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Ideal cardiovascular health and incidence of atherosclerotic cardiovascular disease among Chinese adults: the China-PAR project

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Existing evidence on the relationship between cardiovascular health (CVH) metrics and cardiovascular disease (CVD) was primarily derived from western populations. We aimed to evaluate the benefits of ideal CVH metrics on preventing incident atherosclerotic CVD (ASCVD) in Chinese population. This study was conducted among 93,987 adults from the China-PAR project (Prediction for ASCVD Risk in China) who were followed up until 2015. Cox proportional hazard regression models were used to estimate the hazard ratios (HRs) and their corresponding 95% confidence intervals (CIs) of CVH metrics for the risk of ASCVD, including coronary heart disease (CHD), stroke and ASCVD death. We further estimated the population-attributable risk percentage (PAR%) of these metrics in relation to each outcome. We observed gradient inverse associations between the number of ideal CVH metrics and ASCVD incidence. Compared with participants having $\leq$2 ideal CVH metrics, the multi-variable-adjusted HRs (95% CIs) of ASCVD for those with 3, 4, 5, 6 and 7 ideal CVH metrics were 0.83 (0.74–0.93), 0.66 (0.59–0.74), 0.55 (0.48–0.61), 0.44 (0.38–0.50) and 0.24 (0.18–0.31), respectively (*P* for trend <0.0001). Approximately 62.1% of total ASCVD, 38.7% of CHD, 66.4% of stroke, and 60.5% of ASCVD death were attributable to not achieving all the seven ideal CVH metrics. After adjusting effects of ideal health factors, having four ideal health behaviors could independently bring adults health benefits in preventing 17.4% of ASCVD, 18.0% of CHD, 16.7% of stroke, and 10.1% of ASCVD death. Among all the seven CVH metrics, to keep with ideal blood pressure (BP) implied the largest public health gains against various ASCVD events (PAR% between 33.0% and 47.2%), while ideal diet was the metric most difficult to be achieved in the long term. Our study indicates that the more ideal CVH metrics adults have, the less ASCVD burden there is in China. Special efforts of health education and behavior modification should be made on keeping ideal BP and dietary habits in general Chinese population to prevent the epidemic of ASCVD.

cardiovascular health, ASCVD, cohort, China

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INTRODUCTION

Despite encouraging advances in the prevention, diagnosis, and treatment of cardiovascular disease (CVD), CVD remains a major cause of premature death and disability both worldwide and in China (He et al., 2005; GBD 2013 Mortality and Causes of Death Collaborators, 2015). Major modifiable risk factors contributing to CVD have been identified, including smoking, abdominal obesity, unhealthy diet, physical inactivity, hypertension, diabetes, and hypercholesterolemia (Claas and Arnett, 2016; Gu et al., 2006; Yang et al., 2016). The American Heart Association (AHA) has formulated the 2020 Strategic Impact Goals and proposed a new concept of ideal cardiovascular health (CVH), which is defined as the simultaneous presence of four ideal health behaviors (nonsmoking status, ideal body mass index (BMI), regular physical activity (PA), and healthy diet) and three ideal health factors (optimal profile of serum total cholesterol (TC), blood pressure (BP), and blood glucose) (Lloyd-Jones et al., 2010). The AHA 2020 Strategic Impact Goal focused on promotion of CVH and control of risk factors rather than solely preventing the development of specific diseases, aligning more closely with the concept of primordial prevention (Bambs and Reis, 2011).

Recently, data have shown a low prevalence of these ideal CVH metrics in general populations across different countries (Bi et al., 2015; Shay et al., 2012), and many prospective studies have indicated the inverse association between the number of ideal CVH metrics and the risks of acute myocardial infarction (AMI), stroke, heart failure, CVD mortality, and all-cause mortality (Dong et al., 2012; Folsom et al., 2011; Kim et al., 2013; Nayor et al., 2016; Zhang et al., 2013). However, existing evidence was mainly derived from Western populations and two East Asian populations, including a Korean male population (Kim et al., 2013) and a Chinese occupational population (Zhang et al., 2013). It remained unclear about the exact effect of ideal CVH metrics on atherosclerotic CVD (ASCVD) risk among general Chinese populations. Therefore, we performed the current study using three large cohorts from the China-PAR project (Prediction for ASCVD Risk in China) to estimate the joint association and population attributable risk percentage (PAR%) of these CVH metrics in relation to ASCVD incidence.

RESULTS

The baseline characteristics of 37,805 men and 56,182 women are shown in Table 1. Men were slightly elder and more likely to be current drinkers, whereas they more often had high education level, ideal diet (≥2 healthy diet score components), PA, BMI, and TC. By comparison, larger proportions of women were nonsmokers and had ideal BP. The prevalence of ideal status for each CVH metric ranged from 34.15% for ideal BP to 77.91% for ideal fasting glucose. In total, only 7.36% of the study participants had all the seven ideal CVH metrics. Most of participants had 4–6 ideal metrics, with a prevalence of 74.12% in men and 73.26% in women, respectively.

During a median follow-up of 6, 13, and 15 years for the three cohorts, 3,457 ASCVD events, including 788 coronary heart disease (CHD), 2,718 stroke, and 1,383 ASCVD deaths were recorded among the 93,987 participants. As shown in Table 2, a strong inverse gradient relationship was present between the number of ideal CVH metrics and sex- and age-adjusted incidence rate of total ASCVD events as well as each event type. Among participants who met ≤2 ideal CVH metrics, the adjusted incidence was 898.13 per 100,000 person-years for total ASCVD, 259.21 for CHD, 647.38 for stoke, and 359.88 for ASCVD death. In contrast, among those with seven ideal CVH metrics, corresponding incidence was only 194.30, 65.11, 138.30, and 81.33 per 100,000 person-years. The Kaplan-Meier curves also illustrated a graded decreased cumulative incidence of each ASCVD outcome with an increasing number of ideal CVH metrics (Figure 1, P<0.0001 for all log-rank tests).

In the Cox regression models adjusting for age, sex, living region, urbanization, alcohol use, education level, family history of ASCVD and cohort sources, the risk of incident ASCVD significantly reduced with increasing number of ideal CVH metrics. Compared with those having ≤2 ideal metrics, the fully adjusted hazard ratios (HRs) and 95% confidence intervals (CIs) for participants with 3, 4, 5, 6, and 7 ideal metrics were 0.83 (95%CI: 0.74–0.93), 0.66 (95%CI: 0.59–0.74), 0.55 (95%CI: 0.48–0.61), 0.44 (95%CI: 0.38–0.50) and 0.24 (95%CI: 0.18–0.31), respectively (Table 2). To be with a larger number of ideal metrics was also associated with a significantly lower risk of each ASCVD event type (all $P_{\text{for trend}}$<0.0001). The adjusted PAR% was 62.1% for ASCVD events, 38.7% for CHD, 66.4% for stroke, and 60.5% for ASCVD mortality, respectively, for not achieving all the seven ideal CVH metrics. Graphs of splines illustrated a similar monotonous shape of reduced ASCVD risk in association with incremental numbers of ideal CVH metrics, allowing for non-linearity effect (Figure 2). In addition, the results of meta-analysis after pooling cohort-specific HRs kept consistent with the main results from multivariable analyses adjusting for cohort sources (Table S1 in Supporting Information), which suggested minor statistical heterogeneity across three cohorts. In sensitivity analysis, results were essentially similar when cases occurring in the first year after follow-up were removed from the multivariable analyses (Table S2 in Supporting Information). Furthermore, results also remained consistent across subgroups of sex, age, living region, and urbanization (Figures S1–4 in Sup-

Table 1 Baseline characteristics and distribution of each cardiovascular health metric in the study participants, the China-PAR project[a)]

Characteristics	Total (n=93,987)	Men (n=37,805)	Women (n=56,182)	P value
Age, mean (SD), *y*	51.64±11.97	52.03±12.05	51.37±11.92	<0.0001
Northern, *n* (%)	47,120 (50.13)	19,071 (50.45)	28,049 (49.93)	0.1176
Urban, *n* (%)	9,109 (9.69)	4,408 (11.66)	4,701 (8.37)	<0.0001
Drinking, *n* (%)	17,216 (18.32)	15,228 (40.29)	1,988 (3.54)	<0.0001
Education level beyond high school, *n* (%)	12,856 (13.72)	7,124 (18.89)	5,732 (10.23)	<0.0001
Family history of ASCVD, *n* (%)	9,644 (10.26)	3,980 (10.53)	5,664 (10.08)	0.0271
Smoking, *n* (%)				
Ideal	72,352 (76.98)	17,255 (45.64)	55,097 (98.07)	<0.0001
Non-ideal	21,635 (23.02)	20,550 (54.36)	1,085 (1.93)	
Body mass index, *n* (%)				
Ideal	61,688 (65.63)	26,098 (69.03)	35,590 (63.35)	<0.0001
Non-ideal	32,299 (34.37)	11,707 (30.97)	20,592 (36.65)	
Physical activity, *n* (%)				
Ideal	62,284 (66.27)	26,252 (69.44)	36,032 (64.13)	<0.0001
Non-ideal	31,703 (33.73)	11,553 (30.56)	20,150 (35.87)	
Healthy diet score, *n* (%)				
Ideal*	64,820 (68.97)	28,342 (74.97)	36,478 (64.93)	<0.0001
Non-ideal	29,167 (31.03)	9,463 (25.03)	19,704 (35.07)	
Total cholesterol, *n* (%)				
Ideal	72,249 (76.87)	29,947 (79.21)	42,302 (75.29)	<0.0001
Non-ideal	21,738 (23.13)	7,858 (20.79)	13,880 (24.71)	
Blood pressure, *n* (%)				
Ideal	32,099 (34.15)	11,316 (29.93)	20,783 (36.99)	<0.0001
Non-ideal	61,888 (65.85)	26,489 (70.07)	35,399 (63.01)	
Fasting plasma glucose, *n* (%)				
Ideal	73,225 (77.91)	29,451 (77.90)	43,774 (77.91)	0.9646
Non-ideal	20,762 (22.09)	8,354 (22.10)	12,408 (22.09)	
No. of ideal CVH metrics, *n* (%)				
0	77 (0.08)	71 (0.19)	6 (0.01)	<0.0001
1	980 (1.04)	550 (1.45)	430 (0.77)	
2	4,545 (4.84)	2,138 (5.66)	2,407 (4.28)	
3	12,288 (13.07)	5,554 (14.69)	6,734 (11.99)	
4	22,324 (23.75)	10,027 (26.52)	12,297 (21.89)	
5	27,066 (28.80)	11,194 (29.61)	15,872 (28.25)	
6	19,792 (21.06)	6,802 (17.99)	12,990 (23.12)	
7	6,915 (7.36)	1,469 (3.89)	5,446 (9.69)	

a) Abbreviations: SD, standard deviation; ASCVD, atherosclerotic cardiovascular disease; CVH, cardiovascular health; China-PAR project, Prediction for ASCVD Risk in China. The definition of seven ideal CVH metrics is shown in Table S4 in Supporting Information. *, Ideal diet was defined as healthy diet score ≥2 components (fruits and vegetables ≥500 g d^{-1}; fish ≥200 g $week^{-1}$; soybean products ≥125 g d^{-1}; red meat <75 g d^{-1}; tea ≥50 g $month^{-1}$).

porting Information). However, significant interactions were observed between age groups and ideal CVH metrics for ASCVD, CHD, and stroke, indicating a greater protection effect of ideal metrics on younger participants. Gender differences were only noted for the relationship between the number of ideal CVH metrics and CHD incidence. There was no significant interaction between living region or urbanization and the number of ideal CVH metrics.

Figure S5 in Supporting Information displayed the age- and sex-adjusted ASCVD incidence rates by a combination of the numbers of ideal health behaviors and factors. As a whole, the gradient for lower ASCVD incidence rates was generally observed across increasing ideal health behaviors and factors. Likewise, even after adjusting for potential

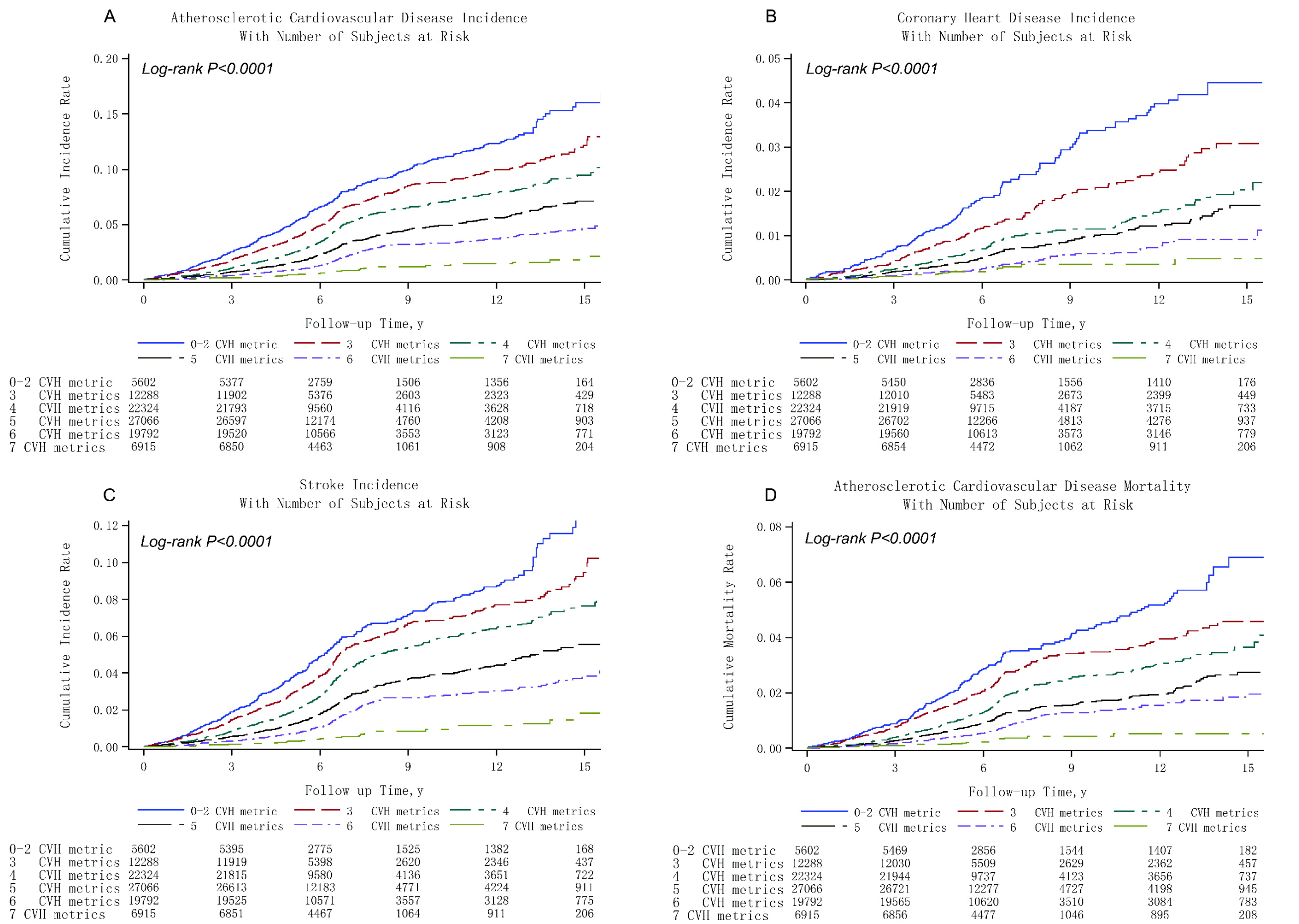

Figure 1 Kaplan-Meier curves for cumulative incidence of ASCVD (A), CHD (B), stroke (C), and ASCVD death (D) according to six cardiovascular health metrics groups, the China-PAR project. ASCVD, atherosclerotic cardiovascular disease; CHD, coronary heart disease; China-PAR project, Prediction for ASCVD Risk in China.

covariates, we observed similar graded relationship between the different numbers of ideal health behaviors/factors and ASCVD risk. The adjusted PAR% of not achieving 4 ideal health behaviors was 17.4% for ASCVD events, 18.0% for CHD, 16.7% for stroke, and 10.1% for ASCVD death after adjusting for potential covariates as well as the number of ideal health factors (Table 3).

Ideal status of seven individual CVH metric was consistently associated with lower age- and sex-adjusted incidence rate of ASCVD events (Table 4). Among all the metrics, ideal BP status was associated with the greatest risk reduction of each outcome and ranked the first according to the magnitude of PAR% after multivariable adjustment (PAR% of 44.1% for ASCVD events, 33.0% for CHD, 46.0% for stroke, and 47.2% for ASCVD mortality). Likewise, healthy diet exerted a protective effect against ASCVD, stroke and ASCVD death with an adjusted PAR% of 5.1%, 5.4% and 7.9%, respectively. Besides, nonsmoking status, adequate PA, having normal levels of BMI, TC, and fasting glucose also contributed to moderate health benefits for various ASCVD events.

DISCUSSION

Using three large Chinese prospective cohorts, we observed a graded inverse association between the number of ideal CVH metrics at baseline and the risk of various ASCVD events. It was estimated that 62.1% of ASCVD events could have been averted if all participants had seven ideal CVH metrics. In the seven ideal CVH metrics, keeping ideal BP and dietary habits would play a crucial role in the primordial prevention of ASCVD in China.

Our study indicated that the presence of more ideal CVH metrics at baseline was associated with a markedly lower risk of ASCVD during the follow-up, which was consistent with other studies in other racial populations (Dong et al., 2012; Folsom et al., 2011; Nayor et al., 2016). For example, individuals in our study with seven ideal metrics were 76% less likely to develop ASCVD compared with those with ≤2 metrics. A similar dose-response pattern was also observed for CHD, stroke, and ASCVD death irrespective of sex, age, living region, or urbanization level of residence. Presumably, up to 62.1% of ASCVD, 38.7% of CHD, 66.4% of stroke,

Table 2 Adjusted hazard ratios and population-attributable risk percentage for ASCVD events according to the number of ideal cardiovascular health metrics, the China-PAR project[a)]

Characteristics	Total	Number of ideal cardiovascular health metrics						P value for trend	Adjusted PAR% (95% CI)[§]
		0–2 (n=5,602)	3 (n=12,288)	4 (n=22,324)	5 (n=27,066)	6 (n=19,792)	7 (n=6,915)		
ASCVD events[*]									
Cases	3,457	463	750	976	811	397	60		
Total person-years	680,413.64	42,061.07	88,821.06	158,730.06	193,944.80	145,672.97	51,183.68		
Age-, sex-adjusted incidence rate[†]	508.07	898.13	721.75	579.40	458.22	364.07	194.30		
Age-, sex-adjusted HR (95% CI)		1 (reference)	0.82 (0.73–0.92)	0.64 (0.58–0.72)	0.51 (0.46–0.58)	0.39 (0.34–0.45)	0.20 (0.15–0.26)	<0.0001	
Fully adjusted HR (95% CI)[‡]		1 (reference)	0.83 (0.74–0.93)	0.66 (0.59–0.74)	0.55 (0.48–0.61)	0.44 (0.38–0.50)	0.24 (0.18–0.31)	<0.0001	62.1 (50.5–71.4)
CHD									
Cases	788	135	179	201	178	76	19		
Total person-years	685,538.03	42,863.85	90,012.30	160,211.13	195,068.79	146,135.98	51,245.98		
Age-, sex-adjusted incidence rate[†]	114.95	259.21	168.95	119.52	100.03	71.74	65.11		
Age-, sex-adjusted HR (95% CI)		1 (reference)	0.68 (0.54–0.85)	0.46 (0.37–0.58)	0.40 (0.32–0.50)	0.27 (0.21–0.36)	0.24 (0.15–0.38)	<0.0001	
Fully adjusted HR (95% CI)[‡]		1 (reference)	0.72 (0.57–0.90)	0.52 (0.42–0.65)	0.48 (0.38–0.61)	0.36 (0.27–0.49)	0.35 (0.22–0.58)	<0.0001	38.7 (5.5–64.2)
Stroke									
Cases	2,718	339	583	785	643	325	43		
Total person-years	681,713.16	42,311.08	89,119.12	159,076.90	194,194.54	145,781.57	51,229.94		
Age-, sex-adjusted incidence rate[†]	398.70	647.38	556.40	466.61	362.41	295.87	138.30		
Age-, sex-adjusted HR (95% CI)		1 (reference)	0.88 (0.77–1.00)	0.72 (0.63–0.82)	0.56 (0.49–0.64)	0.44 (0.38–0.51)	0.19 (0.14–0.26)	<0.0001	
Fully adjusted HR (95% CI)[‡]		1 (reference)	0.87 (0.76–0.99)	0.71 (0.62–0.81)	0.56 (0.49–0.65)	0.45 (0.39–0.53)	0.21 (0.15–0.28)	<0.0001	66.4 (54.1–75.9)
ASCVD death									
Cases	1,383	198	306	378	317	162	22		
Total person-years	684,215.37	42,910.47	89,861.24	159,918.42	194,606.32	145,760.31	51,158.6		
Age-, sex-adjusted incidence rate[†]	202.13	359.88	280.60	220.49	181.31	157.36	81.33		
Age-, sex-adjusted HR (95% CI)		1 (reference)	0.79 (0.66–0.95)	0.60 (0.51–0.72)	0.51 (0.43–0.61)	0.43 (0.35–0.52)	0.21 (0.13–0.32)	<0.0001	
Fully adjusted HR (95% CI)[‡]		1 (reference)	0.82 (0.68–0.98)	0.64 (0.54–0.76)	0.56 (0.46–0.67)	0.49 (0.39–0.61)	0.26 (0.16–0.40)	<0.0001	60.5 (39.8–75.3)

a) Abbreviations: ASCVD, atherosclerotic cardiovascular disease; HR, hazard ratio; CI, confidence interval, PAR%, population-attributable risk percentage; China-PAR project, Prediction for ASCVD Risk in China. *, ASCVD events were defined as the first occurrence of nonfatal acute myocardial infarction (AMI), or coronary heart disease (CHD) death or fatal or non-fatal stroke. †, The age- and sex-adjusted incidence rates (per 100,000 person-years) were calculated by the number of ideal CVH metrics using Poisson regression model. ‡, Adjusted for age, sex, living region, urbanization, drinking status, education level, family history of ASCVD, and cohort sources. §, The PAR% adjusted for age, sex, living region, urbanization, drinking status, education level, family history of ASCVD, and cohort sources. It indicated the proportion of the outcome (e.g. ASCVD event/CHD/Stroke/ASCVD death) attributable to not achieving all the seven ideal CVH metrics.

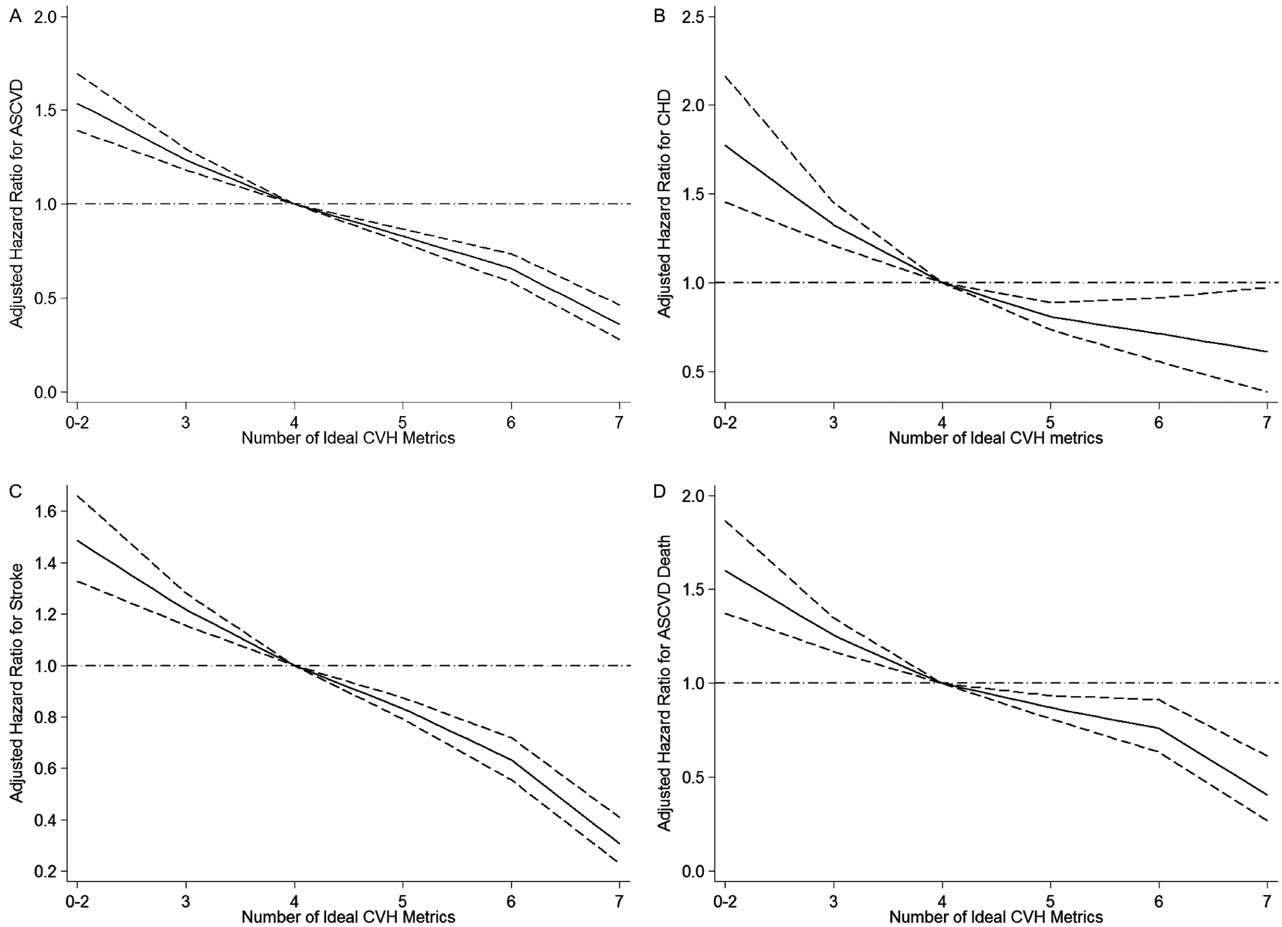

Figure 2 Multivariable-adjusted association between hazard ratio for ASCVD (A), CHD (B), stroke (C), and ASCVD death (D) and the number of ideal cardiovascular health metrics (modeled as continuous variable), the China-PAR project. ASCVD, atherosclerotic cardiovascular disease; CHD, coronary heart disease; China-PAR project, Prediction for ASCVD Risk in China.

Table 3 Adjusted hazard ratios for the risk of ASCVD events according to the number of ideal health behaviors or ideal health factors, the China-PAR project[a)]

Characteristics	Number of ideal health behaviors				*P* value for trend	Number of ideal health factors				*P* value for trend	Adjusted PAR%[‡] (95% CI)
	0–1 (*n*=7,068)	2 (*n*=26,519)	3 (*n*=40,079)	4 (*n*=20,321)		0 (*n*=6,087)	1 (*n*=21,689)	2 (*n*=42,749)	3 (*n*=23,462)		
ASCVD events*											
Fully adjusted HR (95% CI)[†]	1 (reference)	0.97 (0.87–1.09)	0.86 (0.77–0.97)	0.74 (0.65–0.85)	<0.0001	1 (reference)	0.75 (0.67–0.83)	0.58 (0.52–0.65)	0.33 (0.29–0.39)	<0.0001	17.4 (9.4, 25.2)
CHD											
Fully adjusted HR (95% CI)[†]	1 (reference)	0.86 (0.69–1.07)	0.78 (0.62–0.97)	0.68 (0.52–0.90)	0.0042	1 (reference)	0.70 (0.57–0.87)	0.49 (0.40–0.61)	0.40 (0.30–0.53)	<0.0001	18.0 (0.6, 34.3)
Stroke											
Fully adjusted HR (95% CI)[†]	1 (reference)	1.01 (0.88–1.15)	0.88 (0.77–1.00)	0.75 (0.65–0.88)	<0.0001	1 (reference)	0.75 (0.67–0.85)	0.60 (0.53–0.68)	0.31 (0.26–0.37)	<0.0001	16.7 (7.7, 25.3)
ASCVD death											
Fully adjusted HR (95% CI)[†]	1 (reference)	0.98 (0.83–1.17)	0.87 (0.73–1.04)	0.84 (0.68–1.04)	0.0221	1 (reference)	0.64 (0.55–0.76)	0.54 (0.46–0.64)	0.33 (0.26–0.42)	<0.0001	10.1 (–3.2, 23.0)

a) Abbreviations: ASCVD, atherosclerotic cardiovascular disease; HR, hazard ratio; CI, confidence interval; PAR%, population-attributable risk percentage; China-PAR project, Prediction for ASCVD Risk in China. *, ASCVD events were defined as the first occurrence of nonfatal acute myocardial infarction (AMI), or coronary heart disease (CHD) death or fatal or non-fatal stroke. †, Adjusted for age, sex, living region, urbanization, drinking status, education level, family history of ASCVD, cohort sources, and number of ideal health behaviors/factors. ‡, The PAR% adjusted for age, sex, living region, urbanization, drinking status, education level, family history of ASCVD, cohort sources, and number of ideal health factors. It indicated the proportion of the outcome (e.g. ASCVD event/CHD/Stroke/ASCVD death) attributable to not achieving all the four ideal health behaviors, after adjusting for the effect of ideal health factors.

Table 4 Adjusted hazard ratios and population-attributable risk percentage for the ASCVD events according to the status of each cardiovascular health metric, the China-PAR project[a)]

CVH metrics	ASCVD events*			CHD			Stroke			ASCVD death		
	Adjusted incidence rate†	Fully adjusted HR (95% CI)‡	Adjusted PAR% (95% CI)§	Adjusted incidence rate†	Fully adjusted HR (95% CI)‡	Adjusted PAR% (95% CI)§	Adjusted incidence rate†	Fully adjusted HR (95% CI)‡	Adjusted PAR% (95% CI)§	Adjusted incidence rate†	Fully adjusted HR (95% CI)‡	Adjusted PAR% (95% CI)§
Smoking												
Non-ideal	513.49	1 (reference)		121.22	1 (reference)		405.01	1 (reference)		196.64	1 (reference)	
Ideal	506.29	0.86 (0.79–0.94)	3.6 (1.0–6.2)	112.88	0.81 (0.68–0.98)	5.5 (0.2–10.8)	396.63	0.86 (0.78–0.95)	3.5 (0.7–6.4)	203.94	0.98 (0.85–1.12)	0.3 (−3.7–4.3)
Body mass index												
Non-ideal	618.65	1 (reference)		131.49	1 (reference)		490.29	1 (reference)		209.62	1 (reference)	
Ideal	452.38	0.87 (0.81–0.93)	5.0 (1.9–8.0)	106.58	1.00 (0.86–1.16)	NA	352.51	0.84 (0.77–0.91)	6.5 (3.1–9.9)	198.33	1.12 (1.00–1.27)	NA
Physical activity												
Non-ideal	544.05	1 (reference)		143.37	1 (reference)		404.93	1 (reference)		227.97	1 (reference)	
Ideal	488.54	0.99 (0.92–1.06)	1.4 (−1.7–4.5)	99.47	0.83 (0.71–0.97)	8.7 (1.7–15.6)	395.32	1.03 (0.95–1.12)	NA	188.12	0.86 (0.77–0.97)	7.7 (2.6–12.7)
Healthy diet score												
Non-ideal	598.73	1 (reference)		130.79	1 (reference)		472.67	1 (reference)		255.54	1 (reference)	
Ideal	469.86	0.90 (0.84–0.96)	5.1 (2.5–7.8)	108.26	0.93 (0.80–1.08)	3.4 (−1.9–8.7)	367.53	0.89 (0.82–0.96)	5.4 (2.5–8.3)	179.58	0.85 (0.76–0.96)	7.9 (3.6–12.2)
Total cholesterol												
Non-ideal	624.47	1 (reference)		165.48	1 (reference)		466.30	1 (reference)		249.26	1 (reference)	
Ideal	469.76	0.83 (0.77–0.89)	7.0 (4.4–9.7)	98.23	0.70 (0.61–0.82)	12.6 (6.8–18.3)	376.41	0.86 (0.79–0.94)	5.3 (2.4–8.2)	186.54	0.80 (0.71–0.90)	8.0 (3.9–12.0)
Blood pressure												
Non-ideal	629.65	1 (reference)		137.27	1 (reference)		497.43	1 (reference)		249.79	1 (reference)	
Ideal	297.89	0.51 (0.46–0.56)	44.1 (38.6–49.3)	76.06	0.63 (0.51–0.77)	33.0 (20.4–44.4)	227.74	0.47 (0.42–0.53)	46.0 (39.9–51.7)	118.77	0.48 (0.41–0.57)	47.2 (38.4–55.1)
Fasting plasma glucose												
Non-ideal	694.14	1 (reference)		169.27	1 (reference)		534.38	1 (reference)		276.05	1 (reference)	
Ideal	456.57	0.78 (0.72–0.84)	8.0 (5.3–10.6)	99.83	0.77 (0.66–0.90)	8.8 (3.2–14.2)	361.10	0.78 (0.72–0.85)	7.5 (4.5–10.4)	181.49	0.80 (0.72–0.90)	7.6 (3.5–11.8)

a) Abbreviations: ASCVD, atherosclerotic cardiovascular disease; CVH, cardiovascular health; HR, hazard ratio; CI, confidence interval; PAR%, population-attributable risk percentage; NA, not available; China-PAR project, Prediction for ASCVD Risk in China. *, ASCVD events were defined as the first occurrence of nonfatal acute myocardial infarction (AMI), or coronary heart disease (CHD) death or fatal or non-fatal stroke. †, The age- and sex-adjusted incidence rates (per 100,000 person-years) were calculated by the status of each CVH metric using Poisson regression model. ‡, Adjusted for age, sex, living region, urbanization, drinking status, education level, family history of ASCVD, cohort sources, and other CVH metrics. §, The PAR% adjusted for age, sex, living region, urbanization, drinking status, education level, family history of ASCVD, cohort sources, and other CVH metrics. It indicated the proportion of the outcome (e.g. ASCVD event/CHD/Stroke/ASCVD death) attributable to not achieving ideal level for each CVH metric.

and 60.5% of ASCVD death could be eliminated or postponed if people achieved all the seven ideal CVH metrics. Therefore, focusing on primordial prevention through achieving a greater number of ideal CVH metrics is projected to substantially alleviate the disease burden of ASCVD in China. However, in the short term, it is more realistic to encourage adults for the gradual attainment of the seven ideal CVH metrics by one after another.

Health behaviors strongly influenced the major CVD risk factors, including high BP, fasting glucose, and TC. We found benefits of ideal health behaviors on incident ASCVD event after adjusting for ideal health factors. For example, adults with four ideal health behaviors were 26% less likely to develop ASCVD compared with those having ≤1 health behavior (Table 3). The protection afforded by ideal health behaviors might involve pathways in addition to optimizing the levels of health factors, such as influencing endothelial function and inflammation (Montero et al., 2012; Nahrendorf and Swirski, 2015). Achieving four ideal health behaviors could bring adults substantial health benefits in preventing 17.4% of ASCVD, 18.0% of CHD, 16.7% of stroke, and 10.1% of ASCVD death after adjusting for ideal health factors. This explicitly highlighted ideal health behaviors as crucial for promoting CVH, independent of ideal health factors.

In light of the abundant evidence on the health benefits of ideal health behaviors and factors, it is indispensable to prioritize these health metrics to efficiently reduce the economic burdens of ASCVD in China. Among aforementioned metrics, ideal BP was associated with the largest adjusted PAR% for various ASCVD events (33.0%–47.2%), as has been proved elsewhere (Yang et al., 2012). It is well known that BP is the leading modifiable risk factor for CVD both worldwide and in China (Gakidou et al., 2017; Yang et al., 2013). Hypertension affected approximately 270 million individuals in China in 2010, while BP control would provide a considerable reduction in CVD deaths (Gu et al., 2015; He et al., 2009). Thus, primordial prevention of elevated BP should be deemed as the top public-health priority in ASCVD prevention in China. By comparison, healthy diet, nonsmoking status, adequate PA, ideal BMI, TC, and fasting glucose were associated with moderate PAR% for various ASCVD events. But among them, the CVH metric that provided the most significant challenge and opportunity for improvement was keeping a healthy diet (Bi et al., 2015; Folsom et al., 2011; Shay et al., 2012; Yang et al., 2012). Only about one in 25 Chinese adults met AHA's criteria of ideal diet (≥4 healthy diet score components) in the current study, which was similar to other reports in general Chinese population (Bi et al., 2015; Wu et al., 2013). The low prevalence of ideal diet might finally slow the process of improving CVH. The current findings suggested that ideal BP and dietary habits were the top two CVH metrics noteworthy in general Chinese population.

Our study has several strengths. To the best of our knowledge, this is the first study to comprehensively investigate the relationship between CVH metrics and multiple ASCVD outcomes using a nationwide sample in China. The China-PAR project is a population-based prospective study with a low rate of loss to follow-up (7.21%). The inclusion of a population with diverse sociodemographic characteristics in different provinces makes our results more broadly applicable to the general Chinese population. Besides, our results derived from the most recent cohorts with the last follow-up time of 2015 will generalize better to contemporary Chinese populations. Furthermore, prior studies documenting this relationship in Chinese usually used simplified metrics or narrower CVD definitions, such as using salt intake as a surrogate of diet quality or focusing on stroke as endpoint alone (Zhang et al., 2013). Our study extended the existing findings to the complete AHA's definition of CVH in relation to a combined ASCVD endpoint. Finally, the large sample size, standardized data-collection protocols and rigorous quality control ensure the identification of the true association.

Besides, the current findings emphasize health policies and strategies targeting at the promotion of CVH and prevention of ASCVD among Chinese population. By strengthening health education with a focus on seven ideal CVH metrics and creating health-supporting environment and facility such as the bicycle-sharing system, healthy lifestyles in adults are to be improved toward the goal of Health China.

Some drawbacks of the study warrant consideration. First, we used a different definition of ideal diet to comply with Chinese dietary habits based on food frequency questionnaire in current survey. Thus, our results could not be compared directly with other studies conducted in Western population using the AHA's ideal CVH criteria. Additionally, we only used one single measure of CVH metrics at the baseline, which may vary over several years of follow-up and lead to underestimation of the true association. Finally, comparison of characteristics between included participants and those lost to follow-up revealed that included participants formed a less healthy sample than those lost to follow-up (Table S3 in Supporting Information). This could have led to an overestimation of the probable association. In spite of these limitations above, the strength of association, the temporal sequence (CVH status antedated ASCVD incidence), a dose-response relationship and the consistency in multiple analyses proved the observed association to be a causal one.

METHODS

Study population

The study participants were derived from three cohorts in the

China-PAR project, including the China Multi-Center Collaborative Study of Cardiovascular Epidemiology (China MUCA-1998), the International Collaborative Study of CVD in Asia (InterASIA) and the Community Intervention of Metabolic Syndrome in China & Chinese Family Health Study (CIMIC). The China-MUCA (1992–1994) cohort in the China-PAR project was not included in these analyses due to lack of data on PA and diet. Details of the project's design have been illustrated elsewhere (Yang et al., 2016). Briefly, a total of 113,448 adults were enrolled in the three cohorts. The China MUCA-1998, InterASIA, and CIMIC cohort were established in 1998, 2000–2001, and 2007–2008, respectively. The first follow-up survey for both the China MUCA-1998 and the InterASIA study was conducted from 2007 to 2008, and the second was conducted from 2012 to 2015, while the CIMIC study was only followed up once from 2012 to 2015. The China-PAR project was approved by the Institutional Review Board at Fuwai Hospital in Beijing and all participating institutions. Written informed consents were obtained from all study participants before data collection.

Of the 105,263 (92.79%) participants who had follow-up data, 633 participants aged less than 20 years old were excluded. Additional exclusion of those with a history of ASCVD at entry or without complete data on CVH metrics reduced the sample size to 93,987 for the current analyses (Figure S6 in Supporting Information).

Data collection

A standardized questionnaire comprising information on demographic characteristics, lifestyle information, history of chronic diseases and medication were administrated by trained interviewers. The identification of preexisting ASCVD was defined as any self-reported previous physician-diagnosis of myocardial infarction or stroke. Smoking status and age of starting and quitting smoking were also self-reported. Physical activity was assessed by asking how much time the participant spent on rigorous/moderate/light PA per day over the previous 12 months. Habitual dietary intake was collected by asking the frequency of consumption and portion size of typical food items during the past year. To minimize potential recall bias, first, we provided training sessions for interviewers on dietary intake and certified the qualified ones with standard training protocols of food frequency. Second, we intentionally made efforts on obtaining food intake information by using standardized questionnaires consisting of closed-end, easy to understand questions with appropriate response options. Weight and height were measured according to a standard protocol, and BMI was calculated as weight in kilograms divided by height in meters squared. Three BP measurements were obtained by trained observers after at least a 5-min sitting rest of each participant. The average of three BP readings was used in the analyses. In addition, blood samples were drawn from participants after fasting for at least 10 h to measure serum glucose and lipid levels. We also collected information on the use of anti-hypertensive, lipid-lowering and glucose-lowering medications within the past two weeks. Hospital records or death certificates were collected to obtain information on disease status and vital outcome events during the follow-up period.

AHA's CVH metrics

Each of the seven CVH metrics was categorized as ideal or non-ideal according to AHA's definition except for healthy diet score (Table S4 in Supporting Information). A modified healthy diet score for Chinese was defined in accordance with AHA's recommended diet goals (Lloyd-Jones et al., 2010) and the most recent "Dietary Guidelines for Chinese Residents" (Wang et al., 2016). In addition to fruits, vegetables and fish, the daily intake of soybean products, red meat and monthly consumption of tea were also taken into consideration based on our food questionnaire and the reported associations of these items with CVD (Bellavia et al., 2016; Rebholz et al., 2013; Zhang et al., 2015).

Definition of ASCVD

ASCVD was defined as the first occurrence of nonfatal AMI, or CHD death or fatal or non-fatal stroke. The definitions of AMI, CHD death, and stroke were elaborated in our previous study (Yang et al., 2016). We further classified the total ASCVD events into three event types, including CHD (fatal or nonfatal CHD events), stroke (fatal or nonfatal stroke events) and ASCVD death.

Quality control

A stringent quality control program was implemented to ensure the validity and reliability of the study data. All investigators and research staff underwent a training session about the use of standardized protocols and instruments for data collection. All blood samples were measured with uniform methods. Data were double-entered into a database and then checked for correction. An expert committee at Fuwai Hospital reviewed and adjudicated all the final end-point events by reviewing all incidence and death records. Two committee members independently verified the events, and discrepancies were resolved by discussion with other committee members.

Statistical analysis

Sex-specific means or corresponding percentages of baseline variables were calculated. Differences in means or percentages between men and women were examined with *t*-test or *chi*-square test, respectively. Person-years of follow-up for each participant were calculated as the difference between the date of baseline examination and the date of ASCVD event occurrence, death, or the last follow-up interview, whichever came first. We further calculated the age- and sex-adjusted incidence rate of total ASCVD events and each event type per 100,000 person-years using Poisson regression models (Zhao, 1999).

All the participants were classified into six groups as follows: ≤2, 3, 4, 5, 6 and 7 ideal CVH metrics. The Kaplan-Meier survival curves for cumulative incidence of the six groups were drawn, and the log-rank test was conducted to determine the difference across these groups. HRs and corresponding 95% CIs for ASCVD risk were calculated using Cox proportional hazards regression models for the individual and clustering of CVH metrics. The analyses were performed with first adjustment for age and sex, and further adjustment for living region (northern/southern), urbanization (urban/rural), alcohol use, education level (less than high school/high school education or above), family history of ASCVD, and cohort sources. Analyses for each metric were additionally adjusted for other metrics. Tests of trend for HRs across CVH-metric categories were performed by including the ordinal categories as a continuous variable in the Cox models. Restricted cubic splines were further used to flexibly model potential dose-response association between the number of ideal CVH metrics as a continuous variable and the risk of ASCVD events. The PAR% and 95% CIs were calculated using the %PAR macro developed by Spiegelman et al. (Spiegelman et al., 2007). All the above analyses were done for the incidence of total ASCVD events and each event type individually.

To assess potential selection bias, we compared the baseline characteristics between the participants included in these analyses and those lost to follow-up. In a sensitivity analysis, we repeated the analyses after exclusion of participants who developed ASCVD events during the first year. Furthermore, we conducted stratified analyses to examine potential effect modification by factors including sex, age group, living region, and urbanization. To test for potential heterogeneities across three different cohorts, we conducted cohort-stratified Cox proportional-hazards analyses and a meta-analysis was used to combine the cohort-specific estimates with the fixed-effect models since minor heterogeneity existed across three cohorts (all P for heterogeneity>0.05, most I^2<50%).

The proportional hazards assumption of the Cox models was examined with Schoenfeld residuals and found to be met (Schoenfeld, 1982). Data were analyzed by using SAS 9.3 and Stata 11.0 software. All statistical tests were two-sided, and a P value <0.05 was considered statistically significant.

CONCLUSIONS

The gradient inverse association between ideal CVH metrics and various ASCVD events development supports the application of AHA's CVH metrics for ASCVD risk assessment and health promotion among general Chinese adults. Promotion of CVH is considered as a key part of the population health agenda.

Compliance and ethics *The author(s) declare that they have no conflict of interest.*

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SUPPORTING INFORMATION

Table S1 Adjusted hazard ratios for the risk of ASCVD events according to the number of ideal cardiovascular health metrics, stratified by cohorts of the China-PAR project

Table S2 Adjusted hazard ratios for the risk of ASCVD events according to the number of ideal cardiovascular health metrics when cases occurring in the first year after follow-up were removed

Table S3 Comparison of baseline characteristics between included individuals and those lost to follow up

Table S4 Definition of ideal cardiovascular health metrics (>20 years of age) in this study

Figure S1 Adjusted hazard ratios for total ASCVD events by the number of ideal cardiovascular health metrics and subgroups of sex, age group, living region, and urbanization.

Figure S2 Adjusted hazard ratios for CHD by the number of ideal cardiovascular health metrics and subgroups of sex, age group, living region, and urbanization.

Figure S3 Adjusted hazard ratios for stroke by the number of ideal cardiovascular health metrics and subgroups of sex, age group, living region, and urbanization.

Figure S4 Adjusted hazard ratios for ASCVD death by the number of ideal cardiovascular health metrics and subgroups of sex, age group, living region, and urbanization.

Figure S5 Age- and sex-adjusted incidence rates of ASCVD events according to the number of ideal health behaviors and ideal health factors.

Figure S6 Flowchart of the study.

The supporting information is available online at http://life.scichina.com and https://link.springer.com. The supporting materials are published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.