysis was then used to develop the regression equation.

## Statistics

Data are presented as means and standard deviations. Alpha was set at 0.05 which is accepted as significant. Exploratory stepwise regression was used to determine whether triceps extension load is a significant predictor of bench press loads and to develop a prediction equation for the exercise.

# CHAPTER 4

# RESULTS

## Participants

The sample consisted of 50 women who resistance trained 2-3 times a week for at least three months. The physical characteristics of the participants are presented in Table 1.

## Multiple regression Analyses

Stepwise multiple regression analysis revealed significant 3-variable, 2-variable and 1-variable equations. The variables that significantly predicted the 4RM chest press were 4RM triceps brachii weight ($p<.001$), chest circumference ($p<.001$), and percent body fat ($p<.006$). Height, weight, arm length, flexed right arm, and RPE values did not contribute significantly to the model ($p>0.05$).

The analysis produced the following three equations shown in Table 2. The $R^2$ value for the one variable equation (Four RM triceps pull down) was .624. Adding chest circumference to the equation increased the $R^2$ to .742. Finally, adding percent body fat to the equation increased the $R^2$ to .782 (Table 4). Coefficients are presented in Table 3. Correlations and p values are displayed in Table 5. Equation 1 accounted for 64.4% of the variance, equation 2 accounted for 74.2% of the variance, and equation 3 explained 78.2% of the variance.

| **TABLE 1 Subject Characteristics** | **MEAN±SD** |
|---|---|
| Variable | Total (N=50) |
| Age (y) | 23.98±4.95 |
| Height (cm) | 165.28±7.20 |
| Weight (kg) | 62.43±13.33 |
| % Body Fat | 24.86±6.11 |
| % Fat Trunk | 24.11±6.89 |
| % Fat Right Arm | 21.02±5.89 |
| % Fat Left Arm | 20.1±5.89 |
| Right Limb Length(cm) | 53.39±5.93 |
| Left Limb Length (cm) | 52.57±7.56 |
| Chest Circumference (cm) | 84.54±4.03 |
| Flexed Right Arm (cm) | 29.95±8.84 |
| Shoulder Width (cm) | 41.67±3.02 |
| Grip Width Chest Press(cm) | 50.88±9.30 |
| 4RM Chest Press (kg) | 35.54±7.19 |
| 4RM Triceps Extension (kg) | 22.09±5.14 |
| RPE CR10 Chest Press | 7.14±2.16 |
| RPE B620 Chest Press | 16.34±1.83 |
| RPE CR10 Triceps Extension | 7.3±2.43 |
| RPE B620 Triceps Extension | 16.24±1.97 |

**TABLE 2 Equations**

| Variables | Equation |
|---|---|
| (#1) 4RM Triceps Extension Weight | 4RM CP= 11.139 + 1.105(4RM_T) |
| (#2) 4RM T + Chest Circumference | 4RM CP= -41.282 +.870(4RM_T) +.681(Chest) |
| 4RM T + Chest C + % Body Fat | 4RM CP= -46.7+.802(4RM_T) +.838 (Chest) -.254 (Body fat) |

**TABLE 3: Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 11.139 | 2.809 | | 3.965 | .000 |
| | Four_RM_T | 1.105 | .124 | .790 | 8.916 | .000 |
| 2 | (Constant) | -41.282 | 11.557 | | -3.572 | .001 |
| | Four_RM_T | .870 | .115 | .622 | 7.535 | .000 |
| | Chest | .681 | .147 | .382 | 4.633 | .000 |
| 3 | (Constant) | -46.706 | 10.896 | | -4.286 | .000 |
| | Four_RM_T | .802 | .110 | .573 | 7.304 | .000 |
| | Chest | .838 | .147 | .470 | 5.707 | .000 |
| | Body_fat | -.254 | .087 | -.216 | -2.910 | .006 |

a. Dependent Variable: Four_RM_C

**TABLE 4: Model Summary[d]**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .790[a] | .624 | .616 | 4.45840 |
| 2 | .861[b] | .742 | .731 | 3.73315 |
| 3 | .884[c] | .782 | .767 | 3.46774 |

a. Predictors: (Constant), Four_RM_T

b. Predictors: (Constant), Four_RM_T, Chest

**TABLE 5:Correlations**

| | | Four_RM_C | Four_RM_T | Chest | Body_fat |
|---|---|---|---|---|---|
| Four_RM_C | Pearson Correlation | 1 | .790** | .655** | -.098 |
| | Sig. (2-tailed) | | .000 | .000 | .500 |
| | N | 50 | 50 | 50 | 50 |
| Four_RM_T | Pearson Correlation | .790** | 1 | .439** | -.047 |
| | Sig. (2-tailed) | .000 | | .001 | .746 |
| | N | 50 | 50 | 50 | 50 |
| Chest | Pearson Correlation | .655** | .439** | 1 | .308* |
| | Sig. (2-tailed) | .000 | .001 | | .029 |
| | N | 50 | 50 | 50 | 50 |
| Body_fat | Pearson Correlation | -.098 | -.047 | .308* | 1 |
| | Sig. (2-tailed) | .500 | .746 | .029 | |
| | N | 50 | 50 | 50 | 50 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

# CHAPTER 5

## Discussion of Results

The authors' believed that, this is the first study to use trained women and predict upper body strength. The current study was designed to see whether there was a linear relationship between the bench press and the lying triceps extension exercise. In addition, we hoped to develop a prediction equation for the purpose of prescribing bench press exercise loads from triceps loads using a 4RM submaximal load in trained women (90% of 1RM). Two significant variables were found (4RM triceps brachii extension and chest circumference) to develop regression equations, along with a third variable (percent body fat). Using only the 4RM triceps brachii extension, a significant prediction equation was derived that explained 62% of the variance. Using both the 4RM triceps brachii extension and chest circumference, the prediction equation accounted for 74% of the variation. Then by adding in percent body, equation three accounted for 88% of the variation.

In comparison, Ebben et al. (2008) found that the deadlift, lunge, step up, and leg extension were significant predictors to the 6RM squat weight, developing four regression equations using the 6RM squat load to predict each exercise. $R^2$ values ranged from 0.67 to 0.81, which is similar to the current study of 0.62 to 0.78. In a different investigation, Ebben et al. (2010) used the squat load another time to determine hamstring resistance training loads. The following exercises were used: seated leg curl, stiff leg dead lift, single leg stiff leg deadlift, and good morning exercise. When regression analysis was run, squat load was a significant predictor of each exercise and four additional regression equations were developed from prediction of an opposite muscle group. Wong et al. (2010) followed similar protocols as Ebben et al. (2008, 2010) and performed 6RM of the following exercises: back half squat, deadlift, leg press, step up, and lunge. Results demonstrated that the 6RM squat load was significant ($p<0.0001$), as compared to the current study, correlating between $R^2$ values of 0.55 to 0.78 (Ebben et al., 2010) and $R^2$ values of 0.57 to 0.85 (Wong et al., 2010). Four regression equations were then developed. The following three studies were able to create regression equations in comparison to the current study. In addition, Ebben et al. (2010, 2008) and Wong et al. (2010) developed equations from opposing muscle groups, as the 4RM triceps brachii extension was able to predict the 4RM bench press in the current study. The 4RM was able to produce similar results to the 6RM.

Anthropometrics was another key factor in development of the regression equation to predict 4RM chest press strength. Mayhew et al. (1993) determined the relationship between selected anthropometric dimensions and strength performances in male athletes. Specific anthropometric dimensions used were height, weight, lean body mass, BMI, arm circumference, thigh circumference, and calf girth. When determining upper body strength via the bench press, significant variables included arm circumference and percent body fat, as compared to the 4RM prediction, as well as arm cross sectional area. Unlike the current study, arm circumference and BMI contributed to the regression equation developed. Similarly, percent body fat when added increased the $R^2$ value to 0.87. Willdarson and Bressel (2004) predicted the 10RM squat mass from leg press mass. They used the following anthropometric measurements: height, weight, and limb length, in addition to leg press strength. In comparison to the current study, limb length and body mass were not significant predictors ($p>0.05$). Leg press strength was able to predict squat strength, as the 4RM triceps brachii extension was able to predict the 4RM bench press. Mayhew et al. (1993) used body dimensions to predict strength performances. Measurements used were height, weight, chest and arm circumference, percent fat, and body mass. The highest correlations to strength performance were arm circumference, chest circumference, and body mass. In contrast, the results of the present investigation found that body fat was the most obvious factor contributing to the amount of weight lifted, instead of body mass. It appears that in males' body mass is adequate to predict 1RM; however in females our results indicate that the more sensitive measure of percent body fat is required. Reynolds et al. (2006) developed a regression equation to predict 1RM. He attempted to see if chest circumference, flexed right arm circumference, and percent body fat could be incorporated along with the 5RM, 10RM, and 20RM bench press. Unlike the present 4RM study, chest circumference and percent body fat were not significant. In comparison to the present study, arm circumference was not significant. The 5RM load was the best predictor of the 1RM in the bench press. Similar loads were able to be predicted in the equation of Reynolds et al (2006). Ballman et al. (1999) isolated five principal factors: muscle size, limb length, shoulder and hip diameters, and age. The study produced a regression equation from the anthropometric dimensions in the 1RM bench press. In comparison to the present study, chest circumference and percent fat were significant and limb length and shoulder width were not significant. In general anthropometrics seem to be able to predict strength loads in different muscle groups.

Differences in these studies resulted in the use of different populations. The present study used trained women, where only one other study (Ebben et al., 2010) used resistance trained females (N=13). Due to the fact of a small number of women, the equation of Ebben et al. (2010) was not significant for female participants when predicting hamstring loads from squat loads. A high correlation was found when using karate athletes (Wong et al., 2010), signifying the need to develop separate regression equations depending on the specific population (i.e. males and females). Many investigators who used male athletes (Jerry L. Mayhew, McCormick, Piper, Kurth, & Arnold, 1993; J.L. Mayhew et al., 1993; Reynolds et al., 2006; Willardson & Bressel, 2004) showed significance in the arm circumference and limb lengths; where in trained women who participated in the current study it was not significant. The flexed right arm was significant in untrained women (Ballmann et al., 1999) when developing the regression equation. In the current study flexed right arm circumference was not significant. These results demonstrate the need of having different equations depending on gender and resistance training experience.

RPE has been shown in the literature to correspond to exercise intensity (Egan, 2003; Eston & Evans, 2009; Focht, 2007; Tomporowski, 2001). Eston et al. (2009) recorded RPE following three intensities: 20%, 50%, and 60% of the

1RM.  Results related heavier loads with higher RPE, as well as showing the Borg 6-20 scale to be a significant predictor of 1RM ($p<0.001$).  In the contrast, the Borg 6-20 scale was unable to predict the 4RM in the current study.  Egan (2003) looked at the overall effectiveness of the Borg CR-10 scale.  RPE was determined 30 minutes following each training session.  The results showed a significant difference between mean RPE values for each intensity ($p <0.05$), as well as a significant difference between the average RPE value and the session RPE value during each intensity for the bench press exercise.  The researchers (Ebben et al. (2003)) found evidence that it may be possible to predict session RPE value for the bench press based on the individual set RPE values of the workout unlike the results of the current study, where the Borg CR-10 was not able to even come close to predicting the 4RM chest press.  Focht (2007) obtained RPE following each set during the resistance exercise session.  Results showed RPE yielded significant main effects for intensity ($p<0.003$).  Although, when women selected their own load, RPE was only equal to 56% of the individuals 1RM. Therefore this makes it difficult to predict RPE from different exercise loads as presented in the current study.  RPE is a good tool when it comes to figuring out how hard an individual is working, but when trying to predict exercise intensity from RPE, it is not as effective.

Finally, the measurements of the present study were performed in trained women.  The present results are most specific to exercises performed at loads that are similar to those used in the study and with individuals whose physical characteristics are similar to those participants in the present study.  A limitation found in the present study was the truthfulness of participants to their strength training status. Future studies may want to have an inclusion criterion of women who resistance trained for at least six months or have a survey signifying how many days and what muscle groups they train and require participants to be familiar with the exercises being performed in the study.

## Practical Application

Exercise load assignment should be based on testing data as opposed to trial and error. Using a 1RM is impractical for personal trainers, strength coaches etc. when devising exercise programs due to the risk of injury. Predicting a 4RM for larger muscle groups is an efficient way to guide an individual in the right direction during training. As a result of this study, trained women have their own equation to help predict upper body strength using simple measurements of a 4RM tricep extension exercise, chest circumference, and percent body fat.

# APPENDIX I

**Department of Kinesiology and Nutrition Sciences**

# INFORMED CONSENT FORM

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**TITLE OF STUDY:** Predicting Chest Press Strength from a 4RM Triceps Brachii Exercise in Trained Women

**INVESTIGATOR(S):** Dr. Tony Santo and Krystina Moschella

**CONTACT INFORMATION:** If you have any questions or concerns about the study, please contact Dr. Santo at (702) 895-5329 or Krystina Moschella (617) 291-1300.

For questions regarding the rights of research subjects, any complaints or comments regarding the manner in which the study is being conducted you may contact the **UNLV Office of Research Integrity – Human Subjects Research at (702) 895-2794 or toll free at 877-895-2794 or via email at IRB@unlv.edu.**

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**<u>Purpose of the Study</u>**

To provide a safe method to predict chest press strength, limiting injury risk.
To devise a regression equation for women athletes.

**<u>Participants</u>**

You are eligible to participate in the study because you fit these criteria: you strength train 2-3 times a week, have been strength training for 3 months or more, you are not male, and are between the ages of 18-45. Pregnant women or women who think they may be pregnant may not participate in this study due to that bone mineral density is determined using a dual-energy X-ray absorptiometry (DEXA), a diagnostic X-ray device.

The UNLV Radiation Safety Office has developed the UNLV Reproductive Health Program to ensure that people occupationally exposed to radiation at UNLV are aware of the risks associated with their exposure. In addition, the principles of radiation protection require that ALL doses (this includes medical examinations) be kept As Low As Reasonable Achievable (ALARA).
This is of particular concern in a study such as this because a developing fetus is especially sensitive to radiation exposure in the first trimester of pregnancy

**<u>Procedures</u>**

If you volunteer to participate in this study, you will be asked to do the following: you will report to the UNLV Exercise Physiology laboratory, building MPE room # 312 ; allow 45 minutes for testing.
Also, you will be asked to report after an overnight fast to obtain a finger prick sample of blood for Vitamin D status. Snacks (i.e. granola bars & fruit) will be provided once the DEXA scan is complete.

Following the DEXA scan, your height and weight will be measured, as well as your chest circumference, upper arm circumference, full arm lengths, grip distance by a measuring tape , and percent body fat by the use of the DEXA. Then a 4RM chest press and triceps extension exercise will be performed.
To create an accurate regression (mathematical) equation, a four repetition maximum chest press and lying tricep extension exercises will be used. After these measurements are taken, you will participate in a general and dynamic warm up that will assist in decreasing the possibility for soreness. This warm up will be completed prior to the exercises. You will be allowed to warm up according to personal preferences using light weights. The warm up will consist of five to ten minutes of slow, low-intensity activity, such as a dumbbell bench press (any exercise similar to a bench press movement). After the warm up is complete a 2-3 minute rest period will be provided.

Chest Press 4RM: You will grasp the bar in a position slightly greater than shoulder width, with the elbow at 90 degrees and feet flat on the ground with the knees bent. A spotter will assist you in lifting the bar from the support rack with weights secure on the bar using clips. Next, an estimated weight will be determined to ensure that you are within you recognized capacity (10-12 repetitions). You will then rest for a period of three to five minutes. Resistance will then be progressively increased by 5 to 10 pounds until you can only complete 4 repetitions.

Triceps Brachii 4RM: This will follow the same protocol as the chest press. The exercise used for the triceps extension repetition maximum will be the barbell lying tricep extension.

Following the completion of both exercises, a static cool down will be advised to help minimize soreness.

**Benefits of Participation**

There may be little direct benefits to you as a participant in this study. However, you will come away knowing your height, weight, limb length, bicep and chest circumference, percent body fat (how much fat you have), and lean body mass ( how much muscle you have). The main benefit of the study will be an establishment of the validity and reliability of a new prediction equation that will aim to predict chest press strength from triceps brachii strength. Creating this equation will help increase the safety of these exercises to you as an athlete

**Risks of Participation**

This study involves minimal risk to you. The dose that a subject receives from the evaluation of bone mineral density is approximately three (3) millirem (x-ray). Three millirem is less than 1% of the dose that we receive annually as a result of living in Las Vegas and is 0.6% of the limit for exposure of declared pregnant radiation workers. For any female, there is a possibility that you are pregnant but do not know that you are. If it is found that you are pregnant after the study, you should know that the potential for damage of the exposed fetus is extremely low. Concern for damage to an exposed fetus is typically expressed at a dose level of greater than 5,000 millirem. The International Commission on Radiological Protection recommends that a one time fetal dose should not exceed 10,000 to 20,000 millirem.The radiation exposure of the DEXA scan is minimal and is approximately the same amount of radiation you receive living in Nevada for less than 3 days. If you are uncomfortable with blood draws, fainting may occur. You may experience soreness the next day from the 4RM lifts due to this strenuous exercise, but it should be alleviated within 2-3 days. The warm up and cool down will help to decrease the soreness. In addition, weight from the chest press or tricep extension could fall on you, but an experienced spotter will be there to assist you as you attempt the 4RM chest press and triceps extension as well as clips to hold the weights in place.

**Cost /Compensation**

There will not be any financial cost to you to participate in this study. The study will take 45 minutes of your time; however there is no compensation for your time.

**Contact Information**

If you have any questions or concerns about the study, you may contact Dr. Antonio Santo at Antonio.Santo@unlv.edu. For questions regarding the rights of research subjects, any complaints or comments regarding the manner in which the study is being conducted you may contact the UNLV Office of Research Integrity – Human Subjects at 702-895-2794 or toll free at 877-895-2794 or via email at IRB@unlv.edu.

**Voluntary Participation**

Your participation in this study is completely voluntary. You may refuse to participate in this study or in any part of this study and you may withdraw at any time without prejudice to your relations with the University. You are encouraged to ask questions about this study prior to the beginning or at any time during the study. You will be given a copy of this form.

**Confidentiality**

All information gathered in this study will be kept completely confidential. Only those persons who are directly related to this study (i.e.: researchers, data analysts) will have access to your data. No reference will be made in written or oral materials, which could link you to this study. All records will be stored in the laboratory for a period of 3 years. After 3 years, any documentation with identifiable information (e.g., name) will be destroyed. Unidentifiable data will be stored in locked storage indefinitely.

**Freedom of Consent:**

I have read the above information carefully and I am aware of the tests/procedures to be performed. Knowing these risks and having the opportunity to ask questions, I agree (consent) to participate in this study. I understand that I have a right to withdraw from this study at any time without prejudice. I am at least 18 years old and a copy of the informed consent has been given to me.

______________________________ ______________

Signature of Participant Date

______________________________

Participant Name (Please Print)

______________________________ ______________

Signature of Witness Date

APPENDIX II

**Table 6 Excluded Variables[a]**

| Model | | Beta In | T | Sig. | Partial Correlation | Collinearity Statistics |
|---|---|---|---|---|---|---|
| | | | | | | Tolerance |
| 1 | Age | .079[b] | .886 | .380 | .128 | .997 |
| | Height | .214[b] | 2.548 | .014 | .348 | .996 |
| | Weight | .069[b] | .748 | .458 | .108 | .932 |
| | Body_fat | -.061[b] | -.680 | .500 | -.099 | .998 |
| | R_Limb | .101[b] | 1.137 | .261 | .164 | .990 |
| | L_Limb | .120[b] | 1.365 | .179 | .195 | .993 |
| | Flexed_R | .157[b] | 1.812 | .076 | .256 | .993 |
| | Shoulder_W | .138[b] | 1.544 | .129 | .220 | .959 |
| | Chest | .382[b] | 4.633 | .000 | .560 | .807 |
| | Grip | .204[b] | 2.408 | .020 | .331 | .998 |
| | RPE_C_CR 10 | .067[b] | .751 | .457 | .109 | 1.000 |
| | RPE_C_620 | .063[b] | .710 | .481 | .103 | 1.000 |
| | RPE_T_CR 10 | .064[b] | .714 | .479 | .104 | .984 |
| | RPE_T_610 | .115[b] | 1.288 | .204 | .185 | .974 |
| 2 | Age | .114[c] | 1.548 | .128 | .223 | .987 |
| | Height | .121[c] | 1.578 | .122 | .227 | .905 |
| | Weight | -.021[c] | -.262 | .794 | -.039 | .874 |
| | Body_fat | -.216[c] | -2.910 | .006 | -.394 | .864 |
| | R_Limb | .051[c] | .669 | .507 | .098 | .968 |
| | L_Limb | .092[c] | 1.237 | .222 | .179 | .986 |
| | Flexed_R | .068[c] | .878 | .385 | .128 | .919 |
| | Shoulder_W | .045[c] | .570 | .571 | .084 | .887 |
| | Grip | .146[c] | 2.002 | .051 | .283 | .966 |
| | RPE_C_CR 10 | .109[c] | 1.483 | .145 | .214 | .986 |
| | RPE_C_620 | .062[c] | .830 | .411 | .121 | 1.000 |
| | RPE_T_CR 10 | .076[c] | 1.016 | .315 | .148 | .983 |
| | RPE_T_610 | .138[c] | 1.880 | .066 | .267 | .970 |
| 3 | Age | .038[d] | .490 | .626 | .073 | .821 |
| | Height | .089[d] | 1.212 | .232 | .178 | .880 |
| | Weight | .030[d] | .395 | .695 | .059 | .828 |
| | R_Limb | .061[d] | .867 | .391 | .128 | .965 |
| | L_Limb | .085[d] | 1.231 | .225 | .180 | .985 |
| | Flexed_R | .006[d] | .083 | .935 | .012 | .837 |

| | | | | | |
|---|---|---|---|---|---|
| Shoulder_W | .100[d] | 1.344 | .186 | .196 | .839 |
| Grip | .081[d] | 1.077 | .287 | .159 | .830 |
| RPE_C_CR 10 | .104[d] | 1.517 | .136 | .221 | .985 |
| RPE_C_620 | .059[d] | .859 | .395 | .127 | 1.000 |
| RPE_T_CR 10 | .071[d] | 1.016 | .315 | .150 | .982 |
| RPE_T_610 | .112[d] | 1.615 | .113 | .234 | .952 |

a. Dependent Variable: Four_RM_C
b. Predictors in the Model: (Constant), Four_RM_T
c. Predictors in the Model: (Constant), Four_RM_T, Chest
d. Predictors in the Model: (Constant), Four_RM_T, Chest, Body_fat

**Table 7 ANOVA[a]**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 1580.153 | 1 | 1580.153 | 79.495 | .000[b] |
| | Residual | 954.113 | 48 | 19.877 | | |
| | Total | 2534.267 | 49 | | | |
| 2 | Regression | 1879.254 | 2 | 939.627 | 67.422 | .000[c] |
| | Residual | 655.013 | 47 | 13.936 | | |
| | Total | 2534.267 | 49 | | | |
| 3 | Regression | 1981.105 | 3 | 660.368 | 54.915 | .000[d] |
| | Residual | 553.161 | 46 | 12.025 | | |
| | Total | 2534.267 | 49 | | | |

a. Dependent Variable: Four_RM_C
b. Predictors: (Constant), Four_RM_T
c. Predictors: (Constant), Four_RM_T, Chest
d. Predictors: (Constant), Four_RM_T, Chest, Body_fat

**Table 8 Residuals Statistics[a]**

| | Minimum | Maximum | Mean | Std. Deviation | N |
|---|---|---|---|---|---|
| Predicted Value | 20.3704 | 47.7940 | 35.5494 | 6.35852 | 50 |
| Residual | -7.09369 | 8.82800 | .00000 | 3.35991 | 50 |
| Std. Predicted Value | -2.387 | 1.926 | .000 | 1.000 | 50 |
| Std. Residual | -2.046 | 2.546 | .000 | .969 | 50 |

a. Dependent Variable: Four_RM_C

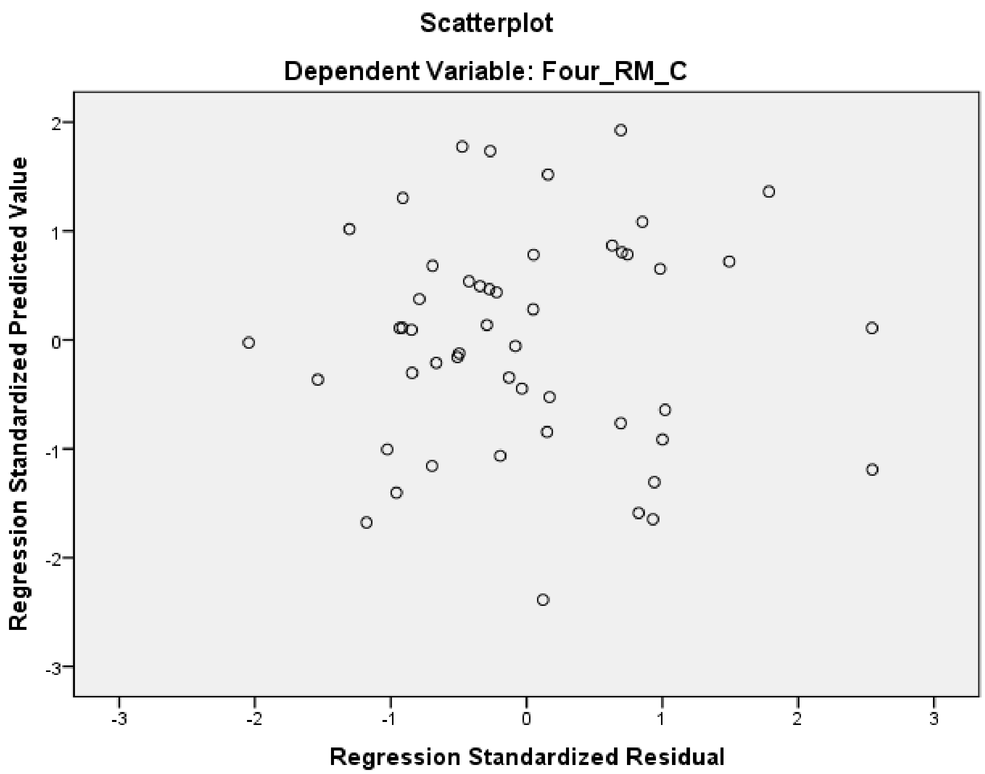


**Table 9 $R^2$ Values**

| Study | $R^2$ |
|---|---|
| 4RM Study | 0.62-0.78 |
| Ebben et al.(2008) | 0.67-0.81 |
| Ebben et al. (2010) | 0.55-0.78 |
| Wong et al. (2010) | 0.57-0.87 |

# APPENDIX III

| Equation | R value | repetitions |
|---|---|---|
| Abadie & wentworth (2000) | cp 0.91, sps 0.92, kes 0.94 | 5-10RM |
| Braith et al.( | BP 0.89 | 7-10RM |
| Ebben et al.(2010) | LC 0.58, SLDL .82, SLSDL 0.80, GM 0.79 | 6RM |
| Dohoney et al. (2002) | BP 0.97/0.91, TE 0.90/0.86 | 4-6 & 7-10RM |
| Abadie et al.(1999) | BP 0.969 | 7-10RM |
| Jidovtseff et al.(2011) | BP 0.95 | LD0 |
| Mayhew et al.(1992) | BP 0.98 | 2-15 RM |
| Wong et al. (2010) | DL 0.86, LP 0.76, L 0.86m SU 0.92 | 6RM |
| Ebben et al.(2008) | DL 0.81, L 0.62, SU, 0.71, LE 0.67 | 6RM |
| Epley (1985) | ALL 0.97 | 20-100% 1RM |
| Mayhew et al.(1993) | ALL 0.89 | 20-100% 1RM |
| Desgorces et al.(2010) | Total 0.97, H 0.99, HE 0.98 | 75-95% 1RM |
| Rontu et al.(2010) | BP0 .88, 0.92, 0.96,0.97, 0.97 | 50,60,70,80,90% 1RM |
| Kravitz et al.(2003) | S 0.98, BP 0.98, DL 0.98 | 70,70, 80% 1RM |
| Brzycki et al.(1993) | BP 0.85, SQ 0.67 | 70% 1RM |
| Epley (1985) | BP 0.91, SQ 0.95 | 70% 1RM |
| Lander (1985) | BP 0.86, SQ 0.70 | 70% 1RM |
| Mayhew et al. (1992) | BP 0.91, SQ 0.95 | 70% 1RM |
| Berger (1970) | BP 0.97, BC .84 | 85% 1RM |
| O'Connor et al.(1989) | BP .98, BC .91 | 85% 1RM |
| Whisenant et al.(2003) | BP 0.93 | 75,80,85% 1RM |
| Knutzen et al.(1999) | UpperB 0.77-0.9, LowerB 0.6-0.8 | 1-3RM |
| Reynolds et al.(2006) | LP 0.97, BP 0.99 | 5RM |
| LeSeuer et al.(1997) | BP 0.95 | RTF |
| Cummings & Finn et al.(1998) | BP 0.94 | 4-8RM |
| Mayhew et al. (2004) | BP 0.96 | RTF |
| Mayhew et al. (1995) | BP 0.93 | RTF |
| Wood et. al | .81-.98 | 50-90%1RM |
| Ballman et. al | BM 0.53, LBM 0.68, AC 0.71 | Anthro. |

APPENDIX IV

Created Prediction Equations

Abadie et al.(1999)

1RM=8.8147+1.1828(7-10RM)

- Using a 7-10RM to predict 1RM in the bench press

Jidovtseff et al.(2011)

1RM= (0.871LD0) – 0.624

LD0 = load velocity relationship

- Using the lead velocity relationship to predict 1RM

Kemmler et al. (2006)

KLM equation

Optimal cubic curve

w $(0.988-0.0000584r^3 + 0.00190 r^2 +0.0104 r)$,

W= load of measurement L and r, is the number of repetitions

- Accurately predicted 1RM from RTF with mean and absolute differences between actual 1RM and predicted 1RM for the 4 exercises of 1.5-3.1% and with coefficients of variation of <3.3%.

The minimum of the set

$|(a,b,c,d) \text{ in } R^4 \mid \sum(w (ar^3 +br^2 + cr +d)- R)^2 |$

A,b,c,d= 4 exercises

Mayhew et al. (1992)

1) Exponential regression equation: Percent 1RM= $52.2 + 41.9e^{-0.955reps}$

Correlation coeffient of r=0.80, SEE ±6.4%

e= standard errors

Mayhew et.al Prediction Equation

2)1RM bench press (kg) = rep weight (kg)/(predicted percent 1RM/100)

The relationship between repetitions and percent 1RM

Willardson and Bressel (2004)

1) Novice group squat mass= leg press mass(0.210) + 36.244kg,

2) Advanced group squat mass = leg press mass(0.310) + 19.438kg, and (c) subject pool squat mass= leg press mass (0.354) + 2.235kg.

- predicting a 10RM for the free weight parallel squat using the 45 degree angled leg press

Braith et al.(1993)

1) Untrained participants- 1RM= 1.554(7-10RM weight) – 5.181

2) Trained athletes- 1RM= 1.172 (7-10RM weight) + 7.704

- using a 7-10RM load to predict 1RM for knee extension strength

Abadie and Wentworth (2000)

1) CPS1RM (Ryan et al.)= 7.24 + (1.05 CPS)

CPS= chest press strength
2) KES1RM (Ryan et al.) = 4.67 + (1.14 KES)
KES= knee extension strength
3) SPS1RM (Ryan et al.) = 1.43 + (1.20)
SPS= shoulder press strength

- Using a 5-10RM

Dohoney et al. (2002) 10 regression equations

| Resistance Exercise | Prediction Equations for 7-10 RM tests | r | Adjusted $R^2$ | SEE | SEE/1-RM (%) |
|---|---|---|---|---|---|
| Bench Press | -24.62 + (1.12 x Wt) + (5.09 x reps) | 0.97 | 0.93 | 11.0 | 5.6 |
| Inclined Press | -9.85 + (1.02 x Wt) + (5.70 x reps) | 0.96 | 0.90 | 11.9 | 6.9 |
| Triceps Extension | 6.74 + (0.99 x Wt) + (1.61 x reps) | 0.93 | 0.86 | 6.4 | 6.0 |
| Biceps Curl | 19.97 + (0.81 x Wt) + (2.31 x reps) | 0.89 | 0.78 | 6.4 | 6.3 |
| Leg Extension | 82.07 + (0.76 x Wt) + (5.66 x reps) | 0.82 | 0.66 | 26.3 | 8.4 |

| Resistance Exercise | Prediction Equations for 7-10 RM tests | r | Adjusted $R^2$ | SEE | SEE/1-RM (%) |
|---|---|---|---|---|---|
| Bench Press | -1.89 + (1.16 x Wt) + (1.68 x reps) | 0.95 | 0.91 | 13.5 | 6.9 |
| Inclined Press | 12.14 + (1.16 x Wt) + (0.10 x reps) | 0.93 | 0.86 | 14.3 | 8.3 |
| Triceps Extension | -9.76 + (1.02 x Wt) + (3.56 x reps) | 0.91 | 0.82 | 7.2 | 6.9 |
| Biceps Curl | 23.90 + (0.77 x Wt) + (2.16 x reps) | 0.84 | 0.68 | 7.7 | 7.6 |
| Leg Extension | 95.00 + (0.65 x Wt) + (8.52 x reps) | 0.76 | 0.56 | 30.1 | 9.7 |

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Microsoft Office 2007 and internet/E-mail

Thesis Title: Predicting Chest Press Strength from a 4RM Triceps Brachii Exercise in Trained Women

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