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Joint trajectories of body mass index and waist circumference in early-life to mid-life adulthood and incident hypertension: the China Health and Nutrition Survey

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ABSTRACT

Objective This longitudinal study aims to identify distinct trajectories of body mass index (BMI) and waist circumference (WC) during 20–60 years old, and explore their joint effect on incident hypertension.

Design A longitudinal cohort study.

Setting China Health and Nutrition Survey, 1993–2011.

Participants The longitudinal cohort included 6571 participants (3063 men) who had BMI and WC repeatedly measured 3–7 times before incident hypertension or loss to follow-up.

Outcomes Hypertension was defined as systolic blood pressure/diastolic blood pressure>140/90 mm Hg or diagnosis by medical records or taking antihypertensive medication.

Results Two distinct trajectories were characterised for both BMI and WC: low-increasing and high-increasing. Jointly, subjects were divided into four groups: normal (n=4963), WC-increasing (n=620), BMI-increasing (n=309) and BMI&WC-increasing (n=679). Compared with the normal group, the adjusted HRs and 95% CIs for hypertension were 1.43 (1.19 to 1.74), 1.51 (1.19 to 1.92) and 1.76 (1.45 to 2.14) for WC-increasing, BMI-increasing and BMI&WC-increasing groups, respectively. The model-estimated levels and slopes of BMI and WC were calculated at each age point in 1-year interval according to the model parameters and their first derivatives, respectively. The associations between model-estimated levels and hypertension increased with age, with adjusted ORs and 95% CIs ranging from 0.92 (0.86 to 0.98) to 1.57 (1.47 to 1.67) for BMI and 0.98 (0.92 to 1.05) to 1.44 (1.35 to 1.53) for WC. Conversely, the ORs (95% CIs) of level-adjusted linear slopes decreased with age, ranging from 1.47 (1.38 to 1.57) to 0.97 (0.92 to 1.03) for BMI and 1.36 (1.28 to 1.45) to 0.99 (0.93 to 1.06) for WC.

Conclusions Our study demonstrates that the joint trajectories of BMI and WC have significant effect on future hypertension risk, and the changing slopes of BMI and WC during young adulthood are independent risk factors. Both BMI and WC should be paid more attention to prevent hypertension, and young adulthood may be a crucial period for intervention.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ The community-based longitudinal study, with large sample size and repeated measurements, was used to explore the distinct trajectories of body mass index (BMI) and waist circumference (WC) in early-life to mid-life adulthood.
⇒ Distinct trajectories of BMI and WC were identified by the latent class growth mixed model, and their joint effect on incident hypertension was explored.
⇒ The trajectory parameters, model-estimated levels and linear slopes, were examined to identify the critical period for early prevention of hypertension.
⇒ Unmeasurable covariates may cause potential confounding bias.

INTRODUCTION

As a major risk factor for cardiovascular disease, hypertension is a severe problem in public health.[1] The prevalence of hypertension has increased rapidly over decades,[2] causing heavy burden to the health system in China.[3 4] Obesity is regarded as an important risk factor for incident hypertension,[5 6] and it could be evaluated by many indicators, such as body mass index (BMI) and waist circumference (WC).[7 8] The relationship between single obesity indicators and incident hypertension has been well established in observation studies.[5–9] However, the joint effect of those indicators on hypertension is largely unknown in a life course perspective.

Generally, obesity is divided into systemic obesity and abdominal obesity.[8 9] Systemic obesity is mainly defined by BMI, while the abdominal obesity is often defined by WC.[8] The levels of BMI and WC reflect different aspects of obesity,[5–12] and their joint trajectories present the heterogeneous longitudinal changing patterns of body shape. Previous research has showed that BMI and WC were associated with hypertension in both cross-sectional[5–12] and longitudinal studies.[13–15] However, these studies mainly focused on the BMI and WC separately,[10–15] and the joint effect of BMI and WC trajectories on incident hypertension is still unclarified. We hypothesised that individuals in different joint trajectory group of BMI and WC may present different risk of hypertension, and a critical period may exist in early-life to mid-life adulthood for early prevention of hypertension.

Using data from the China Health and Nutrition Survey (CHNS), this study aims to identify BMI and WC trajectories during early-life to mid-life adulthood (20–60 years), explore the joint effect of BMI and WC trajectories on incident hypertension, and determine the potential critical period for the development of hypertension.

Subjects and methods

Study cohort

As an ongoing longitudinal cohort, the CHNS is implemented by national and local governments.[16 17] It is aimed at understanding how the economic and social transformation of Chinese society affects the health and nutritional status of Chinese population. Data from Beijing, Shanghai, Guizhou, Henan, Chongqing, Heilongjiang, Liaoning, Jiangsu, Zhejiang, Hubei, Hunan, Shaanxi, Shandong, Guangxi and Yunnan were collected by a multistage, random cluster process. During 1989–2011, a total of 9 cross-sectional surveys have been completed, covering 4400 households with 33 348 individuals.

In this current study, we excluded individuals younger than 20 years old or older than 60 years old (n=12 147), with BMI lower than 15 kg/m^2 or higher than 40 kg/m^2 (n=799), with WC greater than 120 cm (n=1632), and with less than three follow-up visits before loss to follow-up or incident hypertension (n=12 199). Finally, 6571 normotensive adult subjects, with 3–7 times visits, were included in this study. The mean follow-up time was 11.8 years (SD=4.2 years). BMI and WC measurements after the onset of hypertension (outcome) were excluded in our analyses. Online supplemental table S1 shows excluded respondents (n=26 777) were generally younger man, with lower baseline BMI, higher baseline systolic blood pressure (SBP) and diastolic blood pressure (DBP), lower proportion of smokers and alcohol consumers than those included.

Examinations

Standing height without shoes was measured to the nearest 0.2 cm using a portable SECA stadiometer (SECA, Hamburg, Germany) at each follow-up.[18] Weight was measured to the nearest 0.1 kg in light clothing without shoes on a dedicated scale that was routinely calibrated.[18] We calculated BMI as weight in kilograms divided by height in metres squared. Smoker was defined as ever smoking cigarettes (including ex-smoker and current smoker). Alcohol drinker was defined as alcohol consumption (including beer, liquor or wine) ≥25 g (for man) or ≥15 g (for woman) per week.

WC was defined as the midway between the lowest costal margin and the superior margin of the iliac crest, and was measured in centimetres using a SECA tapeline during 1993–2011.[18] After resting 5 min in a seated position, SBP and DBP were measured three times on the right upper arm using a standard mercury sphygmomanometer during 1991–2011.[18] The mean of the last two measurements was used for analyses.

Outcome

Hypertension was defined as SBP/DBP≥140/90 mm Hg and/or diagnosis by medical records and/or taking antihypertensive medication. Data for SBP, DBP, taking antihypertensive medication and incidence of diagnosis hypertension were first collected in 1991, and subsequently in 1993, 1997, 2000, 2004, 2006, 2009 and 2011 survey.

Statistical methods

The latent class growth mixed model (LCGMM) was used to identify different trajectory patterns of BMI and WC.[19] The latent class trajectories of BMI and WC were specified as functions of age (centred to 42 years, the mean age of the cohort). Multiple LCGMMs with different trajectory shapes, including linear and non-linear parameters were tested using the strategy we previously described.[19] We chose the best-fitting model for BMI and WC trajectory according to the BIC criterion while ensuring that each group has an acceptable proportion of the population and posterior probability. In the joint analyses, comprehensively considering the trajectories of BMI and WC, subjects were assigned into different joint groups.

The relationship between the joint group membership and incident hypertension were explored using Cox proportional hazard models. We established four models: model 1 with no covariates, model 2 with adjustment for baseline age, gender and baseline BMI, model 3 with further adjustment for baseline SBP and model 4 with further adjustment for smoking and alcohol drinking. Baseline WC was not adjusted due to its collinearity with baseline BMI (r=0.68).

According to the model parameters and their first derivatives, the model-estimated levels and linear slopes of BMI and WC were calculated at each age point in 1-year interval, respectively.[20] Logistic regression models were used to examine the associations of model-estimated levels and linear slopes of BMI and WC at each age point with incident hypertension. Before logistic regression analyses, the model-estimated linear slope values of BMI and WC at each age point were adjusted for their corresponding levels to avoid collinearity of levels and linear slopes in the same model.[20 21] Standardised ORs of levels and level-adjusted slopes of BMI and WC for incident hypertension were estimated, adjusted for gender, baseline SBP, smoking and alcohol drinking.

Table 1 Baseline characteristics by incident hypertension at follow-up

Variable	Total	Normotensives	Incident hypertension	P value
N	6571	5156	1415	
Age, years	35.4 (8.6)	34.8 (8.8)	37.8 (7.4)	<0.001
Males, n (%)	3063 (46.6)	2329 (45.2)	734 (51.9)	<0.001
BMI, kg/m^2	22.0 (2.7)	21.8 (2.6)	22.9 (2.9)	<0.001
WC, cm	75.8 (8.4)	75.2 (8.2)	78.0 (8.8)	<0.001
SBP, mm Hg	110.0 (103.0, 120.0)	110.0 (101.0, 120.0)	116.0 (108.0, 120.0)	<0.001
DBP, mm Hg	74.0 (70.0, 80.0)	72.5 (68.0, 80.0)	77.5 (70.0, 80.0)	<0.001
Smoker, n (%)	2123 (32.5)	1578 (30.8)	545 (38.8)	<0.001
Drinker, n (%)	2312 (35.5)	1712 (33.6)	600 (42.7)	<0.001
Follow-up, years	11.8 (4.2)	12.0 (4.3)	11.3 (3.9)	<0.001

Study variables are presented as mean (SD), median (IQR) or n (%), appropriately.
BMI, body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure; WC, waist circumference.

Variables were described using mean (SD), median (IQR) and n (%), as appropriate. All analyses were performed using R V.4.0.4. Hypothesis tests were two sided, and p<0.05 was considered statistically significant.

Patient and public involvement

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

RESULTS

Table 1 presents baseline characteristics of study variables by incident hypertension groups during follow-up. Incident hypertension subjects (n=1415) were more likely to be older males, with higher BMI, WC, SBP and DBP, higher proportions of smokers and alcohol drinkers than normotensives.

Online supplemental tables S2 and S3 summarise LCGMM results of the BMI and WC trajectory model fitting process. We fitted models from one class to three classes of linear, quadratic and cubic curves. According to statistical criteria above, a model of quadratic parameters with two classes was chosen for both BMI and WC as the best fit. Online supplemental tables S4 and S5 present parameter estimates for the best-fitting two-class quadratic LCGMM of BMI and WC, respectively.

Figure 1 shows the longitudinal trajectories of BMI (figure 1A) and WC (figure 1B) during 20–60 years old for 6571 participants. Both BMI and WC had two distinct trajectories, labelled as low-increasing (n (%)=5583 (84.96%) for BMI and 5272 (80.53%) for WC) and high-increasing (n (%)=988 (15.04%) for BMI and 1299 (19.47%) for WC). Compared with the subjects in low-increasing group, those in the high-increasing group had similar predicted levels at age 20 years but higher linear slopes from 20 to 60 years.

Online supplemental table S6 shows HRs and 95% CIs for the association between the BMI trajectory group membership and incident hypertension. Compared with the BMI low-increasing group, HR (95% CI) for the BMI high-increasing group was 1.49 (1.26 to 1.75), adjusted for baseline age, gender, baseline BMI, baseline WC, baseline SBP, smoking and alcohol drinking. Online supplemental table S7 presents HRs and 95% CIs for the relationship between the WC trajectory classes and incident hypertension. Compared with the WC low-increasing group, HR (95% CI) for the WC high-increasing group was 1.43 (1.22 to 1.68), adjusted for the same covariates above.

Jointly, subjects were divided into four joint groups according to their BMI and WC trajectories, named as normal (n=4963), WC-increasing (n=620), BMI-increasing (n=309) and BMI&WC-increasing (n=679). Individuals in the normal, WC-increasing, BMI-increasing and BMI&WC-increasing group had low-increasing WC and BMI, low-increasing BMI and high-increasing WC, high-increasing BMI and low-increasing WC, and high-increasing BMI and WC, respectively. Table 2 summarises the baseline characteristics of study variables by joint classes. Compared with the normal group, individuals in the BMI&WC-increasing group were more likely to be younger men with higher baseline BMI, WC, SBP and DBP, and higher proportions of smoking and alcohol drinking.

Table 3 presents HRs and 95% CIs for the association between joint group membership and incident hypertension. Compared with the normal group, the HRs (95% CIs) for WC-increasing, BMI-increasing and BMI&WC-increasing group were 1.55 (1.31 to 1.83), 1.69 (1.36 to 2.10) and 1.98 (1.71 to 2.28) in unadjusted model, respectively. After adjustment for baseline age, gender, baseline BMI, SBP, smoking and drinking status, these joint groups were still significantly associated with incident hypertension, whose HRs (95% CIs) were 1.43 (1.19 to 1.74), 1.51 (1.19 to 1.92) and 1.76 (1.45 to 2.14), respectively.

Online supplemental tables S8 and S9 show model-estimated levels and linear slopes of BMI and WC in means

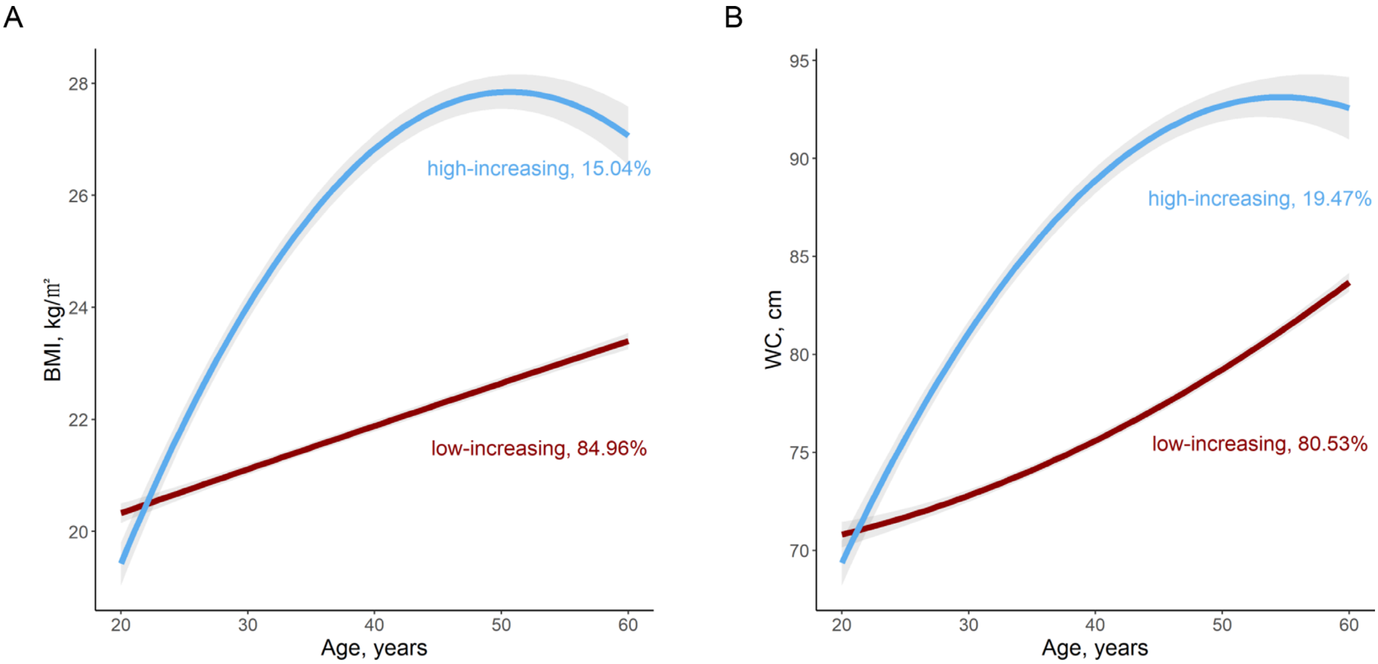

Figure 1 (A) Predicted trajectories of BMI during 20–60 years old. The trajectories were shown in solid lines, and the 95% CIs were shown in shadow. The proportions in each trajectory were shown below solid lines. BMI, body mass index (see detailed information on the curve parameters in online supplemental table S4). (B) Predicted trajectories of WC during 20–60 years old. The trajectories were shown in solid lines, and the 95% CIs were shown in shadow. The proportions in each trajectory were shown below solid lines. WC, waist circumference (see detailed information on the curve parameters in online supplemental table S5).

(SD) by incident hypertension at follow-up. Figure 2 shows the change of model-estimated levels and linear slopes of BMI and WC during age 20–60 years in hypertension and normotension group. In figure 2A, the levels increased and linear slopes decreased with age during 20–60 in both hypertension and normotension groups. However, the hypertension group had higher levels and steeper rate of change than the normotension group. Similar results were found in WC (figure 2B). Noticeably, the difference in change rate of WC linear slopes was large between the hypertension group and normotension group.

Figure 3 presents ORs and 95% CIs of model-estimated levels and level-adjusted linear slopes of BMI and WC for incident hypertension, adjusted for gender, baseline SBP, smoking and alcohol drinking. The association between model-estimated levels and hypertension increased during 20–60 years old, with adjusted ORs and 95% CIs ranging from 0.92 (0.86 to 0.98) to 1.57 (1.47 to 1.67) for BMI and 0.98 (0.92 to 1.05) to 1.44 (1.35 to 1.53) for WC. This association became significant at age 25 or above for BMI and at age 23 or above for WC. Conversely, the standardised ORs (95% CIs) of level-adjusted linear slopes decreased with age,

Table 2 Characteristics at baseline and incident hypertension at follow-up by joint trajectory groups

Variable	Normal	WC-increasing	BMI-increasing	BMI&WC-increasing	P value
N	4963	620	309	679	
Age, years	36.3 (8.6)	32.8 (8.2)	34.3 (8.3)	31.8 (7.7)	<0.001
Males, n (%)	2019 (40.7)	557 (89.8)	33 (10.7)	454 (66.9)	<0.001
BMI, kg/m^2	21.3 (2.2)	22.8 (2.3)	24.5 (3.1)	25.0 (3.4)	<0.001
WC, cm	73.8 (7.0)	81.3 (8.7)	78.9 (8.2)	84.1 (9.9)	<0.001
SBP, mm Hg	110.0 (101.0, 120.0)	117.5 (110.0, 120.0)	110.0 (105.0, 120.0)	116.0 (108.0, 120.0)	<0.001
DBP, mm Hg	72.5 (68.0, 80.0)	77.0 (70.0, 80.0)	73.0 (68.8, 80.0)	77.0 (70.0, 80.0)	<0.001
Smoker, n (%)	1435 (29.1)	364 (59.4)	30 (9.8)	294 (43.5)	<0.001
Drinker, n (%)	1563 (31.8)	370 (60.3)	58 (18.9)	321 (48.0)	<0.001
Hypertension, n (%)	935 (18.8)	159 (25.6)	89 (28.8)	232 (34.2)	<0.001

Study variables are presented as mean (SD), median (IQR) or n (%), appropriately.
BMI, body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure; WC, waist circumference.

Table 3 HRs and 95% CIs of joint trajectory groups for incident hypertension

	Model 1	Model 2	Model 3	Model 4
Joint trajectory groups				
Normal	Reference	Reference	Reference	Reference
WC-increasing	1.55 (1.31 to 1.83)	1.51 (1.25 to 1.82)	1.41 (1.17 to 1.71)	1.43 (1.19 to 1.74)
BM-increasing	1.69 (1.36 to 2.10)	1.47 (1.16 to 1.87)	1.48 (1.17 to 1.89)	1.51 (1.19 to 1.92)
BMI&WC-increasing	1.98 (1.71 to 2.28)	1.74 (1.44 to 2.10)	1.73 (1.42 to 2.10)	1.76 (1.45 to 2.14)
Covariates				
Baseline age		1.07 (1.06 to 1.08)	1.07 (1.06 to 1.08)	1.07 (1.06 to 1.08)
Female		0.77 (0.69 to 0.87)	0.89 (0.79 to 1.00)	1.01 (0.85 to 1.18)
Baseline BMI		1.10 (1.08 to 1.13)	1.07 (1.05 to 1.10)	1.07 (1.05 to 1.10)
Baseline SBP			1.03 (1.02 to 1.04)	1.03 (1.02 to 1.04)
Smoker				1.12 (0.96 to 1.30)
Drinker				1.10 (0.96 to 1.26)

BMI, body mass index; WC, waist circumference; SBP, systolic blood pressure.

ranging from 1.47 (1.38 to 1.57) to 0.97 (0.92 to 1.03) for BMI and 1.36 (1.28 to 1.45) to 0.99 (0.93 to 1.06) for WC. The associations of level-adjusted linear slopes with incident hypertension were no longer significant at age 55, indicating the importance of BMI and WC slopes in young adulthood.

DISCUSSION

In this longitudinal study, we identified two distinct trajectories for both BMI and WC during 20–60 years old in Chinese population, and found a joint effect of BMI and WC trajectories on incident hypertension. The model-estimated levels and level adjusted slopes at each age point in a 1-year interval were further calculated for both BMI and WC, and their associations with hypertension were estimated. Though previous studies have demonstrated BMI or WC trajectories were associated with hypertension separately, the joint effect of BMI and WC trajectories was unclarified. Our observations support that BMI and WC trajectories have synergistic effect on future hypertension risk, and the changing slopes of BMI and WC during young adulthood are independent risk factors. Therefore, we suggest controlling both BMI and WC in young adulthood to prevent hypertension.

In the current study, we identified two trajectories for BMI. The low-increasing group, with baseline BMI around 20 kg/m^2, increased slowly during the 20–60 years period, while the high-increasing group with lower baseline BMI increased rapidly. Some studies, using data from China, the UK and Finland, explored BMI trajectories

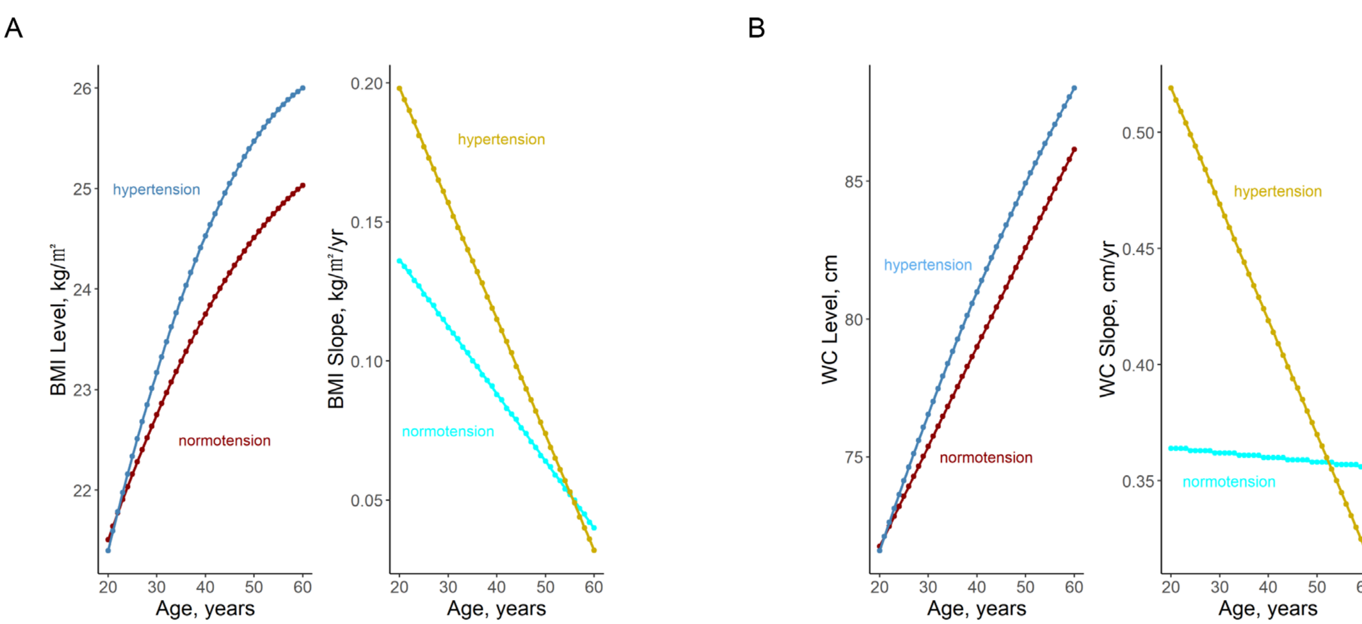

Figure 2 (A) The mean of model-estimated levels and level-adjusted linear slopes of BMI during 20–60 years old by incident hypertension. (B) The mean of model-estimated levels and level-adjusted linear slopes of WC during 20–60 years old by incident hypertension. BMI, body mass index; WC, waist circumference.

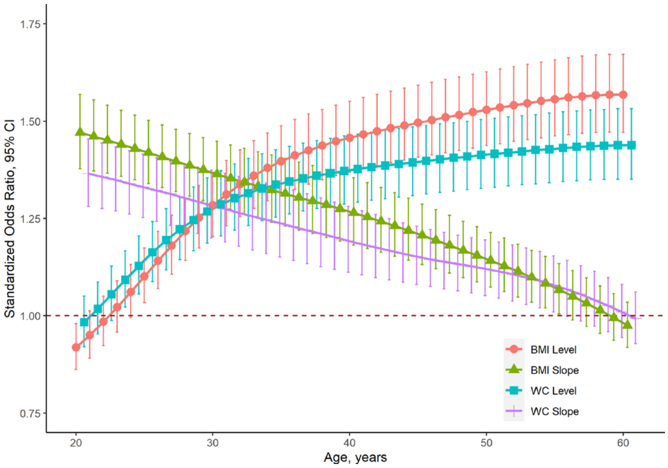

Figure 3 Standardised ORs and 95% CIs of model-estimated levels and level-adjusted linear slopes of BMI and WC during 20–60 years old by age for incident hypertension, adjusted for gender, baseline SBP, smoking and alcohol drinking. BMI, body mass index; SBP, systolic blood pressure; WC, waist circumference.

for childhood and early adulthood, showed that BMI may have 2–6 trajectories.[13 14 20–25] Though the numbers of trajectories were different among these studies, they all discovered a low-increasing or low-stable group and a high-increasing group,[13 1420–25] which was in line with our results. Two distinct trajectories of WC were also identified in this study. The low-increasing group, with baseline WC around 70 cm, persisted 70–80 cm during early-life to mid-life adulthood, while the high-increasing group with same baseline WC increased gradually from 70 to 95 cm. To our knowledge, the literatures on WC trajectories are still limited. Jeon *et al*[15] showed five trajectories for WC in individuals aged 40 years or older using data from Korea. Cheng *et al*[26] presented that WC may have four trajectories among Chinese population during 18–50 years old. However, these previous researches did not consider the subject-specific random effect, which was a strength in our study.[15 26]

Generally, obesity is divided into systemic obesity and abdominal obesity. Only studying the relationship between BMI or WC and hypertension is insufficient.[13–15 20 21] The joint effect of BMI and WC on hypertension should be explored. In this study, we divided participants into four subgroups according to their BMI and WC trajectories. Compared with the normal group, BMI&WC-increasing group had a higher risk of incident hypertension after adjustment for some covariates, indicating that the joint effect of BMI and WC trajectories was significant associated with hypertension. Previous researches showed BMI or WC trajectories were associated with hypertension.[13–15 20 26] However, these studies mainly focused on the BMI and WC trajectories separately, ignoring the complementary effect between BMI and WC on incident hypertension.[13–15 20 21 26] Hu *et al*[8] found a joint effect of BMI and WC on hypertension in a cross-sectional study, nevertheless, the longitudinal changing patterns of both BMI and WC were not considered in that study. To our knowledge, the joint effect of BMI and WC trajectories was largely unknown. Our study supports a synergistic effect between BMI and WC trajectories on incident hypertension, highlighted that we should take more attention to control both BMI and WC in early adulthood.

In this longitudinal study, the model-estimated levels increased with age and the model-estimated slopes decreased with age for both BMI and WC, which was in line with our previous studies.[20 21] The standardised ORs were calculated for both model-estimated levels and level-adjusted slopes, after adjusting for gender, baseline SBP, smoking and alcohol drinking. Our results showed that for both BMI and WC, level-adjusted slopes had higher ORs than model-estimated levels before 30 years old. It may indicate slopes of BMI and WC are more important than their levels in early adulthood and 20–30 may be a critical period for early prevention of hypertension, which is similar with previous studies.[20 21] Interestingly, our longitudinal study found that the linear slopes of BMI had higher ORs than those of WC during 20–25 years old. Similarly, in 43–60 years old, the levels of BMI had higher ORs than those of WC. These results may indicate that BMI plays a more important role than WC in incident hypertension during both early-life and mid-life adulthood in Chinese population.

According to the life course epidemiology theory,[27–29] exposure at a particular period in the life span has a long-term effect on the physiological function and anatomical structure and may eventually lead to some diseases. In the current study, individuals with high-increasing trajectory patterns of BMI and WC may have some changes in physiological aspect during early adulthood, including aorta root thickening, premature vascular ageing and endothelial dysfunction.[30–32] These changes may have accumulated effects on the way to incident hypertension. Previous research has reported meaningful high prevalence of premature vascular ageing in younger than 40 years people.[31] Endothelial dysfunction may also play an important role in developing hypertension[32] and it may impact early aorta root thickening.[30] Furthermore, aorta root size may play a causative role in the pathogenesis of systolic hypertension.[30]

There are some important strengths in our study. The current study is a community-based longitudinal study with large sample size and repeated measurements. It allows us to use LCGMM to explore trajectory of BMI and WC. The LCGMM can identify distinct trajectory for subgroup participants and permits us to analyse the relationship between model-estimated levels and level-adjusted slopes and hypertension to reveal the critical period in life course. Moreover, the joint effect of BMI and WC trajectories on incident hypertension was explored, which was rarely reported in previous researches. On the other hand, some limitations should be acknowledged. First, the covariates we used may be insufficient. Some unavailable covariates, such as physically fitness, may impact the prevalence of incident hypertension. Second, CHNS was a survey concentrated on Chinese population, suggesting our study may not be generalizable to other ethnic population. Finally, there are many indicators of obesity, besides BMI and WC. Further studies should consider more indicators such as body fat percentage and fat free mass to explore the relationship between those indicators and incident hypertension.

In conclusion, the current study identified two distinct trajectories of BMI and WC from early-life to mid-life adulthood, and found complementary trajectory patterns between BMI and WC (620 (9.4%) and 309 (4.7%) participants for WC-increasing only trajectory and BMI-increasing only trajectory). From a life course perspective, our study demonstrates the joint trajectories of BMI and WC have significant effect on future hypertension risk, and the changing slopes of BMI and WC during young adulthood are independent risk factors. These results emphasise that both BMI and WC should be paid more attention to prevent hypertension, and young adulthood may be a crucial period for intervention. More targeted strategies in the prevention of hypertension should be emphasised among early adulthood. Public health intervention for controlling modifiable risk factors during young adulthood may reduce the future prevalence and burden of hypertension among Chinese.

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Contributors YQ, CL, JL, BF, YL, CS and XZ generated the hypothesis and contributed to analytic strategy and wrote the manuscript. CS and XZ supervised the field activities and data collection and edited the manuscript. XZ was the guarantor of this study.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants. The protocol was approved by the Ethics Committee of the National Institute for Nutrition and Health, China CDC (no. 201524). Informed consent was obtained from all subjects before the investigation. 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.

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Supplemental Materials

Joint Trajectories of Body Mass Index and Waist Circumference in Early to Mid-life Adulthood and Incident Hypertension: the China Health and Nutrition Survey

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Trajectory Analysis

Repeated trajectory analyses were performed to identify the latent classes by changing the number of groups from 2 to 3, with the same starting values calculated from the 1-group model. The shapes and optimal number of groups were determined by the following criteria: 1) Bayesian information criterion (BIC) decreased at least 20; 2) high mean posterior class membership probabilities (> 0.65); 3) high mean posterior probabilities (> 0.7). Estimation of latent class models was performed with lcmm (version 1.7.8) package in R (version 4.0.4). To avoid convergence towards local maxima, LCGMM models with 2 or 3 classes were performed for several times with different sets of random starting value based on 1-class model. Finally, according to criteria above, a model of quadratic parameters with two classes was chosen for both BMI and WC as the best fit. The final model of BMI was described as:

$$BMI_{\mathrm{ij}} \mid_{\mathrm{c}_{\mathrm{i}=g}} = (\upsilon_{0g} + u_{0\mathrm{i}g}) + (\upsilon_{1g} + u_{1ig})age + (\upsilon_{2g} + u_{2ig})age^2 + \varepsilon_{ij}$$

where υ =(υ_{0g}, υ_{1g}, υ_{2g}) is a vector of fixed effect parameters in the group “g”, u =(u_{0ig}, u_{1ig}, u_{2ig}) is a vector of random effect parameters of the individual “i” in the group “g”, ε_{ij} is an unknown error term (the model of WC is similar with BMI).

Table S1. Baseline characteristics of participants included and excluded.

Variable	Excluded	Included	*P*-Value
N	26777	6571	
Age, y	30.8 (23.0)	35.4 (8.6)	<0.001
Male, n (%)	12931 (48.3)	3063 (46.6)	0.017
BMI, kg/m^2	20.9 (4.8)	22.0 (2.7)	<0.001
WC, cm	75.9 (15.6)	75.8 (8.4)	0.365
SBP, mm Hg	116.0 [102.0, 129.0]	110.0 [103.0, 120.0]	<0.001
DBP, mm Hg	75.0 [68.0, 81.0]	74.0 [70.0, 80.0]	<0.001
Smoker, n (%)	4475 (27.2)	2123 (32.5)	<0.001
Drinker, n (%)	5162 (29.4)	2312 (35.5)	<0.001

BMI indicates body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure; WC, waist circumference.

Table S2. Latent Class Growth Mixture Models (LCGMM) results of model fitting process for BMI.

No. Latent class	Polynomial degree	Log-Lik	BIC	% Participants per class	Mean posterior probabilities	% Posterior probabilities > 70%
1	Linear	-59740	119525	100	na	na
	Quadratic	-59623	119308	100	na	na
	Cubic	-59604	119289	100	na	na
2	Linear	-59299	118678	9.98/90.02	0.79/0.95	66.92/95.38
	Quadratic	**-59122**	**118351**	**84.96/15.04**	**0.93/0.81**	**93.19/72.37**
	Cubic	-59120	118373	15.17/84.83	0.82/0.93	73.22/93.00
3	Linear	-59190	118495	24.97/72.12/2.91	0.74/0.87/0.79	56.98/84.30/67.02
	Quadratic	-58989	118128	73.40/23.09/3.51	0.88/0.73/0.78	85.32/57.61/64.07
	Cubic	-58985	118155	4.34/78.45/17.21	0.74/0.90/0.73	58.25/88.13/54.38

BMI indicate body mass index; NO. Latent class: latent class number of the model; Log-Lik: the maximum Log-Likelihood; BIC: the Bayesian information Criterion; % Participants per class: proportion of participants per class; The best fitting model is highlighted in bold characters. (na: not applicable)

Table S3. Latent Class Growth Mixture Models (LCGMM) results of model fitting process for WC.

No. Latent class	Polynomial degree	Log-Lik	BIC	% Participants per class	Mean posterior probabilities	% Posterior probabilities > 70%
1	Linear	-98380	196839	100	na	na
	Quadratic	-98387	196836	100	na	na
	Cubic	-98397	196839	100	na	na
2	Linear	-98042	196163	83.32/16.68	0.92/0.78	91.98/65.42
	Quadratic	**-97946**	**195998**	**80.53/19.47**	**0.92/0.80**	**91.35/68.67**
	Cubic	-97940	196012	80.18/19.82	0.92/0.80	91.41/69.79
3	Linear	-98008	195918	50.95/36.74/12.81	0.95/0.89/0.77	96.19/86.74/63.06
	Quadratic	-97875	195900	54.95/9.34/35.71	0.80/0.77/0.70	70.99/64.12/50.57
	Cubic	-97866	195112	50.46/36.74/12.80	0.71/0.87/0.68	52.88/84.85/42.74

WC indicate waist circumference; NO. Latent class: latent class number of the model; Log-Lik: the maximum Log-Likelihood; BIC: the Bayesian information Criterion; % Participants per class: proportion of participants per class; The best fitting model is highlighted in bold characters. (na: not applicable)

Table S4. Parameters estimates for the best fitting 2-class quadratic Latent Class Growth Mixture Model for BMI.

		Intercept (se)*	Linear (se)	Quadratic (se)
Fixed effect				
	Group 1	23.519 (0.0487)	0.077 (0.0024)	-5×10^{-5} (0.0002)
	Group 2	27.177 (0.1337)	0.155 (0.0076)	-0.009 (0.0005)
Random effects: variance-covariance matrix				
$\sigma^2_{int} = 3.88$				
$\sigma^2_{linear\ slope} = 0.0105$				
$\sigma^2_{quadratic\ slope} < 0.001$				
$\sigma^2_{error} = 1.24$				

se = standard error; BMI = body mass index.

*: Intercept interpreted as the expected level of BMI in kg/m^2 at 42 years of age (centering to the mean age of the sample)

Table S5. Parameters estimates for the best fitting 2-class quadratic Latent Class Growth Mixture Model for WC.

		Intercept (se)*	Linear (se)	Quadratic (se)
Fixed effect				
	Group 1	76.890 (0.1459)	0.338 (0.0084)	0.004 (0.0006)
	Group 2	89.963 (0.3340)	0.501 (0.0226)	-0.020 (0.0015)
Random effects: variance-covariance matrix				
$\sigma^2_{int} = 24.31$				
$\sigma^2_{linear\ slope} = 0.0984$				
$\sigma^2_{quadratic\ slope} < 0.001$				
$\sigma^2_{error} = 5.38$				

se = standard error; WC = waist circumference.

*: Intercept interpreted as the expected level of WC in cm at 42 years of age (centering to the mean age of the sample)

Table S6. Hazard Ratios and 95% of BMI Trajectory Groups for Incident Hypertension

	Model 1	Model 2	Model 3	Model 4
Trajectory groups				
Low-increasing group	Reference	Reference	Reference	Reference
High-increasing group	1.79 (1.58, 2.03)	1.44 (1.22, 1.69)	1.47 (1.25, 1.73)	1.49 (1.26, 1.75)
Covariates				
Age, y		1.07 (1.06, 1.08)	1.06 (1.05, 1.07)	1.06 (1.05, 1.07)
Female		0.74 (0.67, 0.83)	0.86 (0.77, 0.96)	0.97 (0.83, 1.14)
Baseline BMI		1.09 (1.06, 1.12)	1.07 (1.04, 1.10)	1.07 (1.04, 1.10)
Baseline WC		1.01 (1.00,1.02)	1.01 (1.00, 1.02)	1.01 (1.00, 1.02)
Baseline SBP			1.03 (1.02, 1.04)	1.03 (1.02, 1.04)
Smoker				1.11 (0.96, 1.30)
Drinker				1.11 (0.97, 1.27)

BMI, body mass index; SBP, systolic blood pressure; WC, waist circumference.

Table S7. Hazard Ratios and 95% of WC Trajectory Groups for Incident Hypertension

	Model 1	Model 2	Model 3	Model 4
Trajectory groups				
Low-increasing group	Reference	Reference	Reference	Reference
High-increasing group	1.71 (1.53, 1.93)	1.45 (1.24, 1.69)	1.42 (1.21, 1.66)	1.43 (1.22, 1.68)
Covariates				
Age, y		1.07 (1.06, 1.08)	1.06 (1.05, 1.07)	1.06 (1.05, 1.07)
Female		0.80 (0.72, 0.90)	0.92 (0.82, 1.03)	1.04 (0.89, 1.23)
Baseline BMI		1.10 (1.07, 1.13)	1.08 (1.05, 1.11)	1.08 (1.05, 1.11)
Baseline WC		1.01 (1.00, 1.02)	1.00 (0.99, 1.01)	1.01 (1.00, 1.02)
Baseline SBP			1.03 (1.02, 1.04)	1.03 (1.02, 1.04)
Smoker				1.12 (0.96, 1.30)
Drinker				1.10 (0.96, 1.26)

BMI, body mass index; SBP, systolic blood pressure; WC, waist circumference.

Table S8. Model-estimated levels and linear slopes of BMI in means (SD) by incident hypertension at follow-up

	BMI Level (kg/m^2)			**BMI Slope (kg/m^2/year)**		
Age, (years)	NTN	HTN	*P*-Value	NTN	HTN	*P*-Value
20	21.50 (2.03)	21.40 (1.95)	0.068	0.14 (0.17)	0.20 (0.21)	<0.001
21	21.64 (1.96)	21.59 (1.87)	0.407	0.13 (0.17)	0.19 (0.20)	<0.001
22	21.77 (1.90)	21.78 (1.82)	0.828	0.13 (0.16)	0.19 (0.19)	<0.001
23	21.90 (1.85)	21.97 (1.78)	0.199	0.13 (0.16)	0.19 (0.19)	<0.001
24	22.03 (1.82)	22.16 (1.76)	0.019	0.13 (0.15)	0.18 (0.18)	<0.001
25	22.16 (1.80)	22.34 (1.76)	<0.001	0.12 (0.15)	0.18 (0.17)	<0.001
26	22.28 (1.79)	22.51 (1.77)	<0.001	0.12 (0.14)	0.17 (0.17)	<0.001
27	22.40 (1.79)	22.68 (1.80)	<0.001	0.12 (0.14)	0.17 (0.16)	<0.001
28	22.52 (1.80)	22.85 (1.84)	<0.001	0.12 (0.13)	0.16 (0.15)	<0.001
29	22.64 (1.82)	23.01 (1.88)	<0.001	0.11 (0.13)	0.16 (0.15)	<0.001
30	22.75 (1.84)	23.17 (1.94)	<0.001	0.11 (0.12)	0.16 (0.14)	<0.001
31	22.86 (1.87)	23.32 (1.99)	<0.001	0.11 (0.12)	0.15 (0.13)	<0.001
32	22.97 (1.90)	23.48 (2.05)	<0.001	0.11 (0.11)	0.15 (0.13)	<0.001
33	23.07 (1.93)	23.62 (2.11)	<0.001	0.10 (0.11)	0.14 (0.12)	<0.001
34	23.18 (1.97)	23.76 (2.17)	<0.001	0.10 (0.10)	0.14 (0.11)	<0.001
35	23.28 (2.00)	23.90 (2.23)	<0.001	0.10 (0.10)	0.14 (0.11)	<0.001
36	23.38 (2.04)	24.04 (2.28)	<0.001	0.10 (0.09)	0.13 (0.10)	<0.001
37	23.48 (2.07)	24.16 (2.33)	<0.001	0.09 (0.09)	0.13 (0.10)	<0.001
38	23.57 (2.11)	24.29 (2.38)	<0.001	0.09 (0.09)	0.12 (0.09)	<0.001
39	23.66 (2.14)	24.41 (2.43)	<0.001	0.09 (0.08)	0.12 (0.09)	<0.001
40	23.75 (2.17)	24.53 (2.47)	<0.001	0.09 (0.08)	0.11 (0.08)	<0.001
41	23.84 (2.20)	24.64 (2.51)	<0.001	0.09 (0.07)	0.11 (0.08)	<0.001
42	23.92 (2.22)	24.75 (2.55)	<0.001	0.08 (0.07)	0.11 (0.07)	<0.001
43	24.01 (2.25)	24.85 (2.58)	<0.001	0.08 (0.07)	0.10 (0.07)	<0.001
44	24.08 (2.27)	24.96 (2.60)	<0.001	0.08 (0.07)	0.10 (0.07)	<0.001
45	24.16 (2.28)	25.05 (2.62)	<0.001	0.08 (0.07)	0.09 (0.07)	<0.001
46	24.24 (2.30)	25.14 (2.64)	<0.001	0.07 (0.07)	0.09 (0.07)	<0.001
47	24.31 (2.31)	25.23 (2.65)	<0.001	0.07 (0.07)	0.09 (0.07)	<0.001

48	24.38 (2.32)	25.32 (2.66)	<0.001	0.07 (0.07)	0.08 (0.07)	<0.001
49	24.45 (2.33)	25.40 (2.66)	<0.001	0.07 (0.07)	0.08 (0.07)	<0.001
50	24.51 (2.33)	25.47 (2.66)	<0.001	0.06 (0.07)	0.07 (0.07)	<0.001
51	24.58 (2.33)	25.54 (2.65)	<0.001	0.06 (0.07)	0.07 (0.07)	<0.001
52	24.64 (2.33)	25.61 (2.64)	<0.001	0.06 (0.07)	0.06 (0.08)	0.008
53	24.69 (2.33)	25.67 (2.62)	<0.001	0.06 (0.07)	0.06 (0.08)	0.075
54	24.75 (2.33)	25.73 (2.60)	<0.001	0.05 (0.08)	0.06 (0.09)	0.316
55	24.80 (2.32)	25.79 (2.58)	<0.001	0.05 (0.08)	0.05 (0.09)	0.766
56	24.85 (2.31)	25.84 (2.56)	<0.001	0.05 (0.08)	0.05 (0.10)	0.737
57	24.90 (2.30)	25.88 (2.53)	<0.001	0.05 (0.09)	0.04 (0.10)	0.367
58	24.95 (2.29)	25.93 (2.50)	<0.001	0.04 (0.09)	0.04 (0.11)	0.159
59	25.00 (2.28)	25.96 (2.48)	<0.001	0.04 (0.10)	0.04 (0.11)	0.063
60	25.03 (2.27)	26.00 (2.45)	<0.001	0.04 (0.10)	0.03 (0.12)	0.023

NTN = normotension; HTN = hypertension.

Table S9. Model-estimated levels and linear slopes of WC in means (SD) by incident hypertension at follow-up

	WC Level (cm)			**WC Slope (cm/year)**		
Age, (years)	NTN	HTN	*P*-Value	NTN	HTN	*P*-Value
20	71.75 (4.90)	71.60 (4.52)	0.271	0.36 (0.50)	0.52 (0.57)	<0.001
21	72.12 (4.80)	72.12 (4.45)	0.997	0.36 (0.48)	0.51 (0.55)	<0.001
22	72.48 (4.75)	72.63 (4.44)	0.272	0.36 (0.46)	0.51 (0.53)	<0.001
23	72.84 (4.73)	73.13 (4.48)	0.032	0.36 (0.45)	0.50 (0.51)	<0.001
24	73.21 (4.76)	73.64 (4.58)	0.002	0.36 (0.43)	0.50 (0.49)	<0.001
25	73.57 (4.81)	74.13 (4.71)	<0.001	0.36 (0.42)	0.49 (0.47)	<0.001
26	73.93 (4.89)	74.63 (4.88)	<0.001	0.36 (0.40)	0.49 (0.45)	<0.001
27	74.30 (5.00)	75.11 (5.06)	<0.001	0.36 (0.38)	0.48 (0.43)	<0.001
28	74.66 (5.12)	75.59 (5.26)	<0.001	0.36 (0.37)	0.48 (0.41)	<0.001
29	75.02 (5.25)	76.07 (5.47)	<0.001	0.36 (0.35)	0.47 (0.39)	<0.001
30	75.38 (5.38)	76.54 (5.68)	<0.001	0.36 (0.34)	0.47 (0.37)	<0.001
31	75.75 (5.25)	77.01 (5.90)	<0.001	0.36 (0.32)	0.46 (0.35)	<0.001
32	76.11 (5.67)	77.47 (6.10)	<0.001	0.36 (0.31)	0.46 (0.33)	<0.001
33	76.47 (5.81)	77.93 (6.30)	<0.001	0.36 (0.29)	0.45 (0.31)	<0.001
34	76.83 (5.95)	78.38 (6.50)	<0.001	0.36 (0.28)	0.45 (0.30)	<0.001
35	77.19 (6.08)	78.83 (6.68)	<0.001	0.36 (0.26)	0.44 (0.28)	<0.001
36	77.55 (6.21)	79.27 (6.85)	<0.001	0.36 (0.25)	0.44 (0.26)	<0.001
37	77.91 (6.33)	79.71 (7.01)	<0.001	0.36 (0.24)	0.43 (0.25)	<0.001
38	78.27 (6.44)	80.14 (7.15)	<0.001	0.36 (0.23)	0.43 (0.23)	<0.001
39	78.63 (6.54)	80.56 (7.28)	<0.001	0.36 (0.22)	0.42 (0.22)	<0.001
40	78.99 (6.63)	80.99 (7.39)	<0.001	0.36 (0.21)	0.42 (0.20)	<0.001
41	79.35 (6.71)	81.40 (7.49)	<0.001	0.36 (0.20)	0.41 (0.19)	<0.001
42	79.71 (6.78)	81.82 (7.58)	<0.001	0.36 (0.19)	0.41 (0.18)	<0.001
43	80.07 (6.83)	82.22 (7.64)	<0.001	0.36 (0.19)	0.40 (0.17)	<0.001
44	80.43 (6.88)	82.62 (7.70)	<0.001	0.36 (0.18)	0.40 (0.17)	<0.001
45	80.79 (6.92)	83.02 (7.73)	<0.001	0.36 (0.18)	0.39 (0.17)	<0.001
46	81.15 (6.94)	83.41 (7.75)	<0.001	0.36 (0.18)	0.39 (0.17)	<0.001
47	81.51 (6.95)	83.80 (7.75)	<0.001	0.36 (0.18)	0.38 (0.17)	<0.001

48	81.87 (6.96)	84.18 (7.74)	<0.001	0.36 (0.19)	0.38 (0.17)	<0.001
49	82.23 (6.95)	84.56 (7.72)	<0.001	0.36 (0.19)	0.37 (0.18)	0.006
50	82.59 (6.93)	84.93 (7.67)	<0.001	0.36 (0.20)	0.37 (0.19)	0.074
51	82.94 (6.90)	85.30 (7.72)	<0.001	0.36 (0.21)	0.36 (0.20)	0.355
52	83.30 (6.86)	85.66 (7.55)	<0.001	0.36 (0.22)	0.36 (0.22)	0.883
53	83.66 (6.81)	86.02 (7.46)	<0.001	0.36 (0.23)	0.35 (0.23)	0.586
54	84.02 (6.76)	86.37 (7.37)	<0.001	0.36 (0.24)	0.35 (0.25)	0.248
55	84.37 (6.70)	86.72 (7.26)	<0.001	0.36 (0.25)	0.34 (0.26)	0.091
56	84.73 (6.63)	87.06 (7.14)	<0.001	0.36 (0.26)	0.34 (0.28)	0.030
57	85.09 (6.56)	87.40 (7.02)	<0.001	0.36 (0.28)	0.33 (0.30)	0.010
58	85.45 (6.48)	87.73 (6.89)	<0.001	0.36 (0.29)	0.33 (0.32)	0.003
59	85.80 (6.41)	88.06 (6.75)	<0.001	0.36 (0.31)	0.32 (0.33)	0.001
60	86.16 (6.34)	88.38 (6.61)	<0.001	0.36 (0.32)	0.32 (0.35)	<0.001

NTN = normotension; HTN = hypertension.