Lean Mass and Fat Mass as Contributors to Physical Fitness in an Overweight and Obese African American Population

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Objective: To determine the association of lean vs fat mass with fitness in healthy, overweight and obese African Americans from families with early-onset coronary disease.

Design: Cross-sectional study.

Setting: Baltimore, Maryland.

Participants: 191 healthy, overweight, sedentary African Americans (69% women; aged 44.8 ± 11 years; body mass index 34 ± 5 kg/m^2).

Main Outcome Measures: Anthropometrics, smoking, blood pressure, lipids, c-reactive protein, and glucose were assessed with standard methods; body composition was determined by dual energy X-ray absorptiometry; cardiorespiratory fitness was expressed as VO_{2peak} attained during a maximal treadmill test.

Results: In both men and women, greater lean mass was independently associated with higher VO_{2peak} ($P<.05$) and explained >21% of the variance in VO_{2peak}, adjusted for body mass index, fat mass, important covariables, and nonindependence of families.

Conclusions: In this cross-sectional study, lean mass was the key determinant of cardiorespiratory fitness, independent of sex, age, and magnitude of obesity. These data provide a strong rationale for examining whether interventions that increase lean mass may also improve fitness, even among high-risk overweight and obese African Americans. (*Ethn Dis.* 2015;25[2]:214–219)

Key Words: Physical Fitness, Body Composition, Obesity, African Americans

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Introduction

Obesity in adults is thought to be in part responsible for high rates of cardiovascular disease, particularly in populations with a high propensity to obesity and cardiovascular risk factors.[1] US African Americans (AA) have a particularly high prevalence of obesity: 38.8% of adult men and 58.6% of adult women.[2] However, AA more often demonstrate greater amounts of metabolically active lean mass for any given body mass index compared to other ethnic groups.[3,4] Lean mass is a key determinant of energy expenditure,[5] an important precursor for higher levels of physical fitness, but AA adults have lower levels of physical fitness across levels of body mass index (BMI) compared with other ethnic groups.[6–8]

Prior studies, primarily in European Americans, have suggested that higher levels of physical fitness are primarily determined by BMI and/or total body fat, after adjusting for age, sex, and habitual physical activity.[9–11] Although obesity-related disease outcomes can be better predicted by a combination of body composition components rather than by BMI alone,[12] less is known about the contribution of lean muscle mass relative to fat mass and BMI to physical fitness in apparently healthy overweight and obese AA adults with a high prevalence of cardiovascular risk factors, particularly in individuals from families with early-onset cardiovascular disease. We examined the extent to which lean mass, fat mass, and the ratio of lean mass to fat mass measured by dual energy X-ray absorptiometry (DEXA) contributed to cardiorespiratory fitness by measuring oxygen uptake during maximal treadmill testing in healthy overweight and obese AA from high-risk families.

We examined the extent to which lean mass, fat mass, and the ratio of lean mass to fat mass measured by dual energy X-ray absorptiometry (DEXA) contributed to cardiorespiratory fitness…

Methods

This study was approved by the Johns Hopkins Medicine Institutional Review Board. All participants gave written informed consent before screening.

African American participants (N=191) were identified from the GeneSTAR (Genetic Study of Atherosclerosis Risk) cohort. Briefly, index cases with documented early-onset (prior to age 60 years) coronary artery disease (CAD) events (myocardial infarction, acute coronary syndromes, coronary artery bypass surgery, percutaneous coronary angioplasty, or stable angina with ≥50% stenosis in one or more vessels treated medically) were identified during hospitalization for a CAD event. The participants' apparently healthy siblings and adult offspring, as well as the adult offspring of their siblings and the other parents of the offspring, were screened for CAD risk

Table 1a. Sample characteristics by fitness quartile in males (*n*=60)

Variable	VO_{2peak} Q1: 1.81–2.54 (*n*=15)	VO_{2peak} Q2: 2.55–2.919 (*n*=15)	VO_{2peak} Q3: 2.92–3.25 (*n*=15)	VO_{2peak} Q4: 3.26–4.714 (*n*=15)	*P*
Age, years	48.5 (9.33)	47.8 (9.31)	46.0 (10.7)	42.4 (13.2)	.4167
Weight, kg[a]	94.4 (12.0)	96.2 (13.4)	95.5 (14.9)	118.1 (18.3)	.0002
Waist circumference, cm	101.0 (11.9)	104.7 (18.4)	99.1 (8.3)	109.7 (12.0)	.1399
Body mass index, kg/m[2a]	31.1 (4.40)	31.3 (3.31)	30.7 (3.43)	36.2 (5.04)	.0020
Systolic blood pressure, mm Hg[a]	127.5 (10.5)	127.8 (13.2)	126.6 (15.0)	127.1 (11.4)	.9882
Diastolic blood pressure, mm Hg	77.5 (9.91)	76.5 (8.89)	73.7 (8.52)	69.2 (10.0)	.0807
Glucose, mmol/L[a]	5.49 (.84)	5.79 (.84)	5.82 (1.02)	5.65 (1.17)	.7599
Insulin, pmol/L[a]	149.0 (61.5)	178.6 (88.7)	144.9 (68.5)	179.9 (111.5)	.7593
QUICKI	.305 (.018)	.298 (.024)	.305 (.020)	.303 (.031)	.8509
hsCRP, mg/L[a]	.314 (.314)	.497 (.398)	.304 (.495)	.468 (.364)	.0507
LDL cholesterol, mmol/L[a]	3.55 (1.62)	3.42 (.66)	2.79 (.83)	2.82 (.80)	.0589
HDL cholesterol, mmol/L[a]	1.28 (.55)	1.23 (.41)	1.20 (.37)	1.18 (.31)	.9770
Triglycerides, mmol/L[a]	1.26 (.67)	1.14 (.65)	1.00 (.42)	1.42 (1.01)	.4841
Stanford physical activity, joules/week[a]	59.5 (2.45)	61.4 (4.52)	59.3 (2.92)	58.6 (1.68)	.1793
Left ventricular mass, g	154.2 (27.0)	168.8 (37.4)	167.5 (28.4)	192.8 (22.4)	.0067
Proportion of total body mass as lean, %[a]	63.9 (4.00)	64.2 (5.09)	66.1 (6.12)	60.5 (6.92)	.0501
Proportion of total body mass as fat, %	32.6 (4.26)	31.9 (5.32)	29.9 (6.41)	36.0 (7.15)	.0480
Total lean mass, kg[a]	59.6 (5.67)	61.0 (5.19)	62.3 (7.01)	69.7 (8.40)	.0008
Total fat mass, kg[a]	30.8 (7.32)	31.1 (8.52)	29.0 (9.98)	42.8 (13.2)	.0058
Lean to fat mass ratio[a]	2.01 (.42)	2.11 (.65)	2.40 (1.00)	1.78 (.53)	.0598
Smoking	40.00	33.33	20.00	33.33	.7633
Hypertension	53.33	46.67	40.00	46.67	.9835
Diabetes	6.67	13.33	13.33	13.33	1.0000
Body mass index classification					
Overweight	53.33	40.00	46.67	13.33	
Obese I	33.33	53.33	33.33	26.67	
Obese II	6.67	6.67	20.00	33.33	
Extremely obese	6.67	0	0	26.67	.0513
Diastolic dysfunction (*n*=49)	54.55	66.67	40.00	45.45	.5810

Data are mean (SD) or %.
[a] *P* from analysis of log-transformed characteristic.

factors. The index cases were not screened and are not included in the analysis. Family members who were overweight or obese (BMI ≥25) at the time of their screening visit and who were not pregnant were invited to participate in screening.

Demographic information, including ethnicity, was determined by self-report obtained from standard questionnaires. A physical examination was performed and medical history was obtained by a study cardiologist and included current use of medications and/or dietary supplements. Smoking status was self-reported with a standard questionnaire,[13] and habitual physical activity was assessed with the Stanford 7-Day Physical Activity Recall;[14] kilocalories expended per week were calculated.

Blood pressure was measured according to JNC VII guidelines.[15] Participants were seated quietly for five minutes prior to each of three blood pressure measurements using a Dinamap automated cuff (GE Healthcare, Inc., Waukesha, WI, USA). The average of the three measures characterized resting blood pressure. Hypertension was defined as an average resting blood pressure ≥ 140/90 mm Hg and /or current use of antihypertensive medications.

Blood was collected after participants had fasted for eight hours. Glucose, insulin, high sensitivity C-reactive protein, total and HDL cholesterol and triglycerides were measured in the Core Laboratory at the Johns Hopkins Bayview Clinical Research Unit; LDL cholesterol was calculated using the Friedewald formula.[16] The quantitative insulin-sensitivity check index (QUICKI), calculated as the 1/(log10 glucose + log10 insulin), was used as a proxy for insulin sensitivity.[17]

In a subset (*n*=181), echocardiography was performed using a Philips Sonos 5500 Phased Array System (Phillips Healthcare, Inc, Andover, MA, USA). Left ventricular (LV) and atrial dimensions were measured using standard techniques; LV mass was calculated using the Penn convention.[18] Mitral inflow was also assessed. Diastolic dysfunction was defined according to Canadian guidelines[19]; participants classified as having mild, moderate or severe dysfunction were combined and compared with participants having no diastolic dysfunction.

Participants were weighed wearing no shoes and light indoor clothing on a calibrated balance scale, and height was measured using a stadiometer; BMI was calculated as weight (kg)/height squared (m^2). Waist circumference was measured three times in the standing position, midway between the lower rib margin and the iliac crest using a cloth tape; the average of the three measures was used in analysis according to methods defined in the National Health and Nutrition Examination Survey.

Dual-energy x-ray absorptiometry (DEXA) was performed using a GE Medical Systems Lunar Prodigy machine software V13 (GE Healthcare, Inc., Waukesha, WI, USA). Total body fat mass, fat free or lean mass, and bone mass in kilograms were determined, and summed to represent total body mass; the proportions of total mass as fat and lean were calculated as fat mass divided by

Table 1b. Characteristics by fitness quartile in females (*n*=131)

Variable	VO_{2peak} Q1: 1.188–1.79 (*n*=33)	VO_{2peak} Q2: 1.80–2.09 (*n*=32)	VO_{2peak} Q3: 2.10–2.34 (*n*=33)	VO_{2peak} Q4: 2.35–3.4 (*n*=33)	*P*
Age, years	48.4 (10.9)	44.3 (10.7)	42.8 (11.6)	39.7 (11.4)	.0179
Weight, kg[a]	85.5 (11.9)	90.9 (11.9)	97.4 (15.0)	102.5 (15.5)	<.0001
Waist circumference, cm	97.4 (10.8)	97.3 (9.19)	103.2 (10.3)	102.3 (13.0)	.0474
Body mass index, kg/m^2[a]	32.6 (4.18)	33.8 (4.79)	35.3 (4.94)	36.6 (5.25)	.0076
Systolic blood pressure, mm Hg[a]	120.4 (14.6)	123.5 (18.1)	119.5 (12.1)	123.0 (15.0)	.7182
Diastolic blood pressure, mm Hg	69.3 (8.43)	71.9 (11.7)	69.5 (6.94)	72.1 (9.11)	.4295
Glucose, mmol/L[a]	5.45 (.746)	5.45 (1.03)	5.24 (.673)	5.23 (.564)	.5616
Insulin, pmol/L[a]	182.3 (80.8)	169.7 (82.6)	170.7 (90.1)	171.2 (83.1)	.8358
QUICKI	.298 (.017)	.301 (.020)	.303 (.020)	.302 (.019)	.6811
hsCRP, mg/L[a]	.754 (.687)	.873 (1.15)	.659 (.511)	.655 (.807)	.3642
LDL cholesterol, mmol/L[a]	3.18 (1.17)	3.04 (.82)	2.90 (.93)	3.10 (1.10)	.8242
HDL cholesterol, mmol/L[a]	1.64 (.450)	1.56 (.401)	1.54 (.447)	1.50 (.384)	.6660
Triglycerides, mmol/L[a]	1.22 (.716)	1.02 (.507)	.949 (.388)	.875 (.509)	.0669
Stanford physical activity, joules/week[a]	57.6 (1.19)	58.7 (5.29)	58.5 (2.02)	58.7 (3.15)	.1769
Left ventricular mass, g	139.9 (23.0)	141.4 (32.5)	141.5 (29.5)	150.9 (31.2)	.4675
Proportion of total body mass as lean, %[a]	50.1 (4.51)	49.7 (4.39)	48.8 (4.73)	49.8 (6.21)	.7487
Proportion of total body mass as fat, %	46.5 (4.60)	46.8 (4.35)	47.8 (4.92)	46.9 (6.40)	.7778
Total lean mass, kg[a]	42.1 (4.72)	44.6 (5.58)	46.8 (7.04)	50.0 (5.84)	<.0001
Total fat mass, kg[a]	39.7 (8.64)	42.4 (8.22)	46.3 (10.0)	48.2 (12.1)	.0048
Lean to fat mass ratio[a]	1.10 (.203)	1.08 (.202)	1.04 (.217)	1.10 (.315)	.7690
Smoking	27.27	21.88	12.12	6.06	.0904
Hypertension	51.52	50.00	33.33	24.24	.0657
Diabetes	9.09	9.38	0	3.03	.2589
Body mass index classification					
Overweight	33.33	28.13	18.18	15.15	
Obese I	39.39	28.13	30.30	18.18	
Obese II	18.18	34.38	30.30	30.30	
Extremely obese	9.09	9.38	21.21	36.36	.0859
Diastolic dysfunction (*n*=106)	32.00	34.62	27.59	19.23	.6281

Data are mean (SD) or %.
[a] *P* from analysis of log-transformed characteristic.

Table 2a. Multivariate linear regression analysis predicting physical fitness in males (*n*=60)

Parameter	Beta	SE	*P*	Partial r^2
Age, years	−.0043	.0022	.0499	1.98
Current smoking	−.1164	.0534	.0291	3.59
(log) Stanford physical activity, joules/week	.004	.006	.5036	.32
(log) Lean mass, kg	.5219	.2486	.0358	27.20
(log) Fat mass, kg	−.2065	.0777	.0079	1.18
Left ventricular mass, g	.0017	.0008	.044	2.72
Body mass index classification				2.34
Extremely obese	.1725	.1375	.2097	
Obese II	.0449	.0453	.3219	
Obese I	.1615	.0935	.0841	
Overweight	reference			

total mass and lean mass divided by total mass, respectively, and expressed as percentages. Lean mass to fat mass ratio was calculated as lean mass divided by fat mass, hereafter referred to as the lean-fat ratio.

Peak oxygen uptake (VO_{2peak}) was measured during maximal treadmill exercise testing using a CareFusion Vmax229 Metabolic/ECG system (CareFusion, Inc., San Diego, Calif, USA). We used a modified Balke protocol where the test began at 3 mph, 0% grade, and increased 2.5% grade every 3 minutes. Participants performed until volitional fatigue. VO_{2peak} was expressed as L/min in order to allow for unbiased examination of body mass and composition associations with cardiorespiratory fitness.

Data were analyzed using SAS v.9.2 (SAS Institute Inc., Cary, NC, USA 2002–2008). As the distributions of our fitness and body composition variables showed minimal overlap by sex, all analyses were performed within sex strata. Categorical variables were analyzed with frequencies, contingency table arrays, chi-square and Fisher's exact tests. Normality was tested using the Kolmogorov-Smirnoff statistic for continuous variables, and non-normal variables were log-transformed and analyzed with analysis of variance (ANOVA). Multivariate regression analyses were performed using the generalized estimating equations (GEE) adjustment to account for intrafamilial correlations. Variables demonstrating statistical significance ($P<.05$) in bivariate associations with fitness were selected for inclusion in the multivariate regression models and retained only if they were not collinear and explained >1% of the variance or were deemed important covariates (age, current smoking, BMI category, and habitual physical activity). Heritabilities were estimated using SAGE v. 6.3 (Statistical Analysis for Genetic Epidemiology, Case Western Reserve University, Cleveland, Ohio, USA, 2012) to assist in determining the extent to which the variables of interest may or may not have a genetic component.

Table 2b. Multivariate linear regression analysis predicting physical fitness in females (*n*=131)

Parameter	Beta	SE	*P*	Partial r^2
Age, years	−.0032	.0011	.0042	4.47
Current smoking	−.1212	.0309	<.0001	5.68
(log) Stanford physical activity, joules/week	.0062	.0043	.1482	1.27
(log) Lean mass, kg	.5312	.1223	<.0001	21.59
(log) Fat mass, kg	.2175	.1104	.0489	2.44
Body mass index classification				.36
Extremely obese	−.0652	.0923	.4795	
Obese II	−.0317	.0504	.5291	
Obese I	−.0559	.0674	.4070	
Overweight	reference			

RESULTS

Sample characteristics for the 191 participants (60 males) by sex-specific quartiles of VO_{2peak} are shown in Tables 1a and 1b. Participants came from 98 families with an average of 1.95 ± 1.3 members per family (range 1 to 8). Participants were obese on average, with moderately high levels of cardiovascular risk factors. Decreasing levels of BMI, lean mass and fat mass, were all significantly associated with incremental quartiles of VO_{2peak}, for both men and women. Increasing levels of LV mass were significantly associated with incremental quartiles of VO_{2peak} in men alone, while decreasing levels of age were significantly associated with incremental quartiles of VO_{2peak} in women alone.

In GEE-adjusted multiple regression analyses, lean mass was the strongest independent contributor to levels of physical fitness in both men and women (Tables 2a and 2b), explaining more than 27% of the variance in VO_{2peak} in men and more than 21% of the variance in VO_{2peak} in women, independent of all other variables including BMI category and level of fat mass. Lean-fat mass ratio was a significant predictor of fitness in men but not women (Tables 3a and 3b). Sensitivity analyses exploring any interaction between sex and lean mass, fat mass, or the lean-fat ratio showed no significant interaction or change in results (data not shown). In the subset of participants who had diastolic dysfunction assessed, adding diastolic dysfunction to the models showed no change in results, and diastolic dysfunction was not a significant independent predictor of fitness (data not shown).

Finally, we estimated heritability for VO_{2peak}, lean and fat mass, and lean-fat ratio in the available 121 relative pairs: 19 parent-offspring, 33 sibling, 14 half-sibling, 14 cousin, and 41 avuncular (Table 4). Fitness, the lean-fat ratio and fat mass adjusted for lean mass were highly and significantly heritable in these families.

Table 3a. Multivariate linear regression analysis predicting physical fitness in males (*n*=60)

Parameter	Beta	SE	*P*	Partial r^2
Age, years	−.0047	.0022	.0353	5.60
Current smoking	−.1387	.0518	.0074	4.24
(log) Stanford physical activity, joules/week	.3858	.4854	.4267	.63
(log) Lean to fat mass ratio	.264	.0861	.0022	5.66
Left ventricular mass, g	.0021	.0007	.0054	14.67
Body mass index classification				6.57
Extremely obese	.2590	.1340	.0533	
Obese II	.0706	.0492	.1518	
Obese I	.2297	.1000	.0216	
Overweight	reference			

DISCUSSION

Even among high-risk overweight and obese AA, lean mass was the key determinant of cardiorespiratory fitness, independent of sex, age, and the magnitude of obesity. We were able to examine several factors hypothesized to be related to fitness, such as left ventricular mass, diastolic dysfunction, and metabolic factors. Still, no other factor was as strong a predictor of fitness as lean mass in both males and females among our overweight and obese population of sedentary African Americans.

Most prior studies have found that fat mass but not lean mass is an independent predictor of fitness,[9,10,20] while few have found that lean mass but not fat mass was an independent predictor of fitness.[21] Most studies have looked only at percentage total body fat without even considering lean mass.[22] In a few instances, when both lean and fat mass were analyzed together, both were independent determinants of fitness.[23] Besides the different ways of using measures of body composition, there has also been considerable variation in assessing fitness. Together, these methodological inconsistencies can produce different associations between body composition and fitness.[21] In our study, so that both lean and fat mass could be included in our fully adjusted models, we chose to analyze absolute cardiorespiratory fitness expressed as VO_{2peak} (L/min) rather than the more traditionally used body weight adjusted cardiorespiratory fitness expressed as VO_{2peak} (mL/kg body weight/min or mL/kg fat free mass/min). Analyzing absolute fitness as VO_{2peak} (L/min) should also reduce the inflated variance explained between body

Table 3b. Multivariate linear regression analysis predicting physical fitness in females (*n*=131)

Parameter	Beta	SE	*P*	Partial r^2
Age, years	−.0042	.0012	.0005	5.29
Current smoking	−.1246	.0358	.0005	7.61
(log) Stanford physical activity, joules/week	1.1645	.3654	.0014	2.66
(log) Lean to fat mass ratio	.1396	.0844	.0981	1.89
Body mass index classification				9.70
Extremely obese	.2038	.0596	.0006	
Obese II	.0495	.0412	.2300	
Obese I	.1620	.0445	.0003	
Overweight	reference			

composition and VO_{2peak} (mL/kg body weight/min or mL/kg fat free mass/min). This should offer a more precise measurement of the relative contributions of lean and fat mass, each in the presence of the other.

The ratio of metabolically active lean muscle mass vs fat mass incorporates both fat and lean mass measurements, but varies markedly in different populations.[24–26] This heterogeneity could explain our lack of statistically significant results for the lean-fat ratio as compared with lean mass alone. While our study indicates that both lean and fat mass are important determinants of fitness, lean mass appears to be a more important determinant of fitness than fat mass. More importantly, both lean and fat mass are mutable. Ross et al have found that reducing fat mass even without weight loss can improve fitness.[27,28] Resistance training alone has been shown to increase lean mass,[29] generally while decreasing fat mass. Increasing lean mass could be a more easily achievable goal than reducing fat, which also requires weight loss and dietary restrictions, activities that are particularly resistant to change. Increasing lean mass however, could be done by adding resistance training to a daily regimen, perhaps without as much hardship. Given that weight regain after loss is more likely to be fat than lean mass and that weight loss is notoriously poorly preserved after weight interventions,[30] it is possible that interventions that increase lean mass may be more effective long-term at improving cardiorespiratory fitness. Interventions that include resistance training to increase lean mass may be particularly effective, especially among high-risk persons who are overweight and obese. Increasing lean mass while decreasing fat mass will improve the lean-fat ratio, which may be particularly important for African Americans, who have greater lean mass than other ethnic groups.

Peak oxygen consumption is a highly genetically determined trait. Our heritability estimates for VO_{2peak} are similar to those reported by others, where estimates have ranged from 44%–59%.[31–33] While our heritability estimates for lean and fat mass were not statistically significant, our heritability estimates for the lean to fat mass ratio and for lean mass adjusted for fat mass were at the high limit of previously reported estimates of lean or fat mass alone, with heritability estimates of fat mass reported from 55%–74% and heritability estimates of lean mass reported from 47–81%.[34–36] It remains likely that genetic factors contribute to exercise capacity through both lean and fat mass.

…it is possible that interventions that increase lean mass may be more effective long-term at improving cardiorespiratory fitness.

Table 4. Age-sex adjusted heritability estimates

Variable	Heritability Estimate	SE	*P*
VO_{2peak}, mL/kg/min	.409	.297	.08397
(log) VO_{2peak}, L/min	.665	.312	.01660
(log) Fat mass, kg	.427	.277	.06140
(log) Lean mass, kg	.139	.232	.2751
(log) Lean-fat ratio	.792	.255	.000973
(log) Fat mass, kg adjusted for (log) lean mass, kg	.783	.258	.001190
(log) Lean mass, kg adjusted for (log) fat mass, kg	.302	.258	.1205

It is important to note that the determinants of fitness differed by sex. Age, smoking status, and habitual physical activity were important for women, while LV mass was important for men. No clear universal biopsychosocial pattern predicting fitness was observed.

Limitations of our study included a smaller sample size for males and the use of peak VO_2 rather than true maximal VO_2. In addition, the cross-sectional nature of our study precluded examining potential causal determinants of fitness.

In conclusion, we found that lean mass was the most significant predictor of fitness in a high-risk population of overweight and obese African American men and women. These cross-sectional data provide a rationale for examining interventions that include a component such as resistance training to increase lean mass as a more effective strategy for improving cardiorespiratory fitness, especially among high-risk African Americans who are overweight and obese.

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