

# BMJ Open Body mass index trajectories and mortality in community-dwelling older adults: population-based cohort study

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## ABSTRACT

**Objective** Both low and high body mass index (BMI) have been associated with greater mortality in older adults. This study aimed to evaluate the trajectory of BMI in the final years of life.

**Methods** A population-based cohort study was conducted including community-dwelling adults in the English Longitudinal Study of Ageing between 1998 and 2012. BMI was evaluated in relation to age and years before death. Number of long-term conditions, cigarette smoking and socioeconomic position were evaluated as effect modifiers.

**Results** Data were analysed for 16 924 participants with 31 857 BMI records; mean age at study starts, 61.6 (SD 10.9) years; mean BMI, 27.5 (4.7) Kg/m<sup>2</sup>. There were 3686 participants (4794 BMI records) who died and 13 238 participants (27 063 BMI records) who were alive at last follow-up. Mean BMI increased with age to 60–69 years but then declined, but the age-related decline was more rapid in decedents. From 4 to 7 years before death or end of study, adjusted mean BMI was 0.87 (95% CI 0.50 to 1.24) Kg/m<sup>2</sup> lower for male decedents than survivors and 1.02 (0.56 to 1.47) lower in women; and from 3 to 0 years before death, BMI was 1.39 (0.98 to 1.80) Kg/m<sup>2</sup> lower in male decedents and 2.12 (1.60 to 2.64) lower in female decedents. Multiple long-term conditions and lower socioeconomic position were associated with higher peak BMI and greater BMI decline; current smoking was associated with lower BMI and greater BMI decline.

**Conclusions** In community-dwelling older adults, mean BMI enters an accelerating decline from up to 8 years before death. Multiple long-term conditions, smoking and lower socioeconomic position are associated with BMI decline.

## INTRODUCTION

The recent increase in obesity has accentuated the development of multiple morbidity at middle and older ages,<sup>1</sup> focusing attention on the association of body mass index (BMI) with mortality.<sup>2</sup> Meta-analyses of cohort studies suggest that there is strong association between BMI and all-cause mortality,<sup>3–5</sup> but there is evidence of ‘U’ or ‘J’-shaped relationship with either low or high BMI being associated with greater mortality than normal body weight or overweight.<sup>6–9</sup> The association of BMI with mortality may vary with age. In middle-age, obesity is associated

## STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ This study analysed data for 16 924 participants with 31 857 body mass index (BMI) records from the English Longitudinal Study of Ageing from 1998 to 2012.
- ⇒ Linear mixed models were employed to estimate the difference in BMI between decedents and survivors by time before death or end of study.
- ⇒ Mortality follow-up ended in 2012 and follow-up for survivors was at predefined time intervals.
- ⇒ Non-response bias and sample attrition have potential to bias estimates

with greater mortality but, over the age of 65 years, mortality may be more strongly associated with low BMI and possible sarcopenia.<sup>10</sup> ‘Reverse causation’ is believed to account for the association of low BMI with mortality, because illnesses leading to death may be associated with weight loss.<sup>11</sup> However, there is only limited direct evidence for reverse causation because only a minority of studies have included longitudinal measurements of body weight.<sup>12</sup> Systolic blood pressure and total cholesterol values show similar patterns of association with either low or high blood pressure or total cholesterol being associated with higher mortality.<sup>13 14</sup> Longitudinal analysis of blood pressure and cholesterol values recorded into electronic health records found evidence that both blood pressure and total cholesterol values decline towards the end of life.<sup>15 16</sup> This supports a possible role of reverse causation in explaining the associations of low blood pressure or low total cholesterol with mortality. We hypothesised that BMI may show a declining trajectory towards the end of life. We aimed to analyse data from a cohort of older adults from the English Longitudinal Study of Ageing (ELSA)<sup>17</sup> in order to evaluate changes in BMI values in the period before death. We also investigated whether there was evidence that BMI trajectories varied for groups of

participants defined by level of morbidity, smoking and socioeconomic position.

## METHODS

### Study design and participants

A retrospective cohort study was conducted using the ELSA.<sup>18</sup> The initial ELSA cohort included community-dwelling adults aged 50 and over, and their younger partners, drawn from households that responded to the Health Survey for England in 1998, 1999 and 2001 (wave 0). Participants were 16 924 participants aged 40–90 years with data for BMI at wave 0. Participants aged less than 40 years were excluded, as were participants aged more than 90 years because their exact ages were not available for analysis. A flowchart for participant and data selection is shown in online supplemental figure 1. Separate data files for each year of data collection at wave 0, and for each subsequent wave, were linked using the unique participant identifier that was employed to track individual participants across waves. Covariate data were drawn from wave 0 files as outlined below.

### Measures

Measurements of height and weight were recorded by nurse fieldworkers at waves 0, 2, 4 and 6. Standing height was measured using a portable stadiometre without shoes. One measurement was taken with participants stretching with the head in the Frankfort plane. Weight was measured in light clothing using portable electronic scales.<sup>19</sup> One BMI value of  $<10 \text{ Kg/m}^2$  was omitted. Mortality was all-cause mortality up to February 2012, the latest date when the ELSA study mortality data were updated from the National Health Service Central Data Registry records.<sup>20</sup> Covariates included age at measurement and the number of years before death. For decedents, years till death were calculated as the difference between the year of death recorded in the ELSA data set and the year of measurement. For survivors, years till end of study were calculated as 2012 (the last year of mortality follow-up) minus the year of measurement. Because follow-up was conducted in waves, only selected values of years till end of study were possible for survivors. Covariate data from wave 0 included gender, ethnicity ('white', 'non-white') highest educational qualifications (categories: not applicable; degree or equivalent; higher education below degree; a level or equivalent; General Certificate of Education Ordinary (GCE O) level or equivalent; other; foreign qualification; no qualification), housing tenure (categories: owner; buying with mortgage including part rent and part mortgage; rented; live rent free; other and not applicable) and social class (categories: professional and managerial or technical; skilled non-manual; skilled manual, semiskilled and unskilled manual; armed forces, other and not applicable). We also included cigarette smoking (never smoked, former occasional smoker and former regular smoker, current smoker), alcohol consumption in units per week ( $<7$ , 7 to

$<14$ , 14 to  $<21$ ,  $\geq 21$  and not known), and number of long-term conditions up to four or more. Eligible long-term conditions included neoplasms, infections and disorders affecting the endocrine, mental health, nervous, eye, ear, cardiac, respiratory, digestive, genitourinary, skin, musculoskeletal and haematological systems.

### Statistical analysis

Recorded BMI values represented the units for analysis. Linear mixed models were employed to model repeated BMI values over time, with a random intercept at the participant-level using the 'xtreg' command in Stata V.14.<sup>21</sup> A test for interaction revealed strong evidence that the association of BMI with either age and or years till death differed by mortality status. Models were, therefore, fitted separately for participants who died (decedents) and those who were alive at the end of follow-up (survivors). Data for men and women were also considered separately.<sup>22</sup> In order to provide a consistent modelling approach, age and years till death were fitted as continuous variables, together with quadratic terms to allow for non-linearity. The mean difference in BMI between survivors and decedents was estimated for the periods 0 to 3, 4 to 7 and 8 or more years before death by fitting linear mixed models with time before death in categories and including participant as a random intercept. These estimates were adjusted for age, age-squared, cigarette smoking, alcohol consumption, number of long-term conditions, social class, housing tenure and education. In order to visualise the data, with more flexible curve fitting, fractional polynomials for age were employed using the 'fpfitci' command in Stata V.14. Curves were estimated separately for subgroups of long-term conditions, cigarette smoking and socioeconomic position including housing tenure and social class.

### Patient and public involvement

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination plans of our research.

## RESULTS

The cohort included 16 924 participants with 31 857 BMI records. There were 3686 participants, with 4794 BMI records, who died; and 13 238 participants, with 27 063 BMI records who did not die at end of follow-up (table 1). Compared with survivors, decedents were older and included more men, current or former smokers, had more long-term conditions and generally had lower socioeconomic position based on social class, housing tenure and educational qualifications (table 1).

Table 2 shows the distribution of mean BMI by gender, age-group and years till death or end of study. Mean BMI was generally similar for men and women, but the SD for BMI was greater in women consistent with the greater prevalence of severe obesity in women. In survivors, mean BMI increased from  $27.1 \text{ Kg/m}^2$  at age 40–44 years to

**Table 1** Characteristics of survivors and decedents at baseline (wave 0)

Variable	Category	Survivors (13 238)	Decedents (3686)
Gender	Female	7625 (58)	1783 (48)
Ethnicity	Non-white	497 (4)	54 (1)
Age (years)	Mean, SD	59 (10)	71 (10)
Smoking	Never	5208 (39)	1013 (27)
	Former	5386 (41)	1798 (49)
	Current	2644 (20)	875 (24)
Alcohol (units per week)	<7	6185 (47)	1706 (46)
	7 to 13	2260 (17)	558 (15)
	14 to 20	1299 (10)	265 (7)
	≥21	2182 (16)	525 (14)
	Not recorded	1312 (10)	632 (17)
LTC count	None	6234 (47)	1061 (29)
	1	4169 (31)	1258 (34)
	2	1941 (15)	832 (23)
	3	660 (5)	372 (10)
	≥4	234 (2)	163 (4)
Social class	Professional	802 (6)	156 (4)
	Managerial	3983 (30)	841 (23)
	Skilled non-manual	2171 (16)	658 (18)
	Skilled manual	3297 (25)	1048 (28)
	Semiskilled manual	1959 (15)	637 (17)
	Unskilled manual	774 (6)	249 (7)
	Not classified	252 (2)	97 (3)
Housing tenure	Owner-occupier	6178 (47)	1998 (54)
	Mortgage holder	4723 (36)	492 (13)
	Rented	2226 (17)	1146 (31)
	Living rent free	111 (1)	50 (1)
Education	Degree	1496 (11)	210 (6)
	College below degree	1461 (11)	233 (6)
	A level or equivalent	884 (7)	138 (4)
	O level or equivalent	2350 (18)	333 (9)
	CSE or other	582 (4)	218 (6)
	Foreign qualifications	1019 (8)	284 (8)
	No qualification	5446 (41)	2270 (62)

Figures are frequencies (per cent of column total).  
CSE, Certificate of Secondary Education; LTC, long-term condition.

28.1 Kg/m<sup>2</sup> between 55 and 74 years, before declining to 26.6 Kg/m<sup>2</sup> at age 85 to 90 years. A similar pattern was observed in decedents, but the highest BMI was observed between 45 and 64 years and the mean BMI in the oldest age-group was lower at 25.6 Kg/m<sup>2</sup>. In survivors, mean BMI tended to increase over time from 27.4 Kg/m<sup>2</sup> at 14 years before the end-of-study to 28.2 Kg/m<sup>2</sup> at the end-of-study. In decedents, mean values were less stable because of the smaller number of observations. However, mean

BMI declined in the last 5 years of life from 27.5 Kg/m<sup>2</sup> 5 years before death to 26.0 Kg/m<sup>2</sup> in the last year of life.

Figure 1 (left panel) shows mean BMI values (points) and predicted BMI values (lines) by single year of age for survivors (blue) and decedents (red). BMI increased up to approximately age 65 years. Over the age of 70 years, mean BMI declined with each increasing year of age, with the decline being more rapid in decedents than survivors. In survivors, points were generally close to predicted values;

**Table 2** Body mass index (BMI) by gender, age-group and years till death or end of study

		Survivors		Decedents	
		Frequency	Mean BMI (SD)	Frequency	Mean BMI (SD)
Gender	Men	11 657	27.8 (4.1)	2496	27.2 (4.5)
	Women	15 406	27.9 (5.3)	2298	27.0 (5.3)
Age at measurement (years)	40–44	411	27.1 (5.8)	7	27.1 (4.5)
	45–54	5294	27.5 (4.8)	283	28.1 (6.3)
	55–64	9436	28.1 (5.0)	732	28.1 (5.4)
	65–74	7724	28.1 (4.7)	1534	27.5 (5.0)
	75–84	3677	27.7 (4.5)	1801	26.6 (4.5)
	85–90	521	26.6 (4.4)	437	25.6 (3.9)
Years till death or end of study	0	3228	28.2 (5.1)	150	26.0 (4.9)
	–1		–	385	26.4 (5.0)
	–2		–	443	26.7 (4.6)
	–3	2483	28.3 (5.3)	448	27.0 (5.2)–
	–4	2314	28.3 (5.0)	416	26.8 (4.9)
	–5		–	425	27.5 (4.9)
	–6		–	471	27.4 (5.2)
	–7	3212	28.0 (4.8)	421	26.9 (5.0)
	–8	2588	27.9 (4.8)	350	27.5 (4.9)
	–9		–	318	27.2 (4.7)
	–10		–	333	27.2 (4.6)
	–11	5261	27.8 (4.7)	242	27.7 (4.7)
	–12			191	28.1 (5.5)
	–13	2621	27.4 (4.6)	165	27.5 (4.7)
	–14	5356	27.4 (4.5)	36	28.0 (4.4)

Figures are mean (SD) BMI.

in decedents, while points were close to predicted values at older ages, at young ages where there were fewer deaths, there were outlying values of either high or low BMI values.

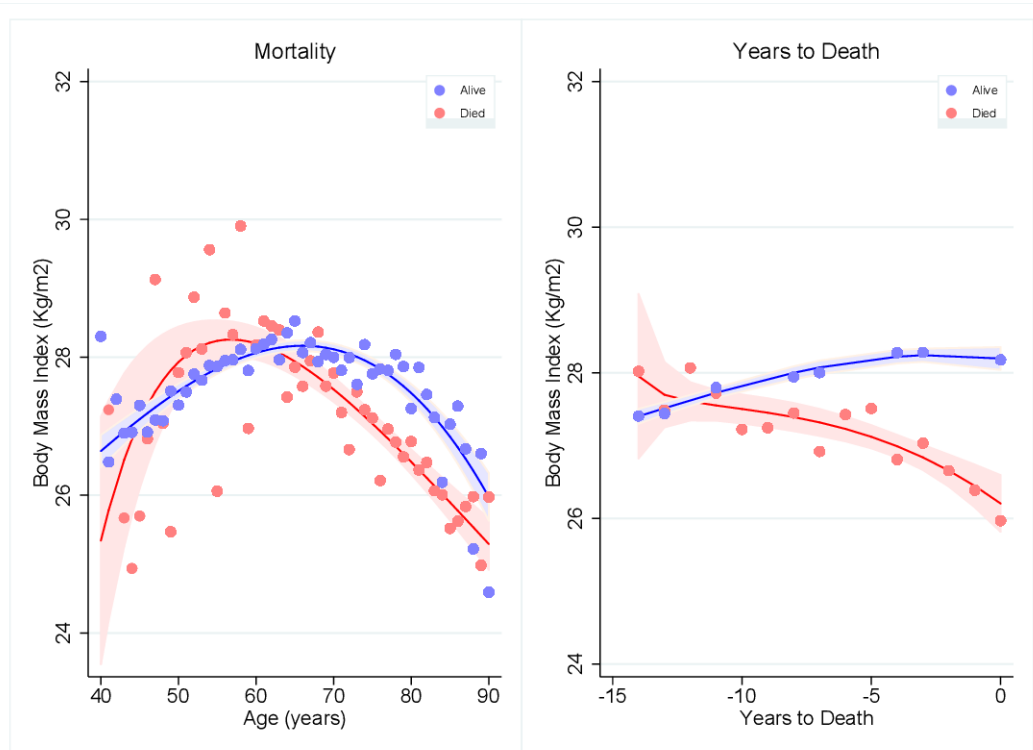
Figure 1 (right panel) shows mean BMI values (95% CIs) by year before death for decedents or end-of-study for survivors, together with predicted values from a fractional polynomial model. While BMI remained stable or increased in survivors, there was evidence of declining BMI towards the end of life in decedents.

Table 3 provides coefficients from linear mixed models. Age was associated with positive coefficients in both decedents and survivors. By contrast, years to death was associated with a positive coefficient in survivors, indicating a generally increasing trend over time up to the end of study; but the equivalent coefficient was negative in decedents, indicating a decreasing trend in BMI towards death. Quadratic terms for age and years to death were associated with negative coefficients consistent with a downward curvature rather than a straight line. As expected, intraparticipant correlation coefficients were high.

Table 4 shows mean differences in BMI between decedents and survivors for 4 year periods before death. Estimates were adjusted for age, smoking, alcohol, long-term conditions and socioeconomic status. At 8 or more years

before death, there was no evidence that BMI differed between decedents and survivors. However, at 4 to 7 years before death, mean BMI was 0.87 (95% CI 0.50 to 1.24) Kg/m<sup>2</sup> lower in male decedents than survivors and 1.02 (0.56 to 1.47) Kg/m<sup>2</sup> lower in female decedents than survivors. In the 4 years leading up to death, mean BMI was 1.39 (95% CI 0.98 to 1.80) Kg/m<sup>2</sup> lower in male decedents than survivors and 2.12 (1.60 to 2.64) Kg/m<sup>2</sup> lower in female decedents than survivors.

We investigated whether BMI trajectories varied for groups of participants defined by covariates that were expected to be associated with mortality. Figure 2 shows BMI trajectories by number of long-term conditions and smoking status at wave 0. BMI values were greater for participants with more long-term conditions (figure 2, left panel), especially at younger ages, but there was convergence of trajectories at older ages, consistent with greater age-related decline for participants with long-term conditions at baseline. Compared with non-smokers, current smokers had lower BMI and ex-smokers had higher BMI values at all ages (figure 2, right panel), but the appearances were suggestive of more accelerated BMI decline in smokers. Lower socioeconomic position in terms of rental housing tenure (figure 3, left panel) or manual



**Figure 1** Mean BMI by age (left panel) and mean BMI by years before death or end of study (right panel) for decedents (red) and survivors (blue). Points are mean BMI values, lines are fractional polynomial prediction plots. Error bands are 95% CIs. BMI, body mass index.

occupational social class (figure 3, right panel) was also associated with higher BMI values in middle age but more accelerated BMI decline at older ages. Alcohol consumption and BMI trajectory are shown for completeness in online supplemental figure 2, with no consistent pattern of association.

## DISCUSSION

### Main findings

BMI enters a decline over the age of 65–70 years, and this decline is earlier and more rapid in decedents than survivors. After adjusting for age and covariates, BMI for decedents was found to show an increasing difference from survivors in the last 8 years of life. Diehr *et al*<sup>23</sup> observed that the processes of ageing and dying may be difficult to distinguish. While BMI decline may be a feature of ageing, accelerated loss of body mass may result from pathological processes leading to mortality.

**Table 3** Regression models for BMI

Variable	Survivors		Decedents	
	Male	Female	Male	Female
Age	0.245 (0.027)	0.375 (0.024)	0.239 (0.090)	0.567 (0.109)
Age <sup>2</sup>	−0.002 (0.000)	−0.003 (0.000)	−0.002 (0.001)	−0.004 (0.001)
Years to death	0.055 (0.014)	0.048 (0.015)	−0.075 (0.052)	−0.300 (0.065)
Years to death squared	−0.002 (0.001)	−0.002 (0.001)	−0.007 (0.004)	−0.022 (0.005)
Constant	21.743 (0.918)	17.041 (0.868)	21.576 (3.113)	9.121 (3.806)
Sigma_u	3.712	4.902	4.160	4.982
Sigma_e	1.506	1.771	1.722	1.877
Rho	0.859	0.886	0.854	0.876

Sigma\_u, participant-level SD; Sigma\_e, observation-level SD; Rho, intra-participant correlation coefficient  
 Figures are coefficients (SE) except where indicated  
 BMI, body mass index.

**Table 4** Mean difference (95% CI) in BMI between decedents and survivors by time before death

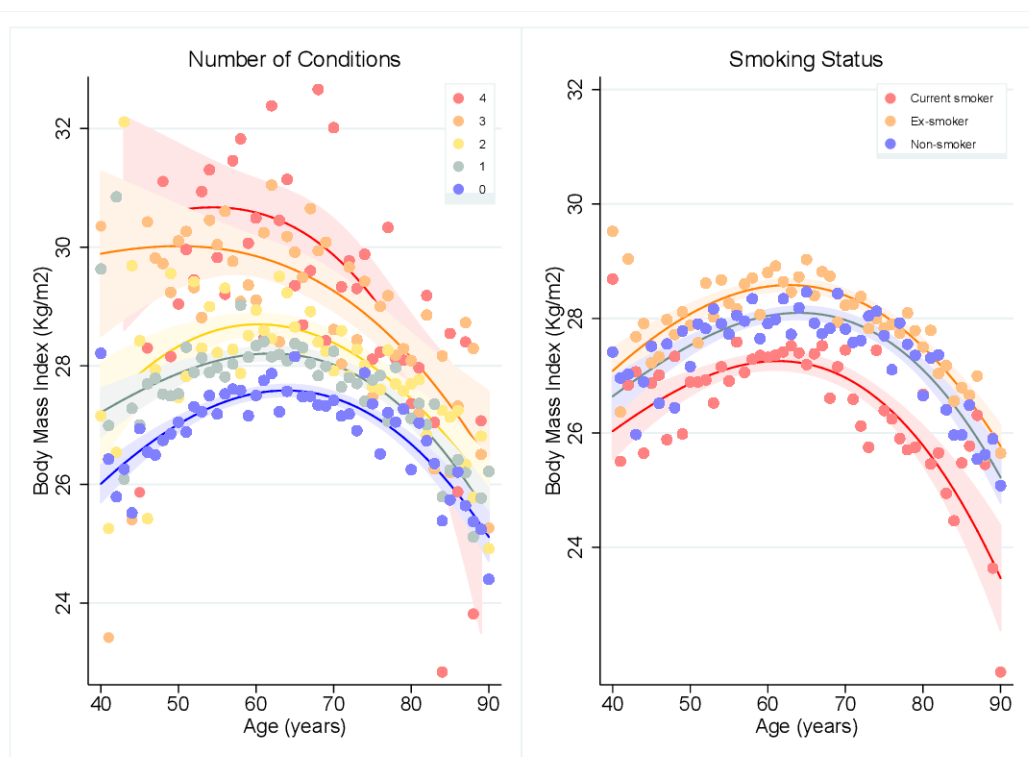
Years before death	Difference in BMI (Kg/m <sup>2</sup> ) between decedents and survivors			
	Men		Women	
	Adjusted mean difference* (95% CI)	P value	Adjusted mean difference* (95% CI)	P value
0–3 years	–1.39 (–1.80 to –0.98)	<0.001	–2.12 (–2.64 to –1.60)	<0.001
4–7 years	–0.87 (–1.24 to –0.50)	<0.001	–1.02 (–1.47 to –0.56)	<0.001
8 or more years	–0.07 (–0.37 to 0.24)	0.664	–0.38 (–0.76 to 0.00)	0.050

\*Estimates were adjusted for age, age<sup>2</sup>, education, housing tenure, social class, cigarette smoking, alcohol consumption and number of long-term conditions.  
BMI, body mass index.

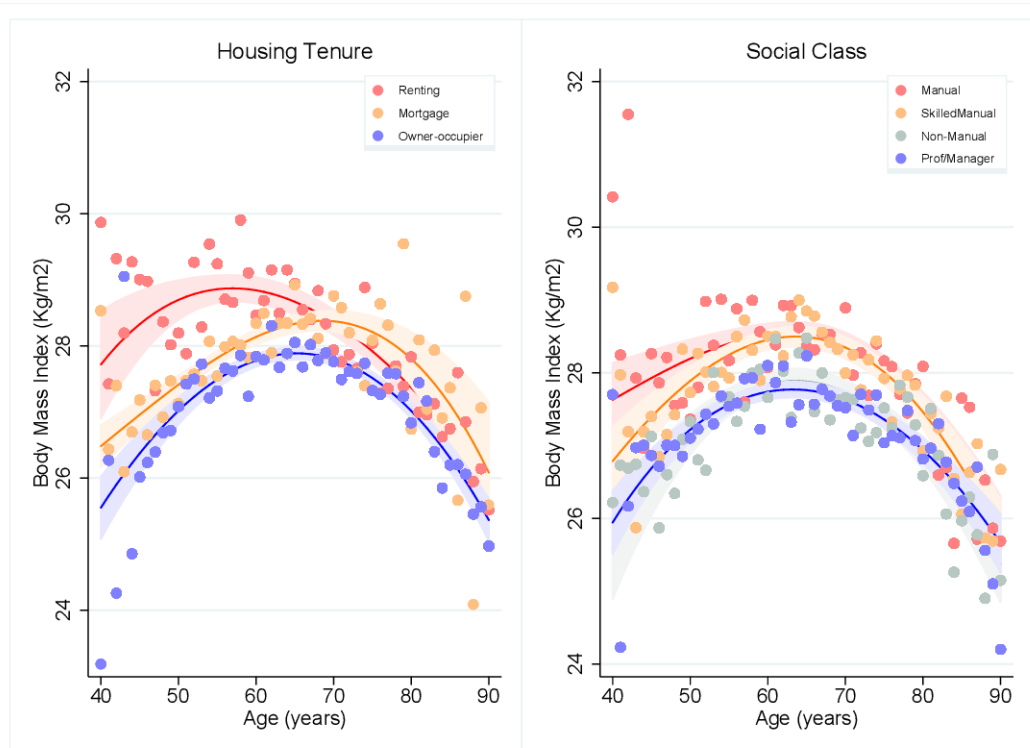
In this study, decedents showed a substantially greater age-related decline in BMI than survivors and the gradient relating BMI to years to death or end of study were of opposite sign for decedents and survivors. We found evidence that variables associated with mortality including multiple long-term conditions, cigarette smoking and lower socioeconomic position were associated with distinct BMI trajectories that could contribute to accelerated BMI decline in decedents. Consequently, associations of lower BMI with mortality<sup>9</sup> are likely to be explained by ‘reverse’ causation, where mortality risk is the predictor of BMI.

### Strengths and limitations

The present analyses drew on data for a well-established, population-based cohort study with well-described measurement techniques.<sup>17</sup> However, in common with most cohort studies, non-response bias and attrition might contribute to bias. The response rate in ELSA was approximately 67% at wave 0 and there was attrition at subsequent waves.<sup>17</sup> The sample might be less representative over time, but this bias might have the effect of diminishing estimated associations if people who were ill were less likely to participate in the study. Mortality follow-up was restricted to the period up to 2012, which was the latest date to which data were linked by the UK Office for National Statistics. Survivors might be misclassified if they died soon after the



**Figure 2** Mean BMI by age and number of long-term conditions (left panel) and mean BMI by age and smoking status (right panel). Points are mean BMI values, lines are fractional polynomial prediction plots. Error bands are 95% CIs. BMI, body mass index.



**Figure 3** Mean BMI by age and housing tenure (left panel) and mean BMI by age and social class (right panel). Points are mean BMI values, lines are fractional polynomial prediction plots. Error bands are 95% CIs. BMI, body mass index.

end of follow-up as in most cohort studies. Follow-up waves of data collection were conducted periodically, and BMI records were limited to those participants who participated in measurements during years in which follow-up waves of data collection were conducted.

### Comparison with other studies

The association of BMI with mortality is controversial. In a highly cited meta-analysis of cohort studies, the Global BMI mortality collaboration found that mortality was lowest at a BMI of 20–25 Kg/m<sup>2</sup>. Flegal *et al*<sup>24</sup> pointed out that this conclusion was only possible if data for smokers, people with pre-existing conditions and people who died in the first 5 years of follow-up were excluded. These exclusions accounted for 60% of data and over 75% of fatal events. BMI has been increasing globally and many populations now have mean BMI values that exceed 25 Kg/m<sup>2</sup><sup>25</sup> with many studies finding that BMI values in the ‘overweight’ category may be associated with low mortality.<sup>26</sup> In the WHO classification of obesity, the mean BMI value for the present ELSA cohort was consistent with ‘overweight’ rather than ‘healthy’ body weight. However, the present results show that BMI trajectories compiled from longitudinal measurements may be more informative than cross-sectional assessment of BMI values in the analysis of associations of BMI and mortality. The importance of variations in body fat distribution and body composition at a given level of BMI is also increasingly recognised. While low body fat mass may be associated with lower mortality, lower lean body mass

may be associated with higher mortality than intermediate values,<sup>27</sup> and sarcopenia is associated with greater mortality at older ages.<sup>28</sup>

### CONCLUSIONS

From a life-course perspective, BMI does not have a unique association with mortality, rather BMI trajectories vary in groups of participants defined by predictors of mortality. There is a more accelerated age-related decline in groups with higher mortality and BMI is found to decline at the end of life. Routine monitoring of BMI trajectories may be informative in clinical settings. From a public health perspective, promoting healthy ageing may require avoidance of excess body weight at younger ages, but preservation of body mass at older ages.

**Contributors** This work was conducted as part of a medical student elective at King’s College London, GKT School of Medicine. Both authors developed the idea for the study. HP conducted data analyses, which MCG replicated and extended. HP drafted the paper and MCG edited the draft. Both authors approved the final draft. MCG is guarantor.

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**Competing interests** None declared.

**Patient consent for publication** Not applicable.

**Ethics approval** This study involves human participants and was approved by London Multicentre Research Ethics Committee. Number not available. Participants gave informed consent to participate in the study before taking part.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Data availability statement** Data are available in a public, open access repository. Data are available in a public, open access repository.[18]

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