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Identification of Cardiometabolic Risk Among Collegiate Football Players

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Context: Excessive fat mass clearly has adverse effects on metabolic processes that can ultimately lead to the development of chronic disease. Early identification of high-risk status may facilitate referral for definitive diagnostic tests and implementation of interventions to reduce cardiometabolic risk.

Objective: To document the prevalence of metabolic syndrome among collegiate football players and to develop a clinical prediction rule that does not require blood analysis to identify players who may possess a high level of cardiometabolic risk.

Design: Cross-sectional cohort study.

Setting: University athletic training research laboratory.

Patients or Other Participants: Sixty-two National Collegiate Athletic Association Division I Football Championship Subdivision football players (age = 19.9 ± 1.2 years, height = 182.6 ± 6.1 cm, mass = 97.4 ± 18.3 kg).

Main Outcome Measure(s): Anthropometric characteristics associated with body fat, isokinetic quadriceps strength, and biometric indicators associated with metabolic syndrome were measured. Participants were classified as high risk or low risk for future development of type 2 diabetes and cardiovascular disease.

Results: The prevalence of metabolic syndrome in the cohort was 19% (12 of 62), and 79% (49 of 62) of the players exceeded the threshold for 1 or more of its 5 components. A 4-factor clinical prediction rule that classified individuals on the basis of waist circumference, blood pressure, quadriceps strength, and ethnic category had 92% sensitivity (95% confidence interval = 65%, 99%) and 76% specificity (95% confidence interval = 63%, 86%) for discrimination of high-risk or low-risk status.

Conclusions: The risk for developing type 2 diabetes and cardiovascular disease appears to be exceptionally high among collegiate football players. A lack of race-specific criteria for the diagnosis of metabolic syndrome almost certainly contributes to an underestimation of the true level of cardiometabolic risk for African American collegiate football players.

Key Words: metabolic syndrome, insulin resistance, abdominal fat

Key Points

- In this Division I football team, metabolic syndrome was found in 19% of players overall, 46% of the linemen, and 14% of the nonlinemen. The cardiometabolic risk in the African American players was almost certainly underestimated.
- For identifying obesity-related health risk, waist circumference was a better discriminator than either body fat percentage or body mass index.
- A quadriceps peak torque/body mass ratio of less than 2.93 (peak torque/body weight less than 0.98) was the optimal cut point for identifying players with metabolic syndrome.
- Our clinical prediction rule identified 92% of players with metabolic syndrome on the basis of waist circumference, systolic or diastolic blood pressure, quadriceps peak torque/body mass ratio, and white ethnicity.

The leading cause of death among middle-aged men in the United States is cardiovascular disease (CVD), which has been strongly associated with inadequate physical activity, poor dietary habits, and genetic predispositions.[1,2] Many people assume that the exceedingly high volume of intense physical activity collegiate athletes perform in preparation for competition produces exemplary health status, but other factors may present long-term health risks for individual athletes. Large body mass provides a competitive advantage in some contact sports, such as American football, but the extent to which body mass is augmented by fat may have very serious health consequences.[3]

Metabolic syndrome (MetS) is a condition that is clearly associated with elevated risk for development of type 2 diabetes and CVD.[4] Because various medical organizations use different combinations of factors to define MetS, as well as different threshold values for designation of a positive factor, estimates of its prevalence in a given population vary substantially.[5,6] Different definitions have been developed by the World Health Organization, the European Group for the Study of Insulin Resistance, the International Diabetes Federation, the American Association of Clinical Endocrinologists and the American College of Endocrinology, and the National Cholesterol Education Program. With the exception of the definition from the American Association of Clinical Endocrinologists and the American College of Endocrinology, excessive abdominal fat is a designated factor for all definitions. All 5 definitions address elevated blood pressure (BP) and blood lipids and either elevated fasting blood glucose or impaired glucose tolerance.[5]

The National Cholesterol Education Program Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults, Adult Treatment Panel III (ATP-III), developed a definition of MetS that was

intended to provide a practical guide for identifying individuals at high risk for CVD in a clinical setting.[7] The ATP-III definition is the one most commonly used in medical research, because its 5 components can be easily measured in large epidemiologic studies.[4] In 2005, the threshold for designating fasting plasma glucose as a positive factor was lowered by the American Heart Association and the National Heart, Lung, and Blood Institute from the original ATP-III value of 6.11 mmol/L (110 mg/dL) or higher to 5.56 mmol/L (100 mg/dL) or higher.[8] With this modification, the ATP-III definition of MetS classifies a person as having the condition when 3 or more of the following factors are positive: (1) large waist circumference (WC) of greater than 102 cm for males or 88 cm for females; (2) elevated BP, with systolic BP of 130 mm Hg or higher or diastolic BP of 85 mm Hg or higher; (3) low level of high-density lipoprotein (HDL) cholesterol at less than 40 mg/dL (1.03 mmol/L) for males and 50 mg/dL (1.29 mmol/L) for females; (4) elevated triglycerides of 150 mg/dL (1.69 mmol/L) or higher; and (5) elevated fasting plasma glucose of 100 mg/dL (5.56 mmol/L) or higher.

The age-adjusted prevalence of MetS in the adult population of the United States has been reported to be approximately 24%,[9] but it varies widely among various subgroups of different ages, sexes, and ethnicities.[6] Prevalence has been reported to be 7% among 20- to 29-year-old adults[9] and 5% among 12- to 17-year-old adolescents.[10] Relatively little information exists in the literature concerning cardiometabolic risk in the college-aged population.[11,12] In the only study[3] documenting the prevalence of MetS among collegiate football players, it was present in 49% of offensive and defensive linemen.

Awareness of cardiometabolic risk may be obscured by a lack of overt symptoms associated with hypertension, elevation of blood lipids, or impaired glucose metabolism. The primary purpose of our study was to establish the prevalence of MetS within a cohort of collegiate football players without regard for position category. Although WC and BP are relatively easy to measure, identifying the other MetS components requires analysis of a blood sample. A cardiometabolic risk screening procedure that does not require acquisition of a blood sample could have great utility as a way of identifying the subset of football team members who should be referred for a thorough clinical assessment that does include blood analysis. A clinical prediction rule is a combination of clearly definable patient characteristics that provides the clinician with a quantifiable likelihood for the existence of a given condition, the prognosis for a positive or negative change in health status, or the realization of benefit from the delivery of a given therapeutic procedure. A secondary purpose of our study was to develop a clinical prediction rule to discriminate between collegiate football players who are likely to have MetS and those who possess a lower level of cardiometabolic risk.

METHODS

Participants

The cohort consisted of 63 members of a National Collegiate Athletic Association Division I Football Championship Subdivision (NCAA Division I–FCS) program, all of whom voluntarily agreed to participate in the research project. The study procedures were reviewed and approved by the Institutional Review Board of the University of Tennessee at Chattanooga, and signed informed consent was obtained from all volunteers. One participant failed to complete all aspects of the study. The remaining 62 participants ranged in age from 19 to 23 years (age = 19.9 ± 1.2 years, height = 182.6 ± 6.1 cm, mass = 97.4 ± 18.3 kg). Participant self-designation of ethnicity identified 55% of the cohort as white (34 of 62) and 45% as African American (28 of 62).

Procedures

Anthropometric measurements included height, body mass, body mass index (BMI), WC, and an estimate of body fat percentage (BF%). The WC was measured above the superior margins of the iliac crests.[13] Air-displacement plethysmography (BOD POD Body Composition System; Life Measurement Instruments, Concord, CA) was used to generate an estimate of fat mass and fat-free mass components of total body mass, from which BF% was calculated. All volunteers wore a tight-fitting elastic garment and a swim cap to compress hair during the air-displacement test procedure. Thoracic gas volume was estimated by the equipment manufacturer's software program on the basis of each participant's height and age, which has been shown to provide adequate precision for group comparisons.[14–16] Air-displacement plethysmography has also been shown to provide reliable measurements of BF% among collegiate football players.[15]

Biometric measurements included systolic BP, diastolic BP, total cholesterol, HDL cholesterol, triglycerides, and fasting plasma glucose. Blood pressure was recorded as the average of 2 consecutive measurements that were obtained from the same arm with the participant in a seated position. A capillary whole-blood specimen was obtained after a 12-hour fast by means of a finger-stick procedure and was analyzed immediately after its collection (Cholestech LDX Analyzer; Cholestech, Inc, Hayward, CA). Several recent reports[17–19] have supported the validity and reliability of measurements derived from the portable blood analysis device that was used in this study. Because values for low-density lipoprotein (LDL) cholesterol are associated with greater error than values for other blood components measured by the device,[18,19] we did not analyze LDL cholesterol.

Quadriceps muscle strength was defined as the concentric quadriceps peak torque to body mass ratio (QPT/BM) measured by an isokinetic dynamometer (Biodex System 2; Biodex Medical Systems, Inc, Shirley, NY) at a velocity of 60°/s for the dominant extremity. For participants without a history of knee injury and those who had a history of bilateral knee injuries, limb dominance was defined on the basis of the extremity the individual would use to kick a ball for maximum distance. For participants with a history of unilateral knee injury, the uninjured extremity was classified as the dominant extremity. Peak torque was determined from 3 maximal-effort repetitions of reciprocal full-range knee extension and flexion movements against resistance. Both interrater agreement and test-retest reliability for isokinetic measurements of concentric

Table 1. Cases Exceeding Thresholds for Specific Adult Treatment Panel III Metabolic Syndrome Components and Exceeding Threshold for Any Component or Any Combination of Components (N = 62)

	% of Cohort (n)
Metabolic syndrome component	
High blood pressure (≥130 mm Hg/≥85 mm Hg)	57 (35)
High waist circumference (>102 cm)	13 (8)
High triglyceride level (≥150 mg/dL)	18 (11)
Low high-density lipoprotein cholesterol (<40 mg/dL)	24 (15)
High fasting glucose level (≥100 mg/dL)	29 (18)
Positive components	
0	21 (13)
1	42 (26)
2	18 (11)
3	14 (9)
4	5 (3)

quadriceps peak torque values are exceptionally good.[20–22] Quadriceps peak torque to body mass ratio calculated using SI units to quantify quadriceps strength in relation to body mass (Nm/kg) yields a QPT/BM value that is 2.99 times greater than the quadriceps peak torque to body weight ratio (QPT/BW) calculated from English units (ft-lb/lb). Because QPT/BW is a widely used clinical indicator of quadriceps performance capability in the United States, its exact value is reported along with the corresponding QPT/BM value.

We classified each participant as either MetS-positive or MetS-negative on the basis of the American Heart Association and the National Heart, Lung, and Blood Institute modification of the ATP-III definition of MetS.[7,8] MetS status was not revealed to any participant or investigator until the data collection process was completed.

Statistical Analysis

Independent *t* tests were used to evaluate the univariate association of each continuous variable with MetS by comparing MetS-positive and MetS-negative group means, with $P < .10$ as the standard for initial selection of potential predictor variables that did not require blood analysis. For each selected continuous variable, a receiver operator characteristic (ROC) curve was generated to plot the relationship between correctly identified MetS-positive cases (sensitivity) and incorrectly classified MetS-negative cases (1 − specificity) at all possible classification cut points. The optimal cut point identified by ROC analysis provided the basis for dichotomization of each participant's value as either positive (1) or negative (0) with regard to the variable's association with MetS-positive status. Chi-square analysis was used to assess the discriminating power of each dichotomized variable, with $P < .10$ as the standard for retention of variables for further development of a clinical prediction model. Logistic regression analysis was then performed to identify the best combination of variables for prediction of MetS-positive status through backward stepwise elimination of variables (SPSS version 16.0; SPSS Inc, Chicago, IL). The criterion used for model selection was the step having the smallest number of predictor variables without a reduction in the maximum R^2 value associated with any other step. The ROC analysis was then used to identify the number of positive dichotomous factors that offered the most accurate prediction of MetS-positive status.

RESULTS

The prevalence of MetS in the cohort was 19% (12 of 62). Frequencies for each ATP-III MetS component and number of positive components are presented in Table 1. Descriptive statistics and *P* values associated with independent *t* tests of group differences for continuous variables are presented in Table 2. Cut points derived from ROC analysis for dichotomization of continuous variables and *P* values associated with χ^2 tests of group differences for dichotomized variables are presented in Table 3. The ROC analysis identified WC greater than 90 cm as a better cut point for prediction of MetS-positive status (92% sensitivity, 64% specificity) than the ATP-III cut point of WC greater than 102 cm (33% sensitivity, 92% specificity). Because ROC analysis confirmed that ≥130 mm Hg was the optimal cut point for systolic BP, the ATP-III definition for high BP was retained as a dichotomous predictor variable. All 6 of the dichotomous variables listed in Table 3 demonstrated statistically significant ($P < .10$) discrimination of MetS-positive and MetS-negative cases.

Backward elimination logistic regression analysis of the 6 dichotomous variables identified WC greater than 90 cm ($\beta = 2.21$), BP greater than 130 mm Hg systolic or 85 mm Hg diastolic ($\beta = .68$), QPT/BM greater than 2.93

Table 2. Descriptive Statistics (Mean ± SD) and *P* Values Associated With Differences Between Group Means

		Metabolic Syndrome		
	Total Cohort	Negative	Positive	
Variable	(N = 62)	(n = 50)	(n = 12)	*P* Value
Body mass index, kg/m²	29.09 ± 4.54	28.40 ± 3.97	31.98 ± 5.76	.013[a]
Body fat, %	15.38 ± 7.02	14.39 ± 6.25	19.50 ± 8.76	.022[a]
Waist circumference, cm	90.55 ± 10.84	88.63 ± 9.87	98.53 ± 11.43	.004[a]
Systolic blood pressure, mm Hg	129.65 ± 6.21	128.66 ± 5.59	133.75 ± 7.20	.010[a]
Diastolic blood pressure, mm Hg	82.00 ± 5.50	81.54 ± 5.20	83.92 ± 6.47	.181
Total cholesterol, mg/dL	169.48 ± 38.07	163.88 ± 36.19	192.83 ± 38.31	.017[a]
High-density lipoprotein cholesterol, mg/dL	48.92 ± 15.03	51.52 ± 13.39	38.08 ± 17.19	.005[a]
Triglycerides, mg/dL	110.06 ± 58.18	91.42 ± 34.34	187.75 ± 73.19	.001[a]
Fasting plasma glucose (mg/dL)	94.00 ± 12.93	92.10 ± 11.55	101.92 ± 15.76	.017[a]
Quadriceps muscle peak torque/ body mass, Nm/kg	3.00 ± 0.52	3.06 ± 0.46	2.71 ± 0 .67	.033[a]

[a] $P < .10$.

Table 3. Cut Points Derived From Receiver Operator Curve Analysis, Cases Classified as Positive for Potential Predictor Variables, and *P* Values Associated With Differences in Frequencies Between Groups

Variable	Cut Point	Metabolic Syndrome, % (n)		*P* Value
		Negative (n = 50)	Positive (n = 12)	
Body mass index, kg/m2	≥28	46% (23)	83% (10)	.020[a]
Body fat, %	≥17	32% (16)	75% (9)	.006[a]
Waist circumference, cm[b]	>90	36% (18)	92% (11)	.001[a]
Blood pressure, mm Hg[b]	≥130/≥85	50% (25)	83% (10)	.036[a]
Quadriceps muscle peak torque/body mass, Nm/kg[b]	<2.93	38% (19)	75% (9)	.021[a]
Ethnic category: white[b]	—	48% (24)	83% (10)	.027[a]

[a] $P < .10$.

[b] Dichotomous variable included in 4-factor prediction model derived from logistic regression analysis.

(quadriceps peak torque/body weight greater than 0.98; β = .85), and white ethnicity (β = 1.46) as the best combination of predictors (model $\chi^2 = 18.26$, $P < .001$, Nagelkerke $R^2 = 0.41$). The ROC analysis of the 4-factor model demonstrated exceptionally good predictive power (area under the curve = 0.847, 95% confidence interval [CI] = 0.727, 0.966 [CIs were generated using the calculator at http://www.cebm.utoronto.ca/practise/ca/statscal]) and identified 3 or more positive factors as the best combination of sensitivity (92%, 95% CI = 65%, 99%) and specificity (76%, 95% CI = 63%, 86%) for prediction of MetS-positive status (Figure). The positive likelihood ratio was 3.83 (95% CI = 2.27, 6.44), which indicates that MetS-positive status was almost 4 times more likely when 3 or more of the 4 predictive factors were positive.

Because ethnic category was among the factors included in the prediction model, descriptive statistics and *P* values associated with independent *t* tests of group differences between white and African American players are presented in Table 4.

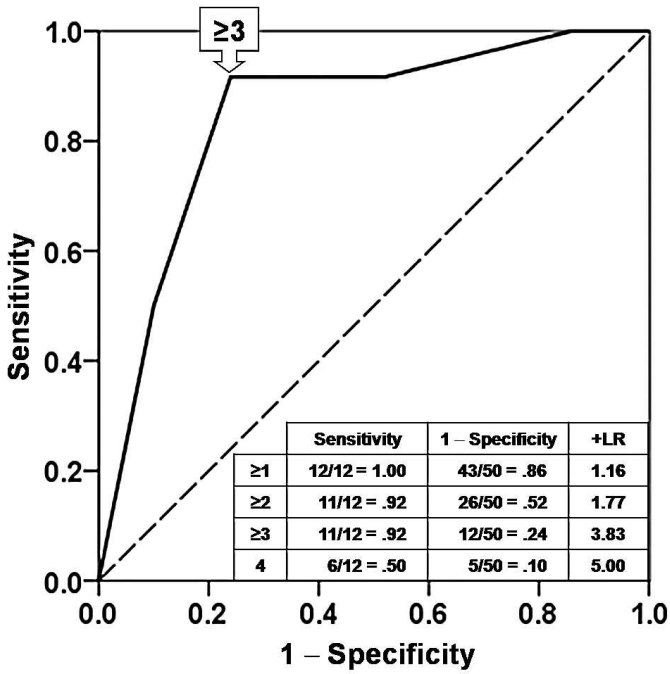

Figure. Receiver operator curve for prediction of high-risk cardiometabolic status on the basis of a 4-factor model: (1) high waist circumference, (2) high blood pressure, (3) low quadriceps muscle peak torque/body mass, and (4) white ethnicity. +LR indicates positive likelihood ratio; Sensitivity, correctly identified MetS-positive cases; 1 – Specificity, incorrectly classified MetS-negative cases.

DISCUSSION

The term *MetS* is often used in a manner that is essentially synonymous with *insulin resistance*, which is specifically defined as defective insulin-mediated glucose disposal. Insulin resistance is central to the development of type 2 diabetes,[1,2,5,23] but no absolute standard exists to classify the result of the complex and prolonged clinical testing procedure required to measure glucose disposal.[23–25] Although the criteria used to diagnose insulin resistance have varied among studies, remarkably similar findings have been reported for its association with MetS. The sensitivity of the ATP-III definition of MetS for identifying insulin resistance is approximately 45% to 50%, and its specificity for excluding insulin resistance is approximately 90% to 95%.[24–27] Although the sensitivity was modest, the high specificity made the odds of insulin resistance as much as 10 times greater for individuals diagnosed with MetS than for those who did not meet the ATP-III definition. Furthermore, modest sensitivity for identifying insulin resistance should not detract from the value of the MetS construct for identifying individuals who may need intensified management of CVD risk.[24,26]

The fact that clustering of CVD risk factors occurs is widely accepted, but the underlying pathophysiology is not understood.[28] A substantial body of epidemiologic evidence has demonstrated that MetS is strongly associated with CVD morbidity and mortality.[1,2,4,27–30] However, some researchers[23,31] have argued that a clear basis for the algorithm that defines the MetS construct is lacking and that diagnosing the condition does not improve prediction of future CVD risk beyond that predicted by its individual components. In a meta-analysis of epidemiologic studies that have used the ATP-III definition, the value of MetS diagnosis as an independent predictor of relative risk for CVD was relatively modest, but it was much more strongly associated with type 2 diabetes.[32] Among individuals diagnosed with type 2 diabetes, CVD is the leading cause of morbidity and mortality.[33] Obesity, insulin resistance, and vascular inflammation are strongly associated with the eventual development of both type 2 diabetes and CVD.[28] Despite debate about unresolved scientific issues pertaining to the MetS construct, cardiometabolic disease risk is clearly increased among individuals who are diagnosed with MetS.[33,34]

Table 4. Descriptive Statistics (Mean ± SD) and *P* Values Associated With Differences Between Means for Ethnic Categories

Variable	White (n = 34)	African American (n = 28)	*P* Value
Body mass index, kg/m2	29.17 ± 3.93	28.99 ± 5.27	.877
Body fat, %	15.82 ± 6.86	14.85 ± 7.30	.590
Waist circumference, cm	92.10 ± 9.34	88.66 ± 12.23	.216
Systolic blood pressure, mm Hg	130.15 ± 6.90	129.04 ± 5.33	.488
Diastolic blood pressure, mm Hg	82.03 ± 5.65	81.96 ± 5.41	.963
Total cholesterol, mg/dL	166.32 ± 34.91	173.32 ± 41.92	.476
High-density lipoprotein cholesterol, mg/dL	44.24 ± 14.23	54.61 ± 14.21	.006[a]
Triglycerides, mg/dL	127.59 ± 66.63	88.79 ± 36.96	.005[a]
Fasting plasma glucose, mg/dL	93.79 ± 13.48	94.25 ± 12.46	.891
Quadriceps muscle peak torque/body mass, Nm/kg	2.99 ± 0.48	3.00 ± 0.57	.934

[a] $P < .01$.

The 19% prevalence of MetS found among the members of the NCAA Division I–FCS football team that comprised our cohort far exceeded the greater than 1% prevalence reported for male college students.[12] Buell et al[3] found a 49% prevalence of MetS for collegiate football linemen (34 of 70), which closely approximates the 46% prevalence among the linemen in our cohort (5 of 11). Because linebackers, defensive ends, tight ends, and fullbacks are not classified as linemen, but they sometimes have similar physical characteristics to interior linemen, we did not include playing position as a factor in our analysis. Among players who were not classified as linemen, the prevalence of MetS was 14% (7 of 51). Although the prevalence of MetS was clearly greater among football linemen than among other players, our findings suggest that assessing cardiometabolic risk should not be limited to position classification.

The logistic regression analysis identified ethnicity as one of the best predictors of MetS-positive status. White players exhibited a prevalence of 29% (10 of 34), whereas only 7% of African American players met the criteria for MetS diagnosis (2 of 28). This difference is consistent with previous findings that African Americans are more insulin resistant than whites at a given level of obesity, yet they paradoxically exhibit a lower triglyceride level and a higher HDL cholesterol level.[6,24,35] Because African American ethnicity is known to present substantially elevated risk for development of type 2 diabetes,[35] race-specific thresholds for high triglycerides and low HDL cholesterol are needed to improve the sensitivity of the MetS construct.[24,36] In comparison with white players, the African American players in our cohort demonstrated a lower triglyceride level ($P = .005$) and a higher HDL cholesterol level ($P = .006$). Because 45% of the cohort comprised African American players, the 19% MetS prevalence for the combined group almost certainly underestimates the actual level of cardiometabolic risk.

Blood analysis is an expensive and inconvenient procedure for assessing the health status of each member of a football team. In addition to the questionable value of ATP-III thresholds for triglycerides and HDL cholesterol for identifying cardiometabolic risk among a large subgroup of football players, the value of fasting hyperglycemia as an indicator of insulin resistance is limited.[24] Hypertension, which is closely linked to abdominal obesity, has been identified as the most important indicator of cardiometabolic risk.[37] Adipose-derived inflammatory cytokines (ie, interleukin-6 and tumor necrosis factor-α) have been linked to hypertension, dyslipidemia, and insulin resistance.[31,32] Thus, measurements derived from blood analysis may be less important than measurements of BP and obesity for identifying cardiometabolic risk. In fact, WC alone has been reported to predict insulin resistance with greater accuracy than the ATP-III MetS construct.[27]

Body composition was estimated using air-displacement plethysmography to assess the value of BF% for discrimination between players who had 3 or more positive MetS indicators and those with 2 or fewer indicators. Our finding was consistent with that of previous researchers[38] who demonstrated that WC was a better discriminating factor than either BF% or BMI for identifying obesity-related health risk. Because abdominal obesity appears to play a central role in the development of insulin resistance,[39] WC is probably a better predictor of abnormal metabolic physiology than a measurement of general obesity. Previous authors[27] have also demonstrated that WC greater than 92 cm (36 in) provides greater sensitivity for predicting insulin resistance in the general adult population than the ATP threshold of greater than 102 cm (40 in). Similarly, we found that a WC threshold of greater than 90 cm (35 in) was a more sensitive predictor of a collegiate football player's having 3 or more positive MetS indicators than either BF% or BMI. The anthropometric characteristics of collegiate football players are clearly different from those of the general adult population. Because no scientific rationale has been cited as the basis for the ATP-III thresholds,[31] using a WC threshold derived from an ROC analysis of the data was deemed appropriate.

Muscle strength is another factor that appears to distinguish individuals who have elevated cardiometabolic risk from those who possess a sufficiently high level of muscle metabolism to optimize glucose disposal and maintain insulin sensitivity.[40,41] Because the quadriceps muscle group is continuously active during weightbearing and is the largest muscle group in the body, QPT/BM provides a numeric value that represents the relationship between an individual's metabolic capacity and the combination of body fat mass and lean mass. Thus, a low QPT/BM may reflect poor quadriceps strength, excessive body mass, or both factors. Because QPT/BM also relates to knee injury risk, many college football programs include its measurement when assessing player performance capabilities. The ROC analysis identified QPT/BM of less than 2.93 (QPT/BW of less than 0.98) as the optimal cut point for identifying MetS-positive players, which closely approximates the quadriceps strength level

Table 5. Sensitivity, Specificity, and Likelihood Ratios for the Individual Components of a Clinical Prediction Rule for Metabolic Syndrome and the Combination of ≥3 Positive Factors

Predictive Factor	Sensitivity	Specificity	Likelihood Ratio	
			Positive	Negative
Waist circumference, cm: >90	0.92	0.64	2.55	0.13
Blood pressure, mm Hg: ≥130/≥85	0.83	0.50	1.67	0.34
Quadriceps muscle peak torque/body mass, Nm/kg: <2.93	0.75	0.62	1.97	0.40
Ethnic category: white	0.83	0.52	1.74	0.33
Combined factors: ≥3 positive	0.92	0.76	3.83	0.11

that some clinicians consider optimal for reducing knee injury risk (QPT/BW of 1.0 or greater).

The clinical prediction rule developed from logistic regression and ROC analysis has exceptionally good sensitivity for identifying individual collegiate football players with a high level of cardiometabolic risk as defined by the ATP-III MetS construct (Table 5). The prediction model identified 92% of players who were MetS-positive on the basis of having either 3 or 4 of the following: (1) WC greater than 90 cm, (2) systolic or diastolic BP above the ATP-III threshold, (3) QPT/BM less than 2.93 (QPT/BW less than 0.98), or (4) white ethnicity. Players who are classified as high risk by the clinical prediction rule should be referred for blood analysis to precisely define the level of risk. Unfortunately, the current lack of race-specific thresholds for triglycerides and HDL cholesterol almost certainly resulted in an underestimation of the true level of cardiometabolic risk among African American players. Therefore, more definitive diagnostic testing should be considered for any African American player who demonstrates any 2 of the BP, WC, and QPT/BW predictors. Some experts[30,31,42] recommend that the existence of a single cardiometabolic risk factor should prompt a search for the possible existence of others. Among cases predicted to be MetS-positive that were false-positive, 92% (11 of 12) demonstrated high BP.

Cardiorespiratory fitness has been shown to attenuate the risk of CVD mortality associated with MetS in men.[43] Collegiate football players are clearly engaged in an extremely large volume of strenuous physical activity, but the duration and frequency of aerobic training may be insufficient to produce physiologic adaptations associated with low cardiometabolic risk. A strong inverse association has been identified between cardiorespiratory fitness level and the values of the physiologic indicators of MetS,[42,44,45] and physiologic indicators of insulin sensitivity have been positively associated with high levels of enzymes involved in aerobic metabolism.[46–48] Abdominal obesity is responsible for elevating systemic free fatty acids, which has an adverse effect on insulin sensitivity. Although football is characterized by high-intensity, short-duration exertions that almost exclusively rely on anaerobic energy metabolism, aerobic conditioning may enhance performance capabilities through increased intramuscular glycogen storage and improved muscle glucose uptake during maximal exercise.[47,48] Elevating the lactate threshold through long-term aerobic conditioning can increase fatigue resistance during performance of repetitive maximum-effort exertions, but the short-term effect of regular aerobic activity appears to be especially important for maintaining insulin sensitivity. Muscle uptake of glucose depends on the action of the GLUT4 transporter protein, which is responsible for the passage of glucose through the muscle cell's plasma membrane. Aerobic activity stimulates translocation of GLUT4 from intracellular storage sites to the plasma membrane, which substantially improves insulin sensitivity for up to 48 hours.[46–48] Because the beneficial effect of aerobic training on insulin sensitivity does not produce a long-term adaptation, it must be performed on a regular basis to optimize glucose transport.

Like a large segment of the American population, most football players have a strong dietary preference for calorie-dense foods that are high in simple sugars and saturated fat. Excessive consumption of high-calorie foods and beverages, which are relatively inexpensive and readily accessible, will have both immediate and long-term adverse effects on insulin-related metabolic processes.[49] A dietary pattern that includes an abundance of fruits, vegetables, whole-grain cereals, nuts, and legumes; low to moderate amounts of fish and poultry; low consumption of red meat; and moderate consumption of wine has been shown to have an inverse association with CVD mortality.[50] To the greatest extent possible, football programs should promote dietary behaviors that will reduce cardiometabolic risk, which may also enhance athletic performance capabilities.

The extent to which the findings of this study can be generalized depends on the similarity of the characteristics of our cohort to those of other college football teams. A previously reported air-displacement plethysmography estimate of BF% for a cohort of 69 NCAA Division I Football Bowl Subdivision football players[16] was remarkably similar to our estimate for 62 NCAA Division I–FCS players (15.6% and 15.4%, respectively), which strongly suggests that the problem is widespread. Because our findings are based on a relatively small number of MetS-positive cases (n = 12), a study that includes a much larger number of players in multiple programs is needed to confirm the scope of the problem and to validate the accuracy of our clinical prediction rule. The apparent lack of sensitivity of the ATP-III MetS construct for identifying African Americans who possess a high level of cardiometabolic risk is clearly an important concern that needs to be addressed. Further research is also needed to establish an optimal exercise regimen and diet for attaining maximal insulin sensitivity among players with large body mass, which might simultaneously reduce cardiometabolic risk and enhance speed, power, agility, and fatigue resistance.

A large amount of lean body mass clearly provides a competitive advantage in American football, but excessive body fat presents a major health risk that is unlikely to contribute to the effective performance of sport-specific skills. Researchers[12,13] who documented the existence of at least 1 positive component of the ATP-III MetS construct in 27% to 33% of college students interpreted the

prevalence as an alarming finding. Within our cohort of college football players, 79% (49 of 62) demonstrated at least 1 positive MetS component. Athletic trainers, team physicians, football coaches, and athletic program administrators have a responsibility to promote the long-term health of collegiate football players through risk factor screening, referral for definitive diagnostic tests, inclusion of regular aerobic training in the conditioning program, and support for development of healthy dietary behaviors.

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