Individual changes in anthropometric measures after age 60 years: a 15-year longitudinal population-based study

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Abstract

Background: weight loss is commonly observed with ageing. We explored the trajectory of body mass index (BMI) and two proxies of muscle mass—calf circumference (CC) and mid-arm circumference (MAC)—and identified their determinants.

Methods: within the SNAC-K cohort, 2,155 dementia-free participants aged ≥60 years were followed over 15 years. BMI, CC and MAC were measured at baseline and follow-ups. Baseline sociodemographic and lifestyle factors were collected through interviews. Diabetes and vascular disorders were diagnosed by physicians through clinical examination and medical records. Data were analysed using linear mixed-effect models stratified by age (younger-old [<78 years] vs. older-old [≥78 years]).

Results: over the 15-year follow-up, BMI remained stable among participants aged 60 years at baseline (βslope = 0.009 [95% confidence interval −0.006 to 0.024], P = 0.234) and declined significantly among those aged ≥66 years, while CC and MAC declined significantly across all age groups. The decline over 15 years in BMI, CC and MAC separately was 0.435 kg/m², 1.110 cm and 1.455 cm in the younger-old and was 3.480 kg/m², 3.405 cm and 3.390 cm in the older-old. In younger-old adults, higher education was associated with slower declines in all three measures, while vascular disorders and diabetes were associated with faster declines. In older-old adults, vigorous physical activity slowed declines in BMI and CC, while vascular disorders accelerated declines in BMI and MAC.

Conclusions: CC and MAC declined earlier and more steeply than BMI. Cardiometabolic disorders accelerated such declines, while higher education and physical activity could counteract those declines.

Keywords: ageing, body mass index, calf circumference, mid-arm circumference, older people, trajectories

Key Points
- Body mass index (BMI), calf circumference (CC) and mid-arm circumference (MAC) declined with ageing.
- The declines were more evident among older than younger-older people.
- CC and MAC, suggested as proxies of muscle mass, declined earlier and more steeply than BMI.
- Higher education and being physically active, as modifiable factors, could counteract those declines.
- Type 2 diabetes and vascular disorders accelerated the declines in BMI, CC and MAC.
Introduction

Body composition changes with advancing age [1]. In particular, accelerated weight loss, a common age-related decline in late life, is characterized by loss of muscle mass and concurrently increased fat mass [1–3]. Emerging evidence has shown that muscle mass-related weight loss with advancing ageing is related to a variety of adverse health outcomes [4–7].

Body mass index (BMI) is the most widely used anthropometric measure. BMI is a combination of fat and muscle mass, and muscle mass loss might be masked by increased fat mass [1]. Thus, BMI might have poor sensitivity to detect muscle mass loss, especially early in life. The loss of muscle mass among older adults is an indicator of sarcopenia [8], which is a predictor for several adverse outcomes including physical function impairment, disability and mortality [9,10]. Therefore, to disentangle the relation of different components of body composition with ageing, other anthropometric measures have been proposed. Calf (CC) and mid-arm (MAC) circumferences have a good correlation with muscle mass [11–14], and the loss of muscle mass is mainly driven by loss of calf muscle mass [15], and CC and MAC have been suggested as proxies of muscle mass.

Several studies have shown that lifestyle factors (e.g. smoking, alcohol consumption and physical activity) and chronic conditions (e.g. cardiovascular diseases and diabetes) are associated with changes in BMI or muscle mass measured by bioelectrical impedance analysis or dual-energy X-ray absorptiometry (DEXA) [16–21]. Questions remain about the patterns of changes in different anthropometric measures over the life course and the determinants for such changes among older adults. In the present study, we aimed to assess the trajectories of BMI, CC and MAC over a 15-year follow-up among Swedish older adults and to identify sociodemographic, lifestyle and health-related factors that might be associated with these trajectories.

Methods

Study population

The study population was derived from the ongoing population-based Swedish National Study on Aging and Care-Kungsholmen (SNAC-K) including participants aged ≥60 years living at home or in institutions in Kungsholmen, central Stockholm. A total of 3,363 participants were examined at baseline (March 2001 to June 2004). Given the more rapid changes in health and a higher attrition rate among older participants, follow-up assessments were performed every 6 years for the younger age-cohorts (60, 66, 72 years) and every 3 years for the older age-cohorts (≥78 years). In the current study, follow-up data were available until December 2019.

At baseline, we excluded 310 persons with dementia, 11 with missing information on dementia diagnoses, 133 with missing information on BMI, CC or MAC and 38 with missing information on smoking, alcohol consumption or diabetes status. We additionally excluded 716 with no repeated measurement of BMI, CC or MAC during the follow-up (including 339 died and 329 dropped out before the first follow-up examination, and 48 with missing anthropometric measures). Therefore, 2,155 participants remained for the current study. During the follow-up, 744 (34.5%) died and 403 (18.7%) dropped out (Appendix 1 in Supplementary data).

All phases of SNAC-K data collection have been approved by the Karolinska Institutet Ethical Committee and the Regional Ethical Review Board in Stockholm, Sweden. All participants (or a proxy, such as a close family member, in case of severe cognitive impairment) provided informed and written consent at baseline.

Data collection

Data on sociodemographic (age, sex and education) and lifestyle (smoking, alcohol consumption and physical activity) factors, current medication use (e.g. antihypertensive and glucose-lowering medications), and medical conditions were collected by trained staff (nurses and physicians) following a structured protocol (available at http://www.snack.se).

Age was dichotomized into a younger-old (<78 years) and an older-old cohort (≥78 years), according to the SNAC-K study design and given the turning point of fat mass in older adults: fat mass tends to increase with age before the age of 80 years but stabilises or slightly declines thereafter [1]. Educational attainment was categorised as elementary or professional school, high school and university. Smoking status was recorded as never, ex-smoker or current smoker. Alcohol consumption was categorised as no/occasional, light-to-moderate (1–14 drinks per week for men or 1–7 drinks per week for women) or heavy (>14 drinks per week for men or >7 drinks per week for women) drinking [22]. Physical activity was assessed based on the frequency and intensity of physical exercise and categorised into inactive (≤2–3 times/month of light-to-intense exercise), moderate (several times per week or every day of light exercise) and vigorous (several times per week or every day of moderate/intense exercise) [23]. Peripheral blood samples were collected at baseline to measure glycated haemoglobin (HbA1c).

Arterial blood pressure was measured twice on the left arm in a sitting position with a 5-min interval. Hypertension was identified based on systolic and diastolic blood pressure ≥140/90 mmHg or self-report of taking antihypertensive treatment. Ischemic heart disease, heart failure and cerebrovascular disease (registered 5 years prior to the SNAC-K baseline assessment) were ascertained from clinical
examination and identified using the International Classification of Disease 10th version (ICD-10) through the Swedish National Patient Register (NPR). The Swedish NPR covers all inpatients (since 1987) and outpatients (since 2001) in the Swedish health care system [24]. Vascular disorders included ischemic heart disease (ICD-10 codes: I20–22, I24–25, Z951 and Z955), heart failure (I110, I130, I132, I27, I280, I42–43, I50, I515, I517, I528, Z941 and Z943), cerebrovascular disease (G45–46, I60–64, I67 and I69) and hypertension (I10–13 and I15). Type 2 diabetes was identified based on self-reported medical history, glucose-lowering medication use, medical records from the NPR (E11) or HbA1c ≥6.5% [25]. Dementia was diagnosed according to the 'Diagnostic and Statistical Manual of Mental Disorders’, fourth edition criteria and using a validated three-step procedure [26].

Data on the participants’ vital status were collected via linkage to the Swedish Cause of Death Registry.

### Assessment of anthropometric measures

Weight and height were measured with a standard scale in light clothing without shoes by trained staff or self-reported by participants. BMI (kg/m²) was calculated as weight (kg) divided by squared height (m²) and categorised in four groups: underweight (<20 kg/m²), normal (20–25 kg/m²), overweight (25–30 kg/m²) or obese (≥30 kg/m²). MAC was measured at the mid-point between the tip of acromion process and tip of the olecranon process, with the elbow bent at a 90° angle [27]. CC was measured at the point of maximum convexity of the calf with the participants sitting down so that the knee and ankle were each bent to a 90° angle [27]. Both MAC and CC were measured on the right-hand side and rounded to 1 cm.

### Statistical analysis

Baseline characteristics by age groups were compared with the t-test (continuous variables) or chi-square (categorical variables). Linear mixed-effect models were used to determine the separate trajectories of BMI, CC and MAC as a function of follow-up time. Random effects included a random intercept for individuals and a random slope for follow-up time assuming an unstructured covariance structure. We conducted linear mixed-effect models to assess the associations between baseline age groups (5 groups: 60, 66, 72, 78 and 81+ years; 2 groups: <78 and ≥78 years) and changes in BMI, CC and MAC. To compare the magnitude of changes in BMI, CC and MAC over time by age groups, we computed sex-specific z-scores, using the mean and standard deviation from male and female from the study population. To estimate the associations between each factor (selected based on previous literature) [16–21] and annual changes in anthropometric measures, we conducted separate linear mixed-effect models including the factor, the linear follow-up time and their interaction term (each factor × follow-up time) as fixed effects. In the fully adjusted mixed-effect model, we adjusted for sex, education, smoking status, alcohol consumption, physical activity, vascular disorders and diabetes. All analyses were stratified by age group (younger-old and older-old).

Additional statistical analyses are presented in Supplementary data. Statistical analyses were performed using SAS 9.4 (SAS Institute, Cary, NC). All P-values were two-sided, and we defined statistical significance as $P < 0.05$.

### Results

#### Baseline characteristics

At baseline, mean participant age was 71.3 years (standard deviation [SD] 9.6 years), 63.0% were female, and 35.5% had a university education. Compared with the younger-old participants, the older-old participants were more likely to be female, have a lower education level, be more physically inactive and have diabetes and more vascular disorders. However, older-old participants were less likely to be current smokers or heavy drinkers, and had lower BMI, CC and MAC (all $P$-value < 0.05) (Table 1).

### Trajectories of BMI, CC and MAC across age groups

In participants aged 60 years at baseline, BMI remained stable over time ($\beta_{\text{slope}} = 0.009$ [95% confidence interval [CI] −0.006 to 0.024], $P = 0.234$), while CC ($-0.033 [-0.051 to -0.016], P < 0.001$) and MAC ($-0.042 [-0.059 to -0.024], P < 0.001$) declined statistically significantly. All three measures declined significantly among those aged ≥66 years (Figure 1 and Appendix 2 in Supplementary data). In the younger-old (aged <78 years), the 15-year decline was 0.435 (95% CI: 0.274–0.603) kg/m² for BMI, 1.110 (0.938–1.283) cm for CC and 1.455 (1.296–1.615) cm for MAC. In the older-old adults (aged ≥78 years), the 15-year decline was 3.480 (3.081–3.876) kg/m² for BMI, 3.405 (3.039–3.760) cm for CC and 3.390 (3.081–3.707) cm for MAC. The z-scores for CC and MAC decreased more quickly than BMI, especially among the younger-old adults (Figure 2, Appendix 3 in Supplementary data).

### Factors related to trajectories in BMI, CC and MAC across age groups

Among the younger-old, participants with university education showed slower declines in BMI, CC and MAC than those with elementary or professional school education. In addition, vascular disorders and diabetes were associated with a faster speed of decline in all three measures over time (Table 2).

Among the older-old, people who were vigorously physically active had a slower decline in BMI ($\beta_{\text{difference in slope}} = 0.087$ [95% CI: 0.005–0.169]) and CC ($\beta_{\text{difference in slope}} = 0.132$ [95% CI: 0.057–0.207]) compared with those who were physically inactive. A similar trend was also observed for MAC ($\beta_{\text{difference in slope}} = 0.044$ [95% CI: −0.021 to 0.109]), though the result was not statistically significant.
Table 1. Baseline characteristics of the study population by age (<78 vs. ≥78 years) (n = 2,155)

| Characteristics                          | Total   | Younger-old (<78 years) | Older-old (≥78 years) | P-value<sup>a</sup> |
|------------------------------------------|---------|-------------------------|-----------------------|--------------------|
| Number                                   | 2,155   | 1,353                   | 802                   |                    |
| Age, years                               | 71.3 ± 9.6 | 64.8 ± 4.8             | 82.2 ± 4.4            | <0.001             |
| Female                                   | 1,358 (63.0) | 794 (58.7)             | 564 (70.3)            | <0.001             |
| Education level                          |         |                         |                       |                   |
| Elementary/professional school            | 1,166 (54.1) | 591 (43.7)             | 575 (71.7)            |                   |
| High school                              | 225 (10.4) | 161 (11.9)              | 64 (8.0)              |                   |
| University                               | 764 (35.5) | 601 (44.4)              | 163 (20.3)            |                   |
| Smoke status                             |         |                         |                       |                   |
| Never smoker                             | 1,015 (47.1) | 548 (40.5)              | 467 (58.2)            | <0.001             |
| Ex-smoker                                | 849 (39.4) | 581 (42.9)              | 268 (33.4)            |                   |
| Current smoker                           | 291 (13.5) | 224 (16.6)              | 67 (8.4)              |                   |
| Alcohol consumption                      |         |                         |                       | <0.001             |
| No or occasional                         | 619 (28.7) | 267 (19.7)              | 352 (43.9)            |                   |
| Light or moderate                        | 1,152 (53.5) | 803 (59.3)              | 349 (43.5)            |                   |
| Heavy                                    | 384 (17.8) | 283 (20.9)              | 101 (12.6)            |                   |
| Physical activity                        |         |                         |                       | <0.001             |
| Inactive                                 | 483 (22.4) | 236 (17.4)              | 247 (30.8)            |                   |
| Moderate                                 | 1,127 (52.3) | 689 (50.9)              | 438 (54.6)            |                   |
| Vigorous                                 | 545 (25.3) | 428 (31.6)              | 117 (14.6)            |                   |
| Any of vascular disorders<sup>b</sup>    | 1,625 (75.4) | 918 (67.8)              | 707 (88.2)            | <0.001             |
| Ischemic heart disease                   | 265 (12.3) | 96 (7.1)                | 169 (21.1)            | <0.001             |
| Heart failure                            | 128 (5.9) | 24 (1.8)                | 104 (13.0)            | <0.001             |
| Cerebrovascular disease                  | 111 (5.2) | 36 (2.7)                | 75 (9.4)              | <0.001             |
| Hypertension                             | 1,588 (73.7) | 904 (66.8)              | 684 (85.3)            | <0.001             |
| Diabetes                                 | 163 (7.6) | 90 (6.7)                | 73 (9.1)              | 0.038              |
| BMI, kg/m<sup>2</sup>                    | 25.8 ± 3.9 | 26.1 ± 3.8              | 25.3 ± 3.9            | <0.001             |
| Underweight (<20)                        | 90 (4.2) | 36 (2.7)                | 54 (6.7)              | <0.001             |
| Normal (20–25)                           | 893 (41.4) | 542 (40.1)              | 351 (43.8)            |                   |
| Overweight (25–30)                       | 886 (41.1) | 578 (42.7)              | 308 (38.4)            |                   |
| Obese (≥30)                              | 286 (13.3) | 197 (14.6)              | 89 (11.1)             |                   |
| CC, cm                                   | 36.4 ± 3.3 | 37.1 ± 3.2              | 35.2 ± 3.2            | <0.001             |
| MAC, cm                                  | 28.9 ± 3.2 | 29.5 ± 3.0              | 27.8 ± 3.2            | <0.001             |

Data are presented as means ± standard deviations or number (proportion). *-test (for continuous variables) or chi-square (for categorical variables) was used to compare the baseline characteristics between younger-old and older-old. Any of vascular disorder was defined as any of ischemic heart disease, heart failure, cerebrovascular disease or hypertension.

Figure 1. Trajectories of BMI, CC and MAC during 15-year follow-up across age groups.

Moreover, the presence of any vascular disorder was associated with faster decline in BMI (β difference in slope = −0.110 [95% CI: −0.157 to −0.030]) and MAC (β difference in slope = −0.093 [95% CI: −0.157 to −0.030]), though the result was not statistically significant for CC (β difference in slope = −0.035 [95% CI: −0.108 to 0.038]) (Table 3).
Discussion

In this large-scale population-based cohort study of the Swedish older adults, we found that: (i) the trajectories of BMI, CC and MAC declined significantly over the 15-year follow-up, and CC and MAC started declining at an earlier age and had a steeper decline than BMI; (ii) the declines were more pronounced in the older-old vs. younger-old cohorts and (iii) in younger-old adults, vascular disorders and diabetes were associated with accelerated declines in BMI, CC and MAC, whereas higher education decelerated the declines. In the older-old, physical activity was associated with less decline in BMI and CC, while any of vascular disorders was related to faster decline in BMI and MAC though not statistically significant for CC.

Previous longitudinal studies investigating BMI trajectories over the lifespan have indicated that BMI increases until the age of 65 years, thereafter levelling off and starting to decline after the age of 80 [1,3]. In line with these results, we observed a stable or a slight decline in BMI among participants aged 60–75 years and a steeper decline after the age of 78 years over the 15-year follow-up. Our results also showed that CC and MAC declined significantly even among participants aged 60 years and had a steeper decline than BMI over time. Involuntary loss of muscle mass has been reported to start after 50 years, and the decline of BMI in older adults was likely mainly due to the loss of muscle mass [1,2]. However, BMI was not sensitive to detect muscle mass change in younger-old adults, which was also shown in our study. One possible explanation is that the decline in muscle mass might be masked by the increase in fat mass in early late-life [1,28]. CC and MAC have shown high correlations with muscle mass and are easy to perform [11–14]. Moreover, CC was also suggested by the European Working Group on Sarcopenia in Older People to be a proxy of muscle quantity in the absence of other muscle mass methods [8]. These anthropometric measures may be more suitable and practical than using expensive imaging techniques (such as DEXA) in large-scale population-based studies of older adults. To our best knowledge, no previous studies have simultaneously assessed the trajectories of the three indices over time in an older population. The simultaneous decline in the three measures supports the notion of progressive muscle mass loss in ageing [29].

Modifiable factors, such as socioeconomic status and healthy lifestyle, might affect ageing-related body composition changes. Education is commonly used to reflect socioeconomic status. Previous evidence showed that people with less education were more likely to experience weight loss in late life [7,30]. Similarly, we found that university education seemed to be protective against the decline in BMI, CC and MAC, especially for younger-old adults. A prospective study conducted in community-dwelling participants observed that physical activity was associated with the maintenance of muscle mass [31]. The current study further highlighted the possible beneficial effect of physical activity in preserving BMI and CC, especially among older-old adults. Guidelines also recommend physical activity for adults aged ≥65 years to maintain healthy body composition [32]. Existing literature from both human and rodent studies suggests that physical activity could help prevent muscle mass loss by improving mitochondrial function [33,34]. Furthermore, exercise could stimulate numerous signalling pathways that increase protein synthesis [35]. Moreover, we

Figure 2. Trajectories of the z-scores of BMI, CC and MAC during 15-year follow-up among younger-old and older-old participants.
Table 2. $\beta_{slope}$ and 95% CI of the associations of sociodemographic, lifestyle and health conditions with changes in BMI, CC and MAC over 15 years: results from linear mixed models among participants aged <78 years

| Factors                      | BMI $\beta_{slope}$ (95% CI)$^a$ | $\beta_{difference in slope}$ (95% CI)$^a$ | CC $\beta_{slope}$ (95% CI)$^a$ | $\beta_{difference in slope}$ (95% CI)$^a$ | MAC $\beta_{slope}$ (95% CI)$^a$ | $\beta_{difference in slope}$ (95% CI)$^a$ |
|------------------------------|----------------------------------|---------------------------------------------|----------------------------------|---------------------------------------------|----------------------------------|---------------------------------------------|
| Sex                          | Male                             | $-0.016 (-0.033$ to $0.001)$               | $-0.088 (-0.106$ to $-0.070)$ | Reference                                  | $-0.091 (-0.108$ to $-0.074)$ | Reference                                      |
|                              | Female                           | $-0.038 (-0.052$ to $-0.024$)              | $-0.064 (-0.079$ to $-0.049$)   | $0.016 (-0.008$ to $0.041$)                 | $-0.101 (-0.115$ to $-0.087$) | $-0.014 (-0.036$ to $0.009$)                   |
| Education                    | Elementary/professional school    | $-0.048 (-0.065$ to $-0.031$)              | $-0.090 (-0.108$ to $-0.073$)   | Reference                                  | $-0.112 (-0.128$ to $-0.096$) | Reference                                      |
|                              | High school                       | $-0.047 (-0.079$ to $-0.016$)              | $-0.090 (-0.123$ to $-0.057$)   | $0.002 (-0.036$ to $0.039$)                 | $-0.117 (-0.148$ to $-0.087$) | $-0.009 (-0.043$ to $0.026$)                   |
|                              | University                        | $-0.007 (-0.023$ to $0.009$)               | $-0.054 (-0.071$ to $-0.037$)   | $0.034 (0.009$ to $0.058$)                  | $-0.077 (-0.093$ to $0.029$) | $0.006 (0.006$ to $0.052$)                     |
| Smoking status               | Never smoker                      | $-0.032 (-0.049$ to $-0.015$)              | $-0.060 (-0.078$ to $-0.042$)   | Reference                                  | $-0.099 (-0.115$ to $-0.082$) | Reference                                      |
|                              | Ex-smoker                         | $-0.028 (-0.045$ to $-0.011$)              | $-0.083 (-0.101$ to $-0.066$)   | $-0.022 (-0.047$ to $0.003$)                | $-0.101 (-0.117$ to $-0.085$) | $-0.005 (-0.028$ to $0.019$)                   |
|                              | Current smoker                    | $-0.025 (-0.053$ to $0.003$)               | $-0.088 (-0.117$ to $-0.058$)   | $-0.025 (-0.060$ to $0.010$)                | $-0.082 (-0.110$ to $-0.054$) | $0.019 (-0.014$ to $0.052$)                    |
| Alcohol consumption          | No or occasional                  | $-0.036 (-0.059$ to $-0.012$)              | $-0.069 (-0.094$ to $-0.044$)   | $0.005 (-0.027$ to $0.036$)                 | $-0.101 (-0.124$ to $-0.078$) | $-0.010 (-0.039$ to $0.019$)                   |
|                              | Light to moderate                 | $-0.018 (-0.032$ to $-0.004$)              | $-0.076 (-0.090$ to $-0.061$)   | Reference                                  | $-0.091 (-0.105$ to $-0.077$) | Reference                                      |
|                              | Heavy                             | $-0.036 (-0.059$ to $-0.012$)              | $-0.069 (-0.094$ to $-0.044$)   | $0.007 (-0.023$ to $0.037$)                 | $-0.101 (-0.124$ to $-0.078$) | $-0.007 (-0.035$ to $0.020$)                   |
| Physical activity            | Inactive                          | $-0.040 (-0.067$ to $-0.013$)              | $-0.093 (-0.122$ to $-0.064$)   | Reference                                  | $-0.102 (-0.129$ to $-0.076$) | Reference                                      |
|                              | Moderate                          | $-0.034 (-0.050$ to $-0.019$)              | $-0.073 (-0.089$ to $-0.057$)   | $0.017 (-0.016$ to $0.050$)                 | $-0.100 (-0.115$ to $-0.085$) | $0.003 (-0.028$ to $0.034$)                    |
|                              | Vigorous                          | $-0.016 (-0.035$ to $0.003$)               | $-0.066 (-0.086$ to $-0.046$)   | $0.023 (-0.013$ to $0.058$)                 | $-0.090 (-0.108$ to $0.071$) | $0.012 (-0.021$ to $0.044$)                    |
| Vascular disorders           | None                              | $-0.006 (-0.025$ to $0.013$)               | $-0.046 (-0.066$ to $-0.026$)   | Reference                                  | $-0.073 (-0.092$ to $-0.054$) | Reference                                      |
|                              | Any                               | $-0.041 (-0.054$ to $-0.027$)              | $-0.088 (-0.102$ to $-0.074$)   | $-0.035 (-0.060$ to $-0.011$)               | $-0.108 (-0.121$ to $-0.095$) | $-0.030 (-0.053$ to $-0.008$)                   |
| Diabetes                     | No                                | $-0.021 (-0.033$ to $0.010$)               | $-0.068 (-0.080$ to $-0.057$)   | Reference                                  | $-0.091 (-0.102$ to $-0.080$) | Reference                                      |
|                              | Yes                               | $-0.145 (-0.189$ to $-0.101$)              | $-0.158 (-0.205$ to $-0.112$)   | $-0.075 (-0.123$ to $-0.026$)               | $-0.186 (-0.229$ to $-0.143$) | $-0.088 (-0.133$ to $-0.044$)                   |

*a $\beta_{slope}$ (i.e. annual change) for the associations of each factor with changes in BMI, CC and MAC, the specific factor, follow-up years and their interaction term (factor * follow-up time) in the model. b Difference between $\beta_{slope}$ for the associations of each factor with changes in BMI, CC and MAC, adjusting all factors in the table and their interaction term with follow-up years (factors * follow-up time). c Vascular disorder was coded as none, or any of ischemic heart disease, heart failure, cerebrovascular disease or hypertension. Bold values are statistically significant.

found that the effects of physical activity on CC decline were significant among females but not males. This may be because mitochondrial function in females is more sensitive to physical activity [36]. Given the adverse effects of muscle mass loss in older adults, more evidence from intervention studies with sufficient sample sizes and relatively long-term follow-up are warranted to better understand the effect of physical activity in combating muscle mass loss and its role in the promotion of healthy ageing.

The current study also showed that chronic diseases, such as diabetes and vascular disorders, could accelerate the decline in BMI, CC and MAC. These results were consistent with previous literature [3,18,37,38]. A previous study among older Swedish twins reported a steeper decline in BMI in association with type 2 diabetes among female but not male [3]. Research from the Health, Ageing and Body Composition Study also found that older adults (70–79 years) with type 2 diabetes showed more muscle...
mass loss than participants without diabetes [18]. In line with these results, we found that younger-old adults with type 2 diabetes had faster declines in BMI, CC and MAC, with stronger associations among females than males. The reasons for the lack of associations between diabetes and declines in BMI, CC and MAC in older-old adults could be partly due to selective survival, as diabetes is related to mortality [39]. Moreover, greater muscle mass loss has been observed among older adults with vascular disorders [37,38]. Fülster and colleagues reported a higher prevalence of muscle wasting in participants with heart failure from a population-based study [38]. We also found that vascular disorders could accelerate the decline in BMI, CC and MAC both in younger-old and older-old adults. At the biological level, diabetes and vascular disorders are characterized by an increased level of inflammatory markers [37,40], which had been related to decreased muscle mass [41]. It is plausible that the accelerated decline of muscle mass in these

| Table 3. $\beta_{\text{slope}}$ and 95% CI of the associations of sociodemographic, lifestyle and health conditions with changes in BMI, CC and MAC over 15 years: results from linear mixed models among participants aged $\geq$78 years |
|---|---|---|---|---|---|---|---|
| Factors | BMI $\beta_{\text{slope}}$ (95% CI)* | CC $\beta_{\text{slope}}$ (95% CI)* | MAC $\beta_{\text{slope}}$ (95% CI)* |
| Sex | Male | $-0.193 (-0.243$ to $-0.143$ | $-0.203 (-0.249$ to $-0.158$ | $-0.209 (-0.248$ to $-0.169$ |
| | Female | $-0.246 (-0.278$ to $-0.215$ | $-0.030 (-0.094$ to $0.034$ | $-0.235 (-0.263$ to $-0.206$ | $-0.016 (-0.074$ to $0.043$ | $-0.233 (-0.257$ to $-0.208$ | $-0.025 (-0.076$ to $0.026$ |
| Education | Elementary/professional school | $-0.246 (-0.277$ to $-0.214$ | $-0.238 (-0.266$ to $-0.209$ | $-0.234 (-0.259$ to $-0.209$ |
| | High school | $-0.174 (-0.268$ to $-0.080$ | $0.029 (-0.073$ to $0.131$ | $-0.207 (-0.292$ to $0.105$ | $0.012 (-0.082$ to $0.081$ |
| | University | $-0.205 (-0.264$ to $-0.147$ | $0.021 (-0.047$ to $0.090$ | $-0.196 (-0.249$ to $0.087$ | $0.025 (-0.036$ to $0.070$ |
| Smoking status | Never smoker | $-0.241 (-0.275$ to $-0.206$ | $-0.240 (-0.271$ to $-0.208$ | $-0.226 (-0.253$ to $-0.199$ |
| | Ex-smoker | $-0.215 (-0.260$ to $-0.170$ | $0.007 (-0.052$ to $0.066$ | $-0.209 (-0.250$ to $0.074$ | $0.020 (-0.033$ to $0.026$ |
| | Current smoker | $-0.257 (-0.358$ to $-0.156$ | $-0.030 (-0.138$ to $0.077$ | $-0.209 (-0.299$ to $0.122$ | $0.026 (-0.070$ to $0.119$ |
| Alcohol consumption | No or occasional | $-0.223 (-0.297$ to $-0.148$ | $-0.043 (-0.103$ to $0.018$ | $-0.178 (-0.246$ to $0.068$ | $0.014 (-0.041$ to $-0.149$ |
| | Light to moderate | $-0.204 (-0.243$ to $-0.165$ | $0.007 (-0.052$ to $0.066$ | $-0.231 (-0.266$ to $0.074$ | $0.020 (-0.033$ to $0.026$ |
| | Heavy | $-0.223 (-0.297$ to $-0.148$ | $-0.023 (-0.109$ to $0.064$ | $-0.178 (-0.246$ to $0.127$ | $0.048 (-0.031$ to $0.070$ |
| Physical activity | Inactive | $-0.287 (-0.339$ to $-0.234$ | $-0.303 (-0.350$ to $-0.255$ | $-0.264 (-0.306$ to $-0.222$ |
| | Moderate | $-0.226 (-0.261$ to $-0.190$ | $0.051 (-0.013$ to $0.116$ | $-0.214 (-0.246$ to $0.147$ | $0.088 (0.029$ to $0.049$ |
| | Vigorous | $-0.182 (-0.243$ to $-0.120$ | $0.087 (0.005$ to $0.169$ | $-0.165 (-0.220$ to $0.020$ | $0.132 (0.057$ to $0.044$ |
| Vascular disorders | None | $-0.137 (-0.210$ to $-0.064$ | $-0.189 (-0.256$ to $-0.123$ | $-0.216 (-0.244$ to $-0.188$ |
| | Any | $-0.246 (-0.274$ to $-0.218$ | $-0.110 (-0.191$ to $-0.030$ | $-0.232 (-0.258$ to $-0.207$ | $-0.035 (-0.108$ to $0.038$ |
| Diabetes | No | $-0.232 (-0.260$ to $-0.204$ | $-0.228 (-0.253$ to $-0.203$ | $-0.227 (-0.249$ to $-0.206$ |
| | Yes | $-0.227 (-0.322$ to $-0.132$ | $0.033 (-0.066$ to $0.133$ | $-0.214 (-0.301$ to $0.127$ | $0.029 (-0.063$ to $0.121$ |

* $\beta_{\text{slope}}$ (i.e. annual change) for the associations of each factor with changes in BMI, CC and MAC, including the specific factor, follow-up years and their interaction term (factor × follow-up time) in the model. †Difference between $\beta_{\text{slope}}$ for the associations of each factor with changes in BMI, CC and MAC, adjusting all factors in the table and their interaction term with follow-up years (factors × follow-up time). ‡Vascular disorder was coded as none, or any of ischemic heart disease, heart failure, cerebrovascular disease or hypertension. Bold values are statistically significant.
diseases is partly due to shared pathophysiology pathways [37,40,41].

Strengths of our study include the population-based longitudinal study design with a long follow-up and repeated anthropometric measurements. However, some limitations need to be pointed out. Firstly, participants included in the main analyses were healthier than those who were excluded, which may lead to the underestimation of both the decline over time and associations between factors (socio-demographic, lifestyle and health-related factors) and trajectories of measurements. Secondly, BMI was self-reported but not measured in a sub-sample population (n = 462). However, the correlation between self-reported and measured BMI was high (Pearson correlation coefficient’s r = 0.95, P < 0.001). Thirdly, MAC includes subcutaneous fat around the biceps and triceps which might limit its usefulness as a proxy for muscle mass. To this end, previous literature has recommended calculating arm muscle using both arm circumference and triceps skinfold thickness [42], but skinfold thickness was not available in SNAC-K. Fourthly, we were not able to examine the trajectory of visceral fat, which accumulates with ageing and has been associated with several cardio-metabolic chronic diseases and mortality [43]. Fifthly, misclassification may have occurred given that data on lifestyle variables (e.g. smoking habits, alcohol consumption and physical activity) were based on self-report. Sixthly, information on the type of physical activity (i.e. resistance training and aerobic exercise)—which may have different health benefits—was not available [44]. Thus, we could not address the association between muscle mass change and the specific type of exercise. Finally, although we considered a wide range of sociodemographic, lifestyle and health conditions as potential factors, residual confounding could not be completely ruled out.

In summary, BMI, CC and MAC declined significantly over the 15-year follow-up. CC and MAC could detect the decline in muscle mass earlier than BMI, and these declines were more pronounced in older-old (≥78 years) vs. younger-old (<78 years) participants. Furthermore, we found that vascular disorders and diabetes accelerated the declines of BMI, CC and MAC in younger-older adults, but higher education was associated with reduced decline in all three measures. Physical activity seemed to be more beneficial for decelerating the declines in BMI and CC in older-old adults. Our findings underscore the role of social, medical and lifestyle factors in the changes in anthropometric measures in older age.

Supplementary Data: Supplementary data mentioned in the text are available to subscribers in Age and Ageing online.

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