

## Inter-Investigator Reliability of Anthropometric Prediction of 1RM Bench Press in College Football Players

RICHARD M. SCHUMACHER<sup>†1</sup>, JANA L. ARABAS<sup>†1</sup>, JERRY L. MAYHEW<sup>†1,2</sup>, and WILLIAM F. BRECHUE<sup>‡2</sup>

<sup>1</sup>Health and Exercise Sciences Department, Truman State University, Kirksville, MO, USA; <sup>2</sup>Physiology Department, A. T. Still University, Kirksville, MO, USA

<sup>†</sup>Denotes graduate, <sup>‡</sup>Denotes professional author

---

### ABSTRACT

*International Journal of Exercise Science 9(4): 427-436, 2016.* The purpose of this study was to determine the effect of inter-investigator differences in anthropometric assessments on the prediction of one-repetition maximum (1RM) bench press in college football players. Division-II players (n = 34, age = 20.4 ± 1.2 y, 182.3 ± 6.6 cm, 99.1 ± 18.4 kg) were measured for selected anthropometric variables and 1RM bench press at the conclusion of a heavy resistance training program. Triceps, subscapular, and abdominal skinfolds were measured in triplicate by three investigators and used to estimate %fat. Arm circumference was measured around a flexed biceps muscle and was corrected for triceps skinfold to estimate muscle cross-sectional area (CSA). Chest circumference was measured at mid-expiration. Significant differences among the testers were evident in six of the nine anthropometric variables, with the least experienced tester being significantly different from the other testers on seven variables, although average differences among investigators ranged from 1-2% for circumferences to 4-9% for skinfolds. The two more experienced testers were significantly different on only one variable. Overall agreement among testers was high (ICC>0.895) for each variable, with low coefficients of variation (CV<10.7%). Predicted 1RMs for testers (126.9 ± 20.6, 123.4 ± 22.0, and 132.1 ± 28.4 kg, respectively) were not significantly different from actual 1RM (129.2 ± 20.6 kg). Individuals with varying levels of experience appear to have an acceptable level of ability to estimate 1RM bench press using a non-performance anthropometric equation. Minimal experience in anthropometry may not impede strength and conditioning specialists from accurately estimating 1RM bench press.

**KEY WORDS:** Skinfolds, muscular circumferences, strength prediction, measurement variation

### INTRODUCTION

One-repetition maximum (1RM) lifts are one of the major methods of evaluating strength performance among college football players and are considered by most strength and conditioning professionals to be the most valid and reliable measures of

muscular strength. However, there may be occasions when a non-performance technique for estimating maximal strength could be of value to save time, avoid disrupting the training schedule, and minimize potential fatigue and injury of players.

Several non-performance approaches have employed various anthropometric dimensions to identify maximal strength potential (2-4, 7, 11, 17-19, 23, 25, 29). These approaches typically utilize muscle circumferences, skeletal lengths, body composition parameters, or some combination of these to predict strength level. Previous studies have successfully used arm circumference or arm cross-sectional area (CSA) in conjunction with arm length and %fat to estimate 1RM bench press with reasonable success (7, 17-19, 23).

Previous studies have noted different degrees of variation in anthropometric measurements among testers (1, 9, 10, 12, 13, 21, 22). Lacking is information on the effect that variations in measurement technique among different testers might have on the accuracy of anthropometric predictions of strength performance. The presence of considerable variation in anthropometric assessment would limit the utility of non-performance equations for estimating muscular strength. However, an acceptable level of variation among testers might provide support for the use of a non-performance prediction of muscular strength as an estimate of strength potential or a guide to establishing training loads. Therefore, the purpose of this study was to determine the effect of inter-investigator differences in anthropometric assessment on the prediction of 1RM bench press in college football players.

### METHODS

#### *Participants*

Thirty-four Division-II college football players (13 linemen and 21 backs) were measured at the conclusion of a 10-week winter heavy resistance training program

for 1RM bench press, three skinfolds, and two muscle circumferences. Participants were informed of the risks and benefits of the testing program and signed an informed consent document prior to testing. All testing protocols were approved by the university's Institutional Review Board for Studies Involving Human Subjects. No players under 18 years of age or who had sustained an upper-body injury within the previous six months participated in this study.

#### *Protocol*

Upper-body strength was assessed on the same day for all participants with 1RM bench press using the touch-and-go method. All players had a minimum of five years of heavy-resistance training, were skilled in the performance of the lift, and had utilized it routinely throughout their training program. Each player was encouraged to arrive at the testing site well hydrated; in addition, each player had a water bottle available throughout testing.

Each player warmed up using one set of 10 repetitions at 50% of subjectively estimated 1RM, one set of five repetitions at 70%, and one set of two repetitions at 80% of estimated 1RM, followed by single repetitions at 90%, 100%, and 105%. The progression of loads continued until the player was unable to complete a single repetition, with all players reaching 1RM within five attempts. A minimum of five minutes rest was given between single-repetition attempts. Each lift required the player to lower the bar slowly to touch the chest before being pressed immediately to full arms' extension. The head, shoulders, and buttocks remained in contact with the bench throughout the lift. Reliability for

this lift has previously been established at  $r > 0.98$  (20).

Three investigators with varying levels of experience measured selected anthropometric dimensions on each player in random order. Tester 1 (>40 years) and Tester 2 (>15 years) were very experienced at measuring anthropometric variables, while Tester 3 was a strength coach with minimal anthropometric experience (<1 year).

Skinfolds were measured in triplicate on the right side of the body by each investigator at the triceps, subscapular, and abdominal sites according to the procedures suggested by Lohman, Roche, and Martorell (16). Skinfolds were measured using Lange calipers and recorded to the nearest 0.5 mm. The triceps skinfold was measured midway between the acromion process and olecranon process on the posterior aspect of the arm. The subscapular skinfold was measured at an oblique angle two centimeters below the tip of the scapular. The abdominal skinfold was measured vertically one centimeter to the right of the navel. The average of the three measurements was used to represent each site. The sum of the average of the three skinfolds was used to estimate body density using the Lohman equation (15). Density was converted to %fat using the Siri equation (26).

Arm circumference was measured around the flexed right biceps muscle at its greatest circumference. Arm muscle cross-sectional area (CSA) was calculated from arm circumference corrected for triceps skinfold using the Gurney and Jelliffe equation (5). Chest circumference was measured at the

level of the nipples at mid-expiration (16). Measures of circumference were determined with a vinyl tape (Lafayette Instruments, Lafayette, IN, model F00570). The average of the three measurements was used to represent each site for each tester.

Bench press was predicted from arm CSA, body mass index (BMI), and %fat derived from each tester's measurements using the following equation previously developed on Division II players (19):

$$1RM \text{ (kg)} = 0.96 \text{ Arm CSA (cm}^2\text{)} + 3.08 \text{ BMI (kg/m}^2\text{)} - 2.71 \text{ \%fat} - 28.27$$

#### *Statistical Analysis*

Means and standard deviations were calculated for each variable using SPSS version 21 (IBM, Armonk, NY). Multivariate repeated-measures analysis of variance (ANOVA) was used to evaluate the difference among testers for all anthropometric variables and predicted bench press. The alpha level of set at  $p \leq 0.05$ . If sphericity was significant as determined by Mauchly's  $W$ , the Huynh-Feldt adjustment was applied to determine significance. When significance was achieved, the Bonferroni method was used to determine differences. Intraclass correlation coefficients (ICC) were used to assess the degree of agreement among testers for each variable (28). Inter-investigator coefficient of variation (CV%) was estimated according to the formula:  $CV\% = [\sqrt{SS_{tester}/(n-1)}] / \text{mean}$  where:  $SS_{tester}$  = sum of squares among for testers, mean = average of a variable across testers.

## **RESULTS**

Significant differences among testers were evident on seven of the nine

## ANTHROPOMETRIC VARIATION

**Table 1.** Comparison of anthropometric dimensions and predicted 1RM bench press among testers.

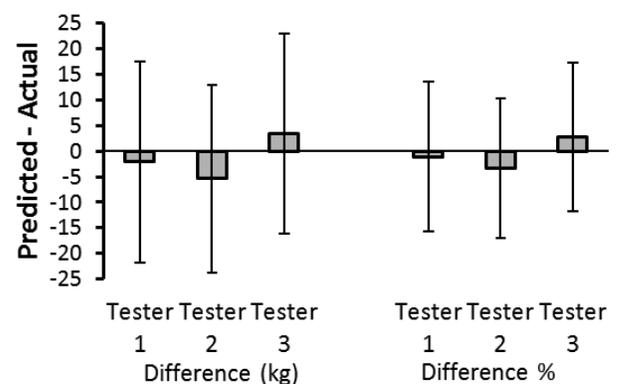
Variable	Tester 1	Tester 2	Tester 3	ICC	CV% <sup>†</sup>	ME (%) <sup>‡</sup>
Triceps SKF (mm)	10.1 ± 3.7	9.7 ± 3.5	11.1 ± 4.1 <sup>a</sup>	0.895	9.9	10.5
Subscapular SKF (mm)	16.6 ± 7.9	16.9 ± 8.4	15.8 ± 6.7	0.971	5.0	2.9
Abdominal SKF (mm)	21.6 ± 9.0	23.8 ± 12.9	18.4 ± 6.7 <sup>b</sup>	0.893	18.8	10.7
Sum of SKF (mm)	48.3 ± 17.9	50.4 ± 23.0	45.1 ± 15.4 <sup>a</sup>	0.947	7.9	5.3
%fat	16.6 ± 5.7	17.2 ± 7.4	15.6 ± 5.0 <sup>a</sup>	0.948	7.2	5.2
FFM (kg)	82.1 ± 10.7	81.1 ± 8.2	83.3 ± 11.7 <sup>b</sup>	0.976	1.9	2.4
Flexed Arm Cir (cm)	39.1 ± 3.8 <sup>d</sup>	38.8 ± 3.7 <sup>d</sup>	39.7 ± 3.8 <sup>d</sup>	0.995	1.8	0.5
Arm CSA (cm <sup>2</sup> )	113.1 ± 28.2	111.3 ± 21.0	115.8 ± 22.2 <sup>b</sup>	0.991	3.0	0.9
Chest Cir (cm)	109.8 ± 8.2 <sup>c</sup>	108.3 ± 7.7	108.8 ± 7.5	0.989	1.0	1.1
Predicted 1RM (kg) <sup>e</sup>	126.9 ± 20.6	123.4 ± 22.0	132.1 ± 28.4 <sup>b</sup>	0.957	5.0	4.3

<sup>†</sup>Inter-investigator coefficient of variable calculated as  $CV\% = [\sqrt{SS_{tester}/(n-1)}]/\text{mean}$ .

<sup>‡</sup>Percent measurement error calculated as  $ME\% = (1 - ICC) \times 100$ . <sup>a</sup>Significantly different from Tester 2. <sup>b</sup>Significantly different from Testers 1 and 2. <sup>c</sup>Significantly different from Testers 2 and 3. <sup>d</sup>Significantly different among all testers. <sup>e</sup>Actual 1RM bench press = 129.2 ± 20.6 kg.

anthropometric variables (Table 1). The tester with the least experience (Tester 3) was significantly different from the other testers on seven variables (triceps, abdominal, and sum of skinfolds, %fat, FFM, flexed arm circumference, and arm CSA), while the two more experienced testers were significantly different on only one variable (flexed arm circumference). Flexed arm circumference was the only variable where all three testers differed significantly. Despite the differences among testers, the inter-tester coefficients (ICC) were considered high for each variable and were supported further by the low CV% for all measurements (Table 1). The similarity among the testers was

reflected further in the agreement of the correlation of anthropometric variables with 1RM bench press (Table 2).



**Figure 1.** Absolute (kg) and relative difference (%) between predicted and actual 1RM (Mean ± SD) among testers.

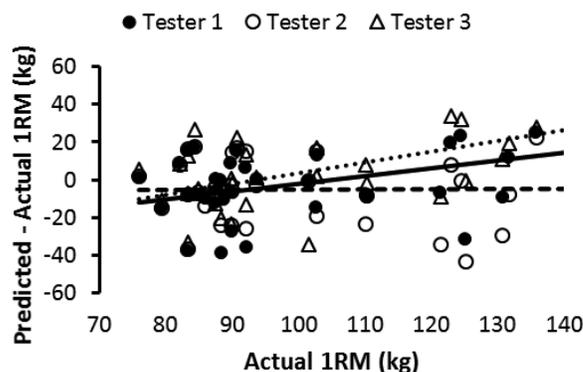
**Table 2.** Pearson correlations between anthropometric variables and 1RM bench press in college football players for different testers (n = 34).

Variable	Tester 1	Tester 2	Tester 3
Triceps SKF (mm)	0.23	0.31	0.31
Subscapular SKF (mm)	0.52**	0.47**	0.47**
Abdominal SKF (mm)	0.37*	0.43*	0.43*
Sum of SKF (mm)	0.46**	0.46**	0.46**
%fat	0.46**	0.46**	0.46**
FFM (kg)	0.47**	0.49**	0.53**
Flexed Arm Cir (cm)	0.70**	0.69**	0.69**
Arm CSA (cm <sup>2</sup> )	0.70**	0.68**	0.68**
Chest Cir (cm)	0.98**	0.64**	0.64**

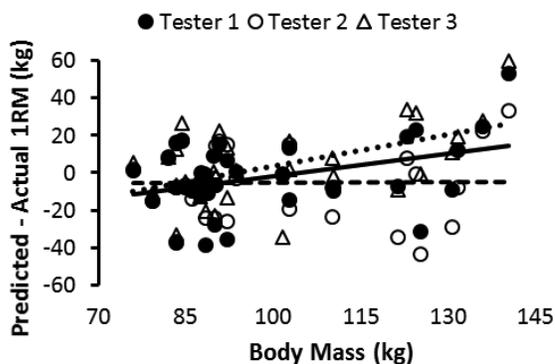
\*p<0.05, \*\*p<0.01

Actual bench press 1RM was 129.2 ± 20.6 kg. Using the anthropometric equation previously developed on Division-II players (19), predicted 1RM bench press values were significantly lower for Testers 1 and 2 than for Tester 3 (Figure 1). However, none of the predicted 1RM differed significantly from the actual values (Table 1). All three testers tended (p>0.12) to overestimate actual 1RM by 3-6% in the lower half of the 1RM continuum (Figure 2). In the upper half of the 1RM continuum, Testers 1 and 2 tended to underestimate 1RM (p<0.01) to a greater degree (4-8%) than did Tester 3 (<1%).

In the lower half of the body mass continuum, all three testers tended (p>0.11) to slightly underestimate the actual 1RM value by 4-6% (Figure 3). In the upper half of the body mass continuum, Tester 3 overestimated the actual 1RM to a significantly greater degree (p<0.01) than Testers 1 and 2; Tester 1 and 2 underestimated by 2-4%, while Tester 3 overestimated by 8%.



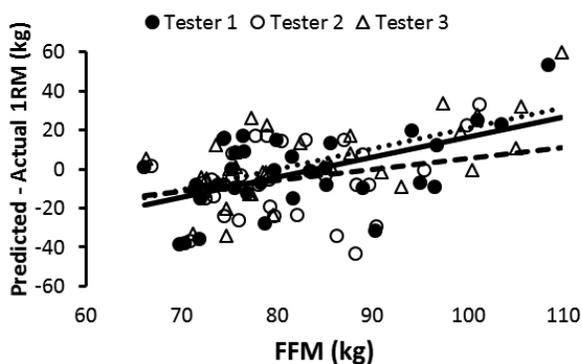
**Figure 2.** Comparison of differences between predicted and actual 1RM with actual 1RM bench press performances for football players (n = 34)(solid line = Tester 1; dashed line = Tester 2; dotted line = Tester 3).



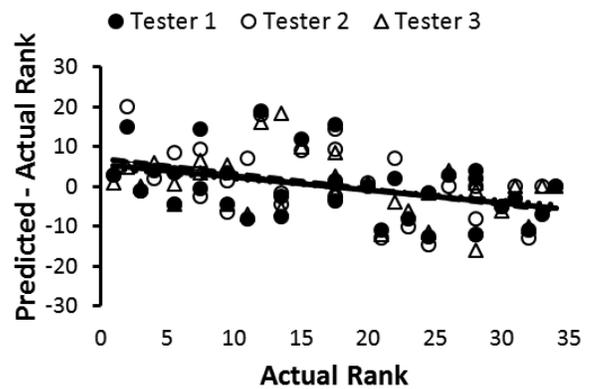
**Figure 3.** Comparison of differences between predicted and actual with body mass for football players (n = 34)(solid line = Tester 1; dashed line = Tester 2; dotted line = Tester 3).

When the difference between predicted and actual 1RM was considered relative to FFM, all three testers tended ( $p=0.07$ ) to underestimate actual 1RM by 3-6% (Figure 4). In the lower half of the FFM continuum, predicted 1RM by Tester 3 was significantly higher than those by Testers 1 and 2, and the latter two did not differ significantly. In the upper half of the FFM continuum, Tester 3 significantly overestimated actual 1RM by 9%, while Tester 1 overestimated by 4% and Tester 2 underestimated by 2%.

The interclass correlation coefficients between predicted and actual 1RM were significant and showed good agreement for Tester 1 (ICC = 0.787), Tester 2 (ICC = 0.775), and Tester 3 (ICC = 0.821). The CV was acceptable for each tester (CV<12.5%). Rank order correlations between predicted and actual 1RM for each tester to determine the position of players relative to their teammates were significant (Tester 1,  $\rho = 0.67$ ; Tester 2,  $\rho = 0.64$ ; Tester 3,  $\rho = 0.73$ ) and did not differ significantly, suggesting good agreement among testers when ranking player strength based on the predicted 1RM (Figure 5).



**Figure 4.** Comparison of differences between predicted and actual 1RM with fat-free mass for football players ( $n = 34$ ) (solid line = Tester 1; dashed line = Tester 2; dotted line = Tester 3).



**Figure 5.** Comparison of the difference between predicted and actual ranks with actual rank of football players for 1RM bench press ( $n = 34$ ).

## DISCUSSION

The major finding of this study suggests that investigator experience may produce only minor differences in the measurement of anthropometric variables in male athletes and therefore may allow reasonable predictions of 1RM bench press from an anthropometric equation. The slight difference among investigators with varying levels of experience does not appear to drastically influence their ability to estimate %fat from skinfold measurement (9, 13, 22). These results disagree with previous studies that suggested that more experience would reduce the difference in skinfold measurement among investigators (12). In an earlier study, investigators utilized a skinfold tester with 17 years of experience as the expert for comparison with two testers who trained for 30 minutes versus two self-taught testers (12). Their results indicated greater inter-investigator reliability for the two testers trained by the expert than for those who were self-taught, which seems logical since the expert would have corrected “errors” by the trainers to his way of testing. A recent study

comparing measurement differences among four investigators, each with more than 15 years of experience, found significant differences in skinfold measurement that manifested in significantly different predicted %fat values (1). These results might call into question testing longevity as a criterion for experience since the years of independent practice may have perfected individual idiosyncrasies that could result in differences in measurement.

Skinfold sites were not marked in the current study, as is typical of a mass testing scenario in an athletic setting (22). Thus, the slight variations in measurement could have been related to the location of skinfold sites by each investigator (24). The average variation among the investigators for the three skinfolds in the current study (5 mm) was identical to that noted previously for the triceps measurement when testers varied their caliper placement by 2.5 cm (24). Jackson et al. (10) earlier noted that the sum of several skinfolds probably has less inter-investigator variance than individual skinfold measurements since the variation among testers are not typically all of the same magnitude or in the same direction. The current study utilized a similar design to that of Jackson et al. (10) in that three testers of differing levels of experience were compared; however, the testers in that study practiced the measurements together prior to actually testing subjects, whereas our testers did not and relied on their previous training to locate and measure anthropometric variables.

The variations among testers in circumference measurements were less than those for skinfolds, which agreed with previous findings (21). The average

variation among testers for arm (0.8 cm) and chest circumferences (2.1 cm) were slightly less than those shown previously (10, 21). Some of the difference in flexed arm and chest measurements could have been due to variations in flexion by the players, as well as slight difference in placement of the tape by investigators. The contribution of skinfold measurement to the estimation of CSA was <3% for each tester, relegating the majority of the variance accounted for in CSA to arm circumference measurement. Since arm CSA accounted for the greatest percent of the known variance in 1RM bench press prediction, the high degree of agreement among the testers (ICC = 0.991) might have been a factor in the non-significant difference of their predicted values with actual 1RM.

The small measurement variations among investigators in the current study also may have contributed to the similarity in their correlations between anthropometric variables and 1RM bench press performance (Table 2). However, the slight variation in anthropometric variables among the investigators produced minor yet significantly higher values for the least experienced tester, even though the predicted 1RM values were not significantly different from the actual 1RM. Although two testers slightly underpredicted and one slightly overpredicted 1RM, 59% of the predicted values were within  $\pm 10\%$  of the actual 1RM (Figure 2). This outcome suggests that investigator differences in anthropometric variables did not produce large differences between each investigator's predicted 1RM and actual 1RM performance (Figure 1). There was a tendency for the testers with greater experience to overestimate 1RM at

higher actual 1RM values, a trend that was similar to that noted when comparing the difference between predicted and actual values to body mass (Figure 3). When the difference between predicted and actual 1RM values were compared across the FFM continuum, players with lower FFM tended to be underpredicted while those with greater FFM tended to be overpredicted (Figure 4).

The good agreement among the testers for ranking players for strength based on predicted 1RM (ICC = 0.94) might allow a convenient method for assessing strength progression without frequent 1RM testing or for estimating strength potential based on size. Future investigation is warranted to assess the reliability among testers with various levels of expertise in anthropometric measurement to determine the smallest worthwhile difference that would be acceptable for indicating that a meaningful change in strength has occurred. Furthermore, it would be helpful to strength and conditioning specialists to have more assessments of reliability of the actual 1RM method in highly trained players in order to evaluate the smallest worthwhile change that would reflect a true improvement in actual strength. A combination of these statistical evaluations could determine the feasibility of using an anthropometric approach to track changes in actual 1RM strength across a training cycle.

In conclusion, anthropometric prediction of upper-body strength in football players shows a modest level of potential as a means of evaluating performance and does not seem to vary greater among testers with differing degrees of experience. However, care should be taken not to set finite limits

on strength potential solely from anthropometric dimensions of players despite the consistent agreement among testers. Neurological factors and muscle fiber characteristics that are not possible to measure with surface anthropometry might exert considerable influence on a player's ability to produce maximum strength performance (6, 14, 27). However, a quick screening procedure using these anthropometric variables would take typically less than two minutes to perform on each player which may suffice when time is limited. The current results suggest that several members of the strength and conditioning staff with varying degrees of experience could perform measurement simultaneously without major loss of accuracy.

## REFERENCES

1. Bird E, Mayhew JL, Schwegler T, Crossgrove L, Etemady A, Peterson N. Inter-investigator reliability in skinfold measurement. *MO J Hlth Phys Educ Rec Dance* 19: 125-130, 2009.
2. Cadore EL, Pinto RS, Brentano MA, Silva RF, da Silva EM, Spinelli R, Correa CS, Krueel LFM. Prediction of one-repetition maximum load by total and lean body mass in trained sand untrained men. *Med Sportiva* 16:111-117, 2012.
3. Caruso J, McLagan J, Shepherd C, Olson N, Taylor S, Gilliland L, Kline D, Detwiler A, Griswold S. Anthropometry as a predictor of front squat performance in American college football players. *Isokinetics Exerc Sci* 17:243-251, 2009.
4. Fry AC, Ciroslan D, Fry MD, LeRoux CD, Schilling BK, Chiu LZF. Anthropometric and performance variables discriminating elite American junior men weightlifters. *J Strength Cond Res* 20:861-866, 2006.
5. Gurney JM, Jelliffe DB. Arm anthropometry in nutritional assessment: nomogram for rapid calculation of muscle circumference and cross-

## ANTHROPOMETRIC VARIATION

- sectional muscle and fat areas. *Amer J Clin Nut* 26: 912-915, 1973.
6. Hakkinen K, Newton RU, Gordon SE, McCormick M, Volek JS, Nindl BC, Gotshalk LA, Campbell WW, Evans WJ, Hakkinen A, Humphries BJ, Kraemer WJ. Changes in morphology, electromyographic activity, and force production characteristics during progressive strength training in young and older men. *J Gerontol Biol Sci* 53A:B415-B423, 1998.
  7. Hart CL, Ward TE, Mayhew JL. Anthropometric correlates of bench press performance following resistance training. *Sports Training Rehab Med* 2: 89-95, 1991.
  8. Himes JH, Roche AF, Sievogel RM. Compressibility of skinfolds and the measurement of subcutaneous fatness. *Am J Clin Nutri* 32: 1734-1740, 1979.
  9. Housh TJ, Johnson GO, Thorland WG, Cisar CJ, Hughes RA, Kenney KB, McDowell SL, Ludvall P. Validity and intertester error of anthropometric estimations of body density. *J Sports Med Phys Fitness* 29: 149-156, 1989.
  10. Jackson AS, Pollock ML, Gettman LR. Intertester reliability of selected skinfold and circumference measurements and percent fat estimates. *Res Quart* 49: 546-551, 1978.
  11. Keogh JW, Hume PA, Pearson SN, Mellow PJ. Can absolute and proportional anthropometric characteristics distinguish stronger and weaker performers? *J Strength Cond Res* 23:2256-2265, 2009.
  12. Kerr L, Wilkerson S, Bandy WD, Ishee J. Reliability and validity of skinfold measurements of trained versus untrained testers. *Isokinetics Exerc Sci* 4: 137-140, 1994.
  13. Klipstein-Grobusch K, Georg T, Boeing H. Interviewer variability in anthropometric measurements and estimates of body composition. *Inter J Epidemiol* 26(1): S174-S180, 1997.
  14. Kristiansen M, Madeleine P, Hanson EA, Samani A. Inter-subject variability of muscle synergies during bench press in power lifters and untrained individuals. *Scan J Med Sci Sports* 25:89-97, 2015.
  15. Lohman TG. Skinfolds and body density and their relation to body fatness: a review. *Hum Biol* 53:181-225, 1981.
  16. Lohman TG, Roche AF, Martorell R (eds). *Anthropometric Standardization Reference Manual*. Champaign, IL: Human Kinetics, 1988.
  17. Mayhew JL, Ball TE, Ward TE, Hart CL, Arnold MD. Relationship of structural dimensions to bench press strength in college males. *J Sports Med Phys Fitness* 31: 135-141, 1991.
  18. Mayhew JL, McCormick TP, Piper FC, Kurth AL, Arnold MD. Relationship of body dimensions to strength performance in adolescent male powerlifters. *Pediatric Exerc Sci* 5: 347-356, 1993.
  19. Mayhew JL, Piper FC, Ware JS. Anthropometric correlates with strength performance among resistance trained athletes. *J Sports Med Phys Fitness* 33: 159-165, 1993.
  20. McGuigan MR, Winchester JB. The relationship between isometric and dynamic strength in college football. *J Sports Sci Med* 7:101-105, 2008.
  21. Mueller WH, Malina RM. Relative reliability of circumferences and skinfolds as measures of body fat distribution. *Am J Phys Anthropol* 72: 437-439, 1987.
  22. Opplinger RA, Clark RR, Kuta JM. Efficacy of skinfold training clinics: a comparison between clinic trained and experienced testers. *Res Quart Exerc Sport* 63: 435-442, 1992.
  23. Pompeu FAMS, Gabriel D, Pena BG, Ribeiro P. Arm cross-section areas: technical implications and applications for body composition and maximal dynamic strength evaluation. *Rev Bras Med Esporte* 10:207-211, 2004.
  24. Ruiz L, Colley JRT, Hamilton PJS. Measurement of triceps skinfold thickness: an investigation of sources of variation. *Brit J Prevent Soc Med* 25: 165-167, 1971.
  25. Siahkouhian M, Hedayatneja M. Correlations of anthropometric and body composition variables with the performance of young elite weightlifters. *J Hum Kinet* 25:125-131, 2010.

## ANTHROPOMETRIC VARIATION

26. Siri WE. Body composition from fluid spaces and density: analysis of methods. Techniques for measuring body composition. J Brozek and A Henschel (Eds). Washington, DC: National Academy of Science NRC, 1961.
27. Widrick JJ, Stelzer JE, Shoepe TC, Garner DP. Functional properties of human muscle fibers after short-term resistance exercise training. *Am J Physiol Regulatory Integrative Comp Physiol* 283:R408-R416, 2002.
28. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res* 19: 231-240 2005.
29. Ye X, Loenneke JP, Fahs CA, Rossow LM, Thiebaud RS, Kim D, Bemben MG, Abe T. Relationship between lifting performance and skeletal muscle mass in elite powerlifters. *J Sports Med Phys Fitness* 53:4090414, 2013.