Zhang *et al. BMC Medicine* (2025) 23:204
https://doi.org/10.1186/s12916-025-04032-y

BMC Medicine

RESEARCH

Open Access

Associations between education and ideal cardiovascular health metrics across 36 low- and middle-income countries

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Abstract

Background The relationship between education and cardiovascular health (CVH) metrics in low- and middle-income countries (LMICs) remains unclear. This study explores the associations between education and ideal cardiovascular health score (CVHS), as well as seven CVH metrics.

Methods This cross-sectional study extracted data from the STEPwise approach to surveillance surveys in 36 LMICs between 2010 and 2020. We assessed CVHS using the sum score in seven metrics defined by American Heart Association: (1) ≥ 150 min/week of moderate, or 75 min/week of vigorous activity, or an equivalent combination; (2) BMI < 25 kg/m^2 for non-Asians (< 23 kg/m^2 for Asians); (3) fruit and vegetable intake ≥ 4.5 servings per day; (4) non-smoking; (5) blood pressure < 120/80 mmHg (untreated); (6) total cholesterol < 200 mg/dL (untreated); and (7) fasting blood glucose < 100 mg/dL (untreated). The ideal CVHS score ranged from 5 to 7. We disaggregated prevalence of ideal CVHS and seven metrics by education, and constructed Poisson regression models to adjust for other socio-economic factors.

Results Among 81,327 adult participants, the overall ideal CVHS prevalence for the studied countries was highest among individuals with primary education (52.9%, 95% CI: 51.0–54.9), surpassing those of other education levels – 48.0% (95% CI: 44.6–51.3, P = 0.003) for those with no education and 39.1% (95% CI: 36.5–41.8, P < 0.001) for those with tertiary education. Five (ideal physical activity, BMI, blood pressure, total cholesterol, and blood glucose) in seven CVH metrics peaked among participants with primary or secondary education. For instance, the prevalence of ideal blood pressure among individuals with primary education was 34.4% (95% CI: 32.7–36.1), higher than the prevalence in other education levels, ranging from 28.6% to 32.3%. These patterns were concentrated in low-income countries and lower-middle-income countries, while in upper-middle-income countries, the prevalence of ideal CVHS increased with higher education levels, ranging from 15.4% for individuals with no education to 33.1% for those with tertiary education.

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Conclusions In LMICs, the association between education and ideal CVHS, along with several CVH metrics, exhibited un inverted U-shape, which may be closely related to the different stages of epidemiologic transition.

Keywords Education, Ideal cardiovascular health score, Ideal cardiovascular health metrics, Inverted U-shape, Low- and middle-income countries

Background

Cardiovascular disease (CVD) remains the leading cause of death worldwide, accounting for 19.8 million fatalities in 2022 alone [1]. Alarmingly, three-quarters of these deaths occur in low- and middle-income countries (LMICs) [2]. Furthermore, the prevalence of CVD in these nations has surged dramatically in recent decades, rising from 11 million in 2000 to 475 million in 2021, which now constitutes nearly 60% of the global disability-adjusted life years lost to CVD [3]. This rising burden highlights the urgent need for primary prevention strategies tailored to LMICs, where resources are limited, and the healthcare systems are under strain. The American Heart Association (AHA) introduced the Life's Simple 7 metrics to promote overall cardiovascular health (CVH) through the assessment of metabolic and behavioral factors, including smoking status, diet, physical activity, BMI, blood pressure, total cholesterol, and blood glucose. This holistic approach provides a comprehensive assessment of CVH, extending beyond the mere clinical absence of disease [4, 5]. Numerous studies have demonstrated that favorable CVH metrics are associated with a reduced risk of CVD events, underscoring their values in the primary prevention of CVD, even in the LMICs [6–8]. Moreover, this approach has been adopted in many LMICs to assess CVH and identify high-risk groups [9], such as Malawi and Bhutan [10, 11].

The level of education attained by individuals is closely linked to the risk of CVD and the performance of CVH metrics [12, 13]. Numerous studies from high-income countries, such as the USA, Japan, and European countries have consistently shown that higher education is associated with a lower risk of CVD, or better performance on CVH metrics [12, 14–19]. For example, a systematic review of 31 studies found that individuals with tertiary education had a 56% lower risk of CVD incidence compared to those with only primary education [20].

Despite ample evidence from high-income countries, the evidence in LMICs has been limited and inconsistent. Studies in Nepal [21], Jamaica [22], and Bhutan [11] found that higher education was associated with a lower likelihood of achieving ideal CVHS, while studies in Peru and Malawi showed no such relationship [23]. Previous literature often focused on specific regions within countries or used relatively small sample sizes, making it challenging to effectively assess the relationship and underscoring the need for a more systematic examination to understand the link between education and CVHS. Regarding individual CVH metrics, the evidence has also been conflicting. For example, a study conducted in Nepal showed a positive association between education and the risk of hypertension [24], whereas the relationship was observed to be negative in Zambia [25].

In this study, using nationally representative data with large sample sizes from 36 LMICs, we investigated the association between education levels and ideal CVHS. Furthermore, the study explored how education levels correlate with each individual CVH metric. This investigation aimed to provide comprehensive insights for formulating future interventions and policies to assist health promotion in CVH in LMICs.

Methods

Study design and participants

This study used the most recent nationally representative cross-sectional household survey data from the STEPwise approach to NCD risk factor surveillance (STEPS) conducted in LMICs between 2010 and 2020. These surveys use a multistage cluster sampling method in most countries, usually targeting individuals aged 18 to 69 with variations across countries. Sampling typically involves two or three stages, depending on the country's context: enumeration areas, households, and individuals. These stages are based on the most recent population and housing census. The sample size required for each country is proportionally allocated to ensure representativeness, and participants are selected systematically within each stage to achieve the desired sample composition [26, 27]. Trained interviewers and clinicians collect information using structured questionnaires. Demographic data and behavioral risk factors (e.g., alcohol consumption, physical activity) are obtained through self-reporting. Interviewers measure height, weight, waist circumference, and blood pressure, and also conduct biochemical assessments, including fasting blood glucose and total cholesterol [28]. All physical and biochemical assessments were conducted following the guidelines Word Health Organization provided, with accurate equipment and rigorous procedures, and details were reported in Additional file 1: Method S1 and elsewhere [26, 27, 29].

Our study included all countries with available information on CVH metrics and covariates, totaling 36 countries. This resulted in a sample of 89,760 individuals aged 18 years and more across these nations. First, we excluded 5252 participants with missing or implausible values, such as systolic blood pressure outside 70–240 mmHg, diastolic blood pressure outside 40–130 mmHg, and blood glucose levels below 40 mg/dL, to uphold measurement quality. Second, we excluded 2759 individuals without recorded education levels. Additionally, 422 pregnant participants were excluded [30]. The final sample included 81,327 eligible participants across the 36 countries for our analyses. The complete flowchart and countries included were presented in Additional file 1: Fig. S1 and Table S1.

Outcomes

The primary outcome of this study was ideal CVHS. Defined by the AHA, it was measured using seven metrics, each with a proven relationship to the risk of CVD [31, 32]. These metrics included three behavioral factors (i.e., diet, smoking status, and physical activity) and four metabolic factors (i.e., BMI, blood pressure, total cholesterol, and blood glucose). Following AHA guidelines, we defined each of these metrics as either non-ideal (0 points) or ideal (1 point) [33]. Following previous studies [5, 34, 35], we computed the CVHS by summing these scores across all metrics, resulting in a scale from 0 to 7, and we classified ideal CVHS as scores ranging from 5 to 7 and non-ideal CVHS as scores ranging from 0 to 4.

We assessed each of the seven metrics as secondary outcomes to explore their patterns associated with education levels, providing insights into potential targeted interventions. Adhering to AHA definitions, we defined each metric as follows: Ideal physical activity was achieved with a minimum of 150 min/week of moderate-intensity activity (such as water aerobics), or 75 min/week of vigorous-intensity activity (such as race walking), or an equivalent combination. Ideal BMI was defined as less than 23 kg/m^2 for Asians and less than 25 kg/m^2 for non-Asians. Ideal diet was assessed by consuming at least 4.5 servings of fruits and vegetables per day. Ideal smoking status was defined as never smoking or having quit for more than 12 months. Ideal blood pressure was defined as less than 120/80 mmHg (untreated). Ideal total cholesterol was less than 200 mg/dL (untreated), and ideal blood glucose was less than 100 mg/dL of fasting plasma glucose (untreated) [33].

Exposure and covariates

Education level was categorized based on the highest attainment according to the information that participants self-reported. Due to the diversity of education categories in STEPS, we recategorized education into four levels according to World Bank and International Standard Classification of Education (ISCED) [36], which were as follows: (1) no education: no formal schooling; (2) primary education: less than primary school, primary school completed, standard 1–5, initial, and O-level completed; (3) secondary education: secondary school incomplete, secondary school completed, junior secondary completed, senior secondary school completed, high school completed, middle grades, standard 6–8, secondary vocational, and secondary higher school completed; (4) tertiary education: college/university completed, post graduate degree, post-secondary completed, bachelor level completed, and A-level completed.

To address potential confounding factors, we considered both demographic and biochemical measurements, including sex (male/female), age groups (18–29, 30–44, 45–59, and 60 or above), marital status (never married, currently married, and former married), employment status (government employee, non-government employee, self-employed, and non-paid), and alcohol consumption (yes/no). We conducted multiple imputations for covariates that had less than 5% missing values using participants' sex, age groups, and alcohol consumption.

Statistical analyses

Firstly, we estimated the prevalence of ideal CVHS and its seven metrics, along with their 95% confidence intervals (CIs), by education levels. Weighted prevalence was calculated considering sample weights, primary sampling units, and the stratified sampling design. Standard errors were adjusted for clustering at the level of the primary sampling unit. Additionally, we reported pooled estimates and estimates stratified by income groups, adjusting for the country's population size at the survey years. To further explore the potential nonlinear associations between education and CVHS, as well as its seven metrics, we also employed years of individuals' education to illustrate the prevalence of ideal CVHS and seven CVH metrics.

Secondly, we examined the associations between education level and ideal CVHS, as well as the seven CVH metrics. We used multivariable Poisson regression models to calculate Prevalence ratios (PRs) and the corresponding 95% CIs, using tertiary education as the reference group. Following previous practice [37], we generated weights combining both the sampling weight and population size of each country in the regression models. In Model 1, we adjusted for country-level fixed effects to account for unobserved, time-invariant country-level characteristics, such as culture norms, political structures, and dietary preferences, which are generally invariant over time but could confound the relationship between education and CVHS. Human Development Index (HDI) of the countries included at the survey year was also adjusted in Model 1 to address the countries' level of development. Model 2 additionally adjusted for participants' sex and age. Model 3 further adjusted additional covariates including marital status, employment status, and alcohol consumption.

Thirdly, we conducted stratified analyses based on World Bank income classification to determine whether the relationships between education and outcomes varied according to national developmental status. In addition, prior research indicated that women and the elderly are more susceptible to CVD incidence [38]. Therefore, we also stratified the analyses by age and sex to assess whether the associations between education and the outcomes varied by age groups and sex.

We performed five sets of sensitivity analyses to further validate our findings. First, we repeated the main analyses excluding participants with missing data for covariates to confirm the robustness of our results without imputed data. Second, due to the missingness that eight countries did not collect information on household wealth, we did not include this as a covariate in our main analyses, despite its notable role in influencing access to high-quality healthcare [39]. In the sensitivity analysis, we excluded these eight countries to incorporate wealth as a covariate and repeated the analyses. Third, since age can exhibit a non-linear relationship with CVD risks, we treated age as a continuous variable with restricted cubic splines (five knots were placed at the fifth, 27.5th, 50th, 72.5th, and 95th percentiles) to account for potential nonlinearities. This was aimed to strengthen our findings on the association between education and ideal CVHS [38]. Fourth, due to the consideration of underweight in LMICs, we redefine ideal BMI as BMI $< 25/23$ kg/m^2 and BMI ≥ 18.5 kg/m^2 to further validate our findings. Finally, due to the difference between included and excluded individuals, we adopted inverse probability weighting to reweight the sample, addressing the potential impact of selection bias. We undertook all analyses using Stata (version 17.0). P values of < 0.05 were considered statistically significant.

Results

Among 81,327 participants across 36 LMICs, 41.3% were male, and 10.0% were aged 60 or above. Among those with higher levels of education, a larger proportion were males − 44.5% among those who had completed tertiary education compared to 30.0% among individuals with no education. Additionally, those with tertiary education showed a higher likelihood to consume alcohol or be government employee compared to those with no education (Table 1). Comparison of characteristics between the sample included and sample excluded due to missing or implausible values were conducted in Additional file 1: Table S2. We showed the prevalence of CVHS and each metric of CVH among all participants in Additional file 1: Table S3. The prevalence of ideal CVHS was 48.8% (95% CI: 47.3–50.3). The prevalence of ideal physical activity, ideal total cholesterol, and ideal blood glucose all exceeded 80%, which was 84.7% (95% CI: 83.7–85.7), 81.9% (95% CI: 80.7–83.0), and 81.6% (95% CI: 80.6–82.5), respectively. The prevalence of ideal fruit and vegetable intake was the lowest among the seven metrics with an average of 15.8% (95% CI: 14.7–16.9).

We presented the prevalence of ideal CVHS by education level in Fig. 1 and Additional file 1: Table S4. The highest prevalence of ideal CVHS was among individuals with primary education at 52.9% (95% CI: 51.0–54.9), much higher than those with no education (48.0%, 95% CI: 44.6–51.3, $P = 0.003$) or tertiary education at 39.1% (95% CI: 36.5–41.8, $P < 0.001$). Upon further examination of each CVH metric, we identified diverse patterns: individuals with primary or secondary education showed the highest prevalence in five out of the seven metrics, including one behavioral metric (ideal physical activity) and four metabolic metrics (ideal BMI, ideal blood pressure, ideal total cholesterol, and ideal blood glucose). This illustrated un inverted U-shape relationship between education and CVH metric prevalence. For example, the prevalence of ideal blood pressure was the highest among individuals with primary education at 34.4% (95% CI: 32.7–36.1), similar to those with secondary education (32.3%, 95% CI: 30.5–34.2, $P = 0.057$), while higher than those with no education (29.0%, 95% CI: 26.6–31.4, $P < 0.001$) or with tertiary education (28.6%, 95% CI: 26.2–31.0, $P < 0.001$). By contrast, for ideal fruit and vegetable intake, the prevalence increased incrementally with higher education levels, from 9.0% (95%CI: 7.3–10.6) among those with no education to 27.0% (95% CI: 24.1–29.9) among those with tertiary education. Conversely, ideal smoking status showed a monotone decrease with higher education levels, from 83.7% (95% CI: 81.8–85.6) among those with no education to 62.8% (95% CI: 59.7–65.8) among those with tertiary education. Additionally, the lowest prevalence in five out of the seven metrics appeared among individuals with tertiary education, including ideal physical activity, ideal BMI, ideal smoking, ideal blood pressure, and ideal total cholesterol.

We further displayed the prevalence of ideal CVHS and seven metrics by years of education in Fig. 2. The inverted U-shape association was observed between years of education and ideal CVHS. Similarly, four metabolic metrics (i.e., ideal BMI, ideal blood pressure, ideal total cholesterol, and ideal blood glucose) and one behavioral metric (ideal physical activity) presented nonlinear associations with years of education, consistent with the results in Fig. 1. The prevalence of ideal fruit and vegetable intake

Table 1 Characteristics of participants by education level

Characteristics	Overall (n = 81,327)	Education level: No education (n = 12,722)	Primary education (n = 32,181)	Secondary education (n = 24,263)	Tertiary education (n = 12,161)	P value[a]
Sex						
Male	33,594 (41.3)	3811 (30.0)	13,594 (42.2)	10,781 (44.4)	5408 (44.5)	< 0.001
Female	47,733 (58.7)	8911 (70.0)	18,587 (57.8)	13,482 (55.6)	6753 (55.5)	
Age, years						
18–29	21,043 (25.9)	1959 (15.4)	8204 (25.5)	8035 (33.1)	2845 (23.4)	< 0.001
30–44	30,259 (37.2)	4344 (34.1)	12,882 (40.0)	8623 (35.5)	4410 (36.3)	
45–59	21,911 (26.9)	4094 (32.2)	8536 (26.5)	5819 (24.0)	3462 (28.5)	
≥ 60	8114 (10.0)	2325 (18.3)	2559 (8.0)	1786 (7.4)	1444 (11.8)	
Marital status						
Never married	14,205 (17.5)	904 (7.1)	4890 (15.2)	5998 (24.7)	2413 (19.8)	< 0.001
Currently married	53,444 (65.7)	8966 (70.5)	21,829 (67.8)	14,749 (60.8)	7900 (65.0)	
Former married	11,343 (14.0)	2653 (20.9)	4371 (13.6)	2729 (11.3)	1590 (13.1)	
Missing	2335 (2.8)	199 (1.5)	1091 (3.4)	787 (3.2)	258 (2.1)	
Employment status						
Government employee	9980 (12.3)	120 (1.0)	1885 (5.9)	3591 (14.8)	4384 (36.1)	< 0.001
Non-government employee	6904 (8.5)	385 (3.0)	2270 (7.1)	2495 (10.3)	1754 (14.4)	
Self-employed	26,201 (32.2)	4966 (39.0)	13,949 (43.3)	5690 (23.4)	1596 (13.1)	
Non-paid	38,050 (46.8)	7228 (56.8)	14,012 (43.5)	12,403 (51.1)	4407 (36.2)	
Missing	192 (0.2)	23 (0.2)	65 (0.2)	84 (0.4)	20 (0.2)	
Alcohol consumption						
No	46,497 (57.2)	8821 (69.3)	18,916 (58.8)	13,663 (56.3)	5097 (41.9)	< 0.001
Yes	34,822 (42.8)	3900 (30.7)	13,262 (41.2)	10,599 (43.7)	7061 (58.1)	
Missing	8 (< 0.1)	1 (< 0.1)	3 (< 0.1)	1 (< 0.1)	3 (< 0.1)	

[a] Differences among groups were compared with chi-squared tests

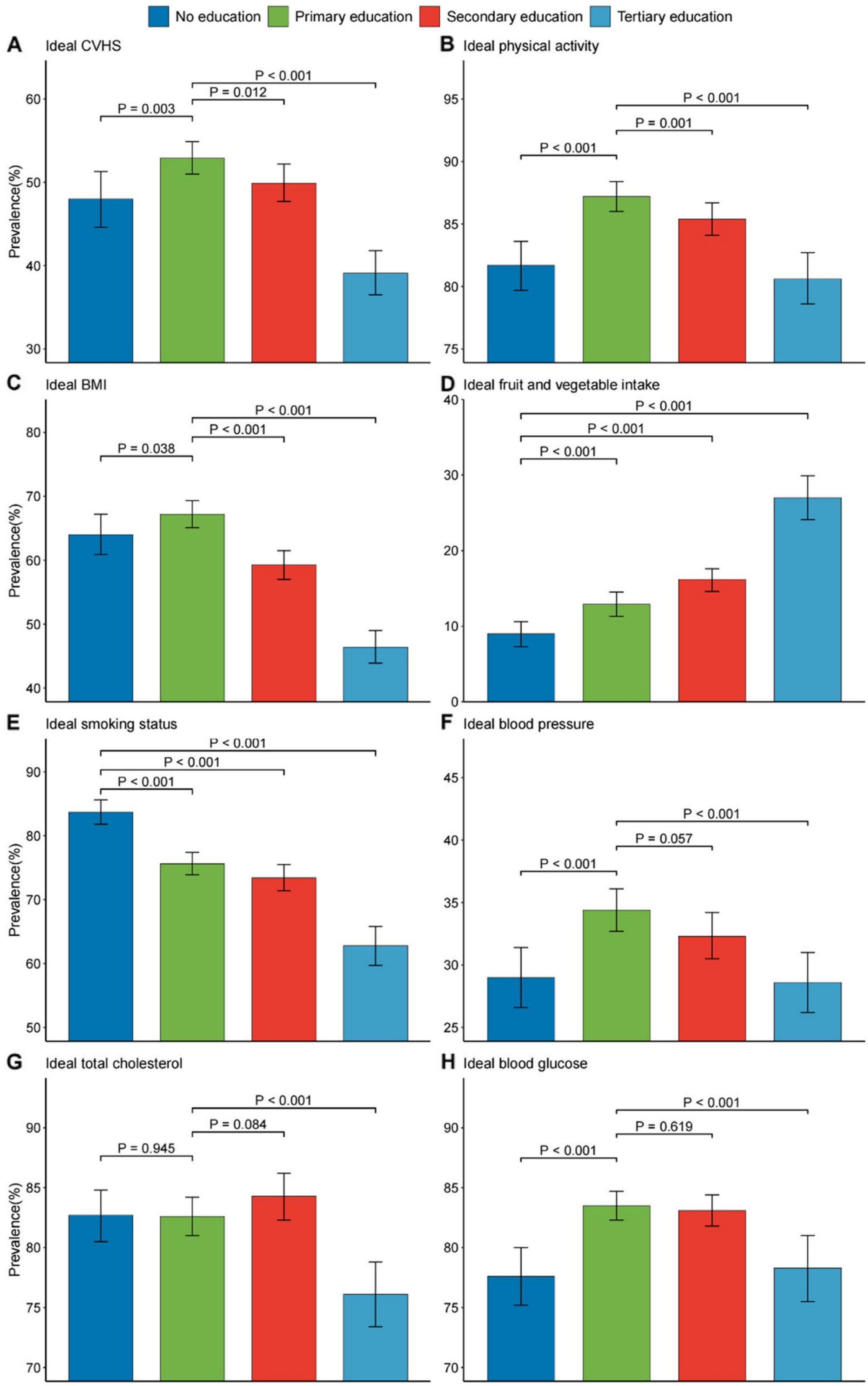
showed a monotone increase with years of education, while the prevalence of ideal smoking status decreased with more years of education.

Additional regression analyses to alleviate confounding were presented in Table 2. After adjusting for country-level fixed effects, HDI, age, and sex in Model 2, individuals with primary and secondary education were more likely to have ideal CVHS compared to those with tertiary education, with PRs of 1.09 (95% CI: 1.03–1.15) and 1.08 (95% CI: 1.02–1.14), respectively. Model 1 and Model 3 with further covariate adjustments showed consistent findings. We presented the regression results for each metric of CVH in Additional file 1: Table S5. The results were highly consistent with the findings above in Fig. 1 with one exception—those with higher education were more likely to reach ideal smoking status.

We reported stratified analyses by country income categories in Fig. 3 and Additional file 1: Table S6. Consistent with the previous findings, we observed the inverted U-shape relationship between education and the prevalence of ideal CVHS in low-income countries (LICs) and lower-middle-income countries (LMCs). However, an almost monotonic relationship was identified among upper-middle-income countries (UMCs). For example, in LICs and LMCs, individuals with primary or secondary education had the highest prevalence of ideal CVHS, at 68.8% (95% CI: 65.4–72.1) and 51.4% (95% CI: 48.3–54.5), respectively. In UMCs, the prevalence of ideal CVHS

(See figure on next page.)

Fig. 1 Weighted prevalence of ideal cardiovascular health score and seven metrics by education level. Data are presented as percentages (95% CI) unless otherwise stated. Prevalences and their 95% CIs are calculated taking into account the complex survey design and using population-based weights. Standard errors are clustered at the primary sampling unit level. *P* values in **A**, **B**, **C**, **F**, **G**, and **H** were calculated with "Primary education" as the reference group, whereas the *P* values in **D** and **E** were calculated with "No education" as the reference group. Abbreviations: CVHS, cardiovascular health score; BMI, body mass index



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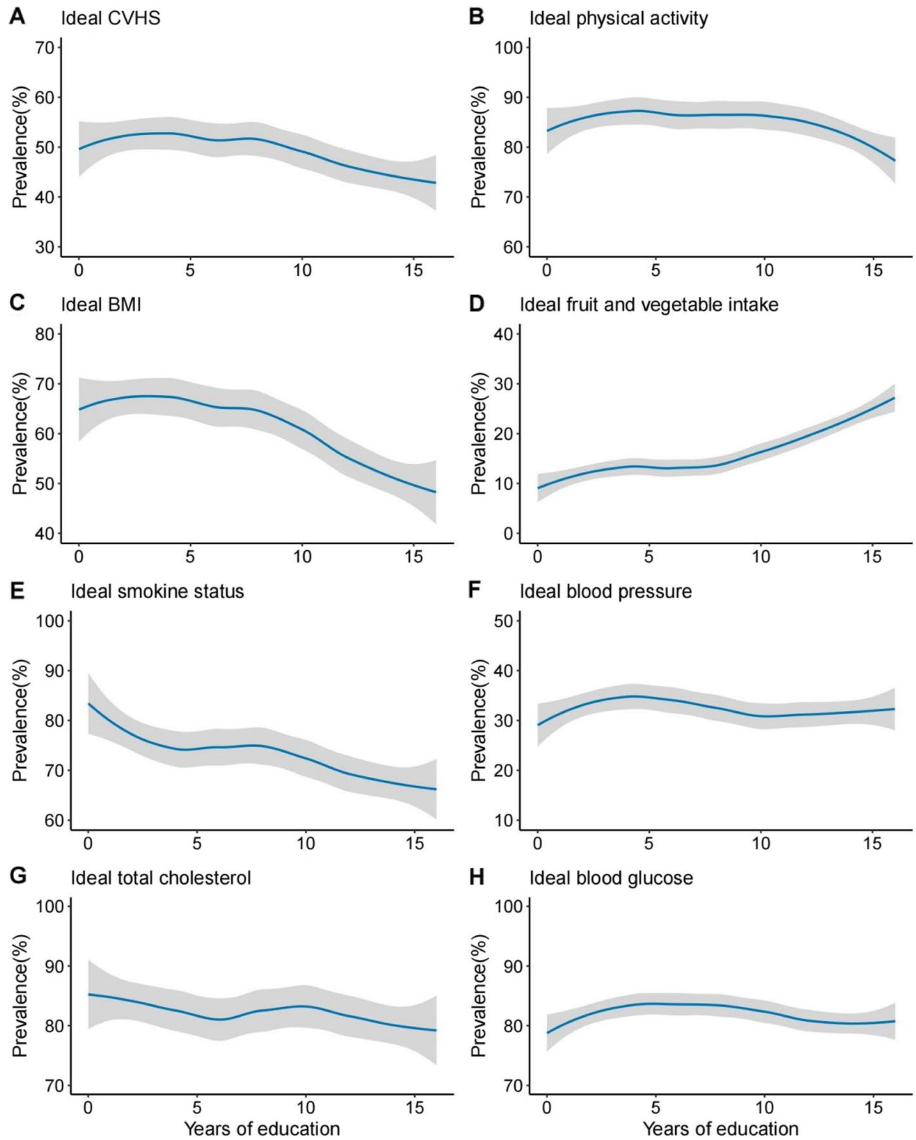

Fig. 2 Associations between years of education and ideal cardiovascular health score and seven metrics. Prevalences data are presented as percentages (95% CI) unless otherwise stated. Prevalences and their 95% CIs are calculated taking into account the complex survey design and using population-based weights. Standard errors are clustered at the primary sampling unit level. Abbreviations: CVHS, cardiovascular health score; BMI, body mass index

presented stepwise increase with education levels from 15.4% (95% CI: 12.1–18.7) among those with no education to 33.1% (95% CI: 30.0–36.1) among those with tertiary education. Stratified analysis by sex also showed a similar nonlinear relationship as above (Additional file 1: Fig. S2). Among different age groups, the nonlinear associations between education and ideal CVHS were only observed among those aged 18 to 29.

Country-level analysis was presented in Additional file 1: Table S7. Among the 36 countries, 22 had the highest prevalence of ideal CVHS among individuals with primary or secondary education. Specifically, seven countries reported the highest prevalence among those with primary education, including Azerbaijan, Eritrea, Ethiopia, Georgia, Myanmar, Rwanda, and Zambia; another 15 countries showed the highest prevalence among those with secondary education, such as Afghanistan, Benin, and Ecuador. Notably, eight out of ten LICs had the highest prevalence of ideal CVHS among those with primary or secondary education. After employing country-specific educational classifications, a non-linear relationship

Table 2 Association between education level and ideal cardiovascular health score (95% CI)

	Prevalence ratio (95% CI)		
	Model 1[a]	**Model 2[b]**	**Model 3[c]**
No education	0.88 (0.82–0.95)	1.05 (0.97–1.13)	1.05 (0.98–1.13)
Primary education	1.04 (0.99–1.11)	1.09 (1.03–1.15)	1.08 (1.02–1.15)
Secondary education	1.09 (1.03–1.16)	1.08 (1.02–1.14)	1.06 (1.00–1.12)
Tertiary education	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)

Abbreviations: CVHS cardiovascular health score, *CI* confidence interval

[a] Model 1: adjusted for country-fixed effects, and human development index

[b] Model 2: model 1 + adjusted for sex and age

[c] Model 3: model 2 + adjusted for marital status, employment status, and alcohol consumption

between education and ideal CVHS was also observed (Additional file 1: Table S8).

Five sensitivity analyses that were conducted to validate our main results can be found in Additional file 1: Table S9–13 and Additional file 1: Fig. S3. Dropping participants with missing covariate information resulted in consistent findings, with the highest PR of 1.08 (95% CI: 1.02–1.15) observed among individuals with primary education compared to those with tertiary education (Additional file 1: Table S9). Additionally, including household wealth quintile (Additional file 1: Table S10), or treating age as a continuous variable with restricted cubic splines (Additional file 1: Table S11) also yielded consistent results. Our sensitivity analysis, in which ideal BMI and ideal CVHS were redefined to take into account undernutrition in LMICs, yielded highly consistent results to the main analyses, i.e., those with primary education showed a higher likelihood to achieve ideal BMI and ideal CVHS. For instance, the highest prevalence of ideal CVHS occurs in those with primary education (47.6%, 95% CI: 45.9–49.4), significantly higher than other education levels (Additional file 1: Table S12 and Additional file 1: Fig. S3). Furthermore, the utilization of inverse probability weighting also reported the inverted U-shape relationship between education and ideal CVHS (Additional file 1: Table S13).

Discussion

Our study yields three novel findings. First, we found un inverted U-shape overall association between education and ideal CVHS among the 36 LMICs included in this study. Individuals with primary or secondary education showed a higher likelihood of reaching the ideal CVHS compared to those with other education levels. Second, the associations between education level and ideal CVH status varied across different CVH metrics. For all metabolic metrics (ideal BMI, ideal blood pressure, ideal total cholesterol, and ideal blood glucose) and one behavioral metric (ideal physical activity), the

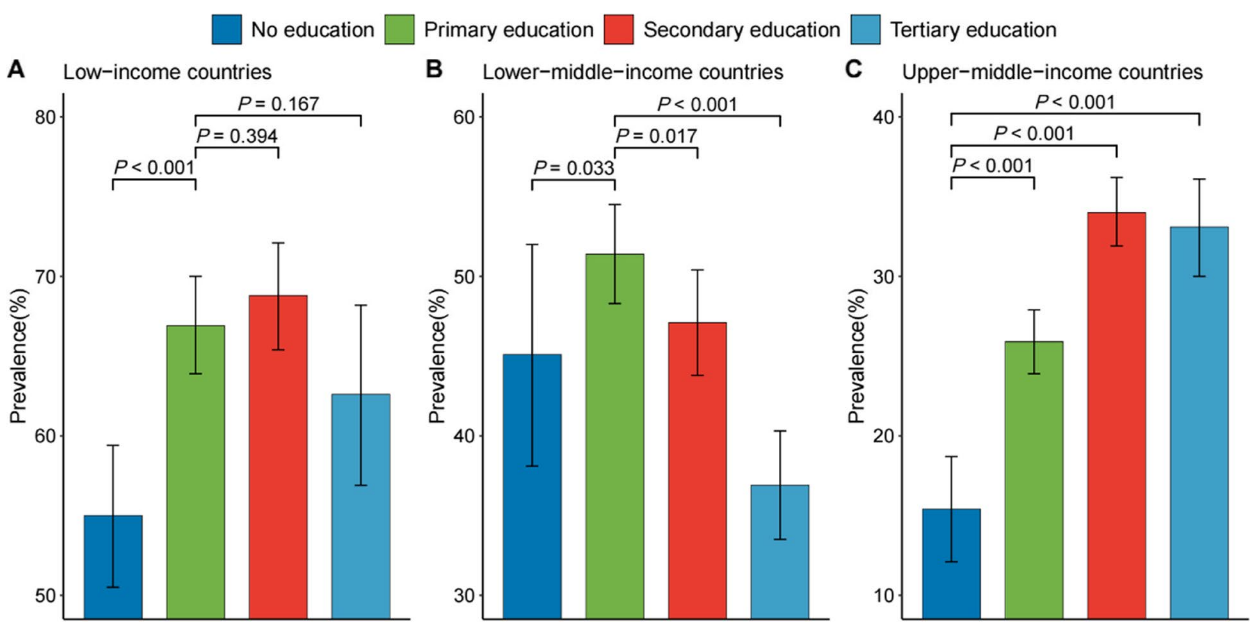

Fig. 3 Association between education level and ideal cardiovascular health score stratified by income categories. Prevalences data are presented as percentages (95% CI) unless otherwise stated. Prevalences and their 95% CIs are calculated taking into account the complex survey design and using population-based weights. Standard errors are clustered at the primary sampling unit level. *P* values in **A** and **B** were calculated with "Primary education" as the reference group, whereas the *P* values in **C** were calculated with "No education" as the reference group

associations also exhibited un inverted U-shape, with the highest prevalence observed among those with primary or secondary education. By contrast, the associations for ideal fruit and vegetable intake and ideal smoking status appeared to be monotonic. Third, the associations between education and ideal CVHS varied across the country's income categories. In LICs and LMCs, individuals with primary and secondary education displayed a higher prevalence of ideal CVHS than those with no education or tertiary education; while in UMCs, we observed a monotone increase in the prevalence of ideal CVHS as education level rose.

Our findings on the inverted U-shape association of education with CVHS and a majority of the CVH metrics provide strong evidence of the rapidly advancing epidemiologic transition in LMICs. Individuals with higher education often possess greater resources and awareness of the benefits of physical activity and the risks of an unhealthy diet. However, the transition from lean hunter-gatherer lifestyles to modern industrialized societies in LMICs has led to decreased physical activity and increased consumption of high-energy foods due to greater purchasing power [24]. This trend is especially evident among those with higher education, who are less likely to perform physically demanding jobs and are less reliant on walking for commuting or work-related tasks [24]. This results in lower energy expenditure and poorer dietary habits [13, 40], contributing to the rising rates of obesity and diabetes reflected in non-ideal BMI, cholesterol, and blood glucose levels [41, 42]. The complex interplay between diet and physical activity during this transition period further demonstrates that the high risk of CVD is no longer limited to socioeconomically advantaged groups in LMICs.

Our findings regarding the heterogeneous relationships between education and CVHS across countries' income classifications further support the theory of epidemiologic transition. UMCs and high-income countries (HICs) are at later stages of the transition, where individuals with higher socioeconomic status (SES) are more likely to possess health-related knowledge and adopt healthy behaviors [43]. By contrast, LICs and LMCs are still in the earlier stages of transition, where individuals with higher SES may be more prone to unhealthy lifestyles such as high-calorie diets and sedentary behavior. However, higher SES may also provide both direct and indirect protection against conditions closely linked with CVDs including obesity, diabetes, dyslipidemia, and hypertension [44]. Thus, both socially disadvantaged and advantaged groups in these countries can face substantial health challenges. Prior research has highlighted varied manifestations of CVDs and CVD risk factors across countries. In UMCs, similar to HICs, individuals with higher education were more likely to have ideal CVHS, as observed in countries like China and the Republic of Serbia [23]. Our findings on the inverted U-shape relationship between education and CVHS in LICs and LMCs are also supported by existing literature, including the documented nonlinear relationship of SES with angina, metabolic risk factors, and BMI in Ghana, Cambodia, and other sub-Saharan African countries [45–47]. Overall, our findings suggest that recognizing the stage of epidemiologic transition that different countries are in is crucial for developing targeted prevention and control measures. Therefore, to further promote CVH, especially fruit and vegetable intake and physical activity in countries across different income categories, economic incentives such as subsidies could be utilized to those with low education in UMCs [48]. In LICs and LMCs, multisectoral collaborations between governments, agricultural producers, and the food industry—such as government-backed cold-chain supply system—could be utilized to enhance the transport and storage of fruit and vegetables [21]. Additionally, investing in infrastructure, such as exercise facilities, could be provided to facilitate CVH for those with lower education levels.

Notably, ideal fruit and vegetable intake demonstrated a monotonic association with higher education. This finding is well supported by previous studies conducted in Europe [49, 50]. Evidence from LMICs has similarly identified a positive association between education and fruit and vegetable intake. Individuals with higher levels of education were more likely to meet the WHO recommendation of approximately five servings per day compared to those with no formal education. Specifically, the risk ratio was 1.22 (95% CI: 1.06–1.41) for individuals with primary education and 1.61 (95% CI: 1.24–2.09) for those with secondary education or higher [51]. In LMICs, substantial evidence indicated that low affordability is a significant barrier to fruit and vegetable consumption [52]. One study showed that the cost relative to income per household member of one serving of fruit can be 50 times higher in LICs than in HICs [52]. Individuals with higher educational attainment might be more likely to afford and have greater access to fresh fruits and vegetables with more purchasing channels [4, 30, 46, 53]. Furthermore, individuals with higher levels of education tend to better understand the importance of consuming sufficient fruits and vegetables [54].

Our findings are subject to several data limitations. First, the cross-sectional design of the STEPS data limits our ability to establish causal relationships, highlighting the necessity for longitudinal studies to more effectively examine these associations in future research. Second, the self-reported behavioral risk factors in STEPS data may introduce potential bias. However, related information such as tobacco use in the STEPS survey was collected based on WHO guidelines or widely-used criteria published in reputable journals. Professionally trained teams and standardized guidelines also ensured accurate data collection, processing, and validation [26]. Third, despite efforts to account for confounders, we could not fully address the influence of other factors that were unmeasured in STEPS. One example is health insurance which may influence both education and CVHS. Fourth, the criteria for ideal CVH metrics are constrained by the availability of more detailed measures in STEPS. For instance, our assessment of ideal diet status focused on fruit and vegetable intake. While this indicator is commonly used to assess diet status [23, 34], other important diet components, such as fiber-rich whole grains, fish, and sugar-sweetened beverages, were not available. Fifth, due to data limitations, we were unable to assess sleep health, which was added as a new metric in the AHA's Life Essential 8. Nevertheless, the remaining seven metrics were still widely recognized as important indicators for measuring CVH. Sixth, given the difficulty in accurately determining an individual's ethnicity as Asian, we provisionally categorized BMI based on the individual's country of residence. Seventh, individuals with comorbidities or other conditions may require different criteria; however, the STEPS database lacks the relevant data to address this variability. Future research should aim to incorporate more specific thresholds for such populations. Eighth, while this study rigorously applied inclusion and exclusion criteria based on key variables such as CVH, the exclusion of individuals with missing or implausible data may introduce selection bias. The small proportion of excluded samples mitigates but does not eliminate this concern. Finally, while our results contribute to understanding the general trends between education and CVH metrics, they should not be overgeneralized across all countries or income levels. Future research should focus on examining these country-specific and income group-specific variations to avoid heterogeneity, providing a more nuanced understanding of the mechanisms that shape CVH metrics.

Conclusions

Despite these limitations, our study is the first known multi-country study to fully explore the associations between education and each individual metric of CVH. In combination with the fact of non-ideal CVD control and rapid progress of epidemiologic transition in LMICs, the inverted U-shape associations between education and ideal CVHS, as well as several CVH metrics identified in our study calls for more specific and tailored policy recommendations. Future research should further delve into the intricacies of this relationship, particularly by identifying mechanisms that can more comprehensively explain the nonlinear associations.

Abbreviations

CVH	Cardiovascular health
LMIC	Low- and middle-income countries
CVHS	Cardiovascular health score
BMI	Body mass index
CVD	Cardiovascular disease
AHA	The American Heart Association
STEPS	STEPwise approach to NCD risk factor surveillance
ISCED	International Standard Classification of Education
CI	Confidence interval
PR	Prevalence ratio
LIC	Low-income countries
LMC	Lower-middle-income countries
UMC	Upper-middle-income countries

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12916-025-04032-y.

Additional file 1: Method S1. Details of data collection on main physical and biochemical factors. Table S1. Countries included in the analysis. Table S2. Comparison of characteristics between sample included and sample excluded due to missing or implausible values. Table S3. Weighted prevalence of ideal cardiovascular score and seven metrics. Table S4. Weighted prevalence of ideal cardiovascular score and seven metrics by education level. Table S5. Associations between education level and seven cardiovascular health metrics. Table S6. Association between education level and ideal cardiovascular health score stratified by income categories. Table S7. Weighted prevalence of ideal cardiovascular score by education level in 36 countries. Table S8. Weighted prevalence of ideal cardiovascular score by country-specific educational classifications in 36 countries. Table S9. Association between education level and ideal cardiovascular health score without using multiple imputation. Table S10. Association between education level and ideal cardiovascular health score without using multiple imputation, additionally adjusted for household wealth quintile. Table S11. Association between education level and ideal cardiovascular health score, with age being considered as a continuous variable using restricted cubic splines. Table S12. Associations between education level and ideal cardiovascular health score, and ideal BMI, with BMI being ideal if BMI < 25/23 kg/m^2 and BMI ≥ 18.5 kg/m^2. Table S13. Associations between education level and ideal cardiovascular health score, using inverse probability weighting. Figure S1. Flow chart showing exclusions and final sample size of the study population. Figure S2. Association between education level and ideal cardiovascular health score stratified by sex and age. Figure S3. Weighted prevalence of ideal cardiovascular health score and ideal BMI by education level, with BMI being ideal if BMI < 25/23 kg/m^2 and BMI ≥ 18.5 kg/m^2.

Acknowledgements

All authors extend the gratitude to the country-level survey teams and participants whose contributions made this research possible.

Authors' contributions

YZ and ZL designed the study; NM, SC, YK acquired the data; YZ analyzed the data, completed the tables and figures, and drafted the manuscript; YZ, GT and ZL are in charge of the interpretation of data; ZL and YQ verified and full reviewed the manuscript; LR, JA, AK, PF, MR, AM, RK, PK, JN, MZ, LZ, FC, CL, VS, and PG reviewed the work critically. All authors read and approved the final manuscript.

Funding

This research is funded by the Research Fund, Vanke School of Public Health, Tsinghua University.

Data availability

This research has been completed utilizing data from the STEPwise approach to surveillance (STEPS) surveys. Data can be acquired from https://www.who.int/teams/noncommunicable-diseases/surveillance/systems-tools/steps.

Declarations

Ethics approval and consent to participate

The STEPS survey adhered to stringent ethical standards, ensuring anonymity, confidentiality, and informed consent. We obtained authorization from STEPS to access and use the datasets. This study received approval from the Tsinghua Ethics Institutional Review Board (Project No. 20220005). Due to the use of secondary data, informed consent was waived by the Tsinghua Ethics Institutional Review Board.

Consent for publication

No applicable.

Competing interests

The authors declare no competing interests.

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Received: 29 October 2024 Accepted: 24 March 2025
Published online: 07 April 2025

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