Predicting Football Players' Dual-Energy X-Ray Absorptiometry Body Composition Using Standard Anthropometric Measures

Jonathan M. Oliver, MEd*; Brad S. Lambert, BS*; Steven E. Martin, PhD†; John S. Green, PhD, FACSM‡; Stephen F. Crouse, PhD, FACSM*

*Applied Exercise Science Laboratory, †FITLIFE Program, and ‡Department of Health and Kinesiology, Texas A&M University, College Station

Context: The recent increase in athlete size, particularly in football athletes of all levels, coupled with the increased health risk associated with obesity warrants continued monitoring of body composition from a health perspective in this population. Equations developed to predict percentage of body fat (%Fat) have been shown to be population specific and might not be accurate for football athletes.

Objective: To develop multiple regression equations using standard anthropometric measurements to estimate dual-energy x-ray absorptiometry %Fat (DEXA%Fat) in collegiate football players.

Design: Controlled laboratory study.

Patients and Other Participants: One hundred fifty-seven National Collegiate Athletic Association Division IA football athletes (age = 20 ± 1 years, height = 185.6 ± 6.5 cm, mass = 103.1 ± 20.4 kg, DEXA%Fat = $19.5 \pm 9.1\%$) participated.

Main Outcome Measure(s): Participants had the following measures: (1) body composition testing with dual-energy x-ray absorptiometry; (2) skinfold measurements in millimeters, including chest, triceps, subscapular, midaxillary, suprailiac,

abdominal (SFAB), and thigh; and (3) standard circumference measurements in centimeters, including ankle, calf, thigh, hip (AHIP), waist, umbilical (AUMB), chest, wrist, forearm, arm, and neck. Regression analysis and fit statistics were used to determine the relationship between DEXA%Fat and each skinfold thickness, sum of all skinfold measures (SFSUM), and individual circumference measures.

Results: Statistical analysis resulted in the development of 3 equations to predict DEXA%Fat: model 1, $(0.178 \cdot \text{AHIP}) + (0.097 \cdot \text{AUMB}) + (0.089 \cdot \text{SFSUM}) - 19.641$; model 2, $(0.193 \cdot \text{AHIP}) + (0.133 \cdot \text{AUMB}) + (0.371 \cdot \text{SFAB}) - 23.0523$; and model 3, $(0.132 \cdot \text{SFSUM}) + 3.530$. The R^2 values were 0.94 for model 1, 0.93 for model 2, and 0.91 for model 3 (for all, $P < .001$).

Conclusions: The equations developed provide an accurate way to assess DEXA%Fat in collegiate football players using standard anthropometric measures so athletic trainers and coaches can monitor these athletes at increased health risk due to increased size.

Key Words: obesity, cardiovascular disease risk, athletes

Key Points

- Body composition testing provides a simple and effective method for monitoring one of the major correlates of performance and the development of cardiovascular disease.
- With simple anthropometric measures, a football athlete's dual-energy x-ray absorptiometry body composition can be estimated and compared for the benefit of performance and health-related recommendations.

A football athlete's body composition is of particular importance for performance. In football, as in many other sports, the size, strength, power, and speed of an athlete relates to on-field performance. In the National Football League (NFL), an increase in body mass or height has been associated with increases in playing time and salary.¹ Because performance depends so strongly on body morphology and composition, the ability to measure these changes in an athlete over time is essential to both coaches and players. In addition to performance, interest in body composition of football athletes is growing because of its effect on health. Obesity continues to rise in the United States, with an estimated 40% of the population expected to be classified as obese by 2040.² Researchers using body mass index (BMI) as a measure of obesity have suggested that up to 56% of football players, including high school

players, are obese.^{3–5} Although the inaccuracy of associating a high BMI with increased risk of mortality has been reported,⁶ the link between obesity in football players and cardiovascular risk has been shown consistently in numerous recent studies.^{3,7,8} This might be due to other pathophysiologic pathways by which obesity increases the risk of developing cardiovascular disease, such as reduced insulin sensitivity, increased free fatty acid turnover, and promotion of systemic inflammation.⁹ Thus, monitoring body composition in football athletes is needed from both health and performance perspectives.

Whereas several methods for determining body composition exist, the most accurate methods require substantial training and certified personnel and carry considerable cost, making their use impractical in most athletic training settings. These accurate techniques include but are not

limited to hydrostatic weighing, dual-energy x-ray absorptiometry (DEXA), computerized axial tomography scan, and air displacement plethysmography. Of these, DEXA has become a widely used technique for body composition because of its relatively fast (range, 10–20 minutes) and accurate results.^{10–13} However, the cost and availability of DEXA still make it difficult for many to use. Additional methods using anthropometric measures (eg, skinfolds and circumferences) aimed at estimating body fat percentage are technically simple to perform, carry a low cost, and require little time to complete; however, they have been shown to be population specific and might not be generalizable to a population of football athletes.^{14–16} Although football players might not be homogeneous in terms of size and body composition, the ability to use a less expensive applied method that is accurate and reliable allows both coaches and athletic trainers to monitor changes in body composition and determine when a more expensive analysis should be ordered. Several equations have been validated for use in male athletes, but they might not be equally effective at predicting body composition in all male athlete subsamples, particularly football and basketball players.¹⁷ Only 2 anthropometric equations have been developed using American football players as the population sample. However, these equations have not predicted body composition in a second university football population.¹⁶ In addition, the increase in obesity^{2–5,7,8} combined with the increase in athlete size over the decades since then^{7,18} suggests a new anthropometric method is required for present-day football athletes. Therefore, the purpose of our study was to develop multiple regression equations using standard anthropometric measures to estimate DEXA-derived body fat percentage (DEXA%-Fat) in collegiate football players. Our goal was to develop the new equations using anthropometric measures that are already widely used and familiar to practitioners to be immediately applied in the field with minimal training and to allow for data previously collected on players to be used retrospectively to predict DEXA%Fat for future comparison.

METHODS

Participants

Participants were recruited during regularly scheduled body composition assessment protocols conducted on football athletes as part of the team evaluation at 2 National Collegiate Athletic Association (NCAA) Division IA bowl-eligible universities. A total of 157 athletes (age range, 17–23 years) participated. Physical characteristics of the population are presented in Table 1. Participants were from a diversity of ethnic backgrounds, including white (n = 57, 36%), African American (n = 94, 60%), Hispanic (n = 2, 1.3%), and other or mixed race (n = 4, 2.5%). The participant sample also comprised athletes at various football playing positions, including defensive back (n = 23, 14.6%), defensive line (n = 16, 10.2%), fullback (n = 2, 1.3%), free safety (n = 4, 2.5%), kicker (n = 3, 1.9%), linebacker (n = 26, 16.6%), long snapper (n = 2, 1.3%), offensive line (n = 28, 17.8%), quarterback (n = 11, 7.0%), running back (n = 9, 5.7%), tight end (n = 5, 3.2%), and wide receiver (n = 28, 17.8%).

Table 1. Physical Characteristics of Football Athletes (N = 157)

Characteristic	Mean ± SD
Age, y	20 ± 1
Height, cm	185.6 ± 6.5
Mass, kg	103.1 ± 20.4
Waist circumference, cm	91.6 ± 11.3
Hip circumference, cm	108.5 ± 10.7
Abdominal skinfold, mm	24.5 ± 14.0
Skinfold, % body fat	15.3 ± 7.9
Dual-energy x-ray absorptiometry, % body fat	19.5 ± 9.1

Participants provided written informed consent before having anthropometric measurements recorded for this study, and the study was approved by the Texas A&M University Institutional Review Board for human subjects research.

Anthropometric Measures

On the day of testing, height and mass were determined using a standard balance scale and stadiometer (Detecto, Webb City, MO) calibrated for accuracy using the manufacturer's guidelines. Height and mass were obtained with the participants in athletic shorts and shirt and in socks or bare feet.

The same 3 skilled technicians (J.M.O., B.S.L., not an author) performed all circumference and skinfold measurements to ensure accuracy. All technicians were trained within the same laboratory. Before initiation of the study, technician accuracy was verified. The intraclass correlation coefficients for the 3 technicians for skinfolds and circumference measures on a separate sample of participants were 0.985 and 0.996, respectively. Seven-site skinfold measurements^{19,20} were taken following techniques described by Harrison et al²¹ and using standard calibrated skinfold calipers (Lange, Beta Technology, Santa Cruz, CA), which maintained constant pressure. The calipers were held in the right hand, the skinfold elevated with the left hand, and the measurement recorded 4 seconds after pressure was released. All measurements were taken on the right side. If the measurement could not be taken due to swelling, injury, or other circumstance, the measurement was excluded. Skinfold fat was measured at the chest, triceps, subscapular (SFSUBS), midaxillary (SFAXILLA), suprailiac, abdominal (SFAB), and thigh (SFTHI) locations in accordance with previously accepted procedures.^{19,20} Two technicians performed a measurement at each site; the 2 measurements at each site were recorded and later averaged for further calculations.

Circumference measurements were taken according to previously described and validated methods²² using a self-retracting, inelastic, nonmetallic measuring tape (Gulick II; Country Technology, Inc, Gays Mills, WI). All measurements were made indoors where temperature was held constant at or around 22°C. Measurements included ankle, calf, thigh (ATHI), hip (AHIP), waist, umbilical (AUMB), chest, wrist, forearm, arm, and neck (ANEC). Participants were barefoot for all circumference measurements, and measurements were performed only on the right side. Measurements were taken without the barrier of clothing. If the area could not be measured due to taping (ankle) or restrictive barrier (arm sling), the measurement was excluded. If swelling was present, the measurement also

Table 2. Model for Prediction Dual-Energy X-Ray Absorptiometry Percentage Body Fat in Football Players and Example Calculation Using Each Model

Model	Equation	R^2	Root Mean Square Error	F	Degrees of Freedom	P
1	$(0.178 \cdot \text{AHIP}) + (0.097 \cdot \text{AUMB}) + (0.089 \cdot \text{SFSUM}) - 19.641$	0.94	2.4	716.49	3,146	<.0001
Example	$(0.178 \cdot 104.1) + (0.097 \cdot 86.05) + (0.089 \cdot 93.5) - 19.641 = 15.56$					
2	$(0.193 \cdot \text{AHIP}) + (0.133 \cdot \text{AUMB}) + (0.371 \cdot \text{SFAB}) - 23.0523$	0.93	2.4	666.44	3,146	<.0001
Example	$(0.193 \cdot 104.1) + (0.133 \cdot 86.05) + (0.371 \cdot 17) - 23.0523 = 15.13$					
3	$(0.132 \cdot \text{SFSUM}) + 3.530$	0.91	2.7	1583.73	1,148	<.0001
Example	$(0.132 \cdot 93.5) + 3.530 = 15.87$					

Abbreviations: AHIP, hip circumference, cm; AUMB, umbilical circumference, cm; SFAB, abdominal skinfold, mm; SFSUM, sum of all skinfold measurements, mm.

was excluded. Two technicians performed a single measurement at each point; these values were averaged for further calculations.

DEXA Measurement

Before DEXA measures, participants were instructed to remove any metal objects that would interfere with testing (Lunar Prodigy; General Electric, Fairfield, CT). A technician (J.M.O., B.S.L., S.E.M., others who were not authors) then assisted the participants in the proper positioning to obtain the most accurate measurement based on the manufacturer's guidelines. All measurements were conducted by personnel (J.M.O., B.S.L., others who were not authors) trained by the manufacturer for accuracy of measurement. The DEXA equipment was calibrated daily according to procedures prescribed by the manufacturer. The reliability and validity of DEXA to determine body composition have been established.^{10–13} To determine the reliability of the DEXAs used in this study, the DEXA body mass was compared with scale weights obtained following the recommendation by Lohman and Chen.²³ The correlations between DEXA body mass and scale-determined weights for the DEXAs used in this study were 0.998 and 0.997.

Statistical Analysis

To provide practitioners the ability to use previously collected data, 3 regression models were developed to predict DEXA%Fat using different predictive variables. We determined predictive variables using collinearity diagnostics for the first 2 models, whereas we developed a third model using only the sum of all skinfold measures (SFSUM) to provide practitioners the ability to evaluate previous data collected when other measurements (ie, circumferences) were excluded. All regression model development, model diagnostics, and other statistical procedures were performed using SAS (version 9.2; SAS Institute Inc, Cary, NC).

The initial regression model was developed to predict DEXA%Fat using the backward stepwise linear regression procedure with age, height, mass, all circumferences, and SFSUM as predictive variables with criteria for entry into model set at $P \leq .10$. A second model was developed to predict DEXA%Fat using backward linear regression that

incorporated age, height, mass, all circumference variables, and all individual skinfold measures as predictive variables with criteria for entry into model again set at $P \leq .10$. A third and final model was developed to determine DEXA%Fat using linear regression and SFSUM as the only predictive variable.

RESULTS

Model 1

Individual skinfold measurements were excluded from initial model selection because of collinearity with SFSUM. Participants with missing values were excluded from model development, resulting in 150 observations for analysis. After backward stepwise linear regression was performed, the resultant model using ANEC, AHIP, AUMB and SFSUM as explanatory variables in the prediction of DEXA%Fat was found to be the best model according to selection analysis. This model yielded a Mallow Cp statistic of 1.56, which was the closest match to the number of model variables. It also had an R^2 value of 0.94. We removed the ANEC because it had the highest standard error compared with other explanatory variables included in the model. After removing the ANEC, the developed model was examined for fit diagnostics and multicollinearity, neither of which attained interpretive significance. The resultant best model is depicted in Table 2. Removal of ANEC did not affect the final R^2 value obtained for the model. A scatter plot of observed by predicted values obtained using the developed model 1 regression equation in addition to a scatter plot of studentized residuals versus predicted values can be found in Figure 1.

Model 2

Age, height, mass, all circumference measures, and all individual skinfold measures were used to construct the second model for predicting DEXA%Fat. As in model 1, 150 observations ($n = 150$) were used for model determination. The best resultant model had a Mallow Cp statistic of 3.78 and an R^2 value of 0.95 and included the following explanatory variables: mass, ANEC, ATHI, AHIP, AUMB, SFSUBS, SFAB, SFAXILLA, and SFTHI. Model diagnostics and fit statistics revealed multicollinearity with the following variables: ANEC, ATHI, SFSUBS,

Figure 1. A, Scatter plot of observed by predicted values and, B, studentized residuals by predicted values for model 1 ($R^2 = 0.94$, $P < .001$). Dual-energy x-ray absorptiometry percentage of body fat = $(0.178 \cdot \text{hip circumference}) + (0.097 \cdot \text{umbilical circumference}) + (0.089 \cdot \text{sum of all skinfold measurements}) - 19.641$. The upper and lower lines indicate 2 SDs.

SFAXILLA, and SFTHI. These variables were excluded, and a final model was obtained and analyzed. No multicollinearity problems were found. The resultant model had an R^2 value of 0.93 (Table 2). A scatter plot of observed by predicted values obtained using the regression equation in addition to a scatter plot of studentized residuals versus predicted values can be found in Figure 2.

Model 3

A third model was examined using only SFSUM as the explanatory variable to predict DEXA%Fat. We used 150 observations for model determination. The resultant equation yielded an R^2 value of 0.91 and demonstrated no

model diagnostic problems (Table 2). Figure 3 provides a scatter plot of observed by predicted values obtained using the regression equation and a scatter plot of studentized residuals versus predicted values.

DISCUSSION

The purpose of our study was to develop multiple regression equations to determine DEXA%Fat using standard anthropometric measures that are easily and readily available to coaches and athletic trainers. We successfully have developed 3 equations based on a sample of NCAA Division IA football players to accurately predict DEXA%Fat using standard anthropometric measures. Therefore, coaches, athletic trainers, and health care

Figure 2. A, Scatter plot of observed by predicted values and, B, studentized residuals by predicted values for model 2 ($R^2 = 0.93$, $P < .001$). Dual-energy x-ray absorptiometry percentage of body fat = $(0.193 \cdot \text{hip circumference}) + (0.133 \cdot \text{umbilical circumference}) + (0.371 \cdot \text{abdominal skinfold}) - 23.0523$. The upper and lower lines indicate 2 SDs.

Figure 3. A, Scatter plot of observed by predicted values and, B, studentized residuals by predicted values for model 3 ($R^2 = 0.91$, $P < .001$). Dual-energy x-ray absorptiometry percentage of body fat = $(0.132 \cdot \text{sum of all skinfold measurements}) + 3.530$. The upper and lower lines indicate 2 SDs.

practitioners can choose the equation that best fits their programs and resources to track changes in body composition.

Our regression equations were designed specifically with the intent of predicting DEXA%Fat because of its widespread use and reported reliability. Researchers have demonstrated the population specificity of equations for estimating body composition.^{10,15} The equations based on one population and applied to others tend to be biased and do not provide an accurate prediction of body composition.²⁴ The model equations and statistics for each model provided in Table 2 highlight the accuracy of the equations developed by our laboratory, with all resultant models having R^2 values greater than 0.90 and the root mean square errors of less than 3. The model fit statistics for all 3 of our developed models were slightly better than the original generalized equations developed by Jackson and Pollock.²⁴ Whereas their models did not use DEXA as the standard, the reliability and validity of DEXA in determining body composition have been established.^{10–12} Table 2 also provides a comparison of the 3 models. Although model 1 resulted in the best prediction accuracy ($R^2 = 0.94$), model 2 provides a secondary option with almost the same predictive accuracy ($R^2 = 0.93$) but with fewer measurements required: 3 compared with 9 in model 1. Model 3 provides an accurate model of predicting DEXA%Fat for practitioners who previously have collected all 7 standard skinfold measures. Because the sum-of-7 skinfold measures have been used widely for many years, model 3 will enable a retrospective estimation of DEXA body composition in football athletes.

Using the measurement methods described, any of the 3 equations can be used in an applied setting for monitoring body composition in football athletes. For example, using each of the models, a player with the measurements of AHIP equal to 104.1 cm, AUMB equal to 86.05 cm, SFAB equal to 17 mm, and SFSUM equal to 93.5 mm would obtain a %Fat of 15.56% using Equation 1, 15.13% using

Equation 2, and 15.87% using Equation 3. Table 2 provides examples using this data in each equation.

We identified only 2 studies in which body composition prediction equations were developed in American football athletes.^{25,26} However, these equations did not accurately predict body composition in another sample of collegiate football players.¹⁶ To develop our equations, we studied 2 university populations and a sample size more than twice that studied in previous investigations of football athletes. In addition, our equations developed in models 1 and 2 achieved higher R^2 values when compared with the R^2 values obtained for prediction of all players in the 2 previously developed equations. This combined with the continued increase in athlete size over the decades supports the need for the development of our equations with today's football athlete as the participant sample.^{1,18}

Coaches have monitored changes in body composition of various athletes for years to determine the efficacy of training programs. Norton and Olds¹ suggested the increase in physical size of players (height and mass) over the 20th century in sports, such as football, is driven by the advantage that size grants these players. An observable pattern of success exists for football players of above-average size.¹ Whereas this increase in size clearly results in performance advantages, it might result in overweight and obese players if monitoring of body composition is not in place. The link between obesity and metabolic syndrome and insulin resistance in football linemen has been reported by Borchers et al.⁷ They noted the presence of obesity in 21% of football players using air displacement plethysmography, with 21% having insulin resistance and 9% presenting with metabolic syndrome.⁷ Their findings were consistent with previous reports of growing obesity in collegiate football players.²⁷

In their study of collegiate football athletes, Buell et al⁸ also reported that linemen in particular had a higher incidence of metabolic syndrome, as well as other markers associated with increased risk of cardiovascular disease,

than other players. Based on studies of NFL players, the trend of obesity and metabolic syndrome in football linemen seems to continue into professional play. In a study of retired NFL players, researchers have shown the prevalence of metabolic syndrome in linemen was 2 times higher than players in other positions.²⁸ Increased risk of developing cardiovascular disease is not limited to football linemen. Tucker et al²⁹ reported the prevalence of hypertension and prehypertension of current NFL players was greater than in the normal population. Taken together, these factors point out the health risk for football athletes and support the need for cost-effective means of tracking risk factors, such as obesity, in these sportsmen at early ages.

The obesity associated with football is not limited to collegiate and professional players. In studies of high school football athletes, researchers have shown an increase in obesity, especially among high school football linemen.^{4,5} Most recently, using BMI as the determining criteria, Laurson and Eisenmann⁴ found 45% (n = 1657) of 3683 high school linemen sampled were classified as overweight, with an overwhelming 9% (n = 331) classified with adult severe obesity. Although limitations exist in the use of BMI for classification of obesity in athletes, the high percentage noted in the discussed studies provides evidence for the growing need to monitor body composition of athletes, particularly football players. Whereas our participant sample was limited to collegiate players, a large percentage (40%, n = 63) was less than 20 years of age. These participants are similar in age and adolescent growth state to high school football players, which suggests our equations might be valuable tools not only for collegiate coaches and athletic trainers but also for those responsible for the health and training of high school football athletes.

CONCLUSIONS

Although football players are involved in intense training throughout the year, these training sessions do not eliminate the need for continued evaluation of player performance and health. Regular body composition testing allows for the efficacy of strength and conditioning training programs to be evaluated throughout the season without the time and cost associated with more expensive equipment, which directly affects player performance; monitoring allows coaches to alter programs to achieve a desired goal. Furthermore, the link between obesity and the development of cardiovascular disease strongly supports the need for regular monitoring of body composition in these athletes. Whereas the cost associated with many tests (eg, metabolic blood panel and blood pressure) is relatively inexpensive, these types of tests can become cost prohibitive in large football programs. Body composition testing provides a simple and effective method for monitoring one of the major correlates of performance and the development of cardiovascular disease. We have shown that, through the use of simple anthropometric measures, a football athlete's DEXA body composition can be estimated and compared for the benefit of performance and health-related recommendations. In future studies, researchers should continue to identify more efficient methods for determining body composition in other athletic populations, including but not limited to the validation of these equations on a sample of athletes from

a different division or through the development of equations specific to population, ethnicity, and position. This might advance our understanding of the changes in body composition that occur due to performance in the sport of football and lead to developing new ways of monitoring the health of football players.

ACKNOWLEDGMENTS

Partial funding for this study was provided by The Sydney and JL Huffines Institute for Sports Medicine and Human Performance, College Station, Texas. Additional equipment and service for this study were provided in part by Gilbert R. Kaats, PhD, and Integrative Health Technologies, San Antonio, Texas. Additional participants, staff, and facilities also were provided by the University of Houston Athletics Department, Texas. We thank Amy Bragg, MS, RD (University of Alabama Athletics); Jonathan Tanguay, MS, RD (Texas A&M University Athletics Department); and Aaron Carbuhn, MS, RD (University of Kansas) for their contributions during data collection.

REFERENCES

1. Norton K, Olds T. Morphological evolution of athletes over the 20th century: causes and consequences. *Sports Med*. 2001;31(11):763–783.
2. Wang Y, Beydoun MA. The obesity epidemic in the United States: gender, age, socioeconomic, racial/ethnic, and geographic characteristics. A systematic review and meta-regression analysis. *Epidemiol Rev*. 2007;29:6–28.
3. Harp JB, Hecht L. Obesity in the National Football League. *JAMA*. 2005;293(9):1061–1062.
4. Laurson KR, Eisenmann JC. Prevalence of overweight among high school football linemen. *JAMA*. 2007;297(4):363–364.
5. Malina RM, Morano PJ, Barron M, et al. Overweight and obesity among youth participants in American football. *J Pediatr*. 2007;151(4):378–382.
6. Romero-Corral A, Montori VM, Somers VK, et al. Association of bodyweight with total mortality and with cardiovascular events in coronary artery disease: a systematic review of cohort studies. *Lancet*. 2006;368(9536):666–678.
7. Borchers JR, Clem KL, Habash DL, Nagaraja HN, Stokley LM, Best TM. Metabolic syndrome and insulin resistance in Division I collegiate football players. *Med Sci Sports Exerc*. 2009;41(12):2105–2110.
8. Buell JL, Calland D, Hanks F, et al. Presence of metabolic syndrome in football linemen. *J Athl Train*. 2008;43(6):608–616.
9. Pi-Sunyer FX. The obesity epidemic: pathophysiology and consequences of obesity. *Obes Res*. 2002;10(suppl 2):97S–104S.
10. Glickman SG, Marn CS, Supiano MA, Dengel DR. Validity and reliability of dual-energy x-ray absorptiometry for the assessment of abdominal adiposity. *J Appl Physiol*. 2004;97(2):509–514.
11. Kohrt WM. Preliminary evidence that DEXA provides an accurate assessment of body composition. *J Appl Physiol*. 1998;84(1):372–377.
12. Mazess RB, Barden HS, Bisek JP, Hanson J. Dual-energy x-ray absorptiometry for total-body and regional bone-mineral and soft-tissue composition. *Am J Clin Nutr*. 1990;51(6):1106–1112.
13. Svendsen OL, Haarbo J, Hassager C, Christiansen C. Accuracy of measurements of body composition by dual-energy x-ray absorptiometry in vivo. *Am J Clin Nutr*. 1993;57(5):605–608.
14. Durnin JBGA, Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: measurement on 481 men and women aged from 16 to 72 years. *Br J Nutr*. 1974;32(1):77–97.
15. Pollock ML, Hickman T, Kendrick Z, Jackson A, Linnerud AC, Dawson G. Prediction of body density in young and middle-aged men. *J Appl Physiol*. 1976;40(3):300–304.

16. Smith JF, Mansfield ER. Body composition prediction in university football players. *Med Sci Sports Exerc.* 1984;16(4):398–405.
17. Sinning WE, Dolny DG, Little KD, et al. Validity of “generalized” equations for body composition analysis in male athletes. *Med Sci Sports Exerc.* 1985;17(1):124–130.
18. Yamamoto JB, Yamamoto BE, Yamamoto PP, Yamamoto LG. Epidemiology of college athlete sizes, 1950s to current. *Res Sports Med.* 2008;16(2):111–127.
19. Jackson AS, Pollock ML. Practical assessment of body composition. *Phys Sportsmed.* 1985;13(5):76–90.
20. Nieman DC. *Exercise Testing and Prescription: A Health-Related Approach.* 7th ed. New York, NY: McGraw-Hill Co, Inc; 2011: 102–116.
21. Harrison GG, Buskirk ER, Carter JEL, et al. Skinfold thicknesses and measurement technique. In: Lohman TG, Roche AF, Martorell R, eds. *Anthropometric Standardization Reference Manual.* Champaign, IL: Human Kinetics; 1988:55–70.
22. Callaway CW, Chumlea WC, Bouchard C, et al. Circumferences. In: Lohman TG, Roche AF, Martorell R, eds. *Anthropometric Standardization Reference Manual.* Champaign, IL: Human Kinetics; 1988:39–54.
23. Lohman TG, Chen Z. Dual X-ray absorptiometry. In: Heymsfield SB, Lohman TG, Wang ZM, Going SB, eds. *Human Body Composition.* 2nd ed. Champaign, IL: Human Kinetics; 2005:63–74.
24. Jackson AS, Pollock ML. Generalized equations for predicting body density of men. *Br J Nutr.* 1978;40(3):497–504.
25. White J, Mayhew JL, Piper FC. Prediction of body composition in college football players. *J Sports Med Phys Fitness.* 1980;20(3):317–324.
26. Wickkiser JD, Kelly JM. The body composition of a college football team. *Med Sci Sports.* 1975;7(3):199–202.
27. Mathews EM, Wagner DR. Prevalence of overweight and obesity in collegiate American football players, by position. *J Am Coll Health.* 2008;57(1):33–38.
28. Miller MA, Croft LB, Belanger AR, et al. Prevalence of metabolic syndrome in retired National Football League football players. *Am J Cardiol.* 2008;101(9):1281–1284.
29. Tucker AM, Vogel RA, Lincoln AE, et al. Prevalence of cardiovascular disease risk factors among National Football League players. *JAMA.* 2009;301(20):2111–2119.

Address correspondence to Jonathan M. Oliver, MEd, Applied Exercise Science Laboratory, Texas A&M University, 114 Netum Steed, TAMU 4243, College Station, TX 77843-4243. Address e-mail to joliver@hlkn.tamu.edu.