ORIGINAL INVESTIGATION

Obesity, Physical Activity, and Mortality in a Prospective Chinese Elderly Cohort

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Background: In older people, it is unclear whether obesity relates to mortality, which calls into question its etiologic role in disease and its public health relevance. This apparent lack of relationship in older people could be an artifactual result of their diverse health states.

Methods: We used Cox regression analysis to determine whether the effect of body mass index (BMI) (calculated as weight in kilograms divided by the square of height in meters) or physical activity on mortality varied with health status in a prospective cohort study of Chinese people 65 years or older enrolled from 1998 to 2000 at all of the 18 Elderly Health Centers of the Hong Kong Government Department of Health. Health status was categorized into 5 morbidity groups using a 12-item index covering illnesses, medications, frailty, and smoking.

Results: After a mean follow-up of 4.1 years, there were 3819 deaths in 54 088 subjects (96.5% successful follow-up). The effect of BMI on mortality varied with baseline health status ($P<.001$). In the healthiest group, obese people (BMI ≥25) had higher mortality (adjusted hazard ratio [HR], 1.54; 95% confidence interval [CI], 1.02-2.33), but in the unhealthiest group they had lower mortality (HR, 0.55; 95% CI, 0.49-0.63) compared with subjects of normal weight. Daily physical activity was associated with lower mortality compared with inactivity in the unhealthiest group (HR, 0.70; 95% CI, 0.61- 0.81) but not in the healthiest group.

Conclusions: In the elderly, the relationship between obesity and mortality varies according to the underlying health status. In those with poor health status, obesity is associated with better outcome, whereas in those with initially good health status, obesity is associated with worse outcome.

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OBESITY AND PHYSICAL INactivity are major universal public health concerns. There is persuasive evidence from prospective studies that obesity and inactivity substantially contribute to all-cause and cause-specific mortality in younger and middle-aged adults,[1] which is consistent with known causal pathways in chronic diseases.[2,3] In older adults (at least 65 years) the relationship between obesity and survival is unclear,[4] which raises questions about its etiologic role, the significance of obesity in deaths attributable to lifestyle habits,[5] and the appropriate public health interventions for the rapidly growing older population worldwide. Understanding the role of obesity and inactivity in older adults is especially urgent in countries such as China where there is increasing obesity and inactivity[6] and an increasing proportion of older people. Hong Kong, with a 95% ethnic Chinese population but a longer history of economic development, can forewarn what may confront older people in mainland China and other developing countries in Asia.

A small number of prospective studies in older Chinese or ethnically similar groups show that physical activity is associated with higher survival rates,[7,8] but higher body mass index (BMI) (calculated as weight in kilograms divided by the square of height in meters) may also be associated with survival.[7,9,10] These latter findings are echoed by a recent large, representative study in the United States showing little excess risk associated with obesity in people 60 years or older.[5] It has been argued that this lack of relationship is an artifact due to reverse causality because lower BMI is the result, not the cause, of underlying illness, so morbidity at baseline can induce reverse causation.[11,12] If baseline health status were a missing variable in the observed obesity-

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Table 1. Comparison of the Sample and the Population of the Same Age Range From Population Surveys*[14-16]

Characteristic	Elderly Health Center Subjects			Age-Matched General Population		
	Male	Female	Total	Male	Female	Total
Persons, No.	18 750	37 417	**56 167**	345 200	401 900	**747 100**
Age group, y						
65-74	66.8	65.3	65.8	66.5	56.9	61.4
75-84	29.7	30.0	29.9	27.9	32.5	30.3
≥85	3.6	4.7	4.3	5.6	10.6	8.3
Cohen effect size†				0.09	0.22	0.15
Smoking status‡§						
Never	39.2	88.4	71.7			
Former smoker	40.8	7.5	18.8	78.2	95.1	87.1
Current smoker	20.0	4.1	9.5	21.8	4.9	12.9
Cohen effect size†				0.04	0.04	0.10
Education						
Tertiary	6.8	1.8	3.5	5.9	2.0	3.8
Secondary	23.5	7.9	13.1	21.3	8.8	14.6
Primary	51.8	29.1	36.7	49.5	30.3	39.2
None	18.0	61.2	46.8	23.3	58.9	42.4
Cohen effect size†				0.13	0.05	0.08
Self-owned housing‡						
Yes	50.0	49.4	49.6			47.9
No	50.0	50.6	50.4			52.0
Cohen effect size†						0.05
Hospital use‡						
In the last year	13.8	12.3	12.8	16.5	15.2	15.8
Cohen effect size†				0.07	0.08	0.08

*Unless otherwise indicated, data are reported as column percentage of population.

†Cohen effect sizes have 3 levels: 0.1 for small, 0.3 for medium, and 0.5 for large.[17] Cohen effect sizes are calculated as $\sqrt{(\Sigma\ (p_{0i} - p_{1i})^2/p_{0i})}$ where the sum is over the categories and p_{0i} is the proportion in the ith category in the population and p_{1i} is the proportion in the ith category in the sample.

‡For direct comparability with population, survey includes only the 18 164 men and 35 596 women in the Elderly Health Center sample living in the community.

§Population survey covers those 60 years or older.

mortality relationship, we would expect heterogeneity across health states for BMI and possibly for physical activity, which might also be the result but not the cause of health status. Identifying whether health status is such a missing variable is crucial to interpreting observed relationships in older people and to assessing public health impacts. Although some studies have attempted to control for reverse causation by excluding deaths in the first few years of follow-up, to our knowledge no studies have examined how a comprehensive assessment of baseline health status affects the relationship between obesity or physical activity and mortality.[13] In a large, prospective cohort of older Chinese people, we examined the effect of obesity and physical activity on mortality, stratified by baseline health status.

METHODS

SAMPLE

In July 1998, 18 Elderly Health Centers were established to deliver health examinations and primary care services for older adults by the Department of Health of the Government of the Hong Kong Special Administrative Region. All residents in Hong Kong 65 years or older were encouraged to enroll. This study covered all 56 167 enrollees from July 1998 to December 2000. More women were enrolled than men; otherwise, the subjects were similar to the general elderly population in age, socioeconomic status, current smoking status, and hospital use (**Table 1**).

Trained nurses and doctors provided health assessments and physical check-ups using structured interviews and comprehensive clinical examinations. The health assessment covered functional status, falls, hospital admissions, weight loss, use of medication, reported chronic illness (hypertension, diabetes, chronic obstructive pulmonary disease [COPD] and/or asthma, heart disease, and stroke), lifestyle habits (physical activity, smoking history, and use of alcohol) and socioeconomic status (education, housing, and monthly expenditure). At the examination, height and weight were recorded, and blood pressure was measured according to standard protocols. Self-reports of chronic diseases were confirmed and supplemented by clinical diagnoses based on history. Physical functioning was assessed using Activities of Daily Living (ADL) (Katz index) and Instrumental Activities of Daily Living (IADL) scales. Cognitive functioning was assessed by the Abbreviated Mental Test–Modified (AMT-M).[18]

Body mass index was classified according to guidelines for the Asian Pacific population[19] (underweight, <18.5; normal, 18.5 to <23; at risk of obesity or overweight, 23 to <25; obese I, 25 to <30; and obese II, ≥30). There were few subjects (6.3%) in the obese II category, so a single category was used as in previous studies in these subjects.[20] Underweight in older people is associated with morbidity[21] and would be expected to be associated with mortality. Physical activity was categorized as none, 30 min/d or less, and more than 30 min/d based on simple questions concerning the frequency per week and duration per session of leisure exercise; simple questions can maximize reliability and validity of physical activity assessment.[22] Consistent with their age, over 85% reported relatively low-intensity exercise such as stretching exercises, walking slowly, or traditional Chinese exercises.

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HEALTH STATUS

There are several morbidity, comorbidity, or prognostic indices for older people, often designed for specific purposes such as predicting short-term mortality in hospitalized patients[23] or to make the best use of restricted subsets of information such as electronic records[24] or self-reports,[25] which may include BMI.[25] Nevertheless, indices based on simple counts of chronic conditions, health services use, and preferably measures of frailty (physical or cognitive functioning) can perform well.[23-26] There is no such validated index for Asians in a primary care setting. Consistent with other prognostic indices, we constructed a simple but comprehensive 12-item index by counting chronic conditions (5 items), use of health services (2 items), and frailty (3 items). We also included an additional 2 items specifically relevant to the obesity-mortality relationship: unintentional weight loss of more than 4.5 kg in the last 6 months and ever smoking.[5] Thus, healthy never smokers and ever smokers were automatically separated into different groups. Chronic diseases included were heart disease, stroke, diabetes, COPD and/or asthma, and hypertension (reported or measured blood pressure ≥140/90 mm Hg). Measures of health service use were regular use of medication and any hospital admission in the last year. Measures of frailty were cognitive impairment (AMT-M score, <8), functional impairment (ADL/IADL score, >12), and 2 or more falls in the last 6 months. Current cancer status was not ascertained because people receiving cancer treatment were not enrolled in the primary care service. Health status was categorized into 5 morbidity groups based on this index, as a count of 0, 1, 2, 3, and 4 or more of the 12 items. As a sensitivity analysis, we also examined 2 morbidity groups, those with and without any morbidity.

FOLLOW-UP

Vital status and causes of death were ascertained from death registration and special outpatient and hospitalization databases in Hong Kong by record linkage using the unique Hong Kong identity card number. The last date of follow-up or the censored date was December 31, 2003. The subjects not found dead or alive by record linkage were followed up by telephone interview from November 2004 to January 2005, after which only 3.5% (1952) remained untraced. Adjusted for age, sex, socioeconomic status, lifestyle habits, and health status, the untraced subjects were no different in BMI or physical activity from the others but were older and had less morbidity. Reanalysis with subjects lost to follow-up assumed to have survived until the end of the study made no substantive difference in the results. Among the 54 216 traced subjects, 3884 had died by December 31, 2003. Causes of death obtained for 3829 were routinely coded by the governmental Department of Health according to the *International Classification of Diseases, Ninth Revision (ICD-9)* before 2001 and *ICD-10* in and after 2001. Most Hong Kong residents die in the hospital, enabling accurate ascertainment of cause of death, which our group has used previously in similar studies.[27] In the present study, after 1952 clients with no follow-up information and 129 clients with missing relevant baseline data were excluded, 54 088 remained for final analysis, including 3819 deaths.

STATISTICAL ANALYSIS

We used χ^2 tests to compare proportions of subject characteristics across BMIs and physical activity groups. The Cox proportional hazards model was used to estimate the hazard ratios (HRs) and the 95% confidence intervals (95% CIs) for all-cause and cause-specific mortality by BMI and physical activity group adjusted for baseline potential confounders (age in 5-year age groups, sex, education, monthly personal expenditure, housing type, ever use of alcohol, and ever smoking), categorized as in **Table 2**. Men and women were analyzed together unless there was evidence that BMI or physical activity had different effects by sex. Possible effect modification was assessed from the significance of interaction terms and the heterogeneity of effect across strata. The proportional hazards assumption was checked by visual inspection of plots of log (–log S) against time, where S was the estimated survival function. For cause-specific analyses, subjects who died of any other causes were regarded as censored at the date of death.[28,29] Ethics approval was obtained from the ethics committee of the Faculty of Medicine, the University of Hong Kong. The study complied with the Declaration of Helsinki.

RESULTS

Table 2 lists sociodemographic, lifestyle, and health status at baseline by BMI and physical activity groups. High BMI was more common in the younger age groups, women, the less educated, and never smokers. Physical inactivity was more common in men and the younger and older age groups. Good health status was associated with normal weight. Poor health status was associated with overweight and underweight.

After a mean (SD) follow-up of 4.1 (0.9) years, 3819 subjects had died. Adjusting for age, sex, socioeconomic status, and lifestyle habits, we found that higher BMI and physical activity were associated with lower mortality (**Table 3**) in a dose-response manner. The lowest risk of mortality was in the highest BMI group (HR, 0.75; 95% CI, 0.70-0.82) compared with the normal BMI group, and in the most active (HR, 0.73; 95% CI, 0.67-0.80) compared with the inactive. Similar HRs were obtained when deaths within the first 2 years were excluded. Similarly adjusted, higher BMI and physical activity were associated with survival for cause-specific mortality. The association between higher BMI and survival was strongest for respiratory mortality and weakest for cardiovascular mortality. Physical activity was more strongly associated with survival from respiratory and cardiovascular mortality than from cancer mortality. There was no evidence that the effect of BMI or physical activity on all-cause mortality varied with sex, education, or ever smoking ($P>.05$ uniformly). Visual inspection (by C.M.S. and a blinded, independent statistician) of log (–log) plots showed that the proportional hazards assumption was satisfied for BMI and physical activity in these models.

The crude 3-year mortality rate increased steadily with the 12-item morbidity index (**Figure**). There was a significant interaction ($P<.001$) between the 5 health status groups and BMI group, though not between health status and physical activity ($P=.61$), physical activity and BMI ($P=.07$), or among all 3 ($P>.50$). Higher BMI was most strongly associated with survival for those with the most morbidity (**Table 4**), had less effect in intermediate health states, and showed reverse effect in the healthy group with no morbidity, where high BMI was significantly associated with mortality (HR, 1.54; 95% CI, 1.02-2.33) compared with normal BMI. In contrast, physical activity was most strongly associated with survival for

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Table 2. Baseline Characteristics of 54 088 Elderly Health Centers Clients in Hong Kong by Body Mass Index and Physical Activity*

	BMI					Physical Activity				
Characteristic	<18.5	18.5 to <23	23 to <25	≥25	*P* Value†	None	≤30 min/d	>30 min/d	*P* Value†	Total
Sex					<.001				<.001	
Female	1900	11 066	7809	15 187		5177	12 990	17 795		**35 962**
	(64.2)	(64.6)	(64.3)	(69.5)		(63.0)	(68.0)	(66.4)		(66.5)
Male	1061	6074	4334	6657		3044	6100	8982		**18 126**
	(35.8)	(35.4)	(35.7)	(30.5)		(37.0)	(32.0)	(33.5)		(33.5)
Age, y					<.001				<.001	
65-69	763	6373	4989	9186		3594	7328	10 389		**21 311**
	(25.8)	(37.2)	(41.1)	(42.1)		(43.7)	(38.4)	(38.8)		(39.4)
70-74	826	5040	3770	7134		2364	5785	8621		**16 770**
	(27.9)	(29.4)	(31.1)	(32.7)		(28.8)	(30.3)	(32.2)		(31.0)
75-79	721	3309	2168	3769		1373	3587	5007		**9967**
	(24.4)	(19.3)	(17.9)	(17.3)		(16.7)	(18.8)	(18.7)		(18.4)
80-84	403	1640	896	1354		608	1651	2034		**4293**
	(13.6)	(9.6)	(7.4)	(6.2)		(7.4)	(8.7)	(7.6)		(7.9)
>85	248	778	320	401		282	739	726		**1747**
	(8.4)	(4.5)	(2.6)	(1.8)		(3.4)	(3.9)	(2.7)		(3.2)
Education					<.001				<.001	
Secondary or above	554	3152	2104	3156		1461	3204	4301		**8966**
	(18.7)	(18.4)	(17.3)	(14.5)		(17.8)	(16.8)	(16.1)		(16.6)
Primary	1108	6712	4566	7520		3133	7041	9732		**19 906**
	(37.4)	(39.2)	(37.6)	(34.4)		(38.1)	(36.9)	(36.3)		(36.8)
No formal education but literate	499	2728	2017	3855		1290	3231	4578		**9099**
	(16.9)	(15.9)	(16.6)	(17.7)		(15.7)	(16.9)	(17.1)		(16.8)
Illiterate	800	4548	3456	7313		2337	5614	8166		**16 117**
	(27.0)	(26.5)	(28.5)	(33.5)		(28.4)	(29.4)	(30.5)		(29.8)
Housing					<.001				<.001	
Public or aided	1502	8179	5799	10511		4302	9278	12 411		**25 991**
	(50.7)	(47.7)	(47.8)	(48.1)		(52.3)	(48.5)	(46.4)		(48.1)
Private	1204	8118	5914	10 574		3686	8754	13 370		**25 810**
	(40.7)	(47.4)	(48.7)	(48.4)		(44.8)	(45.9)	(49.9)		(47.7)
Temporary, institution or others	255	843	430	759		233	1058	996		**2287**
	(8.6)	(4.9)	(3.5)	(3.5)		(2.8)	(5.5)	(3.7)		(4.2)
Monthly personal expenditure, HK $					.005				<.001	
<1000	516	2686	1804	3302		1389	3142	3777		**8308**
	(17.4)	(15.7)	(14.9)	(15.1)		(16.9)	(16.5)	(14.1)		(15.4)
1000-1999	1102	6538	4629	8493		2979	7413	10 370		**20 762**
	(37.2)	(38.1)	(38.1)	(38.9)		(36.2)	(38.8)	(38.7)		(38.4)
2000-2999	916	5121	3716	6530		2329	5486	8468		**16 283**
	(30.9)	(29.9)	(30.6)	(29.9)		(28.3)	(28.7)	(31.6)		(30.1)
≥3000	427	2795	1994	3519		1524	3049	4162		**8735**
	(14.4)	(16.3)	(16.4)	(16.1)		(18.5)	(16.0)	(15.5)		(16.2)
Alcohol					<.001				<.001	
Ever drinker	753	4551	3248	5598		2336	5093	6721		**14 150**
	(25.4)	(26.6)	(26.8)	(25.6)		(28.4)	(26.7)	(25.1)		(26.2)
Smoking					<.001				<.001	
Ever smoker	1198	5329	3390	5427		2831	5421	7092		**15 344**
	(40.5)	(31.1)	(27.9)	(24.8)		(34.4)	(28.4)	(26.5)		(28.4)
Health status (No. of morbidities in 12-item index)					<.001				<.001	
None	344	1916	1089	1445		719	1607	2468		**4794**
	(11.6)	(11.2)	(9.0)	(6.6)		(8.8)	(8.4)	(9.2)		(8.7)
1	722	4339	2792	4487		1933	4273	6134		**12 340**
	(24.4)	(25.3)	(23.0)	(20.5)		(23.5)	(22.4)	(22.9)		(22.8)
2	779	4670	3520	6539		2269	5398	7841		**15 508**
	(26.3)	(27.3)	(29.0)	(29.9)		(27.6)	(28.3)	(29.3)		(28.8)
3	532	3435	2583	5193		1757	4095	5891		**11 743**
	(18.0)	(20.0)	(21.3)	(23.8)		(21.4)	(21.5)	(22.0)		(21.7)
4-12	584	2780	2159	4180		1543	3717	4443		**9703**
	(19.7)	(16.2)	(17.8)	(19.1)		(18.8)	(19.5)	(16.6)		(18.0)

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by the square of height in meters); HK $, Hong Kong dollars (1.00 US $ = 7.80 HK $).

*Unless otherwise indicated, data are reported as number (column percentage) of subjects.

†By χ^2 test.

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Table 3. Risk for All-Cause and Cause-Specific Mortality by Body Mass Index and Physical Activity of Elderly Health Center Clients in Hong Kong*

			BMI					Physical Activity			
Cause of Death	Deaths, No.	Age at Death, Mean (SD), y	<18.5	18.5 to <23	23 to <25	≥25	*P* Value†	None	≤30 m/d	>30 m/d	*P* Value†
All causes	3819	78.7 (6.9)	1.78‡ (1.61-1.97)	1.00	0.84‡ (0.77-0.92)	0.75‡ (0.70-0.82)	<.001	1.00	0.83‡ (0.76-0.91)	0.73‡ (0.67-0.80)	<.001
All causes excluding deaths within first 2 y	2354	79.5 (6.74)	1.72‡ (1.51-1.97)	1.00	0.87§ (0.78-0.97)	0.83‡ (0.75-0.92)	<.001	1.00	0.87§ (0.77-0.98)	0.77‡ (0.69-0.87)	<.001
Cancer	1503	77.1 (6.3)	1.60‡ (1.35-1.91)	1.00	0.81‖ (0.70-0.93)	0.82‖ (0.72-0.92)	<.001	1.00	0.87 (0.75-1.01)	0.86§ (0.74-0.99)	.06
Cardiovascular	1041	79.2 (6.6)	1.13 (0.90-1.42)	1.00	0.97 (0.83-1.14)	0.81§ (0.70-0.94)	.01	1.00	0.79§ (0.67-0.94)	0.63‡ (0.53-0.74)	<.001
Respiratory	563	81.1 (7.0)	3.71‡ (3.02-4.54)	1.00	0.62‡ (0.48-0.81)	0.52‡ (0.41-0.66)	<.001	1.00	0.84 (0.67-1.05)	0.66‖ (0.53-0.84)	<.001
Other and unknown	712	79.1 (7.1)	1.48‖ (1.15-1.89)	1.00	0.86 (0.70-1.05)	0.70§ (0.58-0.84)	<.001	1.00	0.82 (0.66-1.01)	0.70‖ (0.57-0.86)	.001

Abbreviation: BMI, body mass index (calculated as weight in kilograms divided by the square of height in meters).

*Unless otherwise indicated, data are reported hazard ratios (95% confidence intervals) mutually adjusted for age, sex, education, ever-drinking alcohol, ever smoking, monthly personal expenditure, housing and the other category (ie, BMI or physical activity).

†For linear trend.

‡*P*<.001.

§*P*<.05.

‖*P*<.005.

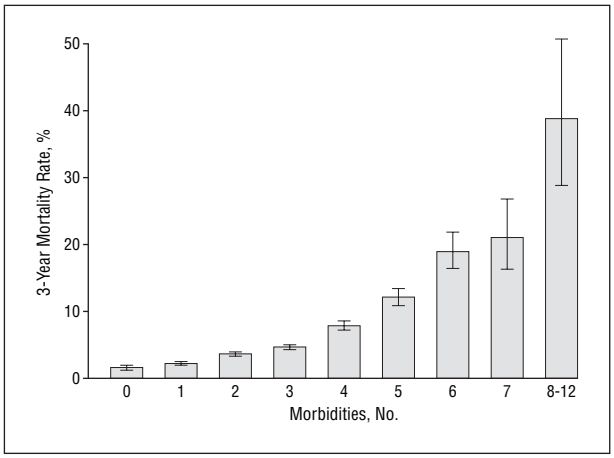

Figure. The Kaplan-Meier estimate of the 3-year mortality rate by number of morbidities in the 12-item index. Range brackets indicate 95% confidence intervals.

those with the most morbidity but unrelated to survival for people with less morbidity. Underweight was consistently associated with higher mortality. This pattern of results persisted within age group stratifications, where there were also significant interactions between health status and BMI for subjects aged 65 to 74 years and those in the 75 years or older groups (*P*<.001 and *P*<.01, respectively). Sensitivity analysis comparing the no morbidity group with the rest also showed significantly different effects by BMI group (*P*=.001).

COMMENT

Overall, consistent with previous studies in older Chinese and Japanese people,[7,9] BMI was apparently inversely related to all-cause mortality. However, the relationship was not consistent, varying with cause of death and most importantly with baseline health status. Respiratory mortality had a steep inverse gradient with BMI, while cardiovascular mortality had a shallower gradient. Inverse gradients between BMI and mortality from some respiratory diseases and heart failure have been found elsewhere.[30,31] In healthy older Chinese people, with a relatively low mortality rate, there was a positive relationship between obesity and mortality, as in younger adults.[32,33] In less healthy older Chinese people, with a higher mortality rate, there was an inverse, dose-response relationship between BMI and mortality, strongest in the group with the most morbidity, which is consistent with other studies of individuals in poor health.[30,31,34] On the other hand, consistent with other studies in older people,[35] physical activity was independently associated with lower mortality.

One interpretation of our results is as an accurate representation of the relationship between adiposity and mortality, given the baseline level of ill health in our population, and thus as an appropriate estimate of the causal effect of adiposity at this life stage on mortality.[5,13] Yet statistical interaction does not imply biological synergy; there is little physiological evidence for a causally protective role of adiposity, strongest in ill health, and respiratory diseases. In addition, physical activity, which normally has a negative relationship with adiposity,[36] had the largest impact on survival for the health states, with the strongest inverse relationship between BMI and mortality. This suggests that for persons in poor health, physical activity is not associated with lower mortality because of its role in reducing the adiposity component of weight. Conversely, for those in good health, there was no relationship between physical activity and mortality,

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Table 4. Risk for All-Cause Mortality by Body Mass Index and Physical Activity of Elderly Health Center Clients in Hong Kong*

Comorbidities, No.	Deaths, No.	BMI					Physical Activity			
		<18.5	18.5 to <23	23 to <25	≥25	*P* Value†	None	≤30 min/d	>30 min/d	*P* Value†
4-12	1481	1.76‡ (1.51-2.07)	1.00	0.72‡ (0.63-0.83)	0.55‡ (0.49-0.63)	<.001	1.00	0.81§ (0.70-0.93)	0.70‡ (0.61-0.81)	<.001
3	894	1.81‡ (1.45-2.26)	1.00	0.70‡ (0.58-0.84)	0.64‡ (0.55-0.75)	<.001	1.00	0.85 (0.70-1.03)	0.77‖ (0.64-0.93)	.01
2	864	2.22‡ (1.81-2.73)	1.00	0.82‖ (0.68-0.99)	0.72‡ (0.61-0.85)	<.001	1.00	0.74§ (0.61-0.90)	0.70‡ (0.58-0.84)	.001
1	446	1.41‖ (1.01-1.97)	1.00	1.04 (0.81-1.33)	0.98 (0.78-1.23)	.68	1.00	0.92 (0.70-1.21)	0.83 (0.63-1.08)	.14
0	134	1.76‖ (1.00-3.08)	1.00	0.96 (0.58-1.59)	1.54‖ (1.02-2.33)	.16	1.00	1.24 (0.71-2.19)	1.15 (0.66-1.99)	.83

Abbreviation: BMI, body mass index (calculated as weight in kilograms divided by the square of height in meters).

*Unless otherwise indicated, data are reported hazard ratios (95% confidence intervals) mutually adjusted for age, sex, education, ever drinking alcohol, ever smoking, monthly personal expenditure, housing and the other category (ie, BMI or physical activity).

†For linear trend.

‡$P<.001$.

§$P<.005$.

‖$P<.05$.

possibly because these older people had greater "constitution reserve" and less "need" for physical activity to maintain health. Overall, it is hard to reconcile these observations with the adiposity component of BMI being the causative factor in the inverse relationship between BMI and mortality in this age group.

Another interpretation is as a survivor effect. As with any cohort of older people, with increasing age, the subjects are progressively more strongly selected survivors. However, health status similarly modified the effect of BMI on mortality in both the younger (65-74 years) and older (≥75 years) groups, which suggests that survivorship is not the main explanation.

Alternatively, and most likely, the interpretation is that BMI at older ages is also a marker of other factors, which may predominate over the effects of adiposity at the end of life but do not negate the role of adiposity in ill health and mortality across the lifespan.[12] These other factors are fitness (including of the immune system) and muscle mass, so that BMI maintenance in older people is an overall marker of health representing a complex interaction of the known pattern of lifetime weight change (gain till about age 65 years, then loss[37]), which is most likely cumulative, detrimental adiposity gain in young to middle age and loss of fat-free mass (cachexia) with increasing age, ill-health,[38] and proximity to death. For a healthy older person, high BMI may represent adiposity, with its well-known detrimental effects. For an older person with multiple health problems, high BMI may indicate that the disease process is not yet overwhelming and extending to cachexia, while lower BMI may indicate overwhelming disease and cachectic weight loss, so BMI represents the severity of disease. Body mass index may appear protective, but only as a marker of health state, not causally. Hence BMI measured at older ages is inappropriate to assess the causal risks of adiposity and should not be interpreted as such.

A weakness of our study is that health status was not assessed using a validated morbidity index, as none appropriate to our setting and study is available. One recent validated example used BMI as a component of health status.[25] However, in keeping with other indices,[23] we included chronic illnesses, health services use, and also the multiple domains relevant to prognosis.[24-26] We also tailored the index to include items specifically relevant to the obesity-mortality relationship, such as ever smoking and unintended weight loss. The index had face validity, with mortality steadily increasing with morbidity count. In addition, comparing those subjects with and without any morbidity produced a similar pattern of risk associated with high BMI in the healthy group and low BMI in the less healthy group.

Second, the subjects were volunteers. However, in Hong Kong, most primary care is fee for service, so the Elderly Health Centers provide a popular service, whose enrollees matched the relevant population quite closely. Moreover, we examined prospective mortality by predefined health states within the cohort.

Third, we focused on all-cause mortality because of the public health implications of interpreting that relationship with BMI in older people. Fourth, as in many epidemiologic studies, we assessed physical activity from questions sufficient only to obtain broad rankings. Nevertheless, physical activity showed clear dose-response effects; any misclassification would make our findings conservative.

Our study had several strengths. The successful follow-up rate was 96.5%. Assuming that those lost to follow-up survived until study end made no difference in the findings. The sample size was large enough to examine interactions. Wide-ranging baseline data covered multiple domains of health. The period of follow-up was relatively short, reducing errors due to change in BMI or baseline health status. In addition, we showed that excluding deaths in the first 2 years of follow-up to allow for reverse causation due to baseline ill health did not change the inverse relationship

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between BMI and mortality, while stratifying by health status revealed the heterogeneous effect of BMI on mortality across health states.

In conclusion, our study is the first to our knowledge to demonstrate that the effect of obesity on mortality varies with health state in older people. There are no known physiologic reasons for this variation; rather, there is evidence to the contrary.[39] Our study adds weight to the hitherto unsubstantiated argument that observed relationships between obesity and mortality in older persons are artifactual results of reverse causality, probably induced by baseline morbidity (the end point of which is death) causing weight loss. Relationships between higher BMI and survival should not be interpreted as causal without considering the often unmeasured effect modification by health status. Moreover, our study is the first to our knowledge to demonstrate that over a short follow-up period (<5 years), high BMI was associated with higher mortality for never-smoking older adults in good health. Recent research suggesting that there are few excess deaths due to obesity[5] should not distract from the urgent need for public health interventions to combat obesity at all ages, possibly with the greatest benefit coming from preventing obesity in the young and middle-aged rather than older people. Nevertheless, proper interpretation of the effects of adiposity in old age is urgent and key to developing effective public health strategies everywhere.

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