Cardiorespiratory Fitness and Adiposity as Mortality Predictors in Older Adults

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Context Although levels of physical activity and aerobic capacity decline with age and the prevalence of obesity tends to increase with age, the independent and joint associations among fitness, adiposity, and mortality in older adults have not been adequately examined.

Objective To determine the association among cardiorespiratory fitness ("fitness"), adiposity, and mortality in older adults.

Design, Setting, and Patients Cohort of 2603 adults aged 60 years or older (mean age, 64.4 [SD, 4.8] years; 19.8% women) enrolled in the Aerobics Center Longitudinal Study who completed a baseline health examination during 1979-2001. Fitness was assessed by a maximal exercise test, and adiposity was assessed by body mass index (BMI), waist circumference, and percent body fat. Low fitness was defined as the lowest fifth of the sex-specific distribution of maximal treadmill exercise test duration. The distributions of BMI, waist circumference, and percent body fat were grouped for analysis according to clinical guidelines.

Main Outcome Measure All-cause mortality through December 31, 2003.

Results There were 450 deaths during a mean follow-up of 12 years and 31 236 person-years of exposure. Death rates per 1000 person-years, adjusted for age, sex, and examination year were 13.9, 13.3, 18.3, and 31.8 across BMI groups of 18.5-24.9, 25.0-29.9, 30.0-34.9, and ≥35.0, respectively ($P=.01$ for trend); 13.3 and 18.2 for normal and high waist circumference (≥88 cm in women; ≥102 cm in men) ($P=.004$); 13.7 and 14.6 for normal and high percent body fat (≥30% in women; ≥25% in men) ($P=.51$); and 32.6, 16.6, 12.8, 12.3, and 8.1 across incremental fifths of fitness ($P<.001$ for trend). The association between waist circumference and mortality persisted after further adjustment for smoking, baseline health status, and BMI ($P=.02$) but not after additional adjustment for fitness ($P=.86$). Fitness predicted mortality risk after further adjustment for smoking, baseline health, and either BMI, waist circumference, or percent body fat ($P<.001$ for trend).

Conclusions In this study population, fitness was a significant mortality predictor in older adults, independent of overall or abdominal adiposity. Clinicians should consider the importance of preserving functional capacity by recommending regular physical activity for older individuals, normal-weight and overweight alike.

JAMA. 2007;298(21):2507-2516 www.jama.com

POPULATION AGING, OBESITY, AND physical inactivity are notable public health challenges. By 2030, 22% of the US population, or 70 million individuals, will be older than 65 years.[1] Approximately 32% of Americans are obese,[2] and the vast majority of US adults do not engage in regular physical activity.[3] A high proportion of adults have levels of functional capacity that are low enough to increase mortality risk.[4] Levels of physical activity and functional aerobic capacity each decline steadily with age,[5,6] while the prevalence of obesity tends to increase with age. Total medical expenditures associated with inactivity and obesity are greatest in the older population, a fact that underscores the significant economic burden to society posed by an aging population of inactive obese individuals.[7]

Prospective studies provide convincing evidence that obesity and physical inactivity each can produce excess mortality risk in middle-aged adults.[8-15] However, data regarding associations among obesity, physical activity, and survival in older adults are sparse and largely equivocal.[16-25] Some studies,[17,18,20-24] but not all,[19,25] have found that obesity-related mortality risk is reduced at older ages. Most of these studies have used body mass index (BMI) as a crude measure of adiposity.[17,19-21,25] Few studies have simultaneously examined physical activity levels and clinical measures of adiposity, such as waist circumference[22-24] or percent body fat,[26,27] in relation to mortality specifically in older adults.[17] Cardiorespiratory fitness (hereafter referred to as "fit-

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ness") is an objective reproducible measure that reflects the functional consequences of recent physical activity habits, disease status, and genetics.[28] To our knowledge, no study has been conducted on the independent and joint associations among fitness, various clinical measures of adiposity, and mortality in older women and men. We therefore examined these associations in a cohort of older adults enrolled in the Aerobics Center Longitudinal Study.

METHODS

Study Population

The present study comprised 2087 men and 516 women aged 60 years or older (mean, 64.4 [SD, 4.8] years; range, 60-100). All participants completed a baseline clinical examination during 1979-2001 at the Cooper Clinic (Dallas, Texas). Study participants came to the clinic for periodic preventive health examinations and for counseling regarding diet, exercise, and other lifestyle factors associated with increased risk of chronic disease. Many participants were referred by their employers for the examination; others were referred by their personal physicians or were self-referred.

Inclusion criteria for the current analysis required participants to have a maximal treadmill exercise test at baseline, during which they must have achieved at least 85% of their age-predicted maximal heart rate (220 minus age in years). We excluded participants with a BMI less than 18.5 (calculated as weight in kilograms divided by height in meters squared) at the baseline examination and those younger than 60 years at baseline. We classified participants by race/ethnicity based on their self-report when checking specific categories on the medical history. These categories are a standard part of the medical history, and we did not collect this information for the present report. The majority of the study participants were white, well-educated, and from middle to upper socioeconomic strata. All participants provided written informed consent to participate in the follow-up study, and the Cooper Institute institutional review board approved the study annually.

Clinical Data

Participants completed a comprehensive health evaluation that included self-reported personal and family health histories; a standardized medical examination by a physician; fasting blood levels of total cholesterol, high-density lipoprotein cholesterol, triglycerides, and glucose; and a maximal treadmill exercise test. Body mass index was calculated from measured weight and height. Percent body fat was assessed with hydrostatic weighing, the sum of 7 skin-fold measures, or both, following standardized protocols.[29] Detailed description of our hydrodensitometry procedures has been published.[13] Fat mass (in kilograms) was calculated as weight (in kilograms) × (percent body fat ÷ 100). Fat-free mass (FFM) (in kilograms) was calculated as weight − fat mass.[13] Waist circumference was measured level with the umbilicus.

Adiposity exposure groups were based on standard clinical definitions for BMI (normal weight, 18.5-24.9; overweight, 25.0-29.9; obese class I, 30.0-34.9; and obese class II, ≥35.0), waist circumference (normal, <88.0 cm for women and <102.0 cm for men; indicating abdominal obesity, ≥88.0 cm for women and ≥102.0 cm for men), and percent body fat (normal, <30% for women and <25% for men; obese, ≥30% for women and ≥25% for men).[30] Because there is no consensus clinical categorization for FFM, groups were based on quintiles of the FFM distribution.

Blood pressure was measured with standard auscultatory methods after the participant had been seated for 5 minutes. Systolic and diastolic blood pressures were recorded as the first and fifth Korotkof sounds, respectively. Abnormal exercise electrocardiogram (ECG) responses included rhythm and conduction disturbances and ischemic ST-T wave abnormalities, as described in detail elsewhere.[31] Previously, we found 90% agreement between the ECG interpretation recorded in our database and that of a group of 3 physicians who read a random sample of 357 patient records.[31] Total cholesterol levels were determined in the Cooper Clinic clinical chemistry laboratory, which participates in and meets the quality control standards of the US Centers for Disease Control and Prevention lipid standardization program.

Baseline medical conditions, such as previous myocardial infarction, stroke, hypertension, diabetes, and hypercholesterolemia, were defined as a history of physician diagnosis, measured phenotypes that met clinical thresholds for a specific condition, or, when appropriate, the combination of both methods. Smoking habits (current smoker or not) and physical activity habits (physically inactive or not) were obtained from a standardized questionnaire.

We determined fitness using a maximal treadmill exercise test and a modified Balke protocol[32] as previously described.[12,13,33,34] Total test time correlates highly ($r \geq 0.92$) with directly measured maximal oxygen uptake in men[35] and women.[36] Participants were encouraged not to hold onto the treadmill handrails. The test end point was volitional exhaustion or termination by the physician for medical reasons.

Fitness was grouped for our primary analysis using quintiles of the sex-specific distribution of maximal exercise duration in the overall Aerobics Center Longitudinal Study population. In secondary analyses we grouped fitness into a binary variable, low fitness (the lowest 20%) compared with higher fitness (the remaining 80%).[33] Individuals in the lowest 20% within each sex group were classified as physically unfit and all others as physically fit.[33] While no consensus clinical definition of low fitness currently exists, the approach we used for defining low fitness is a standardized method in the Aerobics Center Longitudinal Study. Previous reports from that study,[12,13,33,34] including an earlier report in elderly participants,[37] have shown that low fitness by this definition is an independent predictor of morbidity and mortality.

To standardize interpretation of exercise test performance, maximal metabolic equivalent tasks (METs) (1 MET = 3.5 mL O_2 uptake/kg per minute) were estimated based on the final treadmill speed and grade.[38] Exercise durations (in minutes) for the incremental fifths of fitness categories for men were less than 7.8, 7.8-10.4, 10.5-13.0, 13.1-16.4, and greater than 16.4. The corresponding durations for women were less than 5.5, 5.5-6.9, 7.0-8.9, 9.0-11.3, and greater than 11.3. In equivalent MET values, the thresholds that defined these categories were 7.2, 8.5, 9.5, and 10.8 METs for men and 5.8, 6.7, 7.6, and 8.6 METs for women.

Mortality Surveillance

Vital status was ascertained using the National Death Index and death certificates from states in which participant deaths occurred. More than 95% of mortality follow-up is complete by these methods. Causes of death were identified using *International Classification of Diseases, Ninth Revision* codes before 1999, and *International Classification of Diseases, Tenth Revision* codes (in brackets) during 1999-2003 (cardiovascular disease, 390-449.9 [I00-I78]; coronary heart disease, 410-414, 429.2 [I20-I25]; and cancer, 140-208 [C00-C97]).

Statistical Analyses

The follow-up interval was computed from the date of a participant's baseline examination until the date of death for decedents, or until December 31, 2003, for survivors. Descriptive statistics summarized baseline characteristics by survival status and by fitness levels. Groups were compared using *t* tests, χ^2 tests, and *F* tests. We used the Fisher Z transformation to examine the correlations among adiposity measures and exercise duration by assessing Pearson coefficients. We used Cox proportional hazard models to estimate hazard ratios (HRs) and 95% confidence intervals (CIs) of mortality according to fitness, adiposity, age, smoking status, abnormal exercise ECG responses, and baseline medical condition exposure categories. Multivariate analyses included the following 6 baseline covariates: age (years), sex, examination year, current smoker, abnormal exercise ECG responses, and chronic medical conditions (cardiovascular disease [myocardial infarction or stroke], hypertension, diabetes, or hypercholesterolemia). The proportional hazards assumption was examined by comparing the cumulative hazard plots grouped on exposure; no appreciable violations were noted.

Tests of linear trends in mortality rates and risk estimates across exposure categories were computed using ordinal scoring for fitness, FFM, and age

Table 1. Baseline Characteristics by Vital Status in 2603 Older Adults—Aerobics Center Longitudinal Study, 1979-2003

Characteristic	All (n = 2603)	Survivors (n = 2153)	Decedents (n = 450)	*P* Value[a]
Women, No. (%)	516 (19.8)	464 (21.6)	52 (11.6)	<.001
Age, mean (SD), y	64.4 (4.8)	64.2 (4.7)	65.7 (5.0)	<.001
BMI, mean (SD)[b]	26.3 (3.7)	26.4 (3.7)	26.2 (3.9)	.29
BMI-defined weight groups, No. (%)				
18.5-24.9	1020 (39.2)	828 (38.5)	192 (42.7)	.10
25.0-29.9	1206 (46.3)	1010 (46.9)	196 (43.6)	.19
30.0-34.9	316 (12.1)	266 (12.4)	50 (11.1)	.46
≥35.0	61 (2.3)	49 (2.3)	12 (2.7)	.62
Waist circumference, mean (SD), cm	90.3 (19.9)	90.4 (19.3)	90.3 (22.6)	.98
Abdominal obesity, No. (%)[c]	643 (24.7)	528 (24.5)	115 (25.6)	.64
Adiposity measures, mean (SD)[d]				
Percent body fat	26.5 (5.4)	26.5 (5.4)	26.6 (5.6)	.67
Fat-free mass, kg	58.4 (9.4)	58.4 (9.5)	58.5 (8.7)	.89
Fat mass, kg	21.6 (7.2)	21.5 (7.1)	21.8 (7.8)	.40
Treadmill time, mean (SD), min	12.6 (4.8)	12.9 (4.7)	11.0 (4.8)	<.001
Maximal METs, mean (SD)	9.1 (2.2)	9.3 (2.2)	8.4 (2.2)	<.001
Abnormal exercise ECG responses, No. (%)	532 (20.4)	405 (18.8)	127 (28.2)	<.001
Lipids, mean (SD), mg/dL				
Total cholesterol	216.5 (42.2)	216.2 (41.0)	217.8 (47.6)	.51
HDL-C	50.1 (15.6)	50.8 (15.8)	47.1 (14.1)	<.001
Triglycerides	136.7 (85.9)	136.2 (86.5)	139.3 (83.4)	.49
Fasting blood glucose, mean (SD), mg/dL	106.1 (25.2)	105.7 (24.3)	107.9 (29.4)	.15
Physically inactive, No. (%)[e]	657 (25.2)	546 (25.4)	111 (24.7)	.76
Current smoker, No. (%)	235 (9.0)	175 (8.1)	60 (13.3)	<.001
Metabolic syndrome, No. (%)[f]	644 (24.7)	505 (23.5)	139 (30.9)	<.001
Chronic medical condition, No. (%)[g]				
Cardiovascular disease	139 (5.3)	93 (4.3)	46 (10.2)	<.001
Diabetes	266 (10.2)	212 (9.9)	54 (12.0)	.17
Hypertension	1241 (47.7)	993 (46.1)	248 (55.1)	<.001
Hypercholesterolemia	1034 (39.7)	881 (40.9)	153 (34.0)	.006

Abbreviations: BMI, body mass index; ECG, electrocardiogram; HDL-C, high-density lipoprotein cholesterol; METs, maximal metabolic equivalent tasks achieved during treadmill test.

SI conversion factors: To convert total cholesterol and HDL-C values to mmol/L, multiply by 0.0259; triglycerides values to mmol/L, by 0.0113; glucose values to mmol/L, by 0.0555.

[a] For comparison of survivors and decedents.

[b] Calculated as weight in kilograms divided by height in meters squared.

[c] Defined as waist circumference ≥88 cm in women and ≥102 cm in men.

[d] n = 2584 (442 deaths).

[e] Defined as reporting no leisure-time physical activity in the 3 months before the examination, as reported on the standardized medical history/health habits questionnaire.

[f] Defined as the presence of ≥3 of the 5 metabolic risk factors based on National Cholesterol Education Program Adult Treatment Panel III criteria.

[g] Defined as the presence of hypercholesterolemia (history of physician-diagnosed high cholesterol level or measured fasting total cholesterol level ≥240 mg/dL [6.20 mmol/L]) or diabetes (history of physician diagnosis, or use of insulin or measured fasting glucose level ≥126 mg/dL [7.0 mmol/L]); or hypertension (history of physician diagnosis or resting systolic blood pressure ≥140 mm Hg or diastolic blood pressure ≥90 mm Hg); or personal history of physician-diagnosed cardiovascular disease (myocardial infarction or stroke).

groups. Models including BMI also were fitted with BMI squared to assess nonlinearity. We also examined associations between specific causes of death and fitness, BMI, waist circumference, percent body fat, and FFM. In addition, we tested joint associations of adiposity and fitness with all-cause mortality. There were no significant interactions among exposure groups.

Due to the small sample size (516) and number of deaths (52) in women, we were unable to perform a meaningful analysis in women alone. The pattern of the association between fitness, adiposity measurements, and all-cause mortality in men was similar to that observed in analyses of men and women combined. We also examined the potential interaction between sex and other covariates in the Cox regression model, and no significant interactions were observed. We therefore believe that combining women and men is an acceptable alternative. Statistical tests were 2-sided; $P<.05$ was accepted to indicate statistical significance.

RESULTS

Overall, the mean age of participants was 64.4 (SD, 4.8) years, and 20% of the study sample were women. There were 450 deaths during a mean follow-up of 12 years and 31 236 person-years of exposure. Participants' base-

Table 2. Baseline Characteristics by Cardiorespiratory Fitness (Fitness) Categories in 2603 Older Adults—Aerobics Center Longitudinal Study, 1979-2003[a]

		Fitness Quintile, min				
Characteristic	**All (N = 2603)**	**<8.7 (n = 291)**	**8.7-11.2 (n = 448)**	**11.3-13.6 (n = 544)**	**13.7-18.3 (n = 668)**	**≥18.4 (n = 652)**
Women, No. (%)	516 (19.8)	57 (11.1)	93 (18.0)	83 (16.1)	134 (26.0)	149 (28.9)
Age, mean (SD), y	64.4 (4.8)	66.1 (5.0)	65.3 (5.0)	64.4 (4.8)	63.8 (3.9)	63.7 (5.0)
BMI, mean (SD)[b]	26.3 (3.7)	29.0 (4.9)	27.3 (3.9)	27.0 (3.4)	26.0 (3.2)	24.3 (2.6)
BMI-defined weight groups, No. (%)						
18.5-24.9	1020 (39.2)	64 (6.3)	123 (12.1)	153 (15.0)	259 (25.4)	421 (41.3)
25.0-29.9	1206 (46.3)	121 (10.0)	225 (18.7)	293 (24.3)	348 (28.9)	219 (18.2)
30.0-34.9	316 (12.1)	73 (23.1)	85 (26.9)	89 (28.2)	58 (18.4)	11 (3.5)
≥35.0	61 (2.3)	33 (54.1)	15 (24.6)	9 (14.8)	3 (4.9)	1 (1.6)
Waist circumference, mean (SD), cm	90.3 (19.9)	97.8 (23.5)	94.4 (18.0)	92.9 (19.8)	89.4 (18.9)	83.1 (18.1)
Abdominal obesity, No. (%)[c]	643 (24.7)	148 (23.0)	172 (26.8)	166 (25.8)	128 (19.9)	29 (4.5)
Adiposity measures, mean (SD)[d]						
Percent body fat	26.5 (5.4)	29.9 (5.2)	28.5 (4.8)	27.6 (4.7)	26.3 (4.8)	23.1 (5.3)
Fat-free mass, kg	58.4 (9.4)	61.1 (10.5)	58.8 (9.8)	59.5 (9.0)	58.1 (8.9)	56.5 (9.0)
Fat mass, kg	21.6 (7.2)	26.8 (9.2)	23.9 (7.0)	23.1 (6.5)	20.9 (5.9)	17.1 (5.3)
Treadmill time, mean (SD), min	12.6 (4.8)	5.4 (1.6)	8.7 (1.4)	11.3 (1.6)	13.7 (2.1)	18.4 (3.6)
Maximal METs, mean (SD)	9.1 (2.2)	5.8 (0.7)	7.4 (0.6)	8.5 (0.7)	9.7 (1.0)	11.8 (1.7)
Abnormal exercise ECG responses, No. (%)	532 (20.4)	90 (16.9)	122 (22.9)	116 (21.8)	116 (21.8)	88 (16.5)
Lipids, mean (SD), mg/dL						
Total cholesterol	216.5 (42.2)	223.1 (46.9)	216.6 (42.7)	218.2 (39.9)	216.0 (40.9)	212.5 (42.6)
HDL-C	50.1 (15.6)	46.1 (13.4)	48.2 (15.7)	47.4 (14.5)	50.2 (14.6)	55.6 (16.8)
Triglycerides	136.7 (85.9)	164.3 (102.1)	147.5 (91.3)	152.7 (94.5)	134.9 (82.6)	105.1 (55.0)
Fasting blood glucose, mean (SD), mg/dL	106.1 (25.2)	119.1 (42.4)	109.5 (31.0)	105.7 (21.2)	103.6 (18.9)	100.8 (14.7)
Physically inactive, mean (SD), No. (%)[e]	657 (25.2)	142 (48.8)	179 (40.0)	165 (30.3)	113 (16.9)	58 (8.9)
Current smoker, No. (%)	235 (9.0)	43 (18.3)	55 (23.4)	54 (23.0)	50 (21.3)	33 (14.0)
Metabolic syndrome, No. (%)[f]	644 (24.7)	130 (20.2)	159 (24.7)	166 (25.8)	142 (22.1)	47 (7.3)
Chronic medical condition, No. (%)[g]						
Cardiovascular disease	139 (5.3)	30 (21.6)	35 (25.2)	38 (27.3)	20 (14.4)	16 (11.5)
Diabetes	266 (10.2)	66 (24.8)	54 (20.3)	57 (21.4)	58 (21.8)	31 (11.7)
Hypertension	1241 (47.7)	167 (13.5)	245 (19.7)	278 (22.4)	305 (24.6)	246 (19.8)
Hypercholesterolemia	1034 (39.7)	128 (12.4)	174 (16.8)	229 (22.2)	286 (27.7)	217 (21.0)

Abbreviations: BMI, body mass index; ECG, electrocardiogram; HDL-C, high-density lipoprotein cholesterol; METs, maximal metabolic equivalent tasks achieved during treadmill test.
SI conversion factors: To convert total cholesterol and HDL-C values to mmol/L, multiply by 0.0259; triglycerides values to mmol/L, by 0.0113; glucose values to mmol/L, by 0.0555.

[a] All the tests for linear trends across quintiles were significant ($P < .05$).

[b] Calculated as weight in kilograms divided by height in meters squared.

[c] Defined as waist circumference ≥88 cm in women and ≥102 cm in men.

[d] n = 2584 (442 deaths).

[e] Defined as reporting no leisure-time physical activity in the 3 months before the examination as reported on the standardized medical history/health habits questionnaire and is likely to be a crude approximation of actual physical activity habits.

[f] Defined as the presence of ≥3 of the 5 metabolic risk factors based on National Cholesterol Education Program Adult Treatment Panel III criteria.

[g] Defined as the presence of hypercholesterolemia (history of physician-diagnosed high cholesterol level or measured fasting total cholesterol level ≥240 mg/dL [6.20 mmol/L]) or diabetes (history of physician diagnosis, or use of insulin or measured fasting glucose level ≥126 mg/dL [7.0 mmol/L]); or hypertension (history of physician diagnosis or resting systolic blood pressure ≥140 mm Hg or diastolic blood pressure ≥90 mm Hg); or personal history of physician-diagnosed cardiovascular disease (myocardial infarction or stroke).

Table 3. Univariate Associations Between Adiposity Measures and Treadmill Exercise Duration in 2603 Older Adults—Aerobics Center Longitudinal Study, 1979-2003

	Pearson Correlation Coefficients[a]					
Adiposity Measure	BMI	Percent Body Fat	Fat Mass	Fat-Free Mass	Waist Circumference	Treadmill Test Duration
BMI	1.00	0.60	0.87	0.66	0.52	−0.30
Percent body fat		1.00	0.84	0.02	0.23	−0.50
Fat mass			1.00	0.54	0.48	−0.37
Fat-free mass				1.00	0.55	−0.09
Waist circumference					1.00	−0.10
Treadmill test duration						1.00

Abbreviation: BMI, body mass index.

[a] $P < .001$ for all, except coefficient comparing percent body fat and fat-free mass ($P = .26$).

line characteristics by vital status and by fitness categories are summarized in TABLE 1 and TABLE 2. Decedents were older, had lower fitness levels, and had more cardiovascular risk factors than survivors. However, there were no significant differences in adiposity measures across vital status. Participants in the higher fitness groups were for the most part less likely to have risk factors for cardiovascular disease, such as hypertension, diabetes, or high cholesterol levels. TABLE 3 shows that all measures of adiposity and treadmill exercise duration were significantly correlated, except for percent body fat and FFM (r=0.02, P=.26). Body mass index and fat mass were highly correlated, but BMI and waist circumference or percent body fat were only moderately correlated.

TABLE 4 presents all-cause death rates per 1000 person-years for each exposure category, adjusted for age, sex, and examination year. Death rates were 32.6, 16.6, 12.8, 12.3, and 8.1 across incremental fifths of fitness ($P<.001$ for linear trend); 20.4 and 12.1 for individuals with or without abnormal exercise ECG responses, respectively ($P<.001$); 17.7 and 12.0 for those with or without chronic medical conditions, respectively ($P<.001$); and 18.2 and 13.3 for those with or without abdominal obesity, respectively (P=.004). There was a J-shaped relationship between BMI and mortality (quadratic term, P=.01). Excluding individuals who died within 2 years of follow-up did not notably alter the association between the exposures and mortality. No relationship was found between mortality risk and percent body fat or FFM.

TABLE 5 and TABLE 6 show the estimated HRs and 95% CIs for fitness and adiposity exposure categories and all-cause mortality. After adjusting for age, sex, examination year, smoking, abnormal exercise ECG responses, and baseline health conditions (Table 5), HRs of mortality across incremental quintiles of fitness were 1.00, 0.53, 0.44, 0.43, and 0.30 ($P<.001$ for linear trend). Additional adjustment for BMI, waist circumference, percent body fat, or FFM did not meaningfully change the results (Table 5).

When the adiposity categories were adjusted for the same set of covariates (Table 6), individuals with abdominal obesity had a higher mortality risk (HR, 1.25; 95% CI, 1.00-1.56; P=.05), although this relationship did not persist after further adjustment for fitness (HR, 0.99; 95% CI, 0.79-1.25; P=.95). The J-shaped relationship between BMI and mortality remained significant after adjusting for covariates and fitness (P=.005), although most of the interval estimates for the BMI strata are not individually significantly different from those for the reference category. There were no significant associations between mortality and percent body fat or FFM.

Also, we examined joint associations of all-cause mortality, adiposity, and fitness, for which fitness was dichotomized as unfit and fit to preserve sample size and numbers of deaths within each adiposity stratum and to provide greater clinical meaning for physicians and other health professionals working with older populations (TABLE 7). There were no significant interactions noted in analyses that included cross-product interaction terms for each fitness-adiposity exposure combination. Fit participants had lower death rates than unfit participants within each stratum of adiposity, except for the class I and II obesity groups. In most instances, death rates for those with higher fitness were less than half of rates for those who were unfit.

COMMENT

The objective of this study was to evaluate relationships between mortality risk and well-defined measures of adiposity, fat distribution, and fitness in older adults. In age-, sex-, and examination year–adjusted analyses, both BMI and waist circumference were associated with mortality risk, but percent body fat and FFM were not related to mortality. The association between total mortality and waist circumference persisted after adjusting for baseline differences in age, sex, smoking, abnormal exercise ECG responses, and health status. Further adjustment for fitness eliminated the significant mortality risk associated with abdominal obesity. A J-shaped relationship between BMI and mortality remained significant after considering the influences of several covariates, including fitness.

Fitness had a strong inverse association with mortality, and this pattern of results was changed little by adjustments for adiposity or fat distribution.

Thus our primary finding is that both fitness and BMI were strong and independent predictors of all-cause mortality in adults 60 years or older. Other adiposity measures either did not predict mortality (percent body fat, FFM) or did not do so in models adjusted for competing risk predictors (waist circumference).

We previously demonstrated that lower levels of fitness are strongly associated with higher risk of all-cause and cardiovascular disease mortality in younger and middle-aged men with various levels of health status.[12,13,39,40] The analogous relationship is clear within adiposity subgroups.[12,13] Our findings from the current study are consistent with these earlier results from the Aerobics Center Longitudinal Study and expand them to the older segment of the cohort.

Higher levels of fitness were inversely related to all-cause mortality in both normal-weight and overweight BMI subgroups, in those with a normal waist circumference and in those with abdominal obesity, and in those who have normal percent body fat and those who have excessive percent body fat (Table 7). However, obese (BMI ≥30.0) unfit individuals were at no higher risk for mortality when compared with obese fit individuals. The obese I and II groups had relatively small sample sizes and fewer deaths;

Table 4. Risk of All-Cause Mortality Across Exposure Groups in 2603 Older Adults—Aerobics Center Longitudinal Study, 1979-2003

	Person-years	Deaths	Rate per 1000 Person-years[a]	HR (95% CI)[a]	*P* Value
BMI[b]					
18.5-24.9	13 168	192	13.9	1 [Reference]	.01[c]
25.0-29.9	14 412	196	13.3	0.95 (0.78-1.17)	
30.0-34.9	3226	50	18.3	1.31 (0.96-1.80)	
≥35.0	528	12	31.8	2.29 (1.27-4.12)	
Percent body fat					
Normal (<30 women; <25 men)	13 859	180	13.7	1 [Reference]	.51[d]
Obese (≥30 women; ≥25 men)	17 227	262	14.6	1.07 (0.88-1.30)	
Fat-free mass quintiles, kg					
<50.6	6375	72	12.9	1 [Reference]	.10[e]
50.6-56.9	6729	111	14.0	1.08 (0.73-1.60)	
57.0-61.1	6612	95	12.7	0.99 (0.65-1.49)	
61.2-65.9	5998	83	14.3	1.10 (0.72-1.68)	
≥66.0	5366	81	17.9	1.38 (0.90-2.12)	
Waist circumference, cm					
Normal (<88.0 women; <102.0 men)	24 402	335	13.3	1 [Reference]	.004[d]
Abdominal obesity (≥88.0 women; ≥102.0 men)	6925	115	18.2	1.37 (1.11-1.70)	
Fitness quintiles based on treadmill time, min[f]					
<8.7	3381	106	32.6	1 [Reference]	<.001[e]
8.7-11.2	5690	98	16.6	0.51 (0.39-0.67)	
11.3-13.6	6762	95	12.8	0.39 (0.30-0.52)	
13.7-18.3	7729	90	12.3	0.38 (0.29-0.50)	
≥18.4	7772	61	8.1	0.25 (0.18-0.34)	
Abnormal exercise ECG responses					
No	22 789	272	12.1	1 [Reference]	<.001[d]
Yes	8550	178	20.4	1.64 (1.33-2.01)	
Age, y					
60-69	28 095	358	12.4	1 [Reference]	<.001[e]
70-79	2765	82	34.4	2.78 (2.18-3.54)	
≥80	464	10	15.7	1.27 (0.67-2.38)	
Current smoker					
No	28 345	390	14.0	1 [Reference]	.08[d]
Yes	2977	60	17.9	1.28 (0.97-1.69)	
Chronic medical condition					
No	11 689	119	12.0	1 [Reference]	<.001[d]
Yes	19 645	279	17.7	1.48 (1.19-1.84)	

Abbreviations: BMI, body mass index; CI, confidence interval; ECG, electrocardiogram; HR, hazard ratio.

[a] Rates are per 1000 person-years and HRs are adjusted for age, sex, and examination year.

[b] Calculated as weight in kilograms divided by height in meters squared.

[c] For quadratic trend.

[d] For difference.

[e] For linear trend.

[f] Quintiles of cardiorespiratory fitness were based on the distribution of treadmill exercise duration standardized to the group aged ≥60 years in the overall Aerobics Center Longitudinal Study population of women and men. The tabulated values reflect the mean value for the women and men included in this analysis. Metabolic equivalent task levels of fitness associated with each quintile were <7.4, 7.4-8.4, 8.5-9.6, 9.7-11.7, and ≥11.8.

therefore, these results must be confirmed in larger studies. In addition, we observed that fit individuals who were obese (such as those with BMI of 30.0-34.9, abdominal obesity, or excessive percent body fat) had a lower risk of all-cause mortality than did unfit, normal-weight, or lean individuals. Our data therefore suggest that fitness levels in older individuals influence the association of obesity to mortality.

Results concerning the relationship between mortality and obesity in older adults have been inconsistent. Some studies,[18,23,25] but not all,[19,21] have suggested a lower risk of mortality in obese individuals. We found a J-shaped association between mortality and BMI calculated from measured height and weight. The age-, sex-, and examination year–adjusted mortality rate per 1000 person-years was the lowest in the overweight group and the highest in the class II obesity group (Table 4). However, the multivariate-adjusted model (without fitness) showed a nonsignificant association (HR, 0.87; 95% CI, 0.70-1.07) with overweight compared with normal-weight persons (Table 6). The fully adjusted model (including fitness) attenuated the quadratic trend (Table 6). Our findings are consistent with the report from Gale et al,[26] who also found no evidence of increased mortality risk in mildly to moderately overweight women and men aged 65 or older after adjusting for self-reported physical activity.

Further joint analysis (Table 7) showed that in fit individuals the mortality risk was not significantly different across the 4 BMI categories, while in unfit individuals the mortality risk was J-shaped, with lower risk in those with BMI of 25.0-34.9 and higher risk in those with BMI of 18.5-24.9 and 35.0 or greater. These results support the hypothesis that moderate and higher fitness levels favorably influence mortality risk across categories of body composition. Normal-weight individuals in our study had greater longevity only if they were physically fit; furthermore, obese individuals who were fit did not have increased mortality.

The quadratic trend across BMI in the unfit individuals deserves further comment. In general, unfit individuals were inactive at baseline, whereas fit individuals were active. In elderly individuals, BMI is also a marker of other factors such as fitness and muscle mass; therefore, maintaining BMI at older age is an overall marker of health.[17] This may be attributable to competing causes of mortality that become important factors with increasing age. It also may reflect selection factors that have allowed survival to older age.

In older populations, abdominal obesity assessed by waist circumference[22-24] has been a better mortality predictor than BMI. Other indicators of adiposity, such as body fat, also have been examined for mortality associations.[26,27] However, the independent association between body fat and mortality in the older population has not been adequately demonstrated.[14,27] Re-

Table 5. Risk of All-Cause Mortality by Cardiorespiratory Fitness (Fitness) Categories—Aerobics Center Longitudinal Study, 1979-2003

	HR (95% CI) by Fitness Quintile[a]				
Model	<8.7	8.7-11.2	11.3-13.6	13.7-18.3	≥18.4
1[b]	1 [Reference]	0.53 (0.40-0.70)	0.44 (0.33-0.58)	0.43 (0.32-0.58)	0.30 (0.22-0.42)
2[c]	1 [Reference]	0.51 (0.39-0.68)	0.42 (0.31-0.56)	0.40 (0.30-0.55)	0.27 (0.19-0.39)
3[d]	1 [Reference]	0.52 (0.40-0.69)	0.43 (0.32-0.57)	0.42 (0.31-0.56)	0.29 (0.21-0.40)
4[e]	1 [Reference]	0.53 (0.40-0.71)	0.43 (0.32-0.57)	0.41 (0.31-0.56)	0.27 (0.19-0.39)
5[f]	1 [Reference]	0.54 (0.41-0.72)	0.44 (0.33-0.59)	0.44 (0.33-0.59)	0.31 (0.22-0.43)

Abbreviations: CI, confidence interval; CVD, cardiovascular disease; Fitness, cardiorespiratory fitness; HR, hazard ratio.

[a] See Table 4 footnote for definition of fitness quintiles. For all models, $P < .001$ for linear trend across quintiles.

[b] Adjusted for age, sex, examination year, smoking status, abnormal exercise electrocardiogram responses, and baseline health conditions (cardiovascular disease, hypertension, diabetes, and hypercholesterolemia, present or not for each).

[c] Adjusted for covariates listed for model 1 plus body mass index (entered as continuous variable).

[d] Adjusted for covariates listed for model 1 plus waist circumference (entered as continuous variable).

[e] Adjusted for covariates listed for model 1 plus percent body fat (entered as continuous variable).

[f] Adjusted for covariates listed for model 1 plus fat-free mass (entered as continuous variable).

Table 6. Risk of All-Cause Mortality by Adiposity Measures—Aerobics Center Longitudinal Study, 1979-2003

Adiposity Measure[a]	Model 1, HR (95% CI)[b]	*P* Value	Model 2, HR (95% CI)[c]	*P* Value
BMI[d]				
18.5-24.9	1 [Reference]	.004[e]	1 [Reference]	.005[e]
25.0-29.9	0.87 (0.70-1.07)		0.72 (0.58-0.89)	
30.0-34.9	1.11 (0.80-1.53)		0.76 (0.54-1.07)	
≥35.0	1.98 (1.09-3.61)		1.11 (0.60-2.05)	
Waist circumference				
Normal	1 [Reference]	.05[f]	1 [Reference]	.95[f]
Abdominal obesity	1.25 (1.00-1.56)		0.99 (0.79-1.25)	
Percent body fat				
Normal	1 [Reference]	.78[f]	1 [Reference]	.07[f]
Obese	1.03 (0.85-1.25)		0.83 (0.67-1.01)	
Fat-free mass quintiles				
<50.6	1 [Reference]	.36[g]	1 [Reference]	.91[g]
50.6-56.9	1.04 (0.70-1.53)		1.01 (0.69-1.49)	
57.0-61.1	0.92 (0.61-1.38)		0.86 (0.57-1.28)	
61.2-65.9	1.01 (0.66-1.54)		0.90 (0.59-1.37)	
≥66.0	1.21 (0.79-1.86)		1.02 (0.66-1.57)	

Abbreviations: BMI, body mass index; CI, confidence interval; HR, hazard ratio.

[a] See "Methods" for definitions.

[b] Adjusted for age, sex, examination year, smoking status, abnormal exercise electrocardiogram responses, and baseline health conditions (cardiovascular disease, hypertension, diabetes, and hypercholesterolemia, present or not for each).

[c] Adjusted for covariates listed for model 1 plus fitness (entered as continuous variable in minutes).

[d] Calculated as weight in kilograms divided by height in meters squared.

[e] For quadratic trend.

[f] For difference.

[g] For linear trend.

searchers speculate that the controversial association between adiposity and mortality in older individuals may be attributable to selective survival, cohort effects, or unadjusted confounding.[41] We found that BMI or waist circumference, but not percent body fat, predicted overall mortality in adults at least 60 years old. From a practical perspective, these findings suggest that more complicated and expensive body fat measurement does not provide an advantage in assessing mortality risk over more readily available and less expensive obesity measures such as BMI or waist circumference. These findings also suggest that total adiposity per se may not be the factor that increases mortality risk among elderly individuals. Rather, fat distribution and some other factor intrinsic to BMI (eg, frame size) may underlie mortality risk in older adults. Further investigation of the effects of various measures of adiposity on mortality in other elderly populations, and on the potential role of confounding and modifying variables, would contribute usefully to this research area.

Our results also support the hypothesis that higher levels of fitness can reduce the risk of premature death[12,33,42,43] and expand the evidence supporting this relationship in obese older persons. In a prospective cohort of 18 750 Chinese men and 37 417 Chinese women 65 or older, Schooling et al[17] recently reported that self-reported physical activity was strongly associated with lower mortality in a dose-response manner. Our earlier report in older persons in the Aerobics Center Longitudinal Study also demonstrated that lower fitness, an objective measure of functional capacity that is related to recent physical activity habits, is associated with higher risk of all-cause mortality.[37]

However, neither our earlier report nor that by Schooling et al assessed the joint associations of physical activity, BMI, and outcomes. In the current study, we found that fitness is a strong predictor of overall death among older adults, independent of body composition and other mortality risk factors. Additional studies are needed that concurrently evaluate the joint association among objective measures of fitness or activity, body size and fatness, and longevity in the rapidly growing older population.

Increasing evidence suggests that skeletal muscle function (eg, strength, power, endurance) may contribute to improved physical functioning and longevity through biological pathways that are related to but independent of aerobic fitness.[44,45] Fat-free mass was not a significant predictor of mortality risk in the present study. However, it is possible that the quality of FFM (eg, functional phenotype), rather than the absolute amount of FFM, is the key factor in determining health risk. We were unable to include in the present study an objective measure of muscle function to examine its independent and joint relationship with adiposity, fitness, and mortality risk. More data are needed to further explore the role of muscle function in successful aging and enhanced longevity among older adults.

Our study had several strengths. We used standardized and objective measurements of fitness and adiposity and examined their associations with mortality, providing quantitative risk estimates and a lower likelihood of misclassification on the exposure variables. We are unaware of any other report in which these data are available. The extensive baseline physical examination permitted systematic evaluation of the presence or absence of baseline medical conditions. The relatively long follow-up (mean, 12 years) was sufficient to accrue enough fatal end points to allow for assessing the joint associa-

Table 7. Joint Associations of Cardiorespiratory Fitness (Fitness) and Adiposity Measures With All-Cause Mortality—Aerobics Center Longitudinal Study, 1979-2003[a]

	Fit			Unfit			
Adiposity Measure	**No. of Deaths**	**Rate[b]**	**HR (95% CI)[c]**	**No. of Deaths**	**Rate[b]**	**HR (95% CI)[c]**	***P* Value**
BMI[d]							
18.5-24.9	158	1.2	1 [Reference]	34	4.9	3.63 (2.47-5.32)	<.001
25.0-29.9	152	1.2	0.88 (0.70-1.11)	44	2.7	1.74 (1.23-2.46)	<.001
30.0-34.9	32	1.6	1.12 (0.76-1.66)	18	2.5	1.68 (1.02-2.78)	.46
≥35.0	2	1.2	0.86 (0.21-3.50)	10	4.8	3.35 (1.74-6.44)	.05
Waist circumference[e]							
Normal	274	5.1	1 [Reference]	61	14.5	2.84 (2.15-3.75)	<.001
Abdominal obesity	70	6.2	1.21 (0.93-1.58)	45	13.5	2.65 (1.93-3.63)	<.001
Percent body fat[e]							
Normal	151	9.1	1 [Reference]	29	26.8	2.94 (1.97-4.38)	<.001
Obese	190	8.7	0.96 (0.78-1.19)	72	21.8	2.39 (1.81-3.16)	<.001

Abbreviations: BMI, body mass index; CI, confidence interval; HR, hazard ratio.

[a] Cross-product tests of interaction between fitness and adiposity exposures were not statistically significant: fitness-BMI ($\chi^2_1 = 0.05$, *P* = .82); fitness-waist circumference ($\chi^2_1 = 1.38$, *P* = .24); and fitness-percent body fat ($\chi^2_1 = 0.04$, *P* = .84).

[b] All-cause death rates per 1000 person-years adjusted for age, sex, and examination year.

[c] Adjusted for age, sex, examination year, smoking status, abnormal exercise electrocardiogram responses, and presence vs absence of baseline health conditions (cardiovascular disease, hypertension, diabetes, and hypercholesterolemia).

[d] Calculated as weight in kilograms divided by height in meters squared.

[e] See "Methods" for definitions.

tion among risk factors and mortality within adiposity strata.

Limitations of the current study include a focus on participants who were primarily white and well-educated, had middle to upper socioeconomic status, and were physically able to complete a maximal exercise test. The results may not apply to other groups of older adults. However, the homogeneity of our sample strengthens the internal validity of our findings by reducing potential confounding by unmeasured factors related to socioeconomic status, such as income, education, or prestige. Residual confounding from undetected subclinical disease at baseline may exist, although it seems unlikely that it would explain all of the observed association between fitness, adiposity, and mortality, especially given the extensive medical examination performed at baseline. The primary results were not changed meaningfully when deaths in the first 2 years of follow-up were excluded. We did not have adequate information about diet or medication use to study these factors. We focused primarily on all-cause mortality because of the relatively small number of cause-specific deaths, which prevented us from stratifying cause-specific analyses by adiposity measures.

However, some exploratory analyses were performed for associations between fitness, BMI, waist circumference, percent body fat, or FFM and cause-specific mortality (data not shown). In the current study, cardiovascular disease and cancer accounted for 74% of total deaths. After adjusting for age, sex, examination year, and current smoking, fitness was significantly associated with cardiovascular disease, coronary heart disease, and cancer mortality ($P < .05$ for linear trend, for each). However, the associations between adiposity exposures and the above cause-specific mortality outcomes were variable. Future studies should include these important exposures and extend the analysis to these and other specific causes of death with particular interest to public health, such as stroke and diabetes mellitus. Due to a limited sample of women, who contributed relatively few deaths to the analysis, we combined women and men for analyses and adjusted the analyses for sex. In our previous reports on fitness in which we have been able to perform parallel analyses in women and men, results have generally been similar for women and men.[34,46] In this cohort we had only a single baseline assessment of fitness, adiposity measurements, and other exposures; thus, we could not examine whether changes in any of these variables occurred during follow-up and whether this may have influenced the study results.

In conclusion, in this prospective study of adults 60 years or older, low fitness predicted higher risk of all-cause mortality after adjustment for potential confounding factors, including adiposity. Fit individuals had greater longevity than unfit individuals, regardless of their body composition or fat distribution. Our data provide further evidence regarding the complex long-term relationship among fitness, body size, and survival. It may be possible to reduce all-cause death rates among older adults, including those who are obese, by promoting regular physical activity, such as brisk walking for 30 minutes or more on most days of the week (about 8 kcal/kg per week), which will keep most individuals out of the low-fitness category.[43] Enhancing functional capacity also should allow older adults to achieve a healthy lifestyle and to enjoy longer life in better health.

Author Contributions: Drs Sui and Blair had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Sui, LaMonte, Blair.
Acquisition of data: Sui, LaMonte, Blair.
Analysis and interpretation of data: Sui, LaMonte, Laditka, Hardin, Chase, Hooker, Blair.
Drafting of the manuscript: Sui, LaMonte, Laditka, Hardin, Chase, Hooker, Blair.
Critical revision of the manuscript for important intellectual content: Sui, LaMonte, Laditka, Hardin, Hooker, Blair.
Statistical analysis: Sui, LaMonte, Hardin.

Financial Disclosures: Dr LaMonte reported receiving book royalties (<$1000 per year) from Human Kinetics and honoraria for lectures from scientific, educational, and lay groups. Dr Blair reported receiving book royalties (<$5000 per year) from Human Kinetics; honoraria for service on the medical advisory boards of Jenny Craig, Magellan Health Services, and Matria Health Care; and honoraria for lectures from scientific, educational, and lay groups; research grants from Jenny Craig and BodyMedia Inc; and compensation as an executive lecturer for the University of North Texas. Dr Blair donates these fees to the University of South Carolina Educational Foundation or to other nonprofit groups. No other disclosures were reported.

Funding/Support: The Aerobics Center Longitudinal Study was supported by National Institutes of Health grants AG06945 and HL62508.

Role of the Sponsor: The National Institutes of Health played no role in the design and conduct of the study; the collection, management, analysis, and interpretation of data; or the preparation, review, or approval of the manuscript.

Additional Contributions: We thank the Cooper Clinic physicians and technicians for collecting the baseline data and the staff at the Cooper Institute for data entry and data management.

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