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Association between physique at age 20 and body weight gain from age 20: a cross-sectional study of the Shizuoka-Sakuragaoka Japan Multi-Institutional Collaborative Cohort (J-MICC) Study

Kazuto Tozuka[1], Rie Kawata[1,2], Kana Higuchi[1], Rion Suzuki[1], Mayuko Shibuya[1], Kanako Nakajima[1,3] and Kiyonori Kuriki[1,4]

[1]*Laboratory of Public Health, Graduate Program in Food and Nutritional Sciences, Graduate School of Integrated Pharmaceutical and Nutritional Sciences, University of Shizuoka, Shizuoka, Japan*
[2]*Now with School of Nursing, Department of Nursing, University of Shizuoka, Shizuoka, Japan*
[3]*Now with Department of Nutrition and Dietetics, Faculty of Family and Consumer Sciences, Kamakura Women's University, Kamakura, Japan*
[4]*Laboratory of Public Health, Department of Nutrition and Life Sciences, School of Food and Nutritional Sciences, University of Shizuoka, Shizuoka, Japan*

ABSTRACT

Body weight gain from age 20 (BWG_20yr) is a significant risk factor for lifestyle-related diseases; however, its association with self-perceived physique at age 20 (Physique_20yr) remains unexplored. This study aimed to examine the relationship between self-perceived Physique_20yr and BWG_20yr. This study included 3,068 males and 2,312 females aged 35–79 years. Participants self-reported their body weight at age 20 and categorized their physique as either "muscular" or "obese," followed by selection of one of five levels (Physique_20yr). BWG_20yr was defined as the difference in body mass index between approximately age 20 and baseline. A directed acyclic graph was used to visualize relationships with adjusted factors, and multivariable logistic regression analysis was conducted to assess odds ratio trends and interactions between groups. Differences in trends from "strongly disagree" to "strongly agree" between the muscular and obese groups were observed (p for interaction <0.05 for both sexes). For BWG_20yr ≥2.5 kg/m^2, trends were positive in the muscular group and negative in the obese group in males. In females, no significant trend was observed in the muscular group, whereas a negative trend was observed in the obese group. Similar trends and interactions were noted for BWG_20yr ≥3.5 kg/m^2 (p for interaction <0.05 in males; 0.074 in females). To address potential recall bias, analyses were repeated using two cutoff values exceeding the expected range of recall error, yielding consistent results. These findings suggest that self-perceived Physique_20yr may be associated with BWG_20yr.

Keywords: physique, muscularity, obesity, body weight gain

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Corresponding Author: Kiyonori Kuriki, PhD
Laboratory of Public Health, Department of Nutrition and Life Sciences, School of Food and Nutritional Sciences, University of Shizuoka, 52-1 Yada, Suruga-ku, Shizuoka 422-8526, Japan
Tel: +81-54-264-5563, Fax: +81-54-264-5563, E-mail: kuriki@u-shizuoka-ken.ac.jp

INTRODUCTION

Numerous epidemiological studies have reported body weight gain (BWG) from early adulthood (ie, ages 20–29 years) as a significant risk factor for diseases such as cancer, hypertension, cardiovascular disease, and type 2 diabetes.[1-3] Even a BWG of as little as 5 kg is associated with an increased incidence of these major chronic diseases, highlighting the need for effective strategies to prevent BWG.[2] When assessing changes in body weight, adjustment for height is necessary because such changes may be under- or overestimated because of differences in stature.[4] Accordingly, body mass index (BMI) is widely used as an indicator of weight gain in epidemiological studies.[5,6] According to National Nutrition Survey in Japan, average BMI of Japanese population increases from early adulthood to middle and older age, a pattern that has remained consistent over the past decade.[7] Although the prevalence of obesity has remained stable, increasing number of individuals experiencing BWG among those aged 40–49 years has emerged as a public health concern.[7]

Although compulsory physical education provides opportunities for physical activity during junior and senior high school, these opportunities are often lost after graduation.[8] Early adulthood represents a critical transitional period characterized by environmental changes associated with entry into higher education or employment, and it is the life stage during which the prevalence of overweight and obesity increases most rapidly toward midlife.[9-11] Therefore, accumulating evidence to support obesity prevention strategies targeting individuals at approximately age 20 is warranted. To date, no longitudinal studies have examined the relationship between pre-graduation physique (eg, muscularity or obesity) and BWG. However, research on athletes who maintained muscular physiques has shown that even those with controlled body composition before retirement often experience significant BWG after retirement, leading to obesity.[12-16] Additionally, studies have reported that retired athletes exhibit greater BWG than the general population, regardless of their pre-retirement muscularity.[12,13]

Even when individuals are muscular and non-obese at approximately age 20, BWG during their 20s and beyond is considered to result from a reduction in lean body mass (ie, quantitative muscle loss).[17] Although such evidence exists in athletic populations, it remains unclear whether similar patterns occur in the general population. Therefore, this study aimed to examine the relationship between physique (muscularity or obesity) at approximately age 20 and BWG from age 20 (BWG_20yr) in a general middle-aged and older population.

METHODS

Participants of the study

This study was conducted as part of the Japan Multi-Institutional Collaborative Cohort (J-MICC) Study, with details described elsewhere.[18,19] In brief, the J-MICC Study is a large genome cohort study comprising 14 research sites across Japan. It examines lifestyle and genetic factors associated with lifestyle-related diseases, including cancer, heart disease, and cardiovascular disease, in Japanese population. To contribute to development of prevention strategies targeting working-age population, more than 90,000 participants aged 35–69 years were recruited between 2005 and 2014. The nationwide and regional studies follow common and site-specific protocols and include over 20 years of follow-up to assess health outcomes.

Regarding the Shizuoka-Sakuragaoka J-MICC Study, 6,395 males and females aged 35–79 years from 14 cities and three towns in Shizuoka Prefecture were registered according to common and regional protocols. Individuals scheduled for annual health check-ups at five collaborating institutions were invited to participate. Those who provided informed consent, after reviewing mailed study information and receiving explanations from trained research nurses, were included. The participation rate was 27.6%.[18] After explaining the study's purpose and procedures, written informed consent was obtained from each participant. The study was conducted in accordance with Declaration of Helsinki and Ethical Guidelines for Medical and Biological Research Involving Human Subjects, and was approved by ethics committees of Nagoya University Graduate School of Medicine (No. 2010-0939-8), Aichi Cancer Center Research Institute (No. H2210001A), and University of Shizuoka (No. 22-39).

For the present study, 3,068 males and 2,312 females were selected as eligible participants after excluding individuals who met the following criteria: (1) missing data on lifestyle variables used as potential confounders (n = 319) and (2) missing data on body weight at age 20 (BW_20yr) (n = 696).

Data collection of lifestyle and physique

The self-administered questionnaire included common items for all study sites (eg, current height and weight, BW_20yr, and conventional lifestyle factors) as well as original items, such as self-perceived physique at age 20 (Physique_20yr). A validated short food frequency questionnaire (FFQ) was used to assess habitual dietary intake, including total energy intake.[20-23] Physical activity and exercise levels were calculated as "metabolic equivalents (METs)·h/day".[24] To minimize missing data, trained research nurses reviewed the questionnaires completed by participants, followed by additional verification by two to three nurses using blue and red ink pens. Previous studies have assessed individuals' perceptions of physique (ie, muscularity, obesity, and thinness) using pictorial scales and questionnaires.[25-28] In the present study, participants were asked: "At age 20, were you muscular or obese?" Participants first selected whether they perceived themselves as belonging to the muscular or obese group (Physique_group) and then selected one of five levels (Physique_level). The muscular group included "very little muscle," "little muscle," "normal," "somewhat muscular," and "muscular," whereas the obese group included "thin," "slightly underweight," "normal," "overweight," and "obese." Participants with low muscle mass but higher body weight were classified as overweight or obese.

Definitions of BWG_20yr

Anthropometric measurements, including height and body weight, were obtained by trained nurses during health check-ups (baseline), with participants wearing light clothing. BMI at baseline (BMI_BASE) was calculated accordingly. BMI at age 20 (BMI_20yr) was calculated using self-reported BW_20yr and measured height at baseline. The validity of self-reported body weight was assessed by examining the correlation between measured and self-reported BMI_BASE, yielding Pearson correlation coefficients of $r = 0.98$ for males and $r = 0.99$ for females ($p < 0.001$ for both).[29] Based on our previous study, BWG_20yr was defined as BMI_BASE minus BMI_20yr. Participants with BWG_20yr ≥2.5 kg/m^2 were defined as cases (Model_1, primary outcome), and those with BWG_20yr ≥3.5 kg/m^2 were classified as cases (Model_2, secondary outcome). Based on average height in Japanese population, these thresholds correspond to weight gains[29] of ≥7.5 kg (males) and ≥6.5 kg (females) for Model_1, and ≥10.0 kg (males) and ≥8.4 kg (females) for Model_2. The difference between Model_1 and Model_2 (approximately 2.5 kg) slightly exceeds the reported recall error for self-reported body weight[30] at approximately age 20. To account for potential under- and overestimation of BW_20yr, consistency of risk estimates was examined across both models separately for males and females.

Statistical analysis

All analyses were conducted using R version 4.1.2 (R Foundation for Statistical Computing), with stratification by sex. Continuous and categorical variables were compared using *t*-tests and chi-square tests, respectively, and are presented as means ± standard deviations (SDs) and counts with percentages. Multivariable regression analysis was performed to calculate multivariable-adjusted means (ma-means) and 95% confidence intervals (95% CIs) for BMI_BASE, BMI_20yr, and BWG_20yr. Multivariable logistic regression analysis was used to compute odds ratios (ORs) and 95% CIs, with reference to "neither" of the muscular groups. Given the cross-sectional design, a directed acyclic graph (DAG) was employed to infer causality, considering the temporal relationship between self-perceived Physique_20yr as a cause and BWG_20yr. DAGs were constructed using DAGitty V.3.1 (https://www.dagitty.net/) to elucidate potential confounders.[31] Separate DAGs for males and females are shown in Figs. 1 and 2, respectively. Although energy-adjusted dietary intake of carbohydrates, proteins, and fats was included in the DAGs, these variables were excluded from regression models because of multicollinearity. The following variables identified in the DAGs were adjusted as potential confounders: age, daily activity, leisure activity, total energy intake, sitting duration, years of drinking, and ethanol intake as continuous variables, and academic background (<12, 12, and >12 years), body pain ("yes" or "no"), and current work type ("independent business/executive," "regular employee/public servant," "part-time/temporary worker," and "other"; with "retired person" included for males and "housewife" for females) as categorical variables. Self-perceived Physique_20yr responses were categorized into five levels: "strongly disagree," "disagree," "neither," "agree," and "strongly agree" for muscular and obese groups. "Neither" in the muscular group was used as the reference (OR = 1.00). A *p*-value for trend was calculated from the five levels as ordinary variables (1–5). Interaction was

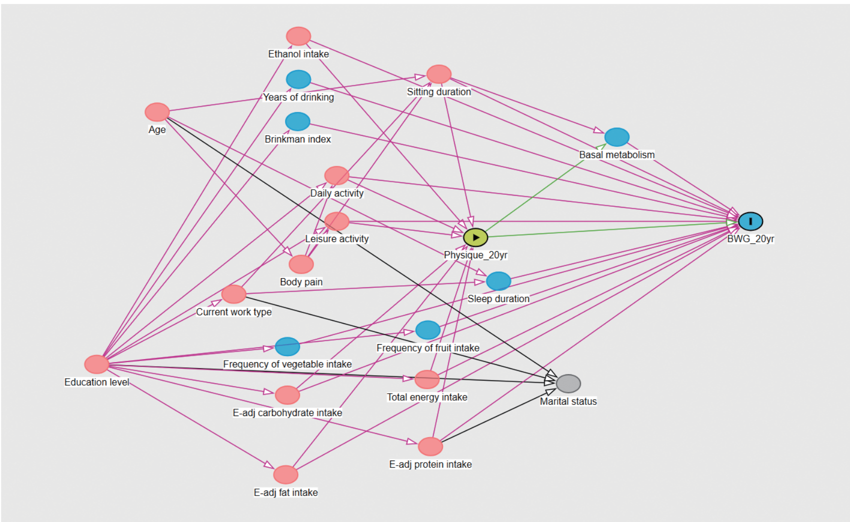

Fig. 1 Association between Physique_20yr and BWG_20yr (males)
In this directed acyclic graph, the triangle within a green circle is the exposure; the square within a blue circle is the outcome; blue circles were ancestors of the outcome; red circles were ancestors of the exposure and outcome (ie, confounders).
Physique_20yr: physique at age 20
BWG_20yr: body weight gain from age 20
E-adj: energy-adjusted

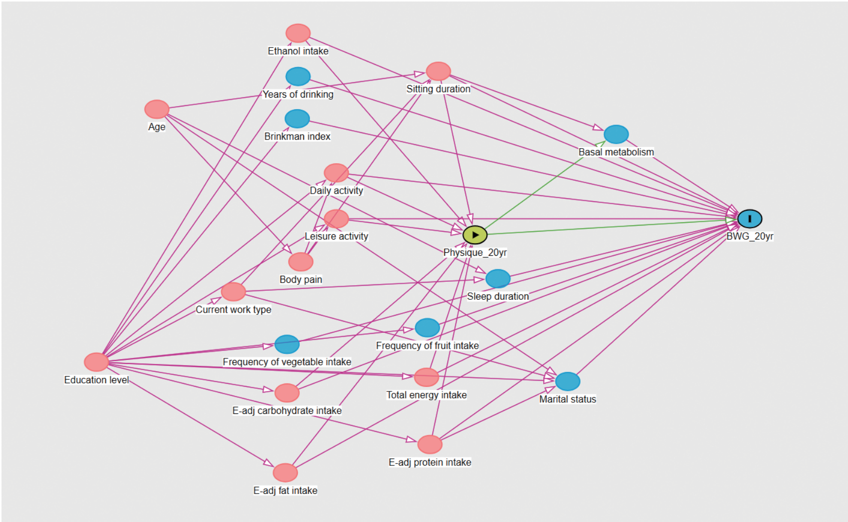

Fig. 2 Association between Physique_20yr and BWG_20yr (females)
In this directed acyclic graph, the triangle within a green circle is the exposure; the square within a blue circle is the outcome; blue circles were ancestors of the outcome; red circles were ancestors of the exposure and outcome (ie, confounders).
Physique_20yr: physique at age 20
BWG_20yr: body weight gain from age 20
E-adj: energy-adjusted

evaluated by including a product term between Physique_group and Physique_level, with the corresponding p-value testing for differences in trends between groups. Statistical significance was defined as a $p < 0.05$. To account for unmeasured confounders, the E-value was estimated using the E-value calculator (https://www.evalue-calculator.com/).[32,33] Additionally, the percentage of correct classifications was used to assess model fitness.

RESULTS

Tables 1 and 2 present the characteristics of male and female participants, categorized into the two self-perceived Physique_20yr groups ("muscular" and "obese") in Model_1 (BWG_20yr ≥2.5 kg/m^2). The characteristics for Model_2 (BWG_20yr ≥3.5 kg/m^2) are shown in Tables 3 and 4. Among males, in both models, cases were younger than controls in the muscular group ($p < 0.05$ for both). Compared with controls, BMI_20yr was lower in cases in the muscular and obese groups, whereas BMI_BASE was higher in cases across both groups ($p < 0.001$ for all comparisons). Among females, no significant differences in age were observed; however, differences were noted in the distribution of self-perceived Physique_20yr within the obese group ($p < 0.001$ for both models).

Table 1 Characteristics for male participants (n = 3,068)

	Model_1 (BWG_20yr ≥ 2.5 kg/m^2)[a]					
	Muscular group			Obese group		
	Cases[b] (n = 827)	Controls[b] (n = 1314)	p value[d]	Cases[b] (n = 359)	Controls[b] (n = 568)	p value[d]
Age (years)[c]	56.9 ± 9.7	58.9 ± 10.9	<0.001	56.1 ± 10.2	56.5 ± 11.4	0.568
BMI_20yr (kg/m^2)[c]	21.3 ± 1.9	21.9 ± 1.8	<0.001	20.2 ± 2.7	21.4 ± 3.2	<0.001
BMI_BASE (kg/m^2)[c]	25.7 ± 2.7	22.1 ± 2.0	<0.001	24.8 ± 3.2	21.5 ± 2.9	<0.001
BWG_20yr (kg/m^2)[c]	4.5 ± 1.9	0.2 ± 1.7	–	4.6 ± 1.9	0.1 ± 1.8	–
Physique around age 20 years, n (%)[e]						
Strongly disagree	3 (0.4)	5 (0.4)	0.364	69 (19.2)	76 (13.4)	0.110
Disagree	40 (4.8)	66 (5.0)		160 (44.4)	252 (44.4)	
Neither agree nor disagree	363 (43.9)	634 (48.2)		76 (21.2)	106 (18.7)	
Agree	244 (29.5)	356 (27.1)		41 (11.4)	93 (16.4)	
Strongly agree	177 (21.4)	253 (19.3)		13 (3.6)	41 (7.2)	
Total energy intake (kcal/day)[c]	1939 ± 306	1976 ± 316	0.008	1917 ± 340	1940 ± 322	0.287
Dairy activity (METs·h/day)[c]	17.9 ± 13.5	21.4 ± 13.9	<0.001	17.2 ± 12.7	18.8 ± 13.7	0.080
Leisure activity (METs·h/day)[c]	2.7 ± 4.2	3.6 ± 5.7	<0.001	2.6 ± 3.8	3.1 ± 4.2	0.057
Sitting duration (h/day)[c]	7.9 ± 3.2	7.2 ± 3.2	<0.001	8.2 ± 3.0	7.6 ± 3.2	0.006
Ethanol intake (g/day)[c]	24.2 ± 28.1	26.2 ± 28.5	0.117	20.2 ± 26.2	21.4 ± 27.0	0.503
Years of drinking (years)[c]	23.8 ± 16.5	26.4 ± 16.9	<0.001	23.0 ± 16.6	23.1 ± 17.1	0.910
Sleeping duration (h)[c]	6.7 ± 1.1	6.9 ± 1.1	<0.001	6.7 ± 1.1	6.8 ± 1.1	0.118
Brinkman index, n (%)						
0	233 (28.2)	425 (32.3)	0.040	109 (30.4)	206 (36.3)	0.275
<400	201 (24.3)	346 (26.3)		96 (26.7)	148 (26.1)	
≥400	365 (44.1)	508 (38.7)		147 (35.7)	203 (35.7)	
Unknown	28 (3.4)	35 (2.7)		7 (1.9)	11 (1.9)	
Body pain, n (%)						
Yes	482 (58.3)	682 (51.9)	0.004	200 (55.7)	300 (52.8)	0.428
No	345 (41.7)	632 (48.1)		159 (44.3)	268 (47.2)	
Current work type, n (%)						
Self-employed, president	287 (34.7)	503 (38.3)	0.018	103 (28.7)	178 (31.3)	0.348
Full-time employees, public servants	362 (43.8)	479 (36.5)		181 (50.4)	251 (44.2)	
Retired person	102 (12.3)	198 (15.1)		49 (13.6)	90 (15.8)	
Part-timer, contract employees	65 (7.9)	116 (8.8)		22 (6.1)	45 (7.9)	
Others	11 (1.3)	18 (1.4)		4 (1.1)	4 (0.7)	
Education level, n (%)						
<12 years	63 (7.6)	136 (10.4)	0.028	21 (5.8)	45 (7.9)	0.309
12 years	362 (43.8)	601 (45.7)		143 (39.8)	236 (41.5)	
>12 years	402 (48.6)	574 (43.7)		194 (54.0)	287 (50.5)	
Unknown	0 (0)	3 (0.2)		1 (0.3)	0 (0)	

BMI: body mass index
BMI_BASE: BMI at baseline
BMI_20yr: BMI at age 20
BWG_20yr: body weight gain from age 20
METs: metabolic equivalents
[a] In Model_1, BWG_20yr ≥2.5 kg/m^2 indicates an increase in BMI of ≥2.5 kg/m^2 from age 20.
[b] Participants with BWG_20yr ≥ 2.5 kg/m^2 were defined as cases, and those with BWG_20yr < 2.5 kg/m^2 as controls.
[c] Values are presented as mean ± standard deviation.
[d] The t-test or χ-square test were used.
[e] Physique around age 20 years was assessed using five levels (from "strongly disagree" to "strongly agree") for both muscular and obese groups.

Table 2 Characteristics for female participants (n = 2,312)

	Model_1 (BWG_20yr ≥ 2.5 kg/m²)[a]					
	Muscular group			Obese group		
	Cases[b] (n = 337)	Controls[b] (n = 706)	p value[d]	Cases[b] (n = 406)	Controls[b] (n = 863)	p value[d]
Age (years)[c]	56.3 ± 9.2	55.5 ± 10.8	0.235	54.8 ± 10.0	54.1 ± 10.7	0.330
BMI_20yr (kg/m²)[c]	20.4 ± 1.8	20.8 ± 1.8	<0.001	20.0 ± 2.6	20.9 ± 2.6	<0.001
BMI_BASE (kg/m²)[c]	25.1 ± 2.8	20.6 ± 2.1	<0.001	25.0 ± 3.9	20.4 ± 2.4	<0.001
BWG_20yr (kg/m²)[c]	4.7 ± 2.1	–0.2 ± 1.8	–	5.1 ± 2.4	–0.5 ± 2.0	–
Physique around age 20 years, n (%)[e]						
Strongly disagree	4 (1.2)	3 (0.4)	0.185	57 (14.0)	59 (6.8)	<0.001
Disagree	28 (8.3)	63 (8.9)		113 (27.8)	169 (19.6)	
Neither agree nor disagree	231 (68.5)	466 (66.0)		135 (33.3)	324 (37.5)	
Agree	43 (12.8)	122 (17.3)		79 (19.5)	258 (29.9)	
Strongly agree	31 (9.2)	52 (7.4)		22 (5.4)	53 (6.1)	
Total energy intake (kcal/day)[c]	1622 ± 241	1599 ± 233	0.136	1597 ± 246	1597 ± 212	0.996
Dairy activity (METs·h/day)[c]	19.2 ± 12.5	18.4 ± 12.4	0.305	16.3 ± 10.9	16.7 ± 11.3	0.556
Leisure activity (METs·h/day)[c]	2.8 ± 4.2	2.9 ± 4.0	0.624	2.2 ± 3.4	2.8 ± 4.1	0.014
Sitting duration (h/day)[c]	7.1 ± 2.9	6.8 ± 2.9	0.234	7.4 ± 2.9	7.2 ± 2.8	0.366
Ethanol intake (g/day)[c]	5.7 ± 14.6	4.9 ± 13.9	0.353	3.9 ± 10.1	4.6 ± 11.1	0.222
Years of drinking (years)[c]	11.2 ± 14.1	10.6 ± 14.4	0.512	8.5 ± 13.4	10.3 ± 13.7	0.031
Sleeping duration (h)[c]	6.4 ± 1.1	6.5 ± 1.0	0.472	6.3 ± 1.1	6.5 ± 0.9	<0.001
Brinkman index, n (%)						
0	276 (81.9)	614 (87.0)	0.088	343 (84.5)	758 (87.8)	0.072
>0	58 (17.2)	86 (12.2)		61 (15.0)	95 (11.0)	
Unknown	3 (0.9)	6 (0.8)		2 (0.5)	10 (1.2)	
Body pain, n (%)						
Yes	231 (68.5)	549 (65.0)	0.290	274 (67.5)	515 (59.7)	0.009
No	106 (31.5)	247 (35.0)		132 (32.5)	348 (40.3)	
Current work type, n (%)						
Self-employed, president	68 (20.2)	123 (17.4)	0.417	69 (17.0)	113 (13.1)	0.070
Full-time employees, public servant	61 (18.1)	153 (21.7)		59 (14.5)	163 (18.9)	
Part-timer, contract employees	105 (31.2)	197 (27.9)		141 (34.7)	290 (33.6)	
Housewife	96 (28.5)	213 (30.2)		118 (29.1)	271 (31.4)	
Others	7 (2.1)	20 (2.8)		19 (4.7)	26 (3.0)	
Education level, n (%)						
<12 years	22 (6.5)	52 (7.4)	0.406	33 (8.1)	52 (6.0)	0.034
12 years	181 (53.7)	360 (51.0)		222 (54.7)	427 (49.5)	
> 12 years	133 (39.5)	294 (41.6)		151 (37.2)	384 (44.5)	
Unknown	1 (0.3)	0 (0)		0 (0)	0 (0)	

BMI: body mass index
BMI_BASE: BMI at baseline
BMI_20yr: BMI at age 20
BWG_20yr: body weight gain from age 20
METs: metabolic equivalents
[a] In Model_1, BWG_20yr ≥2.5 kg/m² indicates an increase in BMI of ≥2.5 kg/m² from age 20.
[b] Participants with BWG_20yr ≥ 2.5 kg/m² were defined as cases, and those with BWG_20yr < 2.5 kg/m² as controls.
[c] Values are presented as mean ± standard deviation.
[d] The t-test or χ-square test were used.
[e] Physique around age 20 years was assessed using five levels (from "strongly disagree" to "strongly agree") for both muscular and obese groups.

Table 3 Characteristics for male participants (n = 3,068)

	Model_2 (BWG_20yr ≥ 3.5 kg/m^2)[a]					
	Muscular group			Obese group		
	Cases[b] (n = 500)	Controls[b] (n = 1641)	p value[d]	Cases[b] (n = 236)	Controls[b] (n = 691)	p value[d]
Age (years)[c]	57.0 ± 9.4	58.5 ± 10.8	0.004	56.0 ± 9.7	56.5 ± 11.4	0.554
BMI_20yr (kg/m^2)[c]	21.2 ± 2.0	21.8 ± 1.8	<0.001	20.0 ± 2.8	21.2 ± 3.1	<0.001
BMI_BASE (kg/m^2)[c]	26.5 ± 2.8	22.6 ± 2.2	<0.001	25.4 ± 3.4	21.8 ± 3.0	<0.001
BWG_20yr (kg/m^2)[c]	5.3 ± 2.0	0.8 ± 1.9	–	5.4 ± 1.9	0.6 ± 2.0	–
Physique around age 20 years, n (%)[e]						
Strongly disagree	2 (0.4)	6 (0.4)	0.381	46 (19.5)	99 (14.3)	0.084
Disagree	22 (4.4)	84 (5.1)		102 (43.2)	310 (44.9)	
Neither agree nor disagree	216 (43.2)	781 (47.6)		52 (22.0)	130 (18.8)	
Agree	149 (29.8)	451 (27.5)		27 (11.4)	107 (15.5)	
Strongly agree	111 (22.2)	319 (19.4)		9 (3.8)	45 (6.5)	
Total energy intake (kcal/day)[c]	1935 ± 308	1970 ± 314	0.030	1908 ± 350	1939 ± 322	0.210
Dairy activity (METs·h/day)[c]	17.4 ± 13.5	20.8 ± 13.9	<0.001	16.2 ± 12.5	18.8 ± 13.6	0.011
Leisure activity (METs·h/day)[c]	2.7 ± 4.3	3.5 ± 5.4	0.001	2.6 ± 3.7	3.0 ± 4.1	0.155
Sitting duration (h/day)[c]	8.0 ± 3.2	7.3 ± 3.2	<0.001	8.4 ± 3.0	7.7 ± 3.2	0.003
Ethanol intake (g/day)[c]	24.6 ± 28.0	25.7 ± 28.5	0.456	20.1 ± 25.7	21.2 ± 27	0.612
Years of drinking (years)[c]	23.7 ± 16.6	25.9 ± 16.8	0.010	22.7 ± 16.8	23.2 ± 17	0.701
Sleeping duration (h)[c]	6.7 ± 1.1	6.8 ± 1.1	0.077	6.7 ± 1.1	6.8 ± 1.1	0.210
Brinkman index, n (%)						
0	145 (29.0)	513 (31.3)	0.064	66 (28.0)	249 (36.0)	0.137
<400	114 (22.8)	433 (26.4)		70 (29.7)	174 (25.2)	
≥400	229 (45.8)	644 (39.2)		96 (40.7)	254 (36.8)	
Unknown	12 (2.4)	51 (3.1)		4 (1.7)	14 (2.0)	
Body pain, n (%)						
Yes	290 (58.0)	874 (53.3)	0.070	141 (59.7)	359 (52.0)	0.046
No	210 (42.0)	767 (46.7)		95 (40.3)	332 (48.0)	
Current work type, n (%)						
Self-employed, president	181 (36.2)	609 (37.1)	0.039	63 (26.7)	218 (31.5)	0.134
Full-time employees, public servants	220 (44.0)	621 (37.8)		123 (52.1)	309 (44.7)	
Retired person	53 (10.6)	247 (15.1)		31 (13.1)	108 (15.6)	
Part-timer, contract employees	38 (7.6)	143 (8.7)		15 (6.4)	52 (7.5)	
Others	8 (1.6)	21 (1.3)		4 (1.7)	4 (0.6)	
Education level, n (%)						
<12 years	37 (7.4)	162 (9.9)	0.216	13 (5.5)	53 (7.7)	0.651
12 years	222 (44.4)	741 (45.2)		97 (41.1)	282 (40.8)	
>12 years	241 (48.2)	735 (44.8)		126 (53.4)	355 (51.4)	
Unknown	0 (0)	3 (0.2)		0 (0)	1 (0.1)	

BMI: body mass index
BMI_BASE: BMI at baseline
BMI_20yr: BMI at age 20
BWG_20yr: body weight gain from age 20
METs: metabolic equivalents
[a] In Model_2, BWG_20yr ≥3.5 kg/m^2 indicates an increase in BMI of ≥3.5 kg/m^2 from age 20.
[b] Participants with BWG_20yr ≥ 3.5 kg/m^2 were defined as cases, and those with BWG_20yr < 3.5 kg/m^2 as controls.
[c] Values are presented as mean ± standard deviation.
[d] The t-test or χ-square test were used.
[e] Physique around age 20 years was assessed using five levels (from "strongly disagree" to "strongly agree") for both muscular and obese groups.

Table 4 Characteristics for female participants (n = 2,312)

	Model_2 (BWG_20yr ≥ 3.5 kg/m²)[a]					
	Muscular group			Obese group		
	Cases[b] (n = 222)	Controls[b] (n = 821)	p value[d]	Cases[b] (n = 288)	Controls[b] (n = 981)	p value[d]
Age (years)[c]	56.4 ± 9.0	55.6 ± 10.6	0.272	54.7 ± 10.3	54.2 ± 10.6	0.472
BMI_20yr (kg/m²)[c]	20.4 ± 1.7	20.8 ± 1.8	0.005	20.1 ± 2.8	20.8 ± 2.6	<0.001
BMI_BASE (kg/m²)[c]	25.9 ± 2.7	21.0 ± 2.3	<0.001	26.0 ± 4.0	20.7 ± 2.5	<0.001
BWG_20yr (kg/m²)[c]	5.6 ± 2.0	0.2 ± 2.0	–	5.9 ± 2.5	–0.1 ± 2.2	–
Physique around age 20 years, n (%)[e]						
Strongly disagree	3 (1.4)	4 (0.5)	0.325	44 (15.3)	72 (7.3)	<0.001
Disagree	17 (7.7)	74 (9.0)		74 (25.7)	208 (21.2)	
Neither agree nor disagree	155 (69.8)	542 (66.0)		89 (30.9)	370 (37.7)	
Agree	28 (12.6)	137 (16.7)		63 (21.9)	274 (27.9)	
Strongly agree	19 (8.6)	64 (7.8)		18 (6.2)	57 (5.8)	
Total energy intake (kcal/day)[c]	1626 ± 251	1601 ± 232	0.175	1596 ± 237	1597 ± 219	0.917
Dairy activity (METs·h/day)[c]	19.7 ± 12.3	18.4 ± 12.4	0.160	15.9 ± 11.1	16.8 ± 11.2	0.219
Leisure activity (METs·h/day)[c]	2.8 ± 4.6	2.9 ± 3.9	0.929	2.2 ± 3.7	2.7 ± 3.9	0.086
Sitting duration (h/day)[c]	7.0 ± 2.8	6.9 ± 3.0	0.786	7.4 ± 3.0	7.3 ± 2.8	0.505
Ethanol intake (g/day)[c]	4.9 ± 13.4	5.2 ± 14.3	0.788	3.9 ± 10.6	4.5 ± 10.9	0.412
Years of drinking (years)[c]	10.4 ± 13.6	10.9 ± 14.5	0.637	8.0 ± 13.2	10.5 ± 13.7	0.017
Sleeping duration (h)[c]	6.5 ± 1.1	6.5 ± 1.0	0.920	6.4 ± 1.1	6.5 ± 1.0	0.099
Brinkman index, n (%)						
0	179 (80.6)	711 (86.6)	0.075	240 (83.3)	861 (87.8)	0.033
>0	41 (18.5)	103 (12.5)		47 (16.3)	109 (11.1)	
Unknown	2 (0.9)	7 (0.9)		1 (0.3)	11 (1.1)	
Body pain, n (%)						
Yes	159 (71.6)	531 (64.7)	0.063	198 (68.8)	591 (60.2)	0.011
No	63 (28.4)	290 (35.3)		90 (31.2)	390 (39.8)	
Current work type, n (%)						
Self-employed, president	44 (19.8)	147 (17.9)	0.449	52 (18.1)	130 (13.3)	0.052
Full-time employees, public servants	36 (16.2)	178 (21.7)		39 (13.5)	183 (18.7)	
Part-timer, contract employees	70 (31.5)	232 (28.3)		104 (36.1)	327 (33.3)	
Housewife	67 (30.2)	242 (29.5)		80 (27.8)	309 (31.5)	
Others	5 (2.3)	22 (2.7)		13 (4.5)	32 (3.3)	
Education level, n (%)						
<12 years	16 (7.2)	58 (7.1)	0.693	26 (9.0)	59 (6.0)	0.134
12 years	122 (55.0)	419 (51.0)		150 (52.1)	499 (50.9)	
>12 years	84 (37.8)	343 (41.8)		112 (38.9)	423 (43.1)	
Unknown	0 (0)	1 (0.1)		0 (0)	4 (0.2)	

BMI: body mass index
BMI_BASE: BMI at baseline
BMI_20yr: BMI at age 20
BWG_20yr: body weight gain from age 20
METs: metabolic equivalents
[a] In Model_2, BWG_20yr ≥3.5 kg/m² indicates an increase in BMI of ≥3.5 kg/m² from age 20.
[b] Participants with BWG_20yr ≥ 3.5 kg/m² were defined as cases, and those with BWG_20yr < 3.5 kg/m² as controls.
[c] Values are presented as mean ± standard deviation.
[d] The t-test or χ-square test were used.
[e] Physique around age 20 years was assessed using five levels (from "strongly disagree" to "strongly agree") for both muscular and obese groups.

Table 5 presents ma-means (95% CIs) for BMI_20yr, BMI_BASE, and BWG_20yr in males and females. Similar trends were observed in both sexes. The ma-mean BMI_20yr among participants who responded "strongly agree" in the muscular group was lower than that among those in the obese group. In both groups, BMI_20yr and BMI_BASE exhibited positive trends from "strongly disagree" to "strongly agree" (p < 0.001 for all) with significant interactions (p for interaction < 0.001). Conversely, BWG_20yr demonstrated a negative trend across these categories within the obese group (p < 0.001 for trend and interaction).

Table 5 The ma-means (95% CIs) of BMI_20yr, BMI_BASE and BWG_20yr

			Strongly disagree	Disagree	Neither	Agree	Strongly agree	p for trend[a,b]	p for interaction[a]
Males	ma-means of BMI_20yr[a]	Muscular	18.7 (16.8–20.6)	20.0 (19.2–20.7)	21.2 (20.6–21.8)	21.7 (21.1–22.3)	22.2 (21.6–22.8)	<0.001	<0.001
		Obese	18.4 (17.7–19.1)	19.3 (18.7–20.0)	21.0 (20.3–21.7)	24.7 (24.0–25.4)	27.3 (26.4–28.2)	<0.001	
	ma-means of BMI_BASE[a]	Muscular	21.3 (18.3–24.2)	22.2 (21.0–23.3)	23.4 (22.5–24.4)	24.1 (23.1–25.0)	24.6 (23.6–25.5)	<0.001	<0.001
		Obese	21.2 (20.1–22.3)	21.8 (20.8–22.7)	23.5 (22.4–24.6)	25.8 (24.7–27.0)	27.9 (26.5–29.3)	<0.001	
	ma-means of BWG_20yr[a]	Muscular	2.57 (−0.22–5.36)	2.19 (1.07–3.31)	2.27 (1.38–3.16)	2.38 (1.48–3.29)	2.38 (1.46–3.31)	0.35	<0.001
		Obese	2.85 (1.79–3.92)	2.44 (1.50–3.37)	2.48 (1.45–3.50)	1.12 (0.05–2.20)	0.57 (−0.76–1.91)	<0.001	
Females	ma-means of BMI_20yr[a]	Muscular	18.3 (16.5–20.0)	19.9 (19.3–20.5)	20.5 (20.0–21.0)	21.7 (21.1–22.3)	21.9 (21.2–22.6)	<0.001	<0.001
		Obese	17.8 (17.2–18.4)	18.4 (17.9–19.0)	20.5 (20.0–21.0)	23.1 (22.6–23.6)	25.1 (24.4–25.8)	<0.001	
	ma-means of BMI_BASE[a]	Muscular	21.7 (18.1–25.3)	21.8 (20.5–23.1)	22.5 (21.6–23.5)	23.1 (21.9–24.3)	23.7 (22.3–25.1)	<0.001	<0.001
		Obese	21.4 (20.1–22.6)	21.0 (20.0–22.1)	22.3 (21.3–23.4)	23.8 (22.8–24.9)	25.8 (24.4–27.1)	<0.001	
	ma-means of BWG_20yr[a]	Muscular	3.44 (0.04–6.85)	1.88 (0.62–3.15)	2.03 (1.09–2.98)	1.40 (0.27–2.53)	1.80 (0.46–3.14)	0.05	<0.001
		Obese	3.56 (2.39–4.74)	2.60 (1.60–3.61)	1.87 (0.91–2.83)	0.69 (−0.31–1.69)	0.65 (−0.67–1.97)	<0.001	

BMI: body mass index
BMI_BASE: BMI at baseline
BMI_20yr: BMI at age 20
BWG_20yr: body weight gain from age 20
ma-mean: multivariable adjusted means
CIs: confidence intervals
[a] Adjusted for confounding factors: age, daily activity, leisure activity, total energy intake, years of drinking and ethanol intake (continuous variables), education level (<12, 12 and >12 years), body pain (yes or no) and current work type ("independent business/executive," "regular employee/public servants," "retired person", "part timer/temporary worker," "others" and "housewife" for females only) (categorical variables).
[b] The relevance of the trends was assessed by assigning ordinal values (1, 2, 3, 4, and 5) to physique levels ("strongly disagree", "disagree", "neither", "agree", and "strongly agree").

Table 6 presents the ORs (95% CIs) for BWG_20yr ≥2.5 kg/m^2 (Model_1) in males and females. The results for BWG_20yr ≥3.5 kg/m^2 (Model_2) are presented in Table 7. In males, using the "neither" category in the muscular group as the reference (OR = 1.00), ORs in Model_1 ranged from 0.99 (0.20–4.11) for "strongly disagree" to 1.22 (0.96–1.55; p for trend = 0.061) for "strongly agree" in the muscular group, and from 1.47 (1.02–2.10) for "strongly disagree" to 0.49 (0.25–0.90; p for trend < 0.005) for “strongly agree” in the obese group. A significant interaction between Physique_group and Physique_level was observed (p for interaction < 0.001), indicating differing trends between groups. In Model_2, ORs ranged from 1.21 (0.17–5.40) to 1.25 (0.95–1.63; p for trend < 0.05) in the muscular group and from 1.58 (1.07–2.32) to 0.67 (0.30–1.35; p for trend < 0.05) in the obese group, with a significant interaction (p for interaction < 0.005). However, E-values were low, and the percentages of correct classification were 62.2% and 76.0%. In females, Model_1 showed no significant ORs in the muscular group, whereas in the obese group, ORs ranged from 2.00 (1.34–3.03) for “strongly disagree” to 0.83 (0.48–1.39; p for trend < 0.001) for “strongly agree.” A significant interaction was observed (p for interaction < 0.01). In Model_2, no significant ORs were observed in the muscular group, whereas ORs in the obese group ranged from 2.17 (1.41–3.31) to 1.07 (0.59–1.85; p for trend < 0.001). The interaction was marginal (p for interaction = 0.074). As in males, E-values were low, and the percentages of correct classification were 68.0% and 78.1%.

Table 6 Multivariable logistic regression analysis for Physique_20yr and BWG_20yr

Model_1 (BWG_20yr ≥ 2.5kg/m²)			Strongly disagree	Disagree	Neither	Agree	Strongly agree	p for trend[a,b]	p for interaction[a,c]
Males	Muscular	ORs (95% CIs)[a]	0.99 (0.20–4.11)	0.96 (0.63–1.46)	1.00 (reference)	1.18 (0.95–1.46)	1.22 (0.96–1.55)	0.061	<0.001
		E-value (CIs)[d]	1.08 (1.00)	1.17 (1.00)		1.39 (1.00)	1.44 (1.00)		
	Obese	ORs (95% CIs)[a]	1.47 (1.02–2.10)	1.04 (0.81–1.32)	1.24 (0.89–1.71)	0.69 (0.46–1.02)	0.49 (0.25–0.90)	0.001	
		E-value (CIs)[d]	1.72 (1.11)	1.16 (1.00)	1.47 (1.00)	1.70 (1.00)	2.21 (1.29)		
Females	Muscular	ORs (95% CIs)[a]	2.67 (0.57–13.9)	0.88 (0.54–1.41)	1.00 (reference)	0.73 (0.49–1.08)	1.25 (0.77–2.02)	0.740	0.004
		E-value (CIs)[d]	2.65 (1.00)	1.33 (1.00)		1.62 (1.00)	1.48 (1.00)		
	Obese	ORs (95% CIs)[a]	2.00 (1.34–3.03)	1.37 (1.02–1.82)	0.85 (0.66–1.11)	0.63 (0.46–0.84)	0.83 (0.48–1.39)	<0.001	
		E-value (CIs)[d]	2.18 (1.58)	1.62 (1.11)	1.39 (1.00)	1.83 (1.41)	1.43 (1.00)		

BWG_20yr: body weight gain from age 20
Physique_20yr: physique at age 20
ORs: odds ratios
CIs: confidence intervals
[a] Adjusted for confounding factors: age, daily activity, leisure activity, total energy intake, years of drinking and ethanol intake (continuous variables), education level (<12, 12 and >12 years), body pain (yes or no) and current work type (“independent business/executive,” “regular employee/public servants,” “retired person,” “part timer/temporary worker,” “others” and “housewife” for females only) (categorical variables).
[b] The relevance of the trends was assessed by assigning ordinal values (1, 2, 3, 4, and 5) to physique levels (“strongly disagree,” “disagree,” “neither,” “agree” and “strongly agree”).
[c] Interaction was calculated as the product of the two Physique_20yr groups and the five physique levels.
[d] E-value CI: the lower limit of the CI was indicated.
The correct classification rate was 62.2% in males and 68.0% in females.

Table 7 Multivariable logistic regression analysis for Physique_20yr and BWG_20yr

Model_2 (BWG_20yr ≥3.5 kg/m^2)			Strongly disagree	Disagree	Neither	Agree	Strongly agree	p for trend[a,b]	p for interaction[a,c]
Males	Muscular	ORs (95% CIs)[a]	1.21 (0.17–5.40)	0.86 (0.51–1.39)	1.00 (reference)	1.19 (0.93–1.51)	1.25 (0.95–1.63)	0.046	0.003
		E-value (CIs)[d]	1.43 (1.00)	1.37 (1.00)		1.41 (1.00)	1.48 (1.00)		
	Obese	ORs (95% CIs)[a]	1.58 (1.07–2.32)	1.13 (0.86–1.48)	1.44 (0.99–2.05)	0.85 (0.53–1.32)	0.67 (0.30–1.35)	0.031	
		E-value (CIs)[d]	1.83 (1.22)	1.32 (1.00)	1.69 (1.00)	1.39 (1.00)	1.74 (1.00)		
Females	Muscular	ORs (95% CIs)[a]	2.69 (0.52–12.6)	0.78 (0.43–1.34)	1.00 (reference)	0.76 (0.48–1.18)	1.11 (0.62–1.89)	0.669	0.074
		E-value (CIs)[d]	2.66 (1.00)	1.52 (1.00)		1.56 (1.00)	1.29 (1.00)		
	Obese	ORs (95% CIs)[a]	2.17 (1.41–3.31)	1.26 (0.91–1.74)	0.85 (0.63–1.14)	0.82 (0.59–1.14)	1.07 (0.59–1.85)	<0.001	
		E-value (CIs)[d]	2.31 (1.66)	1.49 (1.00)	1.33 (1.00)	1.44 (1.00)	1.22 (1.00)		

BWG_20yr: body weight gain from age 20
Physique_20yr: physique at age 20
ORs: odds ratios
CIs: confidence intervals
[a] Adjusted for confounding factors: age, daily activity, leisure activity, total energy intake, years of drinking and ethanol intake (continuous variables), education level (<12, 12 and >12 years), body pain (yes or no) and current work type ("independent business/executive," "regular employee/public servants," "retired person," "part timer/temporary worker," "others" and "housewife" for females only) (categorical variables).
[b] The relevance of the trends was assessed by assigning ordinal values (1, 2, 3, 4, and 5) to physique levels ("strongly disagree," "disagree," "neither," "agree" and "strongly agree").
[c] Interaction was calculated as the product of the two Physique_20yr groups and the five physique levels.
[d] E-value CI: the lower limit of the CI was indicated.
The correct classification rate was 76.0% in males and 78.1% in females.

DISCUSSION

In the present study, for both sexes, differences in the ma-means of BMI_20yr were observed between the muscular and obese groups in the "agree" and "strongly agree" categories of self-perceived Physique_20yr. Consistent with our hypothesis, trends in ORs for BWG_20yr from "strongly disagree" to "strongly agree" differed between the muscular and obese groups. In males, the muscular group showed a positive trend across categories, whereas the obese group showed a negative trend. In females, no significant trend was observed in the muscular group, whereas a negative trend was observed in the obese group. To assess the robustness of these findings to potential recall bias in BWG_20yr, we evaluated consistency across two models defined using thresholds exceeding the expected magnitude of recall error. To our knowledge, this is the first study to demonstrate that middle-aged and older males who perceived themselves as muscular at approximately age 20 may have a higher risk of BWG_20yr than those who perceived themselves as obese. These findings suggest that self-perceived Physique_20yr may provide useful insights for preventing future BWG and that questionnaire-based assessments of past physique may be valuable for population-level risk stratification.

No prior studies have examined the association between Physique_20yr and BWG_20yr in the general population. However, studies of retired athletes who were muscular in early adulthood have shown that many develop increased BMI (ie, overweight or obesity) after retirement.[12-16] Furthermore, some studies indicate that retired athletes experience comparable or greater BWG than the general population.[12,13,16] For instance, a study of retired Indian soccer and field hockey players reported that sedentary retired players had significantly higher BMI than non-players, and that body fat percentages in sedentary retired players and non-athletes were within the borderline obese range (24.7 ± 1.47% and 24.5 ± 3.76%, respectively).[13] This BMI increase was attributed to lifestyle changes, such as reduced physical activity and a more sedentary lifestyle.[13,16] However, a study of retired Irish jockeys found that most retired jockeys experienced weight gain and an increased body fat percentage, despite exercising regularly and maintaining higher physical activity levels than the general male population of the same age.[12] Although this study focused on weight cycling, it remains unclear whether a muscular physique directly contributes to this weight gain.

In males, testosterone levels, which play a key role in maintaining muscle mass, peak at approximately age 20, with muscle mass typically peaking in the mid-20s.[34-36] Muscle mass is strongly linked to basal metabolism, with skeletal muscle accounting for approximately 30% of resting metabolic rate.[37] Even among those who maintain their muscle mass through physical training, some degree of muscle loss is inevitable as a result of declining testosterone levels. This reduction in muscle mass may decrease basal metabolic rate, promoting fat accumulation and contributing to BWG.[38] These mechanisms may explain the positive trend observed in the muscular group from “strongly disagree” to “strongly agree.” In contrast, the negative trend observed across these categories, as shown in Table 5, may reflect a lower likelihood of further weight gain among individuals who were already obese at approximately age 20. In females, extremely thin individuals exhibited the greatest BWG, which may be related to low BMI_20yr and hormonal changes, including declines in estrogen during menopause. As in males, age-related changes in body composition, particularly loss of muscle mass, may contribute to BWG. In addition, female-specific factors, such as reduced estrogen levels and decreased energy expenditure during the menopausal transition, have been reported.[39,40] Furthermore, females who are thin at approximately age 20 may be more susceptible to subsequent BWG,[2] highlighting the importance of lifestyle interventions, including diet and physical activity.[39]

This study has some limitations. First, systematic errors, such as recall bias, should be considered when interpreting our findings, as BMI_20yr was derived from BW_20yr collected through a non-validated self-reported question. However, various studies have demonstrated the validity of self-reported BMI_20yr.[29,30,41,42] One study of participants aged 50 ± 2.21 years reported mean differences between recalled and actual weight at age 18 ranging from –1.98 to +2.13 kg in males and –1.86 to –0.12 kg in females.[30] The difference between the two cutoff values (BWG_20yr ≥2.5 kg/m^2 and ≥3.5 kg/m^2) was approximately 2.5 kg, exceeding the magnitude of recall bias reported in previous studies. To address potential underestimation and overestimation of BW_20yr, we used two models to evaluate the consistency of the findings.[29]

Second, self-perceived Physique_20yr was assessed using a self-reported questionnaire and may be subject to recall bias and misclassification. Participants selected a group (muscular or obese) and then a level within that group, which may have led to misclassification among individuals with mixed characteristics (eg, low muscle mass with higher adiposity). However, self-reported assessments of body shape are commonly used in epidemiological studies.[25-28] In the present study, adjusted mean BMI_20yr values supported a clear distinction between groups in the “agree” and “strongly agree” categories. In addition, the observed associations were consistent across analyses, suggesting that the overall findings are robust. Further studies using objective measures of body composition are warranted.

Third, as this was a cross-sectional study using the baseline database of the Shizuoka-Sakuragaoka J-MICC study, data on lifestyle changes from age 20 onwards were not available. Consequently, it is not possible to accurately assess causality in our findings. To address this limitation, causal inference was carefully considered using DAGs to visualize the association between self-perceived Physique_20yr and BWG_20yr and to identify appropriate confounding factors. Fourth, the E-value measured in this study was low, indicating that the influence of unmeasured confounders cannot be completely ruled out. Greater caution should be exercised when interpreting smaller effect estimates. The percentage of correct classifications was used to evaluate model fitness, yielding values between 62% and 78%, suggesting that the model was appropriate. However, over-interpretation of these findings should be avoided. Further rigorous causal inference and prospective cohort studies are necessary to validate the robustness of these results. Fifth, most missing data may have originated from females with obesity, potentially contributing to selection bias. Finally, participants were recruited from a single prefecture in Japan and were not representative of the entire Japanese population. Nevertheless, the sample comprised residents from 14 cities and 3 towns in the Shizuoka-Sakuragaoka area, providing a diverse regional representation.

In conclusion, trends in BWG_20yr differed between self-perceived muscular and obese groups. In males, a positive trend was observed from “strongly disagree” to “strongly agree” in the muscular group, whereas a negative trend was observed across the same categories in the obese group, indicating opposite patterns of risk. In females, a negative trend was observed only in the obese group. These findings suggest that self-perceived Physique_20yr may be an important factor in preventing weight gain in middle and older age and may inform future population-based prevention strategies.

AUTHOR CONTRIBUTIONS

KK collected all data from study participants and five health check-up centers (which are located in Shizuoka, Japan) and established the database for the Shizuoka-Sakuragaoka J-MICC Study. KT analyzed the data for this study’s purpose. RK, KH, RS, MS, KN, KK, and KT reviewed and commented on the manuscript. All authors have read and approved the final manuscript.

DECLARATION OF COMPETING INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this study.

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DATA AVAILABILITY STATEMENT

The datasets used and analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the authors used ChatGPT (OpenAI) and Gemini (Google) in order to proofread and improve the clarity and readability of the English language. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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REFERENCES

1 Keum N, Greenwood DC, Lee DH, et al. Adult weight gain and adiposity-related cancers: a dose-response meta-analysis of prospective observational studies. *J Natl Cancer Inst*. 2015;107(2):djv088. doi:10.1093/jnci/djv088
2 Zheng Y, Manson JE, Yuan C, et al. Associations of Weight Gain From Early to Middle Adulthood With Major Health Outcomes Later in Life. *JAMA*. 2017;318(3):255–269. doi:10.1001/jama.2017.7092
3 Cui R, Iso H, Tanabe N, Watanabe Y, Tamakoshi A; JACC Study Group. Association between weight change since 20 years of age with mortality from myocardial infarction and chronic heart failure in the Japan collaborative cohort (JACC) study. *Circ J*. 2014;78(3):649–655. doi:10.1253/circj.cj-13-1057
4 Keys A, Fidanza F, Karvonen MJ, Kimura N, Taylor HL. Indices of relative weight and obesity. *Int J Epidemiol*. 2014;43(3):655–665. doi:10.1093/ije/dyu058
5 Kodama S, Horikawa C, Fujihara K, et al. Quantitative relationship between body weight gain in adulthood and incident type 2 diabetes: a meta-analysis. *Obes Rev*. 2014;15(3):202–214. doi:10.1111/obr.12129
6 Song M, Hu FB, Wu K, et al. Trajectory of body shape in early and middle life and all cause and cause specific mortality: results from two prospective US cohort studies. *BMJ*. 2016;353:i2195. doi:10.1136/bmj.i2195
7 National Statistic Center. Portal Site of Official Statistics of Japan (e-Stat). National Health and Nutrition Survey. Published in Japanese. Accessed November 15, 2025. https://www.e-stat.go.jp/stat-search/files?page=1&toukei=00450171&tstat=000001041744
8 Ministry of Education, Culture, Sports, Science and Technology (MEXT). Course of Study (revised in 2017, 2018, and 2019): Official text and commentary. Published in Japanese. Accessed April 28, 2026. https://www.mext.go.jp/a_menu/shotou/new-cs/1384661.htm
9 Caspersen CJ, Pereira MA, Curran KM. Changes in physical activity patterns in the United States, by sex and cross-sectional age. *Med Sci Sports Exerc*. 2000;32(9):1601–1609. doi:10.1097/00005768-200009000-00013
10 Kwan MY, Cairney J, Faulkner GE, Pullenayegum EE. Physical activity and other health-risk behaviors during the transition into early adulthood: a longitudinal cohort study. *Am J Prev Med*. 2012;42(1):14–20. doi:10.1016/j.amepre.2011.08.026
11 Winpenny EM, Smith M, Penney T, et al. Changes in physical activity, diet, and body weight across the education and employment transitions of early adulthood: A systematic review and meta-analysis. *Obes Rev*. 2020;21(4):e12962. doi:10.1111/obr.12962
12 Cullen S, Donohoe A, McGoldrick A, et al. Physiological and health characteristics of ex-jockeys. *J Sci*

Med Sport. 2016;19(4):283–287. doi:10.1016/j.jsams.2015.05.001
13 Dey SK, Ghosh C, Debray P, Chatterjee M. Coronary Artery Disease Risk Factors & Their Association with Physical Activity in Older Athletes. *Eur J Prev Cardiol*. 2002;9(6):383–392. doi:10.1177/174182670200900613
14 Emami M, Behforouz A, Jarahi L, et al. The Risk of Developing Obesity, Insulin Resistance, and Metabolic Syndrome in Former Power-sports Athletes - Does Sports Career Termination Increase the Risk. *Indian J Endocrinol Metab*. 2018;22(4):515–519. doi:10.4103/ijem.IJEM_83_18
15 Arliani GG, Lara PS, Astur DC, Cohen M, Gonçalves JP, Ferretti M. Impact of sports on health of former professional soccer players in Brazil. *Acta Ortop Bras*. 2014;22(4):188–190. doi:10.1590/1413-78522014220400954
16 Melekoğlu T, Sezgin E, Işın A, Türk A. The Effects of a Physically Active Lifestyle on the Health of Former Professional Football Players. *Sports (Basel)*. 2019;7(4):75. doi:10.3390/sports7040075
17 Kim TN, Park MS, Ryu JY, et al. Impact of visceral fat on skeletal muscle mass and vice versa in a prospective cohort study: the Korean Sarcopenic Obesity Study (KSOS). *PLoS One*. 2014;9(12):e115407. doi:10.1371/journal.pone.0115407
18 Hamajima N; J-MICC Study Group. The Japan Multi-Institutional Collaborative Cohort Study (J-MICC Study) to detect gene-environment interactions for cancer. *Asian Pac J Cancer Prev*. 2007;8(2):317–323.
19 Takeuchi K, Naito M, Kawai S, et al. Study Profile of the Japan Multi-institutional Collaborative Cohort (J-MICC) Study. *J Epidemiol*. 2021;31(12):660–668. doi:10.2188/jea.JE20200147
20 Tokudome S, Goto C, Imaeda N, Tokudome Y, Ikeda M, Maki S. Development of a data-based short food frequency questionnaire for assessing nutrient intake by middle-aged Japanese. *Asian Pac J Cancer Prev*. 2004;5(1):40–43.
21 Tokudome Y, Goto C, Imaeda N, et al. Relative validity of a short food frequency questionnaire for assessing nutrient intake versus three-day weighed diet records in middle-aged Japanese. *J Epidemiol*. 2005;15(4):135–145. doi:10.2188/jea.15.135
22 Imaeda N, Goto C, Tokudome Y, Hirose K, Tajima K, Tokudome S. Reproducibility of a short food frequency questionnaire for Japanese general population. *J Epidemiol*. 2007;17(3):100–107. doi:10.2188/jea.17.100
23 Imaeda N, Goto C, Sasakabe T, et al. Reproducibility and validity of food group intake in a short food frequency questionnaire for the middle-aged Japanese population. *Environ Health Prev Med*. 2021;26(1):28. doi:10.1186/s12199-021-00951-3
24 Hara M, Nishida Y, Tanaka K, et al. Moderate-to-vigorous Physical Activity and Sedentary Behavior Are Independently Associated With Renal Function: A Cross-sectional Study. *J Epidemiol*. 2023;33(6):285–293. doi:10.2188/jea.JE20210155
25 Lenart EB, Goldberg JP, Bailey SM, Dallal GE, Koff E. Current and ideal physique choices in exercising and nonexercising college women from a pilot athletic image scale. *Percept Mot Skills*. 1995;81(3 Pt 1):831–848. doi:10.2466/pms.1995.81.3.831
26 Grossbard JR, Neighbors C, Larimer ME. Perceived norms for thinness and muscularity among college students: what do men and women really want? *Eat Behav*. 2011;12(3):192–199. doi:10.1016/j.eatbeh.2011.04.005
27 Ueno T, Yamamoto A, Shimada N, Wasano H. A Comparison between Japanese Male and Female Students of the Kyushu Area Based on an Investigation Concerning Body Shape Consciousness. Article in Japanese. *J Home Econ Jpn*. 2005;56(6):369–378. doi:10.11428/jhej1987.56.369
28 Igarashi T, Sugimoto K, Nishimura H. Reliability and Validity of the Japanese Version of the Drive for Muscularity Scale. Article in Japanese. *Jpn J Couns Sci*. 2011;44(2):158–166. doi:10.11544/cou.44.2_158
29 Suzuki W, Wuren, Kuriki K; Shizuoka-Sakuragaoka J-MICC Study Group. Associations between family factors and body weight gain from 20 years old. *BMC Womens Health*. 2019;19(1):33. doi:10.1186/s12905-019-0719-0
30 Casey VA, Dwyer JT, Berkey CS, Coleman KA, Gardner J, Valadian I. Long-term memory of body weight and past weight satisfaction: a longitudinal follow-up study. *Am J Clin Nutr*. 1991;53(6):1493–1498. doi:10.1093/ajcn/53.6.1493
31 Textor J, van der Zander B, Gilthorpe MS, Liskiewicz M, Ellison GT. Robust causal inference using directed acyclic graphs: the R package "dagitty". *Int J Epidemiol*. 2016;45(6):1887–1894. doi:10.1093/ije/dyw341
32 Mathur MB, Ding P, Riddell CA, VanderWeele TJ. Web Site and R Package for Computing E-values. *Epidemiology*. 2018;29(5):e45–e47. doi:10.1097/EDE.0000000000000864
33 VanderWeele TJ, Ding P. Sensitivity Analysis in Observational Research: Introducing the E-Value. *Ann Intern Med*. 2017;167(4):268–274. doi:10.7326/M16-2607
34 Westerterp KR. Changes in physical activity over the lifespan: impact on body composition and sarcopenic

obesity. *Obes Rev*. 2018;19 Suppl 1:8–13. doi:10.1111/obr.12781
35 Hull HR, Thornton J, Wang J, et al. Fat-free mass index: changes and race/ethnic differences in adulthood. *Int J Obes (Lond)*. 2011;35(1):121–127. doi:10.1038/ijo.2010.111
36 Kelsey TW, Li LQ, Mitchell RT, Whelan A, Anderson RA, Wallace WH. A validated age-related normative model for male total testosterone shows increasing variance but no decline after age 40 years. *PLoS One*. 2014;9(10):e109346. doi:10.1371/journal.pone.0109346
37 Zurlo F, Larson K, Bogardus C, Ravussin E. Skeletal muscle metabolism is a major determinant of resting energy expenditure. *J Clin Invest*. 1990;86(5):1423–1427. doi:10.1172/JCI114857
38 Lizcano F, Guzmán G. Estrogen Deficiency and the Origin of Obesity during Menopause. *Biomed Res Int*. 2014;2014:757461. doi:10.1155/2014/757461
39 Lovejoy JC, Champagne CM, de Jonge L, Xie H, Smith SR. Increased visceral fat and decreased energy expenditure during the menopausal transition. *Int J Obes (Lond)*. 2008;32(6):949–958. doi:10.1038/ijo.2008.25
40 Hurtado MD, Saadedine M, Kapoor E, Shufelt CL, Faubion SS. Weight Gain in Midlife Women. *Curr Obes Rep*. 2024;13(2):352–363. doi:10.1007/s13679-024-00555-2
41 Dahl AK, Hassing LB, Fransson EI, Pedersen NL. Agreement between self-reported and measured height, weight and body mass index in old age—a longitudinal study with 20 years of follow-up. *Age Ageing*. 2010;39(4):445–451. doi:10.1093/ageing/afq038
42 Tamakoshi K, Yatsuya H, Kondo T, et al. The accuracy of long-term recall of past body weight in Japanese adult men. *Int J Obes Relat Metab Disord*. 2003;27(2):247–252. doi:10.1038/sj.ijo.802195