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Fitness, fatness and survival in elderly populations

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Abstract This study examines the relative importance of fitness versus fatness in predicting mortality in elderly populations aged 70 years and over, and whether fitness may account for the 'paradoxical' relationship between better survival and increasing weight. Four thousand community-living Chinese men and women aged 65 years or over were recruited and stratified so that approximately 33% were in each of the age groups: 65–69, 70–74, and 75 or above. Medical history, height, weight, waist–hip ratio, body composition using DEXA, and walking speed were obtained. They were followed up for a mean of 7.0 years to ascertain death. Compared with the high fitness category, those in the moderate and low categories have a 43% and 68% increased risk of mortality at 7 years adjusting for multiple confounders. When mortality risk according to various fatness indicators was examined, only the lowest quartile of BMI, BFI, and FLMR conferred statistically significant increased risk. Fitness categories were significantly associated with all fatness indicators. The finding of fewer people in the high fitness category among the highest quartiles of other fatness indicators suggests that fitness is not the underlying mechanism for the obesity paradox. Within each quartile of fatness indicator, there was a significant trend towards reduced mortality with increasing fitness. In conclusion, the study confirms the beneficial effects of cardiorespiratory fitness on mortality but does not explain the 'obesity paradox'. The findings underscore the importance of maintaining physical fitness through exercise and reconfirm the importance of weight maintenance in reducing mortality risk.

Keywords Body mass index · Body fat · Waist–hip ratio · Fitness · Mortality

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Introduction

An inverse relationship between body mass index and mortality among elderly populations has been documented in several studies among diverse ethnic groups.

Values for body mass index that are considered overweight, as well as other fatness indicators considered to be related to adverse outcomes in the general adult population, appear to confer some survival benefits among elderly populations with mean age of 70–80 years (Auyeung et al. 2010; Flicker et al. 2010; Lee et al. 2011a, b; Stessman et al. 2009; Woo et al. 2001, 2002). Cardiorespiratory fitness has been shown to modulate the adverse health outcomes of obesity in terms of mortality, morbidity, and the development of cardiovascular risk factors (Fogelholm 2010). A review of 36 studies showed that outcomes for participants who were obese and fit were better compared with those with normal weight but were unfit (Fogelholm 2010). However, only two studies examined the elderly population prospectively among Caucasian population aged >60 years (McAuley et al. 2009; Sui et al. 2007), and the lowest mortality was observed in obese men with high fitness, suggesting that in studies of the relationship between fatness and mortality, cardiorespiratory fitness may be a major confounder (McAuley et al. 2010b).

Findings from a previous study using data from the Mr & Ms Os cohort of elderly Chinese aged 65 years and above showed that survival in older men may benefit from being slightly overweight and centrally obese (Auyeung et al. 2010). However, the role of cardiorespiratory fitness in modulating this relationship was not addressed. The relative importance of fitness versus fatness and any interaction between them in predicting adverse outcomes in elderly populations has not been examined. Addressing this question is important in guiding health promotion efforts among the elderly with respect to lifestyle goals. Furthermore, it would contribute to understanding the underlying mechanisms for the obesity paradox (McAuley et al. 2010a). These research questions were explored using available data from a large cohort study.

Methods

Four thousand community-living Chinese men and women aged 65 years or over were recruited for a cohort study on osteoporosis and general health in Hong Kong between August 2001 and December 2003. Recruitment was by notices in senior social centers and housing estates as a large proportion of the elderly population resides in housing estates and attends senior social centers. Talks were given to explain the purpose, procedures, and investigations to be carried out. We excluded those who were unable to walk independently, had bilateral hip replacements, were not competent to give informed consent, and had medical conditions (in the judgment of the study physicians) which made it unlikely that they would survive a follow-up period of at least 4 years. The sample was stratified so that approximately 33% were in each of the age groups: 65–69, 70–74, and 75 or above. The study was approved by the Clinical Research Ethics Committee of the Chinese University of Hong Kong. All participants gave written consent to allow their personal, psychosocial, and physical data thus obtained to be used for research purposes.

A questionnaire containing information regarding demographics and medical history was administered by trained interviewers. Smokers were classified by having ever smoked more than five packs of cigarettes in the past, smoking currently, or never smoked. Medical diagnoses were based on the subjects' report of their physician's diagnoses, supplemented by medications brought to the interviewers. Diabetes, heart disease, and cancer were defined by self-reporting (ever being told to have the condition by a physician). Heart disease included coronary heart disease, heart failure, and myocardial infarction. The number of medications was taken as the total number of medications the participants were taking at the time of the assessment and which they brought to the place of the assessment. The name of the medication was recorded and subsequently classified into broad groups by a medical doctor.

Body weight was measured, with subjects wearing a light dressing gown, by the Physician Balance Beam Scale (Health-O-Meter, Arlington Heights, IL, USA). Height was measured by the Holtain Harpenden stadiometer (Holtain Ltd, Crosswell, UK). Waist circumferences (the circumference around the trunk midway between the rib cage and the pelvis) and hip circumferences (the maximum circumference around the buttock posteriorly and the pubis symphysis anteriorly) were measured with a flexible measuring tape. Only one measurement was taken. Four research assistants were involved in the measurement of the waist and the hip. The inter-rater reliability intra-class correlation using 15 subjects was 0.985 and 0.879 for waist and hip circumference, respectively.

Body composition (total body muscle mass, total body fat mass, and truncal fit mass) was measured by DXA using Hologic Delphi W4500 (Hologic Delphi, auto whole body version 12.4, Hologic Inc, Bedford, MA, USA) at baseline. The upper border of the abdominal region was defined by a horizontal line drawn through the lower one-third of the vertical height between the left midpoint acromion and the external end of left iliac crest. The lower border of the abdominal region was defined by a horizontal line through the external ends of the iliac crests (adapted from Bertin et al. 2000). The abdominal height was reduced to the lower one-third instead of the lower half as in the report by Bertin et al. because the latter method would have included the lungs and heart due to the smaller body size in the Chinese population. We were not able to use the method of measuring abdominal fat as defined by the region between the L1 and L4 vertebrae because many subjects had scoliosis and low bone mass, making the delineation of the upper or lower borders of these vertebrae difficult from a whole-body DXA scan. The relative truncal fat (RTF) was calculated as the proportion of abdominal fat within whole body fat (RTF = truncal fat/whole body fat ×100%). The maximum coefficient of variation for fat is 1.47%. Body mass index (BMI) was calculated by dividing the weight in kilograms by height in square meters. Body fat index (BFI) was calculated as the total body fat mass divided by height in square meters. Fat to lean mass ratio (FLMR), an indicator of fat to muscle mass, was calculated by dividing the total body fat mass by the total body muscle mass. Two indicators of visceral obesity were used: waist to hip ratio (WHR) and relative truncal fat (RTF).

Walking speed was measured using the average time in seconds to complete a walk along a straight line 6 m long. A warm-up period of <5 min was followed by two walks, and the average time recorded. In this study we used this measure as an indicator of cardiorespiratory fitness (CF) as it is easier to incorporate in large cohort studies, compared with maximal oxygen uptake (VO_{2max}) on treadmill or bicycle exercises. In a subgroup of the cohort during a subsequent follow-up, we measured VO_{2max} values in 757 men and 488 women and noted a good age-adjusted correlation between walking speed and VO_{2max} (Υ=0.43, P<0.001) (Yau 2011). This correlation was comparable to another indicator of CF used in other studies, the distance walked over 6 min (Υ=0.51, P<0.001) (Rolland et al. 2004; Simonsick et al. 2001). As we did not carry out the 6-min walk distance test at baseline but only measured the walking speed, the latter was used as a surrogate of CF.

After a mean follow-up period of 7.0±1.3 years, death was ascertained from the Hong Kong government's Death Registry in the Department of Health, with the cause of death classified according to the International Classification of Disease (ICD) version 10 codes.

Statistical analysis

Continuous variables are presented as mean ± SD and categorical variables as absolute and percentage. Descriptive statistics summarized baseline characteristics by BMI category. Subjects were also categorized based on their fitness (using walking speed as indicator, in meters per second) and fatness levels. Cox proportional hazards analyses were used to determine the associations of fitness category with time to death adjusting for age in years, sex, medical history (diabetes, stroke, hypertension, myocardial infarction, angina, and congestive heart failure), cardiovascular disease medications (angiotensin-converting enzyme inhibitors, aspirin, β-blockers, calcium channel blockers, and statins), current smoking, and BMI in kilograms per square meter, or other fatness indices (entered as continuous variables). The associations of each fatness index category with time to death were also determined by Cox proportional hazards analyses. For each fatness index, three multivariate models were undertaken, with the first model adjusting for age in years, sex, medical history, cardiovascular disease medications, and current smoking and the second model adjusting for the covariates included in model 1 with additional adjustment of fitness as a continuous variable, and the third model adjusting for the covariates included in model 2 with additional adjustment of the interaction term between each fatness index and fitness, e.g., BMI in kilograms per square meter × fitness in meters per second. Additionally, fitness–fatness groups were tested using chi-square tests, and the joint effects of fitness and fatness on time to death were determined by Cox proportional hazards analyses. Tests for linear trend in mortality across the fitness category of each fatness quartile were also obtained by using chi-square tests. All analyses were carried out using the Window-based SPSS statistical package (version 17.0; SPSS Inc., Chicago, IL), and P values less than 0.05 were considered statistically significant.

Results

The baseline characteristics of study participants are shown in Table 1. Compared with the high ambulatory

Table 1 Baseline characteristics of study participants

Variable	All (n=4,000)	BMI category Underweight < 18.5 (n=215)	Normal weight 18.5–24.9 (n=2,471)	Overweight 25.0–29.9 (n=1,190)	Obese ≥ 30.0 (n=124)
Demographics					
Age (years)	72.5±5.2	74.7±6.2	72.6±5.3	72.0±4.7	71.8±4.5
Fatness indicators					
BMI (kg/m^2)	23.7±3.3	17.2±1.1	22.3±1.7	26.8±1.3	31.9±1.9
BFI (kg/m^2)	7.1±2.4	3.3±1.2	6.3±1.6	8.8±1.8	12.1±2.1
FLMR (kg/kg)	0.5±0.2	0.3±0.1	0.4±0.1	0.5±0.1	0.7±0.2
WHR (cm/cm)	0.9±0.1	0.8±0.1	0.9±0.1	1.0±0.1	1.0±.01
RTF (kg/kg)	0.5±0.1	0.5±0.1	0.5±0.1	0.6±0.1	0.5±0.0
Medical history					
Diabetes	579 (14.5)	9 (4.2)	341 (13.8)	204 (17.1)	25 (20.2)
Stroke	175 (4.4)	8 (3.7)	111 (4.5)	53 (4.5)	3 (2.4)
Hypertension	1,707 (42.7)	41 (19.1)	955 (38.6)	650 (54.6)	61 (49.2)
Heart attack/coronary/myocardial infarction	393 (9.8)	7 (3.3)	217 (8.8)	149 (12.5)	20 (16.1)
Angina (chest pain)	352 (8.8)	10 (4.7)	186 (7.5)	135 (11.3)	21 (16.9)
Congestive heart failure/enlarged heart	151 (3.8)	7 (3.3)	78 (3.2)	62 (5.2)	4 (3.2)
Current smoker	275 (6.9)	37 (17.2)	176 (7.1)	57 (4.8)	5 (4.0)
Medications					
ACE inhibitor	438 (11.0)	14 (6.5)	230 (9.3)	172 (14.5)	22 (17.7)
Aspirin	446 (11.2)	13 (6.0)	253 (10.2)	162 (13.6)	18 (14.5)
Beta blocker	647 (16.2)	6 (2.8)	341 (13.8)	269 (22.6)	31 (25.0)
Calcium channel blocker	722 (18.1)	17 (7.9)	424 (17.2)	256 (21.5)	25 (20.2)
HMG CoA reductase inhibitor (statin)	238 (6.0)	3 (1.4)	125 (5.1)	98 (8.2)	12 (9.7)
Clinical					
SBP (mm Hg)	142.6±19.3	137.1±21.3	142.0±19.0	144.7±19.0	145.1±21.3
DBP (mm Hg)	77.8±9.2	74.8±9.9	77.4±9.2	78.9±9.0	81.2±8.5
Fitness (walking speed, m/s)[a]	0.97±0.22	0.93±0.25	0.98±0.22	0.95±0.21	0.89±0.21
Fitness category[b]					
Low fitness	1,338 (33.5)	84 (39.1)	763 (30.9)	436 (36.6)	55 (44.4)
Moderate fitness	1,339 (33.5)	63 (29.3)	823 (33.3)	414 (34.8)	39 (31.5)
High fitness	1,323 (33.1)	68 (31.6)	885 (35.8)	340 (28.6)	30 (24.2)

Data are presented as mean ± SD or number (percentage)

ACE angiotensin-converting enzyme inhibitor, *BFI* body fat index, *BMI* body mass index, *DBP* diastolic blood pressure, *FLMR* fat–lean mass ratio, *RTF* relative truncal fat, *SBP* systolic blood pressure, *WHR* waist to hip ratio

[a] Fitness was assessed with a 6-m walk test

[b] Fitness was assessed with a 6-m walk test. Fitness tertiles: 1st, walking speed <0.88 m/s (low fitness); 2nd, walking speed 0.88– <1.05 m/s (moderate fitness); 3 rd, walking speed ≥1.05 m/s (high fitness)

capacity (high fitness) category, those in the moderate and low categories have a 43% and 68% increased risk of mortality at 7 years adjusting for multiple confounders (Table 2). When mortality risk according to

Table 2 Multivariate proportional mortality hazard ratios (HRs) by fitness category in study participants

Fitness category[a]	No. of subjects	No. (%) of deaths	HR (95% CI)					
			Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Low fitness	1,338	209 (15.6)	1.65 (1.30–2.10)**	1.66 (1.30–2.11)**	1.68 (1.32–2.14)**	1.68 (1.32–2.14)**	1.65 (1.29–2.10)**	1.61 (1.27–2.05)**
Moderate fitness	1,339	159 (11.9)	1.41 (1.11–1.80)**	1.43 (1.12–1.81)**	1.44 (1.13–1.83)**	1.44 (1.13–1.83)**	1.41 (1.11–1.80)**	1.41 (1.11–1.80)**
High fitness	1,323	119 (9.0)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)

Model 1, adjusted for age, sex, medical history (diabetes, stroke, hypertension, myocardial infarction, angina, and congestive heart failure), current smoking, and CVD medications (ACE inhibitor, aspirin, beta blocker, calcium channel blocker, and statin)

Model 2, adjusted for covariates listed in model 1 plus BMI (entered as a continuous variable in kilograms per square meter)

Model 3, adjusted for covariates listed in model 1 plus BFI (entered as a continuous variable in kilograms per square meter)

Model 4, adjusted for covariates listed in model 1 plus FLMR (entered as a continuous variable in kilograms per kilogram)

Model 5, adjusted for covariates listed in model 1 plus WHR (entered as a continuous variable in centimeters per centimeter)

Model 6, adjusted for covariates listed in model 1 plus RTF (entered as a continuous variable in kilograms per kilogram)

CI confidence interval

**$P<0.01$

[a] Fitness was assessed with a 6-m walk test. Fitness tertiles: 1st, walking speed <0.88 m/s (low fitness); 2nd, walking speed 0.88– <1.05 m/s (moderate fitness); 3 rd, walking speed ≥1.05 m/s (high fitness)

various fatness indicators was examined, only the lowest quartile of BMI, BFI, and FLMR conferred statistically significant increased risk. The relationship with WHR, an indicator of visceral obesity, showed a U-shape relationship with mortality with the second quartile having the lowest risk. No association was observed with relative truncal fat (Table 3). These results were unchanged when fitness was added as a potential confounder (model 2, Table 3), suggesting that fatness and fitness have independent effects on mortality

Table 3 Multivariate proportional mortality hazard ratios (HRs) by fatness category in study participants

Fatness indicators	No. of subjects	No. (%) of deaths	Model 1		Model 2		Model 3		
			HR (95% CI)	*P* value	HR (95% CI)	*P* value	HR (95% CI)	*P* value	*P* interaction
BMI									
1st quartile	1,000	168 (16.8)	1.63 (1.27–2.11)	0.000	1.63 (1.26–2.10)	0.000	1.37 (1.00–1.88)	0.049	0.066
2nd quartile	1,000	96 (9.6)	1 (reference)	–	1 (reference)	–	1 (reference)	–	
3rd quartile	1,000	115 (11.5)	1.16 (0.88–1.52)	0.298	1.15 (0.88–1.51)	0.318	1.29 (0.95–1.73)	0.099	
4th quartile	1,000	108 (10.8)	1.20 (0.91–1.59)	0.192	1.16 (0.88–1.53)	0.299	1.53 (1.02–2.29)	0.038	
BFI									
1st quartile	1,000	194 (19.4)	1.37 (0.99–1.88)	0.056	1.44 (1.05–1.99)	0.025	1.20 (0.66–2.19)	0.553	0.474
2nd quartile	1,000	118 (11.8)	0.89 (0.64–1.23)	0.485	0.93 (0.67–1.29)	0.676	0.83 (0.52–1.31)	0.421	
3rd quartile	1,000	100 (10.0)	0.90 (0.66–1.23)	0.510	0.92 (0.67–1.26)	0.586	0.85 (0.59–1.24)	0.400	
4th quartile	1,000	75 (7.5)	1 (reference)	–	1 (reference)	–	1 (reference)	–	
FLMR									
1st quartile	1,000	196 (19.6)	1.71 (1.16–2.52)	0.007	1.83 (1.24–2.69)	0.002	1.87 (0.96–3.65)	0.065	0.930
2nd quartile	1,000	139 (13.9)	1.23 (0.84–1.80)	0.287	1.29 (0.88–1.88)	0.192	1.31 (0.78–2.21)	0.314	
3rd quartile	1,000	91 (9.1)	1.11 (0.78–1.56)	0.567	1.14 (0.81–1.60)	0.467	1.15 (0.76–1.72)	0.507	
4th quartile	1,000	61 (6.1)	1 (reference)	–	1 (reference)	–	1 (reference)	–	
WHR									
1st quartile	997	124 (12.4)	1.50 (1.14–1.98)	0.004	1.50 (1.14–1.98)	0.004	1.60 (1.16–2.20)	0.004	0.459
2nd quartile	962	86 (8.9)	1 (reference)	–	1 (reference)	–	1 (reference)	–	
3rd quartile	1,040	139 (13.4)	1.43 (1.09–1.87)	0.010	1.41 (1.08–1.85)	0.013	1.35 (1.01–1.81)	0.045	
4th quartile	1,000	138 (13.8)	1.42 (1.08–1.87)	0.012	1.34 (1.02–1.77)	0.036	1.21 (0.81–1.79)	0.358	
RTF									
1st quartile	1,000	126 (12.6)	1.28 (0.99–1.67)	0.061	1.25 (0.96–1.62)	0.098	1.36 (0.98–1.88)	0.068	0.412
2nd quartile	1,001	106 (10.6)	1 (reference)	–	1 (reference)	–	1 (reference)	–	
3rd quartile	999	125 (12.5)	0.93 (0.72–1.21)	0.606	0.93 (0.71–1.20)	0.565	0.88 (0.66–1.18)	0.384	
4th quartile	1,000	130 (13.0)	0.79 (0.60–1.03)	0.081	0.79 (0.60–1.03)	0.083	0.70 (0.46–1.04)	0.079	

BMI quartiles: 1st, < 21.57; 2nd, 21.57– < 23.53; 3rd, 23.53– < 25.72; 4th, ≥ 25.72. BFI quartiles: 1st, < 5.41; 2nd, 5.41– < 6.88; 3rd, 6.88– < 8.59; 4th, ≥ 8.59. FLMR quartiles: 1st, < 0.34; 2nd, 0.34– < 0.43; 3rd, 0.43– < 0.56; 4th, ≥ 0.56. WHR quartiles: 1st, < 0.88; 2nd, 0.88– < 0.92; 3rd, 0.92– < 0.97; 4th, ≥ 0.97. RTF quartiles: 1st, < 0.50; 2nd, 0.50– < 0.54; 3rd, 0.54– < 0.58; 4th, ≥ 0.58

Model 1, adjusted for age, sex, medical history (diabetes, stroke, hypertension, myocardial infarction, angina, and congestive heart failure/enlarged heart), current smoking, and CVD medications (ACE inhibitor, aspirin, beta blocker, calcium channel blocker, and statin)

Model 2, adjusted for covariates listed in model 1 plus fitness, i.e., walking speed in meters per second (entered as a continuous variable)

Model 3, adjusted for covariates listed in model 2 plus the interaction term between each fatness index and fitness, e.g., BMI in kilograms per square meter × walking speed in meters per second

P interaction = *P* values for interaction between each fatness index and fitness in the Cox proportional hazard model

BFI body fat index, *BMI* body mass index, *CI* confidence interval, *FLMR* fat–lean mass ratio, *RTF* relative truncal fat, *WHR* waist to hip ratio as a health outcome. Additional tests for interaction between fatness and fitness were not statistically significant (model 3, Table 3). However, fitness categories were significantly associated with all fatness indicators (Table 4). The association is generally inverse, with fewer people in the high fitness category among the highest quartiles of fatness indicators, the only exception being RTF. For the highest RTF quartile, there were more people in the high fitness category. The findings of fewer people in the high fitness category among the highest quartiles of other fatness indicators suggest that fitness is not the underlying mechanism for the obesity paradox.

In general, within each quartile of fatness indicator, there was a significant trend towards reduced mortality with increasing fitness. For BMI and FLMR, this trend was not observed for the highest quartile, suggesting that fitness does not have any beneficial effect on health outcome in terms of mortality for those in the highest quartiles of total body fat indicators (BMI, FLMR) (Tables 5 and 6). However, the protective effect of fitness was observed for all quartiles of abdominal obesity indicators (WHR and RTF) including the highest quartile (Tables 7 and 8).

Discussion

This study showed that among an elderly population with a mean age of 72 years, higher measures of body fat, particularly FLMR and RTF, were associated with

Table 4 Fatness indices and fitness categories

Fatness index	Fitness category[a]			*P* value
	Low fitness (*n*=1,338)	Moderate fitness (*n*=1,339)	High fitness (*n*=1,323)	
BMI				
1st quartile	331 (24.7)	330 (24.6)	339 (25.6)	0.000
2nd quartile	314 (23.5)	310 (23.2)	376 (28.4)	
3rd quartile	318 (23.8)	349 (26.1)	333 (25.2)	
4th quartile	375 (28.0)	350 (26.1)	275 (20.8)	
BFI				
1st quartile	286 (21.4)	284 (21.2)	430 (32.5)	0.000
2nd quartile	263 (19.7)	357 (26.7)	380 (28.7)	
3rd quartile	355 (26.5)	339 (25.3)	306 (23.1)	
4th quartile	434 (32.4)	359 (26.8)	207 (15.6)	
FLMR				
1st quartile	265 (19.8)	288 (21.5)	447 (33.8)	0.000
2nd quartile	264 (19.7)	357 (26.7)	379 (28.6)	
3rd quartile	370 (27.7)	340 (25.4)	290 (21.9)	
4th quartile	439 (32.8)	354 (26.4)	207 (15.6)	
WHR				
1st quartile	292 (21.8)	351 (26.2)	354 (26.8)	0.000
2nd quartile	282 (21.1)	323 (24.1)	357 (27.0)	
3rd quartile	339 (25.3)	331 (24.7)	370 (28.0)	
4th quartile	425 (31.8)	334 (24.9)	241 (18.2)	
RTF				
1st quartile	384 (28.7)	343 (25.6)	273 (20.6)	0.000
2nd quartile	348 (26.0)	334 (24.9)	319 (24.1)	
3rd quartile	326 (24.4)	316 (23.6)	357 (27.0)	
4th quartile	280 (20.9)	346 (25.8)	374 (28.3)	

BMI quartiles: 1st, < 21.57; 2nd, 21.57– < 23.53; 3rd, 23.53− < 25.72; 4th, ≥ 25.72. BFI quartiles: 1st, < 5.41; 2nd, 5.41– < 6.88; 3rd, 6.88– < 8.59; 4th, ≥ 8.59. FLMR quartiles: 1st, < 0.34; 2nd, 0.34– < 0.43; 3rd, 0.43– < 0.56; 4th, ≥ 0.56. WHR quartiles: 1st, < 0.88; 2nd, 0.88– < 0.92; 3rd, 0.92– < 0.97; 4th, ≥ 0.97. RTF quartiles: 1st, < 0.50; 2nd, 0.50– < 0.54; 3rd, 0.54– < 0.58; 4th, ≥ 0.58

P values were obtained by using chi-square test

BFI body fat index, *BMI* body mass index, *FLMR* fat–lean mass ratio, *RTF* relative truncal fat, *WHR* waist to hip ratio

[a] Fitness was assessed with a 6-m walk test. Fitness tertiles: 1st, walking speed < 0.88 m/s (low fitness); 2nd, walking speed 0.88– < 1.05 m/s (moderate fitness); 3rd, walking speed ≥ 1.05 m/s (high fitness)

Table 5 Multivariate proportional mortality hazard ratios (HRs) by body mass index (BMI) and fitness category in study participants

Fitness category[a]	No. of subjects	No. (%) of deaths	*P* trend[b]	HR (95% CI)[c]	*P* value
BMI<18.5 (kg/m^2)					
Low fitness	84	29 (34.5)	0.018	3.34 (2.13–5.24)	0.000
Moderate fitness	63	15 (23.8)		2.67 (1.54–4.73)	0.001
High fitness	68	12 (17.6)		2.17 (1.18–4.01)	0.013
BMI 18.5–24.9 (kg/m^2)					
Low fitness	763	115 (15.1)	0.000	1.61 (1.19–2.18)	0.002
Moderate fitness	823	102 (12.4)		1.54 (1.14–2.07)	0.005
High fitness	885	76 (8.6)		1 (reference)	–
BMI 25.0–29.9 (kg/m^2)					
Low fitness	436	59 (13.5)	0.010	1.66 (1.17–2.36)	0.005
Moderate fitness	414	40 (9.7)		1.22 (0.83–1.80)	0.315
High fitness	340	27 (7.9)		0.92 (0.59–1.43)	0.697
BMI≥30.0 (kg/m^2)					
Low fitness	55	6 (10.9)	0.874	1.65 (0.71–3.84)	0.242
Moderate fitness	39	2 (5.1)		0.78 (0.19–3.19)	0.730
High fitness	30	4 (13.3)		1.53 (0.56–4.22)	0.407

BMI body mass index, *CI* confidence interval

[a] Fitness was assessed with a 6-m walk test. Fitness tertiles: 1st, walking speed < 0.88 m/s (low fitness); 2nd, walking speed 0.88– < 1.05 m/s (moderate fitness); 3 rd, walking speed ≥ 1.05 m/s (high fitness)

[b] *P* values for trend were obtained by using chi-square test (linear-by-linear association)

[c] Adjusted for age, sex, medical history (diabetes, stroke, hypertension, myocardial infarction, angina, and congestive heart failure), current smoking, and CVD medications (ACE inhibitor, aspirin, beta blocker, calcium channel blocker, and statin)

lower mortality, confirming results of previous studies using BMI, and the observation of an obesity paradox. It also confirms that lower cardiorespiratory fitness as measured by the 6-m walk was associated with increased mortality. However, no interaction between fatness and fitness measures was detected with respect to mortality, although within each fatness quartile for measures of abdominal fat (RTF and WHR) and for total body fat (BMI and FLMR) except for the highest quartile, increasing levels of fitness was associated with decreasing mortality. Fitness did not account for the obesity paradox, since higher levels of fitness were not present in subjects with higher BMI or other fatness measures, with the exception of RTF. The finding of higher level of fitness in those with higher RTF in Table 4 is difficult to explain, as it is against the trend for other fatness indicators. It is unlikely to be explained by a different association between fitness and abdominal fatness compared with total body fatness, since this was not observed for another measure of abdominal fatness, the waist to hip ratio (WHR). The finding may be related to the method of analysis, since Table 4 represents a cross-sectional association between fatness and fitness, and the results may be misleading compared with prospective analyses using Cox proportional hazards model. Using the latter method, both measures of abdominal fat (WHR and RTF) gave the same trends, with lower hazard ratios for mortality with increasing fatness quartiles and a decreasing mortality trend with increasing fitness within each fatness quartile.

This finding contrasts with other studies of the general adult population (Fogelholm 2010) and does not support the suggestion that fitness may account for the obesity paradox as suggested by McAuley et al. (2010a). Two previous prospective studies were carried out in elderly Caucasian cohorts. Sui et al. (2007) followed up 2087 men and 516 women aged 60–100 years in the USA for a mean of 12 years and showed that for all BMI categories 18–≥ 35 kg/m^2, mortality risk was highest among these classified as unfit compared with those who were fit. In another study of 981 men with a mean age of 65 years, mortality was increased for those

Table 6 Multivariate proportional mortality hazard ratios (HRs) by fat–lean mass ratio (FLMR) and fitness category in study participants

Fitness category[a]	No. of subjects	No. (%) of deaths	*P* trends[b]	HR (95% CI)[c]	*P* value
FLMR 1st quartile					
Low fitness	265	74 (27.9)	0.000	2.16 (1.07–4.39)	0.033
Moderate fitness	288	69 (24.0)		2.31 (1.13–4.70)	0.022
High fitness	447	53 (11.9)		1.15 (0.56–2.36)	0.715
FLMR 2nd quartile					
Low fitness	264	54 (20.5)	0.000	1.59 (0.78–3.24)	0.205
Moderate fitness	357	48 (13.4)		1.30 (0.63–2.67)	0.480
High fitness	379	37 (9.8)		1.00 (0.48–2.09)	0.993
FLMR 3rd quartile					
Low fitness	370	46 (12.4)	0.007	1.44 (0.72–2.89)	0.303
Moderate fitness	340	26 (7.6)		1.02 (0.49–2.13)	0.964
High fitness	290	19 (6.6)		0.97 (0.45–2.11)	0.934
FLMR 4th quartile					
Low fitness	439	35 (8.0)	0.063	1.24 (0.61–2.51)	0.555
Moderate fitness	354	16 (4.5)		0.89 (0.40–1.96)	0.764
High fitness	207	10 (4.8)		1 (reference)	–

FLMR quartiles: 1st, < 0.34; 2nd, 0.34– < 0.43; 3rd, 0.43– < 0.56; 4th, ≥ 0.56

CI confidence interval, *FLMR* fat–lean mass ratio

[a] Fitness was assessed with a 6-m walk test. Fitness tertiles: 1st, walking speed < 0.88 m/s (low fitness); 2nd, walking speed 0.88– < 1.05 m/s (moderate fitness); 3 rd, walking speed ≥ 1.05 m/s (high fitness)

[b] *P* values for trend were obtained by using chi-square test (linear-by-linear association)

[c] Adjusted for age, sex, medical history (diabetes, stroke, hypertension, myocardial infarction, angina, and congestive heart failure), current smoking, and CVD medications (ACE inhibitor, aspirin, beta blocker, calcium channel blocker, and statin)

with BMI < 20 kg/m^2 and decreased with increasing BMI values to ≥ 35 kg/m^2, being lowest in the latter group. Mortality risk also decreased with increasing fitness (McAuley et al. 2009). The lowest mortality risk occurred among the obese, highly fit participants. It is interesting to speculate on the underlying mechanism(s) for the obesity paradox, if cardiorespiratory fitness is unlikely to be a factor. It is possible that among older people aged 70 years and over, weight loss exerts a greater impact on mortality as it may be an indicator of frailty (Morley 2007) and that higher levels of body fat may represent better reserve for episodes of acute illness when negative energy balance is more likely to occur.

This study also provides another novel contribution to existing literature, in that we were able to examine fatness indicators other than BMI, and such analyses have not been carried out previously. It is recognized that BMI may have limitations as the main marker for obesity. Total body fat, fat to lean mass ratio, and the distribution of body fat may be better indicators. The findings of this study also have important implications for public health, in highlighting that promotion/maintenance of fitness reduces mortality even in old age, whatever the level of body fatness. Furthermore, those with the lowest quartile of fatness measures have the highest mortality, irrespective of fitness levels. These findings show that public health guidelines for the general adult population may need to be modified for people aged 70 years and above, placing the emphasis on avoiding of weight loss as well as maintenance of fitness, rather than on weight reduction towards values for middle-age adults. These observations are important in view of the growing numbers of people in this age group, with population ageing in many developed countries.

Another novel aspect of this study is the assessment of walking speed as an indicator of cardiorespiratory fitness. This has not been examined in younger adult

Table 7 Multivariate proportional mortality hazard ratios (HRs) by waist–hip ratio (WHR) and fitness category in study participants

Fitness category[a]	No. of subjects	No. (%) of deaths	*P* trends[b]	HR (95% CI)[c]	*P* value
WHR 1st quartile					
Low fitness	292	52 (17.8)	0.001	2.68 (1.62–4.42)	0.000
Moderate fitness	351	39 (11.1)		2.06 (1.23–3.46)	0.006
High fitness	354	33 (9.3)		1.65 (0.97–2.81)	0.067
WHR 2nd quartile					
Low fitness	282	26 (9.2)	0.177	1.39 (0.79–2.45)	0.260
Moderate fitness	323	37 (11.5)		1.88 (1.12–3.18)	0.017
High fitness	357	23 (6.4)		1 (reference)	–
WHR 3rd quartile					
Low fitness	339	56 (16.5)	0.026	2.42 (1.47–3.96)	0.000
Moderate fitness	331	43 (13.0)		2.04 (1.23–3.39)	0.006
High fitness	370	40 (10.8)		1.60 (0.96–2.67)	0.074
WHR 4th quartile					
Low fitness	425	75 (17.6)	0.002	2.58 (1.60–4.18)	0.000
Moderate fitness	334	40 (12.0)		1.89 (1.13–3.17)	0.016
High fitness	241	23 (9.5)		1.31 (0.73–2.34)	0.366

WHR quartiles: 1st, < 0.88; 2nd, 0.88– < 0.92; 3rd, 0.92– < 0.97; 4th, ≥ 0.97

CI confidence interval, *WHR* waist to hip ratio

[a] Fitness was assessed with a 6-m walk test. Fitness tertiles: 1st, walking speed < 0.88 m/s (low fitness); 2nd, walking speed 0.88– < 1.05 m/s (moderate fitness); 3rd, walking speed ≥ 1.05 m/s (high fitness)

[b] *P* values for trend were obtained by using chi-square test (linear-by-linear association)

[c] Adjusted for age, sex, medical history (diabetes, stroke, hypertension, myocardial infarction, angina, and congestive heart failure), current smoking, and CVD medications (ACE inhibitor, aspirin, beta blocker, calcium channel blocker, and statin)

population, who may undertake treadmill or bicycle test with the measurement of maximal oxygen uptake with little difficulty. However, ageing adults may have increasing difficulty with using this equipment as a result of various stages of functional decline, so alternative safer and less costly assessments based on self-walking test have been developed. These are based on the distance covered by the subject within a defined time. Originally a 12-min walk test was developed to predict maximal oxygen uptake among athletes (Cooper 1968), and later a 6-min walk test became widely used for assessing older people with a wide spectrum of health and functional state (Simonsick et al. 2000; Troosters et al. 1999). We further adapted this measure to use the time taken to walk along a corridor over a distance of 6 m, recognizing that fitness may be underestimated as the warm-up effect may be lost due to the short distance walked. The advantage is that it is quick and suitable for the clinical and epidemiological research settings where associations with health outcomes and monitoring changes with time may be more important than accurate absolute values. The use of walking speed as an indicator of fitness is more accurate than assessment of physical activity using questionnaire such as the Physical Activity Scale for the Elderly (PASE) (Washburn et al. 1993). In a subgroup of 754 men and 488 women in whom maximal oxygen uptake was measured during the follow-up period, the age-adjusted correlation between maximal oxygen uptake with PASE was only 0.24 in men and 0.21 in women (Yau 2011). Recently, slow walking speed was shown to be a predictor of cardiovascular death in a French cohort study (Dumurgier et al. 2009).

Walking speed as a measure of fitness is particularly relevant for older populations with respect to gradual decline into the frail state, a physiological syndrome

Table 8 Multivariate proportional mortality hazard ratios (HRs) by relative truncal fat (RTF) and fitness category in study participants

Fitness category[a]	No. of subjects	No. (%) of deaths	P trends[b]	HR (95% CI)[c]	P value
RTF 1st quartile					
Low fitness	384	60 (15.6)	0.033	2.32 (1.40–3.83)	0.001
Moderate fitness	343	38 (11.1)		1.91 (1.13–3.24)	0.017
High fitness	273	28 (10.3)		1.70 (0.97–2.98)	0.063
RTF 2nd quartile					
Low fitness	348	48 (13.8)	0.004	1.93 (1.15–3.23)	0.012
Moderate fitness	334	36 (10.8)		1.73 (1.02–2.95)	0.043
High fitness	319	22 (6.9)		1 (Reference)	–
RTF 3rd quartile					
Low fitness	326	54 (16.6)	0.003	1.73 (1.05–2.87)	0.033
Moderate fitness	316	39 (12.3)		1.58 (0.94–2.67)	0.087
High fitness	357	32 (9.0)		1.06 (0.61–1.83)	0.837
RTF 4th quartile					
Low fitness	280	47 (16.8)	0.009	1.50 (0.90–2.52)	0.123
Moderate fitness	346	46 (13.3)		1.27 (0.76–2.12)	0.365
High fitness	374	37 (9.9)		0.93 (0.55–1.58)	0.789

RTF quartiles: 1st, < 0.50; 2nd, 0.50– < 0.54; 3rd, 0.54– < 0.58; 4th, ≥ 0.58

CI confidence interval, *RTF* relative truncal fat

[a] Fitness was assessed with a 6-m walk test. Fitness tertiles: 1st, walking speed < 0.88 m/s (low fitness); 2nd, walking speed 0.88– < 1.05 m/s (moderate fitness); 3 rd, walking speed ≥ 1.05 m/s (high fitness)

[b] P values for trend were obtained by using chi-square test (linear-by-linear association)

[c] Adjusted for age, sex, medical history (diabetes, stroke, hypertension, myocardial infarction, angina, and congestive heart failure), current smoking, and CVD medications (ACE inhibitor, aspirin, beta blocker, calcium channel blocker, and statin)

characterized by decreased reserve and diminished resistance to stressors as a result of cumulative decline across multiple physiological systems. Slow walking speed has been included as one of the features of the frailty phenotype (Fried et al. 2001) and indicator of frailty (Harwood and Conroy 2009), as well as one of the definitions of sarcopenia (Cruz-Jentoft et al. 2010). For the latter a cut-off value of walking speed of 1 m/s had been proposed. In our study, the high fitness category had a walking speed of ≥ 1.05 m/s, a value associated with lowest mortality and also ameliorating the adverse impact of body fatness on health outcomes.

There are limitations in this study. The participants were not representative of the Hong Kong population, in that their education level was higher. The results may not be strictly comparable with other studies that used different measures of cardiorespiratory fitness. Nevertheless, we have attempted to validate the use of walking speed in a subsequent subgroup study where maximal oxygen uptake was measured. The numbers of participants in the lowest and highest categories of BMI were smaller compared with those in the 18.5–29.9 kg/m^2 range. It is possible that the findings may be different with larger numbers. We chose these BMI categories for comparison with other studies examining cardiorespiratory fitness with health outcomes. For other fatness indicators, there were larger numbers in each subgroup as quartile values were used. The strengths of this study include the large number of participants, the inclusion of women, the relatively long duration of follow-up, the use of DEXA to measure body composition, and adjustment for multiple potential confounders.

In conclusion, the study confirms the beneficial effects of cardiorespiratory fitness on mortality but does not explain the obesity paradox. The findings underscore the importance of maintaining physical fitness through exercise and re-confirm the importance of weight maintenance in reducing mortality risk.

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References

Auyeung TW, Lee JS, Leung J, Kwok T, Leung PC, Woo J (2010) Survival in older men may benefit from being slightly overweight and centrally obese—a 5-year follow-up study in 4,000 older adults using DXA. J Gerontol A Biol Sci Med Sci 65(1):99–104

Bertin E, Marcus C, Ruiz JC, Eschard JP, Leutenegger M (2000) Measurement of visceral adipose tissue by DXA combined with anthropometry in obese humans. Int J Obes Relat Metab Disord 24(3):263–270

Cooper KH (1968) A means of assessing maximal oxygen intake. Correlation between field and treadmill testing. JAMA 203(3):201–204

Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F et al (2010) Sarcopenia: European consensus on definition and diagnosis: report of the European Working Group on sarcopenia in older people. Age Ageing 39 (4):412–423

Dumurgier J, Elbaz A, Ducimetiere P, Tavernier B, Alperovitch A, Tzourio C (2009) Slow walking speed and cardiovascular death in well functioning older adults: prospective cohort study. BMJ 339:b4460

Flicker L, McCaul KA, Hankey GJ, Jamrozik K, Brown WJ, Byles JE et al (2010) Body mass index and survival in men and women aged 70 to 75. J Am Geriatr Soc 58(2):234–241

Fogelholm M (2010) Physical activity, fitness and fatness: relations to mortality, morbidity and disease risk factors. A systematic review. Obes Rev 11(3):202–221

Fried LP, Tangen CM, Walston J, Newman AB, Hirsch C, Gottdiener J et al (2001) Frailty in older adults: evidence for a phenotype. J Gerontol A Biol Sci Med Sci 56(3): M146–M156

Harwood RH, Conroy SP (2009) Slow walking speed in elderly people. BMJ 339:b4236

Lee CG, Boyko EJ, Nielson CM, Stefanick ML, Bauer DC, Hoffman AR et al (2011a) Mortality risk in older men associated with changes in weight, lean mass, and fat mass. J Am Geriatr Soc 59(2):233–240

Lee JS, Auyeung TW, Kwok T, Li M, Leung J, Woo J (2011b. DOI 10.1007/s11357-011-9272-y). Survival benefit of abdominal adiposity: a 6-year follow-up study with Dual X-ray absorptiometry in 3,978 older adults. Age (Dordr)

McAuley P, Pittsley J, Myers J, Abella J, Froelicher VF (2009) Fitness and fatness as mortality predictors in healthy older men: the veterans exercise testing study. J Gerontol A Biol Sci Med Sci 64(6):695–699

McAuley PA, Kokkinos PF, Oliveira RB, Emerson BT, Myers JN (2010a) Obesity paradox and cardiorespiratory fitness in 12,417 male veterans aged 40 to 70 years. Mayo Clin Proc 85(2):115–121

McAuley PA, Sui X, Blair SN (2010b) Letter by McAuley et al regarding article, "Impact of body mass index and the metabolic syndrome on the risk of cardiovascular disease and death in middle-aged men". Circulation 122(11):e455, author reply e457

Morley JE (2007) Weight loss in older persons: new therapeutic approaches. Curr Pharm Des 13(35):3637–3647

Rolland YM, Cesari M, Miller ME, Penninx BW, Atkinson HH, Pahor M (2004) Reliability of the 400-m usual-pace walk test as an assessment of mobility limitation in older adults. J Am Geriatr Soc 52(6):972–976

Simonsick EM, Gardner AW, Poehlman ET (2000) Assessment of physical function and exercise tolerance in older adults: reproducibility and comparability of five measures. Aging (Milano) 12(4):274–280

Simonsick EM, Montgomery PS, Newman AB, Bauer DC, Harris T (2001) Measuring fitness in healthy older adults: the Health ABC Long Distance Corridor Walk. J Am Geriatr Soc 49(11):1544–1548

Stessman J, Jacobs JM, Ein-Mor E, Bursztyn M (2009) Normal body mass index rather than obesity predicts greater mortality in elderly people: the Jerusalem longitudinal study. J Am Geriatr Soc 57(12):2232–2238

Sui X, LaMonte MJ, Laditka JN, Hardin JW, Chase N, Hooker SP et al (2007) Cardiorespiratory fitness and adiposity as mortality predictors in older adults. JAMA 298(21):2507–2516

Troosters T, Gosselink R, Decramer M (1999) Six minute walking distance in healthy elderly subjects. Eur Respir J 14 (2):270–274

Washburn RA, Smith KW, Jette AM, Janney CA (1993) The Physical Activity Scale for the Elderly (PASE): development and evaluation. J Clin Epidemiol 46(2):153–162

Woo J, Ho SC, Sham A (2001) Longitudinal changes in body mass index and body composition over 3 years and relationship to health outcomes in Hong Kong Chinese age 70 and older. J Am Geriatr Soc 49(6):737–746

Woo J, Ho SC, Yu AL, Sham A (2002) Is waist circumference a useful measure in predicting health outcomes in the elderly? Int J Obes Relat Metab Disord 26(10):1349–1355

Yau CFF (2011) Cardiorespiratory fitness of Hong Kong Chinese elderly and its relationship between physical activity participation and health. The Chinese University of Hong Kong, Shatin