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Muscular Strength Is Inversely Related to Prevalence and Incidence of Obesity in Adult Men

Allen W. Jackson[1], Duck-Chul Lee[2], Xuemei Sui[2], James R. Morrow Jr[1], Timothy S. Church[3], Andrea L. Maslow[4] and Steven N. Blair[2,4]

The purpose of the study was to determine the relation between quintiles of muscular strength after adjustment for age and body weight, and excessive body fat (EBF) and excessive abdominal fat (EAF) when controlling for cardiorespiratory fitness (CRF) and other potential confounders. A two-phased cross-sectional and longitudinal study was conducted assessing the prevalence and incidence of EBF and EAF across quintiles of muscular strength. The sample included 3,258 men (mean age = 42.2 ± 8.9; weight (kg) = 81.2 ± 11.0; BMI = 25.3 ± 2.9; %fat = 19.4 ± 5.8; waist girth (cm) = 91.2 ± 9.0) who completed at least two clinical examinations as part of the Aerobics Center Longitudinal Study (ACLS). Muscular strength was assessed with tests of upper and lower body muscular strength using rack-mounted weights with participants placed into strength quintiles. CRF was measured by a modified Balke treadmill test, %fat via underwater weighing or seven-site skinfold measurements, and waist girth measured at the level of the umbilicus. EBF was defined as ≥25% and EAF was defined as >102 cm. There was a strong inverse gradient across quintiles of muscular strength for prevalence and incidence of EBF and EAF (*P* trend <0.01, each). With the lowest quintile serving as the referent, reductions in risk of EBF and EAF exceeded 70% for the highest strength quintile. Evidence suggests muscular strength may provide protection from EBF and EAF and their related comorbidities.

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INTRODUCTION

There has been a systematic increase in overweight and obesity in US adults with the current percentage of overweight adults at ~60% (1). Maintenance of a healthy body habitus is important to well-being and to lower the risk of morbidity and mortality (2,3). Physical activity and cardiorespiratory fitness (CRF) are important for weight management and for maintaining good health, not only in normal-weight persons but also in those who are overweight or obese (4,5). Previously, we evaluated weight change in 2,501 men who completed four examinations over 5 years. Men who reported physical activity at or above recommended amounts were successful in preventing weight gain (6). We also modeled changes in CRF and changes in body weight in 724 women and 4,599 men who completed three clinical examinations over an average of 7.5 years. Individuals who increased fitness were less likely to gain weight during follow-up (7).

Recent public health recommendations for physical activity (8) provide more emphasis on the importance of resistance training, which leads to higher levels of muscular strength. Typically, a single measure (e.g., grip strength) has been used to evaluate the health benefits of strength (9), and we have shown that a multidimensional (bent-leg curl ups, and one-repetition maximum bench press and leg press) strength assessment shows an inverse association between metabolic syndrome(10,11) and mortality (12). Multidimensional strength measures reflect overall body strength and are more valid than a single measure of strength (13).

There is some evidence that muscular strength may be important in weight maintenance. Mason *et al.* (14), using self-reported BMI, conclude that low strength is a significant predictor of 20-year weight gain in Canadian adults and suggest that resistance training could help attenuate age-related weight gain and ultimately prevent obesity. The benefits of resistance training include increased muscular strength, decreased percent body fat, increased lean body mass, increased insulin sensitivity, and increased basal metabolic rate (15). Thus,

[1]Department of KHPR, University of North Texas, Denton, Texas, USA; [2]Department of Exercise Science, University of South Carolina, Columbia, South Carolina, USA; [3]Preventive Medicine Laboratory, Pennington Biomedical Research Center, Baton Rouge, Louisiana, USA; [4]Department of Epidemiology and Biostatistics, University of South Carolina, Columbia, South Carolina, USA. Correspondence: Allen W. Jackson (Allen.jackson@unt.edu)

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muscular strength could have a role in preventing a positive energy balance and unhealthful weight gain.

The purpose of the present investigation is to examine the relations between muscular strength and obesity as measured by two body composition characteristics, percent body fat, and abdominal fat in adult men. A two-phase approach was used. In the cross-sectional study, the prevalence of obesity across levels of muscular strength was examined. In the longitudinal study, the incidence of obesity, in men who had follow-up clinic examinations, across levels of baseline muscular strength was evaluated. Further, data from the Aerobics Center Longitudinal Study (ACLS) allowed us to evaluate the association of strength to body composition while controlling for an important confounder, CRF, and for other clinical characteristics. The ACLS is a long-term study of almost 40 years that has been conducted at The Cooper Clinic and The Cooper Institute. The study combines a comprehensive clinical, health, and fitness assessment that allows both cross-sectional and longitudinal study of risks for morbidity and mortality outcomes.

METHODS AND PROCEDURES

Participants

The participants were men from the ACLS who completed at least two (baseline, follow-ups) clinical examinations at the Cooper Clinic in Dallas, TX between 1980 and 2006. The specifics of the clinical examination have been described in previous reports (16–19). Participants came to the clinic for periodic examinations and counseling for healthy lifestyles and reduction of chronic disease risk. They were referred by employers, personal physicians, or by themselves. To be included in this study, participants must have completed tests of muscular strength and a treadmill test to voluntary exhaustion during the baseline clinical examination. Smoking status was determined during the clinical exam and recorded as current smoker or nonsmoker (never and past smokers). The majority of the sample was white with mid to upper socioeconomic status. Among the 4,654 men aged 20–79 years who completed muscular strength tests and a treadmill test at baseline, men with abnormal resting or exercise electrocardiogram (n = 254), history of heart attack (n = 51), stroke (n = 5), cancer (n = 19), diabetes (n = 96), hypertension (n = 1,118), and failure to achieve at least 85% of their age-predicted maximal heart rate (220 minus age in years) on the treadmill test (n = 86) were excluded in the cross-sectional study. For the longitudinal study analyses, men with percent body fat ≥25% (n = 520), waist circumference >102 cm (n = 313) at baseline, or men without follow-up percent body fat information (n = 272) were additionally excluded. Because the exclusion criteria were not mutually exclusive (participants might have multiple exclusion factors), the resulting samples were 3,258 men in the cross-sectional study and 2,405 in the longitudinal study. The volunteer participants provided informed consent for the examination and follow-up. The procedures for the protection of human participants in the ongoing ACLS were reviewed and approved annually by the Cooper Institute's Institutional Review Board.

Design

We present two separate sets of analyses in this report. The first analysis was a cross-sectional analysis in all men with measures of muscular strength, adiposity, and fat distribution. We examined the outcome variables excessive body fat (EBF) and excessive abdominal fat (EAF) across quintiles of muscular strength, with consideration of several potentially confounding variables. In a second analysis, we examined the incidence of meeting clinically significant outcomes for percent body fat and waist girth in a subset of men who were below these cut-points at baseline and had at least one follow-up clinical examination.

Primary variables

The principal exposure in this study was muscular strength assessed at the baseline clinical examination. Two tests of strength, 1-repetition maximum bench press (1-RM; upper body) and 1-RM leg press (lower body), were administered. Past research indicates these two tests serve as valid markers of the principal factors of muscular strength (13). The strength tests, a supine bench press and a seated leg press, were conducted with variable resistance Universal weight machines (Universal Equipment, Cedar Rapids, IA). Instructions were provided to each participant on proper lifting technique. Initial loads were 70% (bench press) and 100% (leg press) of the participant's body weight. Participants completed a series of lifts with incremental increases in weight lifted (2.27–4.54 kg) with short rest periods between each lift. Maximal effort was usually achieved after five or fewer lifts. Important to the present investigation, test–retest reliability estimates were 0.90 for the bench press and 0.83 for the leg press indicating acceptable levels of true score and measurement error in the raw strength scores (10). Our strength index used in this study was operationally defined by the following:

1. The 1-RM values for the bench press and leg press were added together to provide a total strength score.
2. The total strength score was regressed on the age and body weight determined at the baseline clinical examination.
3. A standardized residual total strength score was produced from the multiple regression analysis. The standardized residual total strength score was uncorrelated with age (r = 0.0) and body weight (r = 0.0).
4. The participants' residual total strength scores were divided into quintiles (Q1, Q2, Q3, Q4, and Q5) with the lowest strength quintile (Q1) representing the weakest 20% and the highest strength quintile (Q5) representing the strongest 20%. The strength quintiles were established on the cross-sectional study participants and maintained as the final index in the longitudinal study analysis.

These procedures produced a strength index that allowed us to establish quintile cut-points based on 3,258 participants.

The outcome variables were EBF and EAF. These variables were determined by exceeding clinical cut-points for percent body fat and waist girth. Both of these outcomes are associated with higher risk for numerous adverse health outcomes such as hypertension, type 2 diabetes, and coronary heart disease (20–24). These outcomes were assessed in the laboratory as part of the extensive clinical examination. The cut-point to identify EBF was ≥25%. There has been no authoritative consensus report on a cut-point for EBF, but there is support for such a value in the literature (5). Furthermore, this value is the one that we have shown to be associated with higher risk for all-cause and cardiovascular disease mortality (5,23). We selected >102 cm as the cut-point indicative of EAF that has been established by the National Institutes of Health (25). We also have shown this cut-point to identify men at high risk for mortality in the ACLS (5). Percent body fat was assessed by hydrostatic weighing, sum of seven skinfolds, or both. In the clinical examination, some participants chose to go through the underwater weighing process for hydrostatically estimated body density with a mathematical conversion to percent body fat, whereas other participants received a skinfold estimate of percent body fat. Standardized protocols were utilized and specific procedures for the ACLS assessment of percent body fat are available in the literature (5,23,26,27). The correlations between hydrostatically estimated percent body fat and skinfold estimated percent body fat exceed 0.90 for participants who had both measurements (26,27). When available, hydrostatically estimated percent body fat was always used in the analysis. In the cross-sectional study, 1,251 participants were assessed with underwater weighing and 2,007 were assessed with skinfolds. In the longitudinal study, 899 were assessed with underwater weighing and 1,506 with skinfolds. Waist girth was measured at the level of the umbilicus using a plastic anthropometric tape (25).

CRF is a potentially important confounder in evaluating the relation of muscular strength to general obesity and abdominal obesity. CRF has been demonstrated to attenuate weight gain and be inversely related to percent body fat and abdominal obesity (28–31). We measured CRF using the time (minutes) to voluntary exhaustion on a treadmill test using a modified Balke protocol (32). The specific protocol has been described in detail in past reports (16,17). The total time on maximal treadmill tests is highly correlated ($r = 0.92$) with maximal oxygen uptake in men (33).

Statistical analyses

Descriptive statistics, means, standard deviations, and percentages are reported for the entire samples and separated by strength quintiles for both the cross-sectional study and the longitudinal study analyses. Partial correlation analysis was used to examine specific relations while controlling confounders. In the cross-sectional study, prevalence percentages for EBF and EAF were determined for each strength quintile. Logistic regression analysis was used to estimate the odds ratios and 95% confidence intervals across the strength quintiles for EBF and EAF while controlling for important confounders. Two models, (i) controlling age and body weight, and (ii) controlling age, body weight, smoking status, and treadmill time were utilized. In the longitudinal study, the time of follow-up was the interval between the date of baseline clinical examination and the date of the clinical examination when the participant demonstrated EBF or EAF. For participants who never developed excessive fat, the date of the last clinical examination was used in the time of follow-up calculation. The average time of follow-up was 8.3 years. Man-years of exposure were expressed as the sum of the follow-up time across all participants. Incidence rates were expressed per 1,000 man-years after adjustment for age and weight at baseline. Cox proportional regression analysis was used to estimate hazard ratios (HRs) and 95% confidence intervals across the strength quintiles for EBF and EAF while controlling confounding variables. The same two models evaluating confounding variables used in the cross-sectional study were also used in the longitudinal study analyses. The proportional hazards assumption was satisfied by examining the log–log survival plots. In a secondary analysis, we examined body weight change using a 5 (strength quintile) by 2 (time, baseline/follow-up examination) analysis of covariance with repeated measures. The covariates in the analysis were age, time of follow-up, and CRF. As an internal validity check, we used analysis of variance and verified that after controlling for age and body weight, muscular strength for both the bench press and leg press tests significantly increased across the strength quintiles ($P < 0.001$) in both the cross-sectional study and the longitudinal study analyses.

RESULTS

The overall study sample consisted of 3,258 men aged 20–79 years at baseline. All of these men were included in the cross sectional analyses. In addition, 2,405 who were below the EBF and EAF clinical cut-points at baseline and had at least one follow-up examination were included in the longitudinal study analyses.

The cross-sectional study

The descriptive statistics for the characteristics and performance variables are provided in **Table 1**. As anticipated by the statistical control of age and weight in the muscular strength measures, age and body weight, while statistically different, were numerically similar across the strength quintiles (effect sizes 0.10–0.17). This was also true for BMI, which has a high correlation with body weight. In another sample of ACLS men ($n = 23{,}539$), the partial correlation between BMI and body weight was 0.87 after controlling for age. Mean percent body fat and waist girth were incrementally lower ($P < 0.001$) across the strength quintiles with the highest values in Q1 and the lowest values in Q5. Treadmill time was incrementally higher ($P < 0.001$) across the strength quintiles. The partial correlation between treadmill time and the muscular strength index was 0.22 ($P < 0.01$) after controlling for age and weight. The percentage of smokers varied nonsystematically from Q1 to Q5. The partial correlation, adjusting for age, between percent body fat and waist girth was 0.74 ($P < 0.001$). Among men with EBF, 47% had EAF and for men with EAF, 73% demonstrated EBF at the baseline clinical exam.

In **Table 2**, we present the associations between muscular strength and the prevalence of EBF and EAF. The prevalence of EBF drops systematically from a high of 27.2% (Q1) to a low of 8.1% (Q5). The prevalence of EAF drops systematically from Q1 to Q3 but remains similar across Q4 and Q5. For EBF, the logistic regression analysis (Model 1) indicates a strong inverse gradient ($P < 0.001$) between muscular strength quintiles and the prevalence of EBF, and the odds ratios for each quintile are significantly lower than the referent, Q1. In Model 2, with the

Table 1 Descriptive statistics across strength quintiles in 3,258 men

		Muscular strength quintiles*				
	All (n = 3,258)	Q1 (low)	Q2	Q3	Q4	Q5 (high)
Age (year)	42.2 (8.9)	40.7 (8.6)	42.3 (8.3)	43.5 (8.9)	43.3 (9.0)	41.2 (9.4)
Weight (kg)	81.2 (11.0)	82.1 (12.7)	80.8 (10.4)	80.0 (10.0)	80.7 (10.0)	82.3 (11.3)
BMI (kg/m^2)	25.3 (2.9)	25.2 (3.4)	25.0 (2.8)	25.0 (2.7)	25.3 (2.7)	25.8 (3.0)
% Body fat	19.4 (5.8)	21.7 (6.1)	20.2 (5.4)	19.3 (5.2)	18.7 (5.4)	17.3 (5.7)
Waist girth (cm)[a]	91.2 (9.0)	93.0 (9.9)	91.5 (8.7)	90.6 (8.1)	90.9 (9.2)	90.3 (8.8)
Bench press (kg)	71.8 (17.2)	57.9 (10.2)	65.2 (10.1)	69.1 (10.5)	75.1 (11.7)	91.4 (19.8)
Leg press (kg)	135.8 (25.6)	114.3 (19.1)	125.4 (16.4)	132.3 (16.1)	142.6 (17.4)	164.5 (25.3)
Treadmill time (min)	20.8 (4.5)	19.8 (4.7)	20.4 (4.4)	20.8 (4.5)	21.1 (4.4)	22.1 (4.1)
Current smoker (N) (%)	409 (12.6)	85 (13.1)	90 (13.8)	76 (11.7)	90 (13.8)	68 (10.5)

Data are means (s.d.) unless otherwise indicated.
[a] n = 3,094.
*All P values for trend across strength quintiles were <0.001 except for current smoker (P = 0.29).

Table 2 Prevalence of EBF and EAF across strength quintiles in 3,258 men

Strength quintiles	No.	No. of cases	Prevalence (%)	Adjusted odds ratios (95% confidence interval) Model 1[a]	Model 2[b]
EBF (≥25%)					
Q1 (Lowest)	651	177	27.2	1.00	1.00
Q2	653	115	17.6	0.53 (0.38–0.74)	0.55 (0.39–0.78)
Q3	650	94	14.5	0.42 (0.30–0.60)	0.47 (0.32–0.68)
Q4	653	81	12.4	0.30 (0.21–0.43)	0.33 (0.23–0.48)
Q5 (highest)	651	53	8.1	0.13 (0.09–0.20)	0.19 (0.12–0.29)
P value for trend				<0.001	<0.001
EAF[c] (>102 cm)					
Q1 (lowest)	617	92	14.9	1.00	1.00
Q2	619	62	10.0	0.69 (0.40–1.21)	0.75 (0.42–1.34)
Q3	623	50	8.0	0.65 (0.36–1.16)	0.80 (0.43–1.47)
Q4	621	54	8.7	0.51 (0.29–0.89)	0.54 (0.30–0.97)
Q5 (highest)	614	55	9.0	0.23 (0.12–0.41)	0.32 (0.17–0.61)
P value for trend				<0.001	<0.01

EAF, excessive abdominal fatness; EBF, excessive body fatness.
[a]Adjusted for age and body weight. [b]Adjusted for age, body weight, current smoking, and treadmill time. [c]n = 3,094.

Table 3 Descriptive statistics across strength quintiles in 2,405 men with normal EBF and EAF at baseline

	All (n = 2,405)	Muscular strength quintiles* Q1	Q2	Q3	Q4	Q5 (high)
Age (year)	41.6 (8.9)	39.6 (7.9)	41.7 (8.2)	42.9 (8.6)	42.8 (9.2)	40.9 (9.5)
Weight (kg)	78.5 (8.5)	77.4 (8.8)	78.0 (8.4)	77.9 (7.9)	78.9 (8.5)	80.0 (8.8)
BMI (kg/m^2)	24.5 (2.2)	23.8 (2.1)	24.2 (2.1)	24.3 (1.9)	24.7 (2.1)	25.2 (2.3)
% Body fat	17.6 (4.5)	18.8 (4.2)	18.2 (4.1)	17.8 (4.3)	17.3 (4.6)	16.1 (4.8)
Waist girth (cm)[a]	88.6 (6.5)	89.0 (6.5)	88.9 (6.7)	88.3 (6.2)	88.7 (6.3)	88.4 (6.6)
Bench press (kg)	72.3 (17.5)	57.6 (9.6)	64.7 (10.1)	68.5 (10.0)	75.1 (11.8)	91.3 (19.9)
Leg press (kg)	134.4 (24.6)	110.4 (16.9)	122.3 (14.6)	130.6 (14.7)	140.6 (16.1)	161.0 (23.7)
Treadmill time (min)	21.8 (4.2)	21.3 (4.2)	21.4 (4.3)	21.6 (4.1)	21.9 (4.2)	22.6 (3.9)
Current smoker (*N*) (%)	294 (12.2)	57 (13.7)	62 (13.6)	55 (11.1)	69 (13.6)	51 (9.6)

Data are means (s.d.) unless otherwise indicated.
EAF, excessive abdominal fatness; EBF, excessive body fatness.
*All *P* values for trend across strength quintiles were <0.001 except for waist girth (P = 0.56) and current smoker (P = 0.15).
[a]n = 2,138.

addition of control for smoking status and baseline CRF, the findings are remarkably similar. In Model 2, age ($P < 0.001$), body weight ($P < 0.001$), smoking status ($P < 0.02$), and CRF ($P < 0.001$) were independently related to the prevalent EBF with older, heavier, nonsmoking, and less-fit participants having greater odds for EBF.

In Model 1, the odds ratios for prevalent EAF were lower ($P < 0.001$) across the strength quintiles with the odds ratios for Q4 and Q5 being significantly lower than the referent category. In Model 2, the addition of control for smoking status and baseline CRF weakened the association between muscular strength and EAF, but the overall trend was still significant ($P < 0.01$). In Model 2, body weight ($P < 0.001$) and CRF ($P < 0.001$) were independently related to prevalent EAF, with heavier, less-fit participants having higher odds for elevated waist girths.

The longitudinal study

The descriptive statistics for the baseline measures of characteristics and performance variables are provided in Table 3 for the 2,405 men who did not have EBF or EAF at baseline. As in the cross-sectional study, age and body weight, while statistically different, were numerically similar across the strength quintiles (effect sizes 0.13–0.18). BMI was incrementally higher across strength quintiles ($P < 0.001$), whereas percent body fat was incrementally lower across quintiles ($P < 0.001$). Waist girth did not vary significantly ($P = 0.56$) from Q1 to Q5.

Table 4 Incidence of EBF and EAF across strength quintiles in 2,405 men

Strength quintiles	No.	Person-years	No. of cases	Rate[a]	Adjusted hazard ratios (95% confidence interval)	
					Model 1[b]	Model 2[c]
EBF (≥25%)						
Q1 (lowest)	415	2,805	139	60.9	1.00	1.00
Q2	455	3,379	115	34.1	0.56 (0.44–0.72)	0.58 (0.45–0.75)
Q3	496	3,535	113	31.0	0.51 (0.40–0.65)	0.59 (0.46–0.75)
Q4	506	3,641	91	22.2	0.36 (0.28–0.48)	0.41 (0.31–0.53)
Q5 (highest)	533	4,081	72	13.2	0.22 (0.16–0.29)	0.26 (0.19–0.35)
P value for trend					<0.001	<0.001
EAF[d] (>102 cm)						
Q1 (lowest)	364	2,879	39	20.8	1.00	1.00
Q2	410	3,348	39	12.1	0.58 (0.37–0.91)	0.58 (0.37–0.90)
Q3	445	3,601	34	10.1	0.48 (0.30–0.77)	0.53 (0.33–0.84)
Q4	453	3,545	36	8.6	0.41 (0.26–0.66)	0.42 (0.26–0.67)
Q5 (highest)	466	3,650	41	6.0	0.29 (0.18–0.46)	0.31 (0.19–0.49)
P value for trend					<0.001	<0.001

EAF, excessive abdominal fatness; EBF, excessive body fatness.
[a]Per 1,000 man-years adjusted for age and body weight. [b]Adjusted for age and body weight. [c]Adjusted for age, body weight, current smoking, and treadmill time.
[d]*n* = 2,138.

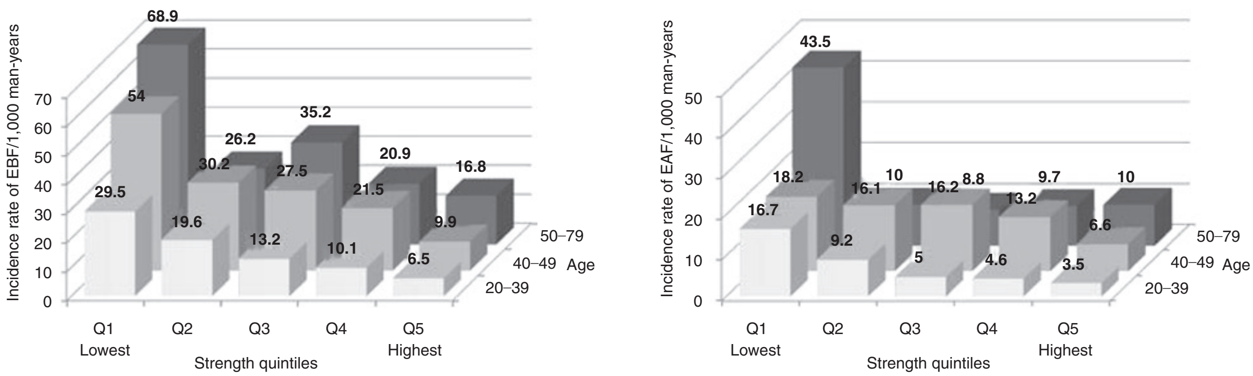

Figure 1 Incidence rates (per 1,000 person-years adjusted for body weight) for EBF and EAF (*n* = 2,138) across strength quintiles and age-groups in 2,405 men—the longitudinal study. EAF, excessive abdominal fatness; EBF, excessive body fatness.

Treadmill time showed an upward trend ($P < 0.001$) across the strength quintiles. The percentage of smokers varied in a nonsystematic manner from Q1 to Q5. Providing internal validity for the longitudinal study sample, the mean BMI, percent body fat, and waist girth values were lower than the cross-sectional study sample for all strength quintiles. The mean treadmill times were greater for the longitudinal study participants than the cross-sectional study participants for Q1 through Q5.

In **Table 4**, we provide associations between muscular strength, and the incidence of EBF and EAF. The incidence rate, adjusted for baseline age and body weight, of EBF dropped from a high of 60.9 per 1,000 man-years (Q1) to a low of 13.2 per 1,000 man-years (Q5). This strong inverse gradient ($P < 0.001$) of lower rates of incident EBF across incremental strength quintiles was supported by the Cox regression analysis results. In Model 1, HRs were progressively lower across strength quintiles with HRs (Q2 through Q5) significantly lower than the referent group. In Model 2, the additional control variables had a small effect on the regression results with a strong inverse gradient ($P < 0.001$) between strength quintile and EBF still present and HRs for Q2 through Q5 significantly lower than the referent, Q1. In Model 2, age ($P < 0.001$), body weight ($P < 0.001$), and CRF ($P < 0.001$) were independently related to incident EBF with older, heavier, and less-fit participants having higher risks for developing an unhealthy level of percent body fat. The rate of incident EAF was incrementally lower across strength quintiles from Q1 (20.8) to Q5 (6.0). This inverse gradient was statistically significant ($P < 0.001$) for both Models 1 and 2 in the regression analyses. The results for Models 1 and 2 were very similar. The HRs for each strength quintile (Q2 through Q5) systematically declined and were significantly lower than the referent, Q1. In Model 2, age

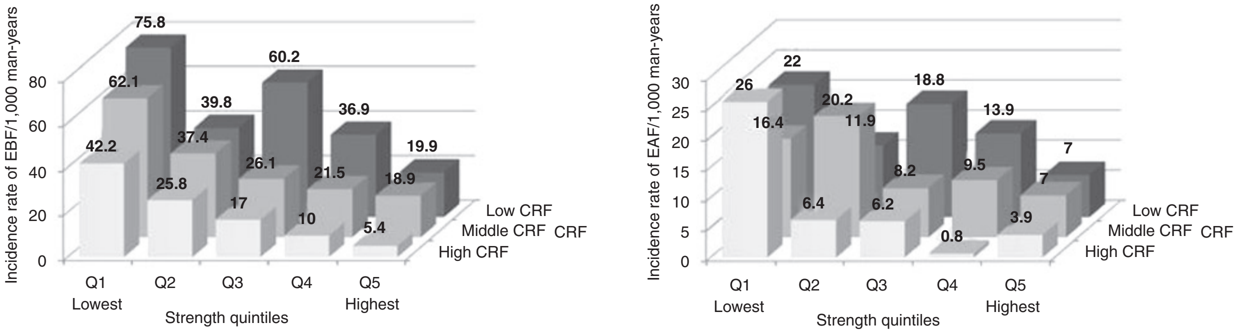

Figure 2 Incidence rates (per 1,000 person-years adjusted for age and body weight) for EBF and EAF ($n = 2{,}138$) across strength quintiles and CRF tertiles in 2,405 men—the longitudinal study. CRF, cardiorespiratory fitness; EAF, excessive abdominal fatness; EBF, excessive body fatness.

($P < 0.01$), body weight ($P < 0.001$), and CRF ($P < 0.001$) were independently related to incident EAF with older, heavier, and less-fit participants demonstrating higher risks for developing an elevated waist girth.

We divided the sample into three age-groups: 20–39, 40–49, and 50–79 years. We also established three CRF groups, low, middle, and high, based on tertiles of performance on the treadmill test. In **Figures 1** and **2**, we present the incidence rates of EBF and EAF across the strength quintiles within age-groups and CRF tertiles. The inverse gradients for the incidence of EBF and EAF across the strength quintiles were generally consistent for each of the three age-groups and three tertiles of CRF.

We examined absolute body weight changes (the cross-sectional study, $n = 3{,}258$ and the longitudinal study, $n = 2{,}405$) with a 5 (strength quintile) by 2 (time, baseline/follow-up examination) analysis of covariance with repeated measures, which indicated significant strength quintile differences ($P < 0.001$) and a significant change in body weight across time ($P < 0.001$). There was no significant interaction ($P = 0.53$). Similar results were found with the longitudinal study. Thus, a consistent body weight increase of ~2 kg within each strength quintile was observed for both the cross-sectional study and the longitudinal study samples.

DISCUSSION

The key finding of our study is that muscular strength is inversely associated with two measures of adiposity, EBF and EAF. This is illustrated in both the cross-sectional and longitudinal analyses. In our two-phase study, we report strong inverse gradients across muscular strength quintiles for prevalence and incidence of EBF and EAF. These results were present after controlling for CRF. In the longitudinal study, the inverse gradient across muscular strength quintiles was consistent across age-groups and CRF tertiles for EBF and EAF. There was a small but significant incrementally greater weight of ~2 kg within each strength quintile.

Previous work with the ACLS dataset has shown muscular strength is associated with all-cause mortality (12,34) and metabolic syndrome (10,11). Previous reports with the ACLS confirmed the inverse relations of muscular strength with the prevalence and incidence of the constellation of risk factors defining metabolic syndrome (10,11). We here indicate the inverse relation with two indices of obesity, one of the metabolic syndrome risk factors. Similarly, other longitudinal studies with 13–20+ years of follow-up have shown relations between musculoskeletal fitness and mortality (9) and unhealthful weight changes (14). Park *et al.* (35) report that a combination of aerobic and resistance training across 24 weeks of training reduces abdominal fat. Schmitz *et al.* (36) report that strength training for a 2-year period can prevent body fatness increase and positively impact intra-abdominal fat in obese and overweight premenopausal women while controlling for accelerometer-assessed physical activity. In the present study, we illustrate that muscular strength is associated with another significant health indicator, body fatness when controlling for an important confounder, CRF. Specifically, once controlling for CRF and other confounders, higher levels of muscular strength were associated with lower levels of body fatness.

As a function of the construction of our strength index, body weight was similar across strength quintiles; however, muscular strength demonstrated an inverse association with both the prevalence and incidence of EBF and EAF. Within each strength quintile, there was a similar absolute body weight (2 kg) increase across an average of 8.3 years of follow-up. These results are consistent with past experimental research examining the relations between resistance training, and body composition and body weight changes. Resistance training generally has produced healthful changes in body composition but small (<1 kg) or no significant changes in body weight (37,38). Resistance training increases the lean body mass that would decrease the percent body fat without reducing overall fat mass or absolute body weight.

What mechanisms might explain the protection muscular strength demonstrated in lowering the prevalence and incidence of EBF and EAF? In a recent study, Izumiya *et al.* (39) used genetic intervention to produce muscular hypertrophy in fast type II glycolytic muscle fibers of mice that were fed high-fat/high-sugar diets to produce obesity. In the intervention animals, the muscular hypertrophy was associated with reductions in body weight, fat mass, plasma glucose, insulin, and leptin. Increases in muscle glucose uptake and glycolysis as well as fat uptake and oxidation in the heart and liver were also observed. Further, when the muscular hypertrophy was experimentally blocked, the positive effects were completely abolished. Izumiya *et al*. (39), and Harrison and Leinwand (15) in a commentary on the study concluded that interventions to produce muscular hypertrophy in fast type II glycolytic muscle fibers may prove to be critical weapons in the fight against obesity and obesity-related comorbidities. In our study, individuals in the higher strength quintiles were able to generate more force, which was presumably due to larger more forceful type II muscle fibers. Thus, our findings on the fitness attribute of muscular strength in humans being protective against the prevalence and incidence of EBF and EAF are in logical agreement with mechanisms explained by Izumiya *et al*. (39). This observation is also supported by the findings of Jurca *et al*. (11) who documented that stronger participants in the ACLS also reported significantly higher levels of participation in resistance training activity.

The present findings, combined with recent muscular strength recommendations (38,40) suggest that resistance training could serve as an important component of one's total fitness regime. As has been recommended (40), resistance and aerobic training combined may have a positive effect on health and specifically on body composition characteristics because of the influence on caloric balance. Importantly, it can be expected that increased muscular fitness will not necessarily be associated with a decrease in total body weight but a more healthful body composition. Recently released public health guidelines for physical activity (8) indicate that muscular strengthening activities should be conducted 2+ days per week as part of a total physical activity program.

A major strength of our study is that it comprised a large sample of adult men from a well-characterized cohort where we have laboratory measurements of muscular strength, CRF, and other important clinical and lifestyle factors. The main finding is that higher levels of muscular strength are associated with lower prevalence and incidence of EBF and EAF, and these associations remained after controlling for CRF and other important confounders. Because muscular strength is the primary fitness result of resistance training, this study provides important epidemiologic evidence that supports the current public health recommendations for resistance exercise (40). Specifically, our data indicate that the current guidelines for resistance training, which would increase or maintain muscular strength, may also contribute to weight control. Limitations are that participants were men, predominantly white, well educated, and from middle-to-upper socioeconomic strata. However, examination of the ACLS measures on health parameters (e.g., blood glucose, blood pressure, and cholesterol) indicates the sample is consistent with the general US population (16,17). Future research on resistance training or muscular fitness should focus on women and additional population subgroups (e.g., ethnicity, race, and socioeconomic status) in the context of unhealthy weight gain, fat distribution, and energy balance. Dietary intake and physical activity including resistance training should be considered or controlled. Randomized trials that control energy intake, and compare volume and types of physical activities, including aerobic, resistance, and combination programs, should be conducted to determine their individual and interactive effects on weight control and energy balance. It is important that these studies be of sufficient duration to ascertain long-term training and dietary effects on changes in body habitus (38).

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DISCLOSURE
The authors declared no conflict of interest.

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