

Ideal cardiovascular health and incident hypertension

The longitudinal community-based Kailuan study

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Abstract

Ideal cardiovascular health (CVH) has been defined by the American Heart Association as the absence of disease and presence of 7 key health factors. Since it is unknown whether cumulative exposure to CVH reduces the risk of developing arterial hypertension, we prospectively examined the potential association between cumulative CVH (cumCVH) score (except for blood pressure metrics) and incident hypertension.

Of the 101,510 participants with an age range of 18 to 98 years in this longitudinal community-based Kailuan study, our cohort included those 15,014 participants without hypertension at baseline and who had follow-up examinations 2, 4, and 6 years later. CumCVH was calculated as the summed CVH score for each examination multiplied by the time between the 2 examinations (points × year). Based on the cumCVH score, the study population was stratified into groups of <44 points, 44 to 48 points, 49 to 54 points, 55 to 59 points, and ≥60 points.

Incidence of hypertension ranged from 16.76% in the lowest cumCVH category to 11.52% in the highest cumCVH category. After adjusting for age, sex, education level, income level, high-sensitivity C-reactive protein concentration, uric acid concentration, resting heart rate, parental history of hypertension at baseline, and medication usage before the third follow-up examination, participants in the highest cumCVH category had a significantly reduced risk of incident hypertension compared with those in the lowest cumCVH category (adjusted odds ratio 0.60, 95% confidence interval 0.50–0.71). For every increase in category based on the cumCVH score, the risk of hypertension decreased by approximately 2% (odds ratio 0.98, 95% confidence interval 0.97–0.98). The effect was consistent across sex and age groups.

A higher cumCVH score is associated with a lower risk of incident hypertension.

Abbreviations: BMI = body mass index, BP = blood pressure, CI = confidence interval, cumCVH = cumulative cardiovascular health, CVH = cardiovascular health, DBP = diastolic blood pressure, OR = odds ratio, SBP = systolic blood pressure.

Keywords: arterial hypertension, hypertension, ideal cardiovascular health, Kailuan study

1. Introduction

Arterial hypertension is the primary and most common risk factor for cardiovascular disease, stroke, end-stage renal disease, and peripheral vascular disease. It has been identified as the leading cause of mortality and the third most common cause of disability-adjusted life-years worldwide.^{1,2} It has been estimated

that the worldwide prevalence of hypertension will increase from 26.4% in 2000 to 29.2% in 2025.^{1,3} Hypertension has become a major global public health burden. Identifying and characterizing modifiable risk factors of hypertension is of high importance for public health and clinical medicine. The results of previous epidemiological studies have suggested that there is an association between greater risk of hypertension and lower physical

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activity,^[4] more marked adiposity,^[5,6] dyslipidemia,^[7] and a diet rich in saturated fatty acids.^[8] Correspondingly, lifestyle modification has been shown to lower arterial blood pressure (BP) and to reduce the risk of hypertension; therefore, it may be an essential component of early interventions in high-risk individuals.^[9–11]

In 2010, the American Heart Association defined seven factors (smoking status, body mass index [BMI], physical activity, healthy dietary score, total cholesterol, BP, and fasting blood glucose) as metrics of cardiovascular health (CVH).^[12] Subsequent studies have revealed that ideal CVH metrics have distinctly protective effects against stroke,^[13] cardiovascular disease,^[14,15] cancer,^[16] and overall mortality.^[17–19] Given that many of these studies involved the nonpopulation-based recruitment of participants, there was a risk of bias due to a referral-based selection artefact. Additionally, the association between the risk of developing hypertension and CVH metrics was not explored. Moreover, as many of the studies were cross-sectional in nature, a change in the CVH metrics during follow-up and its influence on the incidence of hypertension could not be examined. Consequently, recent studies, such as the Framingham Heart Study, have shown that assessment of the duration and grade of CVH metrics as a measure of cumulative exposure was more accurate than a cross-sectional analysis in examining the relationship between CVH metrics and diseases.^[20] In the Framingham Heart Study, cumulative exposure to hyperlipidemia in young adulthood increased the subsequent risk of coronary heart disease.^[20] The Multi-Ethnic Study of Atherosclerosis reported that cumulative exposure to elevated systolic BP (SBP) was correlated with an increase in the spot urine albumin-to-creatinine ratio among adults without diabetes.^[21] As the relationship between the CVH metrics and the development of hypertension has not been explored, given that most previous studies were cross-sectional and not population-based and due to the fact that relevant information on the Chinese population is scarce, we conducted this study to investigate the relationship between cumulative exposure to CVH metrics (except for BP metrics) and incident hypertension in a Chinese population.

2. Methods

The Kailuan study was a prospective cohort study conducted in the community of Kailuan in the industrial city of Tangshan (China).^[15] The study was approved by the ethics committees of Kailuan General Hospital and followed the guidelines outlined in the Declaration of Helsinki. All participants signed a written informed consent form. The Kailuan study included employees and retirees of the Kailuan Group Company, a large coal-mining company located in Tangshan.^[22,23] Between June 2006 and October 2007, a total of 101,510 individuals (81,110 men) aged 18 to 98 years were recruited to participate in the study.

The present study included those individuals from the original study population who had not been diagnosed with hypertension at baseline examination and who underwent follow-up examinations in the years 2008 to 2009, 2010 to 2011, or 2012 to 2013. The study participants were re-examined every 2 years.

At baseline and 2-year follow-up examinations, information about smoking, physical activity, and salt intake was obtained via standardized questionnaires. Smoking status was classified as “never,” “former,” or “current,” based on self-reported information. Never smoking was defined as the ideal health behavior (with respect to smoking). Former smoking was identified as the intermediate health behavior, whereas current

smoking was considered to be the poor health behavior. With respect to physical activity, ideal health behavior, intermediate health behavior, and poor health behavior were defined as ≥ 80 , 1 to 79, and 0 minutes of moderate or vigorous activity per week, respectively.^[13] Since detailed information on diet (eg, intake of fruits, vegetables, or meat) was lacking, we used information on salt intake as a surrogate for information on diet in general. As part of the standardized questionnaire, we asked how much salt participants used when they cooked. Self-reported salt intake was classified as “low,” “medium,” or “high” without that the amount of salt consumed was measured. “Low” salt intake was defined as the ideal diet behavior, whereas medium and high salt intake were defined as the intermediate and poor diet behaviors, respectively. BMI was calculated as body weight (kg) divided by the square of body height (kg/m^2). BP was measured by a mercury sphygmomanometer. Three readings of SBP and diastolic BP (DBP) were taken at 5-minute intervals after participants had rested in a chair for at least 5 minutes. The average of the 3 readings was included in the data analysis. A 10-second 12-lead electrocardiography was used to measure their resting heart rate after they had rested in the supine position for 5 minutes.^[22]

Blood samples were collected from the antecubital vein after overnight fasting. Fasting blood glucose was measured using the hexokinase/glucose-6-phosphate-dehydrogenase method.^[24] Total cholesterol and triglycerides were assessed enzymatically. High-density lipoprotein cholesterol (HDL-C) and low-density lipoprotein cholesterol (LDL-C) levels were determined using a direct test method (interassay coefficient of variation $< 10\%$; Mind Bioengineering Co. Ltd., Shanghai, China).^[25] High-sensitivity C-reactive protein (hs-CRP) concentration was measured by high-sensitivity nephelometry assay (Cias Latex CRP-H, Kanto Chemical, Tokyo, Japan). Serum uric acid (UA) concentration was determined using an oxidase method. All biochemical variables were assessed at the central laboratory of Kailuan General Hospital using a Hitachi autoanalyzer (Hitachi 747; Hitachi, Tokyo, Japan).

According to the definitions presented by the American Heart Association,^[12] BMI was classified as ideal ($< 25 \text{ kg}/\text{m}^2$), intermediate ($25\text{--}29.9 \text{ kg}/\text{m}^2$), or poor ($\geq 30 \text{ kg}/\text{m}^2$). BP was categorized as ideal (SBP $< 120 \text{ mm Hg}$ and DBP $< 80 \text{ mm Hg}$ and untreated), intermediate ($120 \text{ mm Hg} \leq \text{SBP} \leq 139 \text{ mm Hg}$, $80 \text{ mm Hg} \leq \text{DBP} \leq 89 \text{ mm Hg}$, or treated to SBP/DBP $< 120/80 \text{ mm Hg}$), or poor (SBP $\geq 140 \text{ mm Hg}$, DBP $\geq 90 \text{ mm Hg}$, or treated to SBP/DBP $> 120/80 \text{ mm Hg}$). Fasting blood glucose was classified as ideal ($< 5.6 \text{ mmol/L}$ and untreated), intermediate ($5.6\text{--}6.9 \text{ mmol/L}$ or treated to $< 5.6 \text{ mmol/L}$), or poor ($\geq 7.0 \text{ mmol/L}$ or treated to $\geq 5.6 \text{ mmol/L}$). Total cholesterol status was rated as ideal ($< 200 \text{ mg/dL}$ and untreated), intermediate ($200\text{--}239 \text{ mg/dL}$ or treated to $< 200 \text{ mg/dL}$), or poor ($\geq 240 \text{ mg/dL}$ or treated to $\geq 200 \text{ mg/dL}$).

To examine cumulative exposure of 6 CVH metrics (except the BP metric), we created a dichotomized variable for each component of the health metrics: “ideal” was coded as 2, “intermediate” was coded as 1, and “poor” was coded as 0. The total ideal CVH score of each individual was the sum score of the 6 ideal CVH metrics, ranging from 0 to 12. The cumulative CVH (cumCVH) score was defined as the summed CVH score for each examination (baseline or follow-up) multiplied by the time between the 2 consecutive visits in years: $\text{CVH}_1 \times \text{time}_{1-2} \pm \text{CVH}_2 \times \text{time}_{2-3} \pm \text{CVH}_3 \times \text{time}_{3-4}$, where CVH_1 , CVH_2 , and CVH_3 indicate CVH at examinations #1 (baseline), #2, and #3, respectively, and time_{1-2} , time_{2-3} , and time_{3-4} indicate the participant-specific time interval between the consecutive

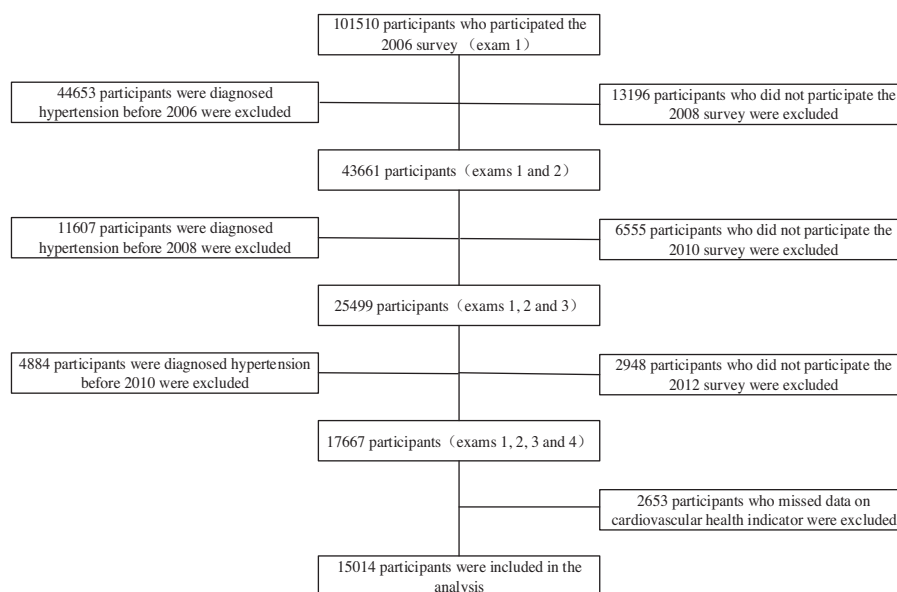


Figure 1. Selection of Kailuan study participants.

examinations #1 to #3 in years. Participants were divided into 5 categories based on the quintiles of the cumCVH score. CumCVH was categorized as <44 points, 44 to 48 points, 49 to 54 points, 55 to 59 points, and ≥ 60 points.

Information on demographic and clinical characteristics (age, sex, alcohol consumption, personal monthly income, level of education, and history of diseases) was collected via questionnaires. According to their age at baseline, study participants were classified into 3 categories: <40 years, 40 to 59 years, and ≥ 60 years. Previous history of diseases, including myocardial infarction, stroke, and cancer, was assessed as self-reported. The use of antihypertensive, cholesterol-lowering, and glucose-lowering medications within the past 2 weeks before the baseline interview was also investigated. The drinking status was classified as “never,” “former,” or “current” according to self-reported information. The self-reported average monthly income was categorized as “<¥600,” “¥600 to 800,” or “ \geq ¥800.” Education level was categorized as “illiteracy or primary school,” “middle school,” and “high school or above.”

Incident hypertension was diagnosed in study participants with an SBP of less than 140 mm Hg; a DBP less than 90 mm Hg; no history of hypertension and no use of antihypertensive drugs at examinations #1 through #3 who had an SBP of at least 140 mm Hg; a DBP of at least 90 mm Hg; and/or use of antihypertensive drugs at examination #4 performed from 2012 to 2013.

Statistical analyses were performed using commercially available software (SAS 9.3; SAS Institute; Cary, NC). Continuous variables were described as the mean \pm standard deviation (SD) and were compared by analysis of variance (ANOVA) or the Kruskal–Wallis test. Categorical variables were described as percentages and were compared using the chi-square test. A logistic regression model was used to estimate the risk of hypertension associated with cumCVH metrics. Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated. We fitted 3 multivariate models to the data. Model 1 adjusted for age and sex. Model 2 further adjusted for education level, income level, and alcohol consumption. Model 3 further adjusted for hs-CRP, UA concentration, resting heart rate, parental history of

hypertension at baseline, and medication usage before the fourth follow-up examination. Because 11 hospitals were responsible for laboratory tests in this study, we used a random-effects model for each hospital to account for potential measurement bias. The interactions between cumCVH and both sex and age on the risk of hypertension were analyzed using multivariate logistic regression. All statistical tests were 2-sided, and the significance level was set at $P < 0.05$.

3. Results

Of the 101,510 individuals who participated in the baseline examination, 86,496 were excluded due to a diagnosis of hypertension before the examination in the period from 2012 to 2013 (61,144 participants, with 44,653 having a diagnosis of hypertension before the period from 2006 to 2007, 11,607 developing hypertension between 2007 and 2009, and 4884 developing hypertension between 2009 and 2011); a missed follow-up examination during the re-examination period of 2008 to 2009, 2010 to 2011, or 2012 to 2013 (22,699 participants); or incomplete CVH metrics data (2653 participants). The remaining 15,014 participants (33.5% women) were included in the present study (Fig. 1).

Compared with the excluded subjects, the individuals included in the present study were significantly younger (43.7 ± 11.1 vs 50.5 ± 13.4 years; $P < 0.001$), had a higher level of education (30.9% vs 24.0%; $P < 0.001$), and had a lower BMI, SBP, DBP, fasting blood glucose, total cholesterol, hs-CRP concentration, UA concentration, and resting heart rate (Table 1).

After comparing the baseline characteristics (data obtained in 2006) across the 5 groups of study participants, it was revealed that the higher cumCVH score was significantly ($P < 0.001$) associated with older age, the female sex, a higher level of education, a higher income, lower alcohol consumption, a lower resting heart rate, lower UA concentration, and lower hs-CRP concentration (Table 2).

In a multivariate regression analysis, with cumCVH score as the dependent variable and the aforementioned variables that

Table 1

Comparison of demographic and other characteristics of participants and nonparticipants.

	Participants	Nonparticipants	P
N	15014	25352	
Age, y	43.70 ± 11.10	50.50 ± 13.37	<0.001
Male sex, n (%)	9984 (66.50)	19246 (75.92)	<0.001
Body mass index, kg/m ²	23.87 ± 3.22	23.96 ± 3.28	<0.001
Divorce, n (%)	146 (0.97)	251 (1.05)	<0.001
High school education level or above, n (%)	4641 (30.93)	5725 (24.04)	<0.001
Income ≥¥800/mo, n (%)	2486 (16.57)	3546 (14.89)	<0.001
Current smoker, n (%)	4270 (28.44)	7328 (30.51)	<0.001
Current alcohol drinker, n (%)	1950 (12.99)	3547 (14.76)	<0.001
Physical activity ≥80 min, n (%)	1669 (11.12)	3264 (13.73)	<0.001
Salt intake, n (%)	1457 (9.70)	2438 (10.25)	<0.001
Systolic blood pressure, mm Hg	114.0 ± 10.9	116.5 ± 11.1	<0.001
Diastolic blood pressure, mm Hg	74.90 ± 7.1	75.7 ± 7.1	<0.001
Fasting blood glucose concentration, mmol/L	5.16 ± 1.20	5.31 ± 1.61	<0.001
Total cholesterol concentration, mmol/L	4.78 ± 1.06	4.86 ± 1.07	<0.001
High-sensitivity C-reactive protein concentration, mg/L	0.56 (0.20–1.50)	0.70 (0.29–1.96)	<0.001
Uric acid concentration, μmol/L	269.72 ± 76.95	282.18 ± 79.00	<0.001
Resting heart rate, beats/min	72.35 ± 9.21	72.67 ± 9.85	0.048

were significantly associated with cumCVH score in the univariate analysis as the independent variables, it was found that cumCVH score was significantly correlated with older age ($P < 0.001$), the female sex ($P < 0.001$), level of education ($P < 0.001$), and level of hs-CRP concentration ($P < 0.001$)

The incidence of new-onset hypertension ranged from 16.76% in the lowest cumCVH category to 11.52% in the highest cumCVH category (Table 3). Compared with participants in the lowest cumCVH category (<44 points), after adjusting for age, sex, education level, income level, hs-CRP concentration, UA concentration, resting heart rate, parental history of hypertension at baseline, and medication usage before the third follow-up examination, participants in the highest cumCVH category (≥60 points) had a significantly reduced risk of hypertension (adjusted OR 0.60, 95% CI 0.50–0.71). For every increase in cumCVH

score category, the risk of hypertension decreased by approximately 2% (OR 0.98, 95% CI 0.97–0.98). The effect was consistent across sex and age groups (Table 3). Significant inverse associations were found in 2 age groups ($P < 0.001$), both for men (P -trend <0.001) and for women (P -trend <0.001). There were significant interactions between cumCVH score and both age (P -interaction <0.001) and sex (P -interaction = 0.013).

To examine the influence of individual CVH metrics on the association between cumCVH score and incident hypertension, a sensitivity analysis was performed after excluding each of the 6 metrics from the total cumCVH score 1 at a time. The association was unaffected after exclusion of individual risk factors (Fig. 2).

Because follow-up time might influence cumCVH score (eg, participants might have a higher cumCVH score at 4-year follow-up than those at 3-year follow-up), we used a time-weighted

Table 2

Characteristics of study participants after stratification by cumulative cardiovascular health factor index.

	Group by cardiovascular health factor index					P
	<44	44–48	49–54	55–59	≥60	
Cumulative cardiovascular health factor index (points)	<44	44–48	49–54	55–59	≥60	
Number of participants (n)	3002	3003	3003	3003	3003	
Cardiovascular health scores	7 (6–7)	8 (7–9)	9 (8–9)	9 (9–10)	10 (9–10)	<0.001
Age, y	42.96 ± 9.86	43.14 ± 10.49	42.65 ± 11.08	43.60 ± 11.40	46.16 ± 12.21	<0.001
Men, n (%)	2761 (91.97)	2369 (78.89)	2008 (66.87)	1545 (51.45)	1301 (43.32)	<0.001
Level of education, n (%)						<0.001
Illiteracy/primary school	147 (4.90)	119 (3.97)	108 (3.60)	106 (3.53)	120 (4.00)	
Middle school	1915 (63.85)	1995 (66.48)	1960 (65.29)	1998 (66.53)	1898 (63.22)	
High school or above	937 (31.24)	887 (29.56)	934 (31.11)	899 (29.94)	984 (32.78)	
Income, ¥/mo (%)						<0.001
<¥600	1115 (37.19)	942 (31.39)	794 (26.46)	692 (23.05)	592 (19.73)	
¥600–800	1306 (43.56)	1560 (51.98)	1753 (58.41)	1858 (61.89)	1904 (63.47)	
≥¥800	577 (19.25)	499 (16.63)	454 (15.13)	452 (15.06)	504 (16.80)	
Alcohol consumption, n (%)						<0.001
Never	1009 (33.62)	1558 (51.92)	1896 (63.16)	2246 (74.84)	2351 (78.31)	
Past	101 (3.37)	88 (2.93)	55 (1.83)	45 (1.50)	37 (1.23)	
Current <1 time/d	1087 (36.22)	883 (29.42)	733 (24.42)	513 (17.09)	455 (15.16)	
Current 1+ times/d	804 (26.79)	472 (15.73)	318 (10.59)	197 (6.56)	159 (5.30)	
Resting heart rate, beats/min	73.28 ± 9.33	72.44 ± 9.15	72.24 ± 9.30	72.20 ± 9.00	71.58 ± 9.17	<0.001
Uric acid concentration, μmol/L	298.1 ± 80.2	274.2 ± 75.5	268.2 ± 76.1	253.7 ± 71.8	254.3 ± 72.1	<0.001
High-sensitivity C-reactive protein concentration, mg/L	0.75 (0.30–2.00)	0.60 (0.23–1.60)	0.57 (0.20–1.50)	0.48 (0.20–1.32)	0.40 (0.16–1.13)	<0.001

Table 3

Associations between incident arterial hypertension and other factors (multivariate analysis; odds ratios, and 95% confidence intervals) in the study participants after stratification by cumulative cardiovascular health factor index.

	Group by cumulative exposure to cardiovascular health factors					1-Category increase	P for trend	P for interaction
	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5			
Total, n	3002	3003	3003	3003	3003			
Number of cases, n (%)	503 (16.76)	424 (14.12)	368 (12.25)	316 (10.52)	346 (11.52)			
Model 1*	1.00	0.81 (0.70–0.94)	0.70 (0.60–0.81)	0.57 (0.48–0.66)	0.55 (0.47–0.65)	0.97 (0.97–0.98)	<0.001	
Model 2†	1.00	0.82 (0.71–0.94)	0.71 (0.61–0.83)	0.57 (0.49–0.68)	0.56 (0.48–0.66)	0.98 (0.97–0.98)	<0.001	
Model 3‡	1.00	0.85 (0.74–0.99)	0.74 (0.63–0.86)	0.61 (0.51–0.72)	0.60 (0.50–0.71)	0.98 (0.97–0.98)	<0.001	
Sex								0.013
Women	40 (16.60)	106 (16.72)	111 (11.16)	124 (8.50)	145 (8.52)			
Model 3‡	1.00	1.21 (0.78–1.86)	0.90 (0.58–1.38)	0.64 (0.42–0.98)	0.58 (0.38–0.88)	0.97 (0.95–0.98)	<0.001	
Men	463 (16.77)	318 (13.42)	257 (12.80)	192 (12.43)	201 (15.45)			
Model 3‡	1.00	0.80 (0.68–0.94)	0.72 (0.60–0.85)	0.64 (0.53–0.78)	0.70 (0.57–0.86)	0.98 (0.97–0.99)	<0.001	
Age, y								<0.001
<40	139 (13.31)	96 (8.72)	82 (6.84)	53 (4.62)	35 (3.69)			
Model 3‡	1.00	0.75 (0.56–0.99)	0.60 (0.44–0.82)	0.47 (0.33–0.68)	0.37 (0.24–0.57)	0.95 (0.94–0.97)	<0.001	
40–59	335 (18.16)	289 (16.48)	239 (14.89)	208 (12.75)	217 (12.83)			
Model 3‡	1.00	0.89 (0.74–1.07)	0.82 (0.67–0.99)	0.65 (0.52–0.80)	0.62 (0.50–0.76)	0.98 (0.97–0.99)	<0.001	
≥60	29 (25.66)	39 (26.35)	47 (23.50)	55 (24.44)	94 (25.82)			
Model 3‡	1.00	1.07 (0.60–1.94)	0.90 (0.51–1.60)	0.94 (0.53–1.67)	1.07 (0.63–1.83)	1.00 (0.98–1.02)	0.82	

* Adjusted for age (years) and sex.

† Adjusted in the same way as model 1 with the addition of education level (elementary school, high school or college, or above), income level (income >600RMB/mo or income ≤600RMB/mo), and alcohol consumption (never, past, current <1time/d, or current 1+ times/d).

‡ Adjusted in the same way as model 2 with the addition of high-sensitivity C-reactive protein concentration, uric acid concentration, resting heart rate, parental history of hypertension at baseline examination, and medication usage before the third follow-up examination.

cumCVH (calculated as $[CVH_1 \times time_{1-2} + CVH_2 \times time_{2-3} + CVH_3 \times time_{3-4}] / [time_{1-2} + time_{2-3} + time_{3-4}]$) model to examine the robustness of our findings. The results revealed that higher time-weighted cumCVH score was significantly associated with a lower risk of incident hypertension (Table 4).

4. Discussion

In this prospective Kailuan study, a higher cumCVH score significantly reduced the risk of incident hypertension. This association remained significant when the total study population was stratified by sex and age, and after adjusting for potentially confounding factors, such as education level, income level, alcohol consumption, parental history of hypertension at baseline, and medication usage before the third follow-up

examination. These findings suggest that optimal CVH status is helpful to reduce the risk of incident hypertension.

These findings were aligned with observations made in previous investigations. The Framingham Heart Study investigators were among the first to develop a hypertension risk prediction model that included age, sex, SBP, DBP, BMI, cigarette smoking, and parental history of hypertension.^[26] The prognostic value of this model was validated in 2 independent cohorts.^[27,28] More studies then began to examine associations between behavioral factors and hypertension risk.^[4–9] Results of a meta-analysis of 13 prospective cohort studies showed an inverse dose-response association between level of recreational physical activity and risk of hypertension.^[4] The Physicians’ Health Study revealed that dyslipidemias led to the development of hypertension.^[7] The Strong Heart Study found that increasing abdominal obesity and

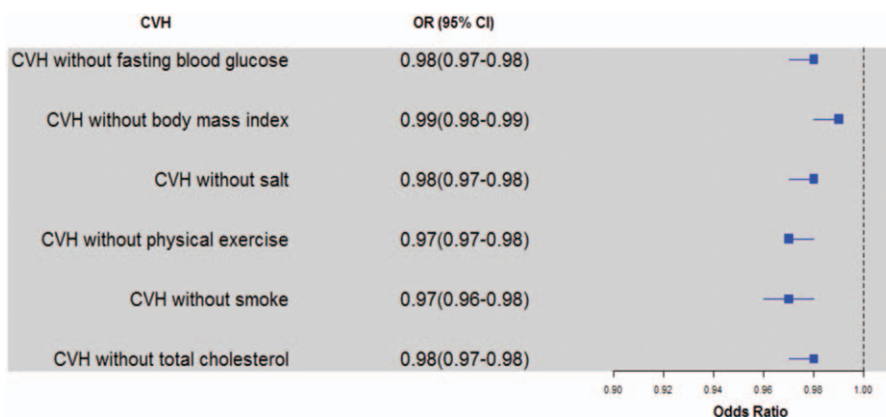


Figure 2. Odds ratios and 95% confident intervals associated with hypertension risk in relation to a 1-score increase in cumulative exposure to cardiovascular health (CVH) factors, after removing each one of the 6 CVH metrics separately. For the models adjusted for age, sex, education level, income level, alcohol consumption, high-sensitivity C-reactive protein concentration, uric acid concentration, resting heart rate, parental history of hypertension at baseline examination, and medication usage before the third follow-up examination.

Table 4

Associations between incident arterial hypertension and other factors (multivariate analysis, odds ratios, and 95% confidence intervals) in the study participants after stratification by time-weighted cumulative cardiovascular health factor index.

	Group by time-weighted cumulative exposure of cardiovascular health factors					1-Score increase	P for trend	P for interaction
	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5			
Total, N	3002	3003	3003	3003	3003			
Case number, n (%)	528 (17.59)	447 (14.89)	397 (13.22)	333 (11.09)	252 (8.39)			
Model 1*	1.00	0.81 (0.71–0.94)	0.71 (0.61–0.82)	0.59 (0.51–0.69)	0.46 (0.38–0.54)	0.83 (0.80–0.86)	<0.001	
Model 2†	1.00	0.82 (0.71–0.94)	0.72 (0.62–0.83)	0.60 (0.51–0.70)	0.46 (0.39–0.55)	0.83 (0.80–0.86)	<0.001	
Model 3‡	1.00	0.86 (0.74–0.99)	0.76 (0.65–0.88)	0.64 (0.54–0.75)	0.49 (0.41–0.59)	0.84 (0.81–0.88)	<0.001	
Sex								<0.01
Women	53 (19.85)	104 (18.57)	118 (13.45)	137 (9.68)	114 (5.97)			
Model 3‡	1.00	1.07 (0.71–1.60)	0.86 (0.58–1.29)	0.66 (0.44–0.99)	0.41 (0.27–0.62)	0.74 (0.68–0.82)	<0.001	
Men	475 (17.37)	343 (14.04)	279 (13.12)	196 (12.35)	138 (12.63)			
Model 3‡	1.00	0.81 (0.69–0.95)	0.73 (0.62–0.87)	0.65 (0.54–0.79)	0.63 (0.51–0.79)	0.88 (0.84–0.92)	<0.001	
Age, y								<0.001
<40	128 (13.06)	102 (10.06)	71 (6.79)	63 (5.67)	41 (3.19)			
Model 3‡	1.00	0.88 (0.66–0.1.17)	0.60 (0.43–0.82)	0.54 (0.38–0.78)	0.34 (0.22–0.52)	0.77 (0.70–0.84)	<0.001	
40–59	350 (18.93)	297 (16.58)	271 (15.69)	218 (13.07)	152 (10.19)			
Model 3‡	1.00	0.86 (0.72–1.03)	0.83 (0.69–1.00)	0.69 (0.56–0.85)	0.51 (0.41–0.65)	0.86 (0.82–0.91)	<0.001	
≥60	50 (28.90)	48 (24.24)	55 (23.91)	52 (23.32)	59 (26.11)			
Model 3‡	1.00	0.76 (0.47–1.25)	0.81 (0.50–1.31)	0.68 (0.41–1.14)	0.85 (0.52–1.39)	0.98 (0.87–1.11)	0.512	

* Adjusted for age (years) and sex.

† Adjusted in the same way as model 1 with the addition of education level (elementary school, high school or college, or above), income level (income >600RMB/mo or income ≤600RMB/mo), and alcohol consumption (never, past, current <1time/d, or current 1+ times/d).

‡ Adjusted in the same way as model 2 with the addition of high-sensitivity C-reactive protein concentration, uric acid concentration, resting heart rate, parental history of hypertension at baseline examination, and medication usage before the third follow-up examination.

an abnormal lipid profile were major predictors of arterial hypertension development in adults who initially had optimal BP.^[29] In addition, dietary fat was an important modifiable risk factor of hypertension in previous studies.^[8,9] A limitation of the studies mentioned above was that the behavioral factors were measured at a single time point without taking into account their change in CVH metrics over time. They neglected any behavioral factors and indexes, including CVH metric changes due to environmental change and aging.

Given the variability in the behavioral factors, we investigated the association between cumulative exposure to behavioral factors (ideal CVH metrics) and hypertension prospectively. We found that study participants with long-time exposure to “ideal” CVH status had a significantly reduced risk of developing hypertension. The results remained unchanged when the population was stratified by sex and age, both of which were associated with other risk factors, such as smoking. In addition, the relationship between cumCVH exposure and incident hypertension decreased in statistical strength, but persisted when 1 of the 6 CVH metrics was removed from the total cumCVH score. It suggested that each of the CVH metrics was influential in reducing the risk of incident hypertension. Furthermore, each of these individual risk factors appeared to be associated with similar hypertension risk, as the correlation between cumCVH exposure and incident hypertension was attenuated to a comparable extent after their individual removal from the model (Fig. 2). These findings also imply that preventative efforts to reduce the development of arterial hypertension that encompass strategies promoting a more holistic approach to optimal vascular health (eg, smoking cessation, weight loss, increased physical activity, and low-fat diet) may yield greater benefits than would be expected by targeting individual health behaviors independently.

The association between higher cumCVH score and lower incidence of hypertension in the follow-up examinations aligns with and may be caused by the known relationships among a low degree of physical activity, a high BMI, smoking, and increased BP.^[4,5,30]

Social inequalities in general influence health and cardiovascular prognoses.^[31–40] This statement holds true for the study population in our investigation. Since we did not include factors, such as socioeconomic background, in the statistical analysis in our study, we could not assess their influence on the relationship between CVH and the incidence of arterial hypertension. Based on previous studies on social inequalities and health and mortality, however, there may be little doubt that individuals with lower socioeconomic status, including a lower level of education, have a lower CVH score, and, therefore, a higher risk of having arterial hypertension at follow-up. Future studies may address the question regarding whether socioeconomic factors had a direct influence on the development of hypertension or whether there was an indirect influence of lifestyle factors, such as diet and amount of physical activity.

The limitations of our study should be mentioned. First, we used self-reported information on salt intake as a surrogate of diet information without measuring the natriuresis for 24 hours. For a subgroup of the study population, however, we compared the self-reported assessment of salt intake with the measurement of 24-hour natriuresis and found a significant correlation ($r=0.78$). This finding may indicate that the self-reported data on salt intake provided some information about salt intake. Second, all participants came from the city of Tangshan and were employees or family members or employees of the Kailuan Group Company; consequently, the study population was not representative of the total Chinese population. Therefore, the findings of our study cannot be generalized to other Chinese populations with a different lifestyle and a different average education level. The strengths of our study included the sample size and the prospective examination of the participants. Third, we included in the study only individuals who were free of arterial hypertension at 3 baseline examinations over a period of 6 years. That is, individuals who were free of arterial hypertension at the first baseline examination, but developed arterial hypertension by the second or third baseline examination were

excluded from the study. As an alternative to the selected study design, we could have included these individuals as incident hypertensive patients in the study. Nevertheless, given that BP measurement performed at a single examination or at two examinations could yield a false-negative diagnosis of arterial hypertension, we chose the design involving 3 negative measurements as baseline for our longitudinal investigation. This research decision may only have strengthened the quality of our study design because it prevented the inclusion of patients, who were inaccurately determined to be normotensive, but who actually had arterial hypertension, into our study population.

In conclusion, a healthy lifestyle as indicated by cumCVH score was related to a reduced risk of having arterial hypertension. Encouraging people to adopt a healthier lifestyle could reduce their risk of developing hypertension.

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