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Mediation factors of the association between coronary heart disease and physical activity among rural residents: a cross-sectional study

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Abstract

There is evidence that physical and chemical factors and risky lifestyle behaviours are significantly correlated with elevated susceptibility to coronary heart disease (CHD). Nevertheless, the mediation factors of this relationship are little investigated. This article attempts to assess the mediating factors between CHD and physical activity (PA) in rural residents. We conducted a cross-sectional study of 9,004 permanent residents in rural regions of Xinxiang County, Henan Province. The correlation between CHD and PA was evaluated using a logistic regression model, as well as the association between CHD and its associated risk factors. The robustness of the outcomes was evaluated through sensitivity analysis. The mediating factors of the correlation between CHD and PA in rural residents were explored through mediation analysis. The results showed that CHD was associated with PA (0.72, 95%CI:0.56–0.95), and the levels of fasting insulin (FINS), total cholesterol (TC), and blood glucose (GLU) were associated with PA (-0.92, 95%CI: (-1.48, -0.37), 0.08, 95%CI: (0.01, 0.15), -0.17, 95%CI: (-0.28, -0.06)). The levels of FINS, TC and GLU had significant mediating effects on the association of PA with CHD (1.00, 95%CI: (-0.0028, 0.0000), 1.00, 95%CI: (-0.0016, 0.0000), 1.00, 95%CI: (-0.0014, 0.0000)). In rural populations, PA is associated with CHD, possibly mediated by FINS, TC and GLU, rather than relying solely on the direct effects of PA.

Keywords Physical activity, Coronary heart disease, Mediator, Potential influencing factors

Background

With rapid socio-economic development, and changes in environment and lifestyle, the prevalence rate of chronic non—communicable diseases (NCDs), such as cancer, diabetes mellitus, dyslipidaemia and obesity has increased globally. Particularly in low- and middle-income countries, the prevalence of NCDs is on the rise, leading to a continuous growth in the burden of these diseases [1]. In China, coronary heart disease (CHD) is a common NCDs. Currently, there are about 330 million people with cardiovascular diseases in China, of whom about 11 million residents benefit from effective interventions. According to the 2019 Cardiovascular Health and Disease Report, CHD mortality rates in rural areas have surpassed and are higher than in urban areas owing to the scarcity of medical service resources and inadequacies in healthcare systems. Therefore, the potential influencing factors that contribute to the current epidemic of

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CHD in rural China should be explored as a matter of urgency. Therefore, it is essential to enhance the prevention level of CHD in order to alleviate the disease burden in rural areas.

In recent years, more and more studies have shown that lifestyle changes, including physical activity (PA), smoking cessation, and dietary modification, play important roles in the prevention and treatment of CHD [2–4]. Although comprehensive intervention strategies (e.g., smoking cessation, dietary control) have been widely shown to be effective in CHD, the independent contribution of a single factor (e.g., PA) in the multidimensional intervention model and its mechanism of action remain significantly controversial, especially in rural areas with poor medical resources, and there is still lack of evidence on how PA affects CHD. This study focused on the independent effect of PA on CHD, and explored the mediating factors of the association between CHD and PA in rural residents, aiming to clarify the core value of its prevention and treatment and provide evidence support for the development of exercise intervention programs. The evidence shows that lifestyle intervention might reduce the CVDs risk, especially in the risk population [5]. According to CDC (Centers for Disease Control and Prevention) surveillance data, approximately 25% of cardiovascular disease mortality could potentially be averted annually through lifestyle modifications and improved control of risk factors [6]. Studies show that population engaged in healthy lifestyles including PA determines 92% lower risk of CHD. PA refers to significantly increasing energy consumption due to skeletal muscle contraction, including traffic PA, leisure activities, occupational PA and domestic PA [7]. Studies have confirmed that increased PA is associated with lower mortality in CHD patients, especially in sedentary patients and patients at higher risk of death [8]. Exercise can increase our body's perception of energy. The results of meta-analysis show that interventions, including supervised PA, have a higher effect on diastolic and systolic blood pressure in supervised PA compared with unsupervised PA [9]. Nevertheless, the impact on alterable risk factors of CHD has not been sufficiently investigated. Since the existence of diversity, there may have been different ways of CHD intervention for people in different regions. Our work aimed to evaluate the influencing factors and intervention means of CHD, especially for rural populations in China. We speculate that PA may reduce the prevalence of CHD by affecting its relevant risk factors.

This study was based on cross-sectional survey data from a prospective cohort study of common NCDs across the countryside regions of Xinxiang County in Henan Province. The study was conducted from April to June 2017 using standardized survey methods and strict quality control measures [10]. In this study, we focused on characterizing the prevalence and potential influencing elements of CHD across countryside region of Xinxiang. In addition, the association between CHD, its potential influencing factors, and PA was analysed, and the mediating role of potential influencing factors of CHD in CHD in rural residents was explored. The findings of this research offer evidence to assist in the prevention and control of CHD in resource-constrained settings.

Materials and methods

Research population

A total of 9004 participants aged 18–69 were selected from rural area in Xinxiang from the rural cohort established in Henan Province, China. The study participants included 687 individuals suffering from CHD, with mean age 59.82 ± 7.84, and 8317 patients without CHD, with mean age 50.26 ± 12.18 years. The residents with serious physical, mental, or medical conditions were excluded. This study excluded the following participants: (1) Severe cardiovascular disease (such as unstable angina, end-stage heart failure); (2) End-stage organ failure (renal disease requiring dialysis, Child–Pugh grade C cirrhosis); (3) Active malignancy or metastatic cancer; (4) uncontrolled psychiatric illness (such as acute phase of schizophrenia, major depressive disorder with suicidal tendencies); (5) Severe immunodeficiency (such as AIDS, long-term use of immunosuppressants); (6) Other health conditions that may interfere with the results of the study or threaten the safety of participants (such as recent major surgery, third trimester). Informed consent has been obtained from all participants for the study. The research protocol has also undergone rigorous review and approval by XYLL-2016176 of Xinxiang Medical University's Ethics Committee for Human Study, in strict compliance with the ethical standards set by the Declaration of Helsinki.

Research plan and evaluation criteria

Questionnaire survey

Data were collected through face-to-face interviews, and each participant was required to complete a detailed questionnaire and physical examination. The standard questionnaire survey comprised the following: information on sociodemographic factors, including name, gender, age and education level, among others; lifestyle characteristics, including dietary intake, PA status, smoking and drinking status (smoking history: at least one cigarette per day and over 6 months, drinking history: at least 12 times a year); and personal history of diseases, including CHD, cancer, diabetes, hypertension, dyslipidaemia, stroke among others). This questionnaire

is available in the published literature. Table 1 presents detailed information on the questionnaire survey.

During the same period, the investigators checked the questionnaire for completeness and logical errors. If there were any questions, participants were called and their answers corrected. A resurvey with repeat measures was performed within 4–6 weeks after the baseline investigation, and a random subsample of participants (2.5%) was checked for data quality issues to ensure reliability.

Physical examination

Once having fasted overnight for a minimum of 8 h, blood, urine, and some fecal samples (10%) were gathered, and anthropometric measurements and clinical examinations were conducted by a trained medical team [11]. Anthropometric measurements included height, weight, body fat rate (BFR), basal metabolic rate (BMR), blood pressure in resting state, heart rate, and electrocardiogram. Participants were measured in height with their shoes removed. Body weight, BFR, and BMR were tested when the participants wore light clothing and their shoes were off. Blood pressure on the right arm and heart rate were examined in resting state with electronic sphygmomanometers (HEM-7071, OMRON, Shanghai, China). To ensure factuality of the measurement result, the average of three results was used for statistical analyses. Subjects were asked to rest for at least 5 min and to avoid tea, alcohol, smoking, or excessive PA within 30 min prior to measurement. Fasting blood glucose (GLU), hemoglobin A1c (HbA1c), total cholesterol (TC), triglycerides (TG), high-density lipoprotein (HDL) and low-density lipoprotein (LDL) levels were tested using an automatic biochemical analyzer (Siemens ADVIA 2400, Germany).

Criteria for disease determination

Patients were defined as having CHD following the receipt of a clinical diagnosis certificate issued by medical units. Other medical histories, such as hypertension, hyperlipidaemia and diabetes were reported by the patients according to hospital diagnoses.

Table 1 Characterization of the research population*

Variable	participants without CHD ($n=8317$)	participants with CHD ($n=687$)	*P* value
Age (years)	50.26 ± 12.18	59.82 ± 7.84	< 0.001
Male, n (%)	3372(40.54)	258(37.55)	0.125
Education, n (%)			< 0.001
Uneducation	720(8.66)	130(18.92)	
Primary school education	1601(19.25)	222(32.31)	
Junior high school education	3439(41.35)	224(32.61)	
Senior high school education	1908(22.94)	102(14.85)	
Undergraduate, graduate	643(7.73)	9(1.31)	
Master or doctor	6(0.07)	0(0.00)	
Smoking, n (%)	2300(27.65)	190(27.66)	0.999
Drinking, n (%)	2149(25.84)	152(22.13)	0.032
Physical activity, n (%)	7565(90.96)	608(88.50)	0.032
SBP (mmHg)	128.11 ± 19.22	134.56 ± 18.59	< 0.001
DBP (mmHg)	81.09 ± 11.50	82.46 ± 10.35	0.002
LDL (mmol/L)	2.85(2.37,3.41)	2.94(2.43,3.50)	0.125
HDL (mmol/L)	1.24(1.05,1.45)	1.18(1.02,1.38)	< 0.001
TC (mmol/L)	5.10(4.50,5.20)	5.20(4.50,5.90)	0.027
TG (mmol/L)	5.19 ± 1.01	5.29 ± 1.11	0.009
GLU (mmol/L)	5.40(5.00,5.90)	5.60(5.20,6.30)	< 0.001
HbA1c (mmol/L)	5.68 ± 0.95	6.05 ± 0.94	< 0.001
FINS (mmol/L)	6.80(4.80,10.00)	7.70(5.50,11.50)	< 0.001
Weight (kg)	66.86 ± 11.64	68.68 ± 11.38	< 0.001
BFR (%)	29.91 ± 6.62	33.05 ± 6.14	< 0.001
BMR (kcal)	1430.23 ± 224.97	1437.78 ± 229.56	0.399

*Data are presented as mean ± SD, M (P_{25}, P_{75}) or n (%). Wilcoxon rank-sum test for continuous variables and χ^2 test for categorical variables. *SBP* Systolic blood pressure, *DBP* Diastolic blood pressure, *LDL* Low-density lipoprotein, *HDL* High-density lipoprotein, *TC* Total cholesterol, *TG* Triglycerides, *GLU* Blood glucose, *HbA1c* Hemoglobin A1c, *FINS* Fasting insulin, *BFR* Body fat rate; BMR, Basal metabolic rate

Criteria for physical determination

The International Physical Activity Questionnaire—Short (IPAQ-S) was applied in this study to assess the PA of the patients [12, 13]. We have made localized adjustments to the questionnaire, considering the characteristics of rural labor, and added examples of agricultural activities such as "hoeing" and "digging" to the questionnaire. PA is divided into physical and non-physical activities according to the IPAQ-S criteria: (1) physical activities includes three levels: low, medium and high intensity; (2) Non-physical activities refers to sedentary behavior. High-intensity activity requires one of the following: (1) vigorous exercise ≥ 3 days per week with a cumulative metabolic equivalent ≥ 1,500 MET-min/week; (2) Mixed exercise (vigorous/moderate-intensity exercise or walking) ≥ 5 days per week with a cumulative metabolic equivalent ≥ 3,000 MET-min/week. Moderate-intensity activity requires one of the following: (1) vigorous exercise for ≥ 20 min per day, ≥ 3 days weekly; (2) Moderate intensity exercise ≥ 30 min per day, ≥ 5 days weekly; (3) Walk ≥ 30 min per day, 5 days a week, ≥ 5 days weekly; (4) Cumulative metabolic equivalent ≥ 600 MET-min/week. Low-intensity PA is defined as activity levels not meeting the above criteria for moderate-to-high intensity.

Statistical analyses

In the statistical analysis, we used the SPSS 25.0 software to check whether the data obey normality with the Kolmogorov–Smirnov test. Data were presented as mean ± SD (normal distribution), median (P_{25}, P_{75}) (non-normal distribution), or n (%) (categorical variables). SPSS 25.0 software was used to analyse the differences in social demographic factors, lifestyle characteristics, physical examination, and clinical examination between subjects with CHD and participants without CHD by Student's t test or non-parametric test. Under the control of key confounding factors, a multivariate logistic regression model was used to analyze the association between CHD, potential influencing factors, and PA, and to test the mediating effect of potential influencing factors on the association between PA and CHD. When the *P* value was less than 0.05, it was considered statistically significant. To assess the robustness of the association between PA and CHD, sensitivity analyses were performed and E-values were calculated. Sensitivity analyses were performed for the unadjusted model, the base model (adjusted for age and gender), and the E-value was calculated. Subsequently, the variables of high-fat diet and high-salt diet were encompassed by the basic model, and the adjusted diet model was constructed and sensitivity analysis was performed. Models were stratified according to high-fat or low-fat, high-salt or low-salt diets and fitted separately to explore heterogeneity of effects. In addition, this study also performed an interaction test between PA and dietary factors to more comprehensively evaluate the combined impact of these factors on cardiovascular disease. Average Causal Mediation Effect (ACME) is a statistic that measures the magnitude of the mediating role of a mediator variable in the association between the independent variable and the dependent variable. It indicates the mean variation in the dependent variable that is brought about by the mediator variable when there is a one—unit rise in the independent variable. ACME evaluated the mediating role of potential influencing factors of CHD between CHD and PA in this study. The potential influencing factor of CHD was thought to be a mediating factor between PA and CHD when the *P* value of ACME was less than 0.05. The Average Direct Effect (ADE) refers to how the independent variable directly impacts the dependent variable while taking into account the presence of mediating variables.

Figure 1 illustrates the relationships among PA (predictor X), potential influencing factor (medium M), and CHD (dependent variable Y). Using standard regression analysis methods, we made the following estimates: (1) TE(the total effect)of PA(X) on CHD(Y), with no adjustment for the underlying influencing factor of CHD (M)-pathway c; (2) the direct impact of PA (X) on CHD (Y), and the potential influencing factors of CHD (M) remain unchanged—pathway c'; (3) the relationship between PA(X) and the proposed potential influencing factor (M)-pathway a of mediated CHD; (4) The association between the potential influencing factor (M) of CHD and the occurrence of CHD (Y) remained unchanged as the independent variable PA (X-pathway b). The regression model used to estimate all pathways can be described using three statistical equations [12].

$$Y = B_0 + cX + confounders \tag{1}$$

$$M = B_o + aX + confounders \tag{2}$$

$$Y = B_o + c\prime X + bM + confounders \tag{3}$$

Our study used the product coefficient method to evaluate the significance of the mediating effect. Equation (1) indicates the TE of X on Y, without controlling for the mediator variable, where Y is the outcome. X is the Independent Variable. B_0 is the intercept term. "c" is the TE of X on Y (the effect when the mediator M is not controlled). "Confounders" represent all other confounders that can affect Y. Equation (2) reflects the mediating effect, where M is the mediator variable. The effect of X on M is represented by "a", which is the path of the independent variable through the first

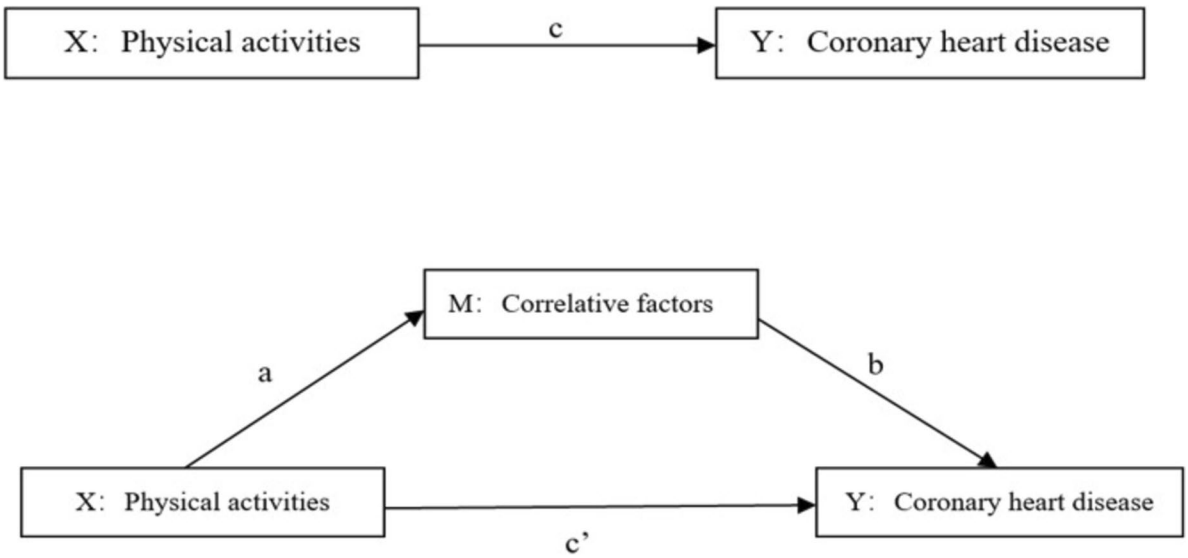

Fig. 1 Conceptual model of the associations between physical activities, potential influencing factors and coronary heart disease. *Path c stands for the overall effect; path c′ denotes the direct impact, and paths a and b indicate indirect effects

half of the mediating variable. This equation describes how the independent variable X affects the mediator M. Equation (3) reflects the direct effect, where " c' " is the direct effect of X on Y (after controlling for the mediating variable M). " b " is the effect of M on Y, which is the second half of the mediation path.

Thus, the TE c is the sum of the direct effect c' and the indirect effect $a \times b$. The formula relationship is: $c = c' + (a \times b)$. If the value of $a \times b$ is not zero, then it indicates a significant mediation effect through M in the X–Y association.

Ethical considerations

The research team supervised the study design, data collection, and analysis to ensure compliance with the principles of beneficence, nonmaleficence, autonomy, and justice. Residents from rural area in Langgongmiao and Qiliying in Xinxiang, Henan were invited to volunteer for this study. Prior to conducting the survey, we elaborated on the extent of the research to them, and all participants signed the informed consent form. All participants did not take any substances or drugs during the study. The study was approved by the ethical standards set by Xinxiang Medical University's Ethics Committee for Human Study (Approval Code: XYLL-2016176; Approval Date: June 9, 2016). All studies adhered to the principles set forth in the Declaration of Helsinki.

Results

Demographic characteristics

Table 1 displays the socio-demographic, lifestyle, and physical examination data from 9,004 rural residents in Xinxiang, Henan Province. Compared to non-CHD individuals, patients with CHD were older, had lower education levels, higher alcohol consumption rates, lower PA levels, and significantly greater body weight ($P < 0.05$). PA levels were significantly lower in individuals with CHD compared to those without ($P < 0.05$). Significant differences in SBP (systolic blood pressure), DBP (diastolic blood pressure), HDL, TC, TG, GLU, HbA1c, FINS and BFR were found between the CHD and non-CHD groups ($P < 0.05$). CHD was related to age, education level, lifestyle, weight and BFR ($P < 0.05$). SBP, DBP, HDL, TC, TG, GLU, HbA1c and FINS were potential contributing factors to CHD.

Association between PA and the potential influencing factors

Logistic regression analysis was performed to examine the association between PA and potential influencing factors of CHD (Table 2). In Model 1, significant associations were observed between FINS, SBP, HDL, TC, GLU, HbA1c, and PA without adjusting for confounders ($P < 0.05$). Model 2 extended Model 1, the age and gender of rural residents were further adjusted, and the results showed that FINS, TC, GLU in Model 2 were significantly correlated with PA ($P < 0.05$).

Table 2 The association between PA and the potential influencing factors

Variable	Model1		Model2	
	β(95%)	*P* value	β(95%)	*P* value
FINS	-0.84 (-1.39, -0.29)	0.033	-0.92 (-1.48, -0.37)	0.001
SBP	-0.19 (-1.56, 1.19)	0.003	0.29 (-0.97, 1.54)	0.660
DBP	-0.42 (-1.24, 0.39)	0.310	0.59 (-0.20, 1.38)	0.140
LDL	0.02 (-0.04, 0.08)	0.490	0.02 (-0.04, 0.08)	0.520
HDL	0.04 (0.01, 0.06)	0.001	0.00 (-0.02, 0.02)	0.920
TG	-0.04 (-0.14, 0.06)	0.410	0.01 (-0.09, 0.11)	0.820
TC	0.14 (0.07, 0.21)	< 0.001	0.08 (0.01, 0.15)	0.020
GLU	-0.17 (-0.28, -0.06)	0.002	-0.17 (-0.28, -0.06)	0.003
HbA1c,	0.08 (0.01, 0.14)	0.030	0.04 (-0.03, 0.11)	0.230

Model 1: unadjusted

Model 2: On the basis of Model 1, adjusting age and gender. *FINS* Fasting insulin, *SBP* Systolic blood pressure, *DBP* Diastolic blood pressure, *LDL* Low-density lipoprotein cholesterol, *HDL* High-density lipoprotein cholesterol, *TG* Triglycerides, *TC* Total cholesterol, *GLU* Blood glucose, *HbA1c* Hemoglobin A1c

Mediation analysis

Through mediation analysis, the potential influencing factors of CHD and their roles in the correlation between CHD and PA were explored. As shown in Table 3, in Model 1, PA was the independent variable, SBP, DBP, LDL, HDL, TG, TC, GLU, HbA1c, and FINS levels were the mediator variables, CHD was the dependent variable (unadjusted for confounders). The ACME was significant for FINS, HDL, TC, GLU, and HbA1c ($P < 0.05$). In Model 2 (adjusted for age and gender), only FINS, TC, and GLU showed significant ACME ($P < 0.05$). These results suggest that in rural Chinese populations, PA may reduce CHD risk partially by influencing FINS, TC, and GLU levels.

Association between PA and CHD and sensitivity analysis

As detailed in Table 4, PA was associated with the prevalence of CHD by multivariate logistic regression analysis. PA was a significant influencing factor for CHD in the crude model, corresponding to the odds ratio (OR) and 95% CI in Model 1 ($P < 0.05$). PA was also an influencing factor for CHD, corresponding to the OR and 95% CI in Model 2 ($P < 0.05$), after adjustment for age and gender. After further adjustment for dietary variables, PA was still an influencing factor for CHD, corresponding to the OR and 95% CI in Model 3 ($P < 0.05$). These results indicate that PA is an influencing factor of CHD. Sensitivity analysis further supported these findings, with E-values of 1.064 (Model 1), 1.167 (Model 2), and 1.165 (Model 3), indicating robustness against unmeasured confounding.

Table 5 shows the association of PA with the risk of CHD in different dietary subgroups. The results showed

Table 3 Mediation analysis of potential influencing factors between PA and CHD

Variable	Model1		Model2	
	OR(95%)	*P* value	OR(95%)	*P* value
FINS				
ACME	1.00 (-0.0023, 0.0000)	0.010	1.00 (-0.0028, 0.0000)	0.010
ADE	0.96 (-0.0404, 0.0000)	0.040	0.96 (-0.0473, 0.0000)	0.030
SBP				
ACME	1.00 (-0.0019, 0.0000)	0.830	1.00 (-0.0003, 0.0000)	0.990
ADE	0.96 (-0.0422, 0.0000)	0.020	0.95 (-0.0468, 0.0000)	0.010
DBP				
ACME	1.00 (-0.0012, 0.0000)	0.310	1.00 (-0.0004, 0.0000)	0.880
ADE	0.96 (-0.0414, 0.0000)	0.030	0.95 (-0.0459, 0.0000)	0.010
LDL				
ACME	1.00 (-0.0003, 0.0000)	0.580	1.00 (-0.0009, 0.0000)	0.550
ADE	0.96 (-0.0004, 0.0000)	0.020	0.95 (-0.0470, 0.0000)	0.020
HDL				
ACME	1.00 (-0.0035, 0.0000)	< 0.001	1.00 (-0.0014, 0.0000)	0.970
ADE	0.96 (-0.0430, 0.0000)	0.060	0.95 (-0.0467, 0.0000)	0.010
TG				
ACME	1.00 (-0.0009, 0.0000)	0.370	1.00 (-0.0006, 0.0000)	0.840
ADE	0.96 (-0.0430, 0.0000)	0.040	0.95 (-0.0465, 0.0000)	0.010
TC				
ACME	1.00 (0.0002, 0.0000)	0.004	1.00 (-0.0016, 0.0000)	0.040
ADE	0.95 (-0.0456, 0.0000)	0.030	0.95 (-0.0455, 0.0000)	0.030
GLU				
ACME	1.00 (-0.0028, 0.0000)	0.002	1.00 (-0.0014, 0.0000)	0.010
ADE	0.96 (-0.0407, 0.0000)	0.040	0.95 (-0.0468, 0.0000)	0.030
HbA1c				
ACME	1.00 (0.0002, 0.0000)	0.040	1.00 (-0.0002, 0.0000)	0.240
ADE	1.00 (0.0002, 0.0000)	0.030	0.95 (-0.0452, 0.0000)	0.030

ACME average causal mediating effect, *ADE* average direct effect, *FINS* Fasting insulin, *SBP* Systolic blood pressure, *DBP* Diastolic blood pressure, *LDL* Low-density lipoprotein cholesterol, *HDL* High-density lipoprotein cholesterol, *TG* Triglycerides, *TC* Total cholesterol, *GLU* Blood glucose, *HbA1c* Hemoglobin A1c

Model 1: unadjusted

Model 2: On the basis of Model 1, adjusting age and gender

Table 4 Relationship between physical activity and coronary heart disease

Variable	Model 1	Model 2	Model 3
OR(95%)	0.77(0.60,0.99)	0.72(0.56,0.95)	0.73(0.56,0.95)
P value	0.033	0.016	0.016
E value	1.064	1.167	1.165

Model 1: unadjusted

Model 2: Based on Model 1, adjusting age and gender

Model 3: Based on Model 2, adjusting dietary variables (high-fat and high-salt)

Table 5 Association analysis of physical activity with coronary heart disease risk in different dietary subgroups

Diet model subgroups	β(95%)	*P* value	E value
High-fat group	0.31 (0.18,0.57)	< 0.001	3.16
low-fat group	0.87 (0.65,1.18)	0.365	1.2
high-salt group	0.70 (0.43,1.21)	0.183	2.14
low-salt group	0.73 (0.54,1.00)	0.043	2.05

Table 6 Analysis of the interaction between physical activity and dietary factors

Interactions	β(95%)	*P* value
Physical activity × High-fat diet	-0.81(0.24,0.85)	0.012
Physical activity × High-salt diet	1.10(0.62,2.04)	0.731

that the protective effect of PA was strongest in the high-fat diet group (β = 0.31, $P < 0.001$). There existed no notable connection between PA and the risk of CHD within the low—fat diet (β = 0.87, $P > 0.05$). The effect of PA was not significant in the high-salt diet (β = 0.70, $P > 0.05$). In people with low-salt diets, PA exerted a certain positive influence on the reduction of CHD risk, but this effect was relatively weak (β = 0.73, $P < 0.05$).

Table 6 shows an analysis of the interaction between PA and dietary factors. The protective effect of PA on CHD was significantly enhanced in people with a high-fat diet (β = -0.81, $P < 0.05$). In contrast, PA's association with CHD did not vary significantly by high-salt diet intake ($P > 0.05$).

Discussion

Cardiovascular disease (CVD) persists as the primary global cause of mortality. And cardiovascular events such as CHD and stroke are associated with high mortality [13, 14]. CHD is caused by fatty deposits on the inner walls of the coronary arteries, leading to plaque formation and narrowing of the arteries. Eventually, it reduces blood flow to the heart and leads to myocardial insufficiency or even a complete loss of blood supply to the heart. Documented studies have suggested that physical and chemical factors, risky lifestyle behaviours (e.g., smoking), high-calorie diets, and sedentary behaviours may increase the risk of CHD [15]. The PA intervention has demonstrated greater efficacy in reducing TC, LDL, TG, BMI, waist circumference and blood pressure. A previous study reported that PA interventions have significant beneficial implications for long-term control of CHD risk factors, which is why PA has an effect on several CVD risk factors [16]. Our findings align with this evidence. The results showed that blood pressure, HDL, LDL, TG, TC, GLU, HbA1c and FINS levels of rural dwellers in Xinxiang, Henan Province were associated with CHD. Importantly, risk factors associated with CHD mediated the association between PA and CHD in our analysis.

As a potential influencing factor of CHD, hypertension increases the tension of the blood vessel wall by increasing the perfusion pressure of the coronary artery and promoting intimal damage and lipid deposition; ultimately, this process causes atherosclerosis, leading to reduced blood flow into the heart and CHD [17]. Hyperglycaemia can thicken the arterial intima. It can bring about dysfunction in vascular endothelium and trigger alterations within the coagulation system [18]. HbA1c is a combination of haemoglobin and glucose in the blood, which can reflect hyperglycemia. Elevated HbA1c promotes dyslipidaemia, vascular endothelial dysfunction, inflammatory responses, and platelet aggregation, ultimately leading to thrombosis [19]. In addition, insulin resistance, as the basis of multiple risk factors for CHD, may be associated with endothelial cell repair disorders, lipid metabolism disorders, and inflammatory factor release [20].

Accumulating evidence suggests that as the intensity of PA increases, so does the importance of improving cardiorespiratory fitness [21]. A recent meta-analysis investigated the vascularization response of patients with heart failure to PA of varying intensities, and concluded that the degree of cardiorespiratory fitness improvement increases with the intensity of PA training [22]. In addition, offsetting risky lifestyle behaviours in prevention programs can reduce chronic disease prevalence and cardiovascular mortality by up to 75 percent [23]. A cohort study encompassing more than 1 million older adults indicated that a higher rate of moderate PA was associated with an 11 percent decrease in the likelihood of developing CVD, but an increase in sedentary behavior was associated with a 27 percent increase in CVD [24]. However, important questions remain, including what the underlying cause of PA's improved cardiopulmonary function is, and what role the above risk factors play between PA and CHD?

Previous studies have shown that age and gender are dependent risk factors for CHD [23]. Therefore, when exploring the relationship between the physical and chemical indicators related to CHD and the prevalence of CHD, these factors will be matched or adjusted. This study found associations between CHD and PA, as well as between PA and potential contributing factors to CHD. The logistic regression analysis of the potential influencing factors of CHD and PA showed that there were significant differences between FINS, HDL, TC, GLU, HbA1c and PA without adjusting for confounders ($P<0.05$). With PA as the independent variable, the potential influencing factors of CHD as the mediating variable, and CHD as the dependent variable, this correlation persists after further adjusting for age and gender confounding factors. There were statistically significant differences between FINS, TC, GLU and CHD ($P<0.05$), and the hazard ratios of other indicators also changed.

CHD is caused by the accumulation of fatty plaques in the coronary arteries, which narrow the lumen of the arteries and make it difficult for blood to pass through them. Even in old age, PA training can potentially restore the endothelial function of coronary microvessels [25, 26]. In fact, PA interventions have been shown to improve retinal microvascular diameter in healthy school-age children [27, 28], as well as in adults, regardless of their cardiovascular (CV) risk status [29–33]. In addition, long-term PA favours arterial dilation and may improve the structure and function of large arteries. There are several underlying mechanisms by which PA benefits have been observed. First, PA has a lipid-lowering effect, and there is a notable connection between lipoprotein levels and the diameter of veins, as high LDL levels are associated with narrower coronary arteries [34]. Second, PA increases nitric oxide (NO) secretion; NO, which is responsible for the relaxation of smooth muscle cells and vasodilation, serves as a crucial regulator of microvascular function. The improvement of retinal microvasculature is largely mediated by the high bioavailability of NO. PA is beneficial to blood flow, which causes higher shear stress, then stimulates the release of NO. Vascular dysfunction is attributed to an imbalance between NO bioavailability and ROS (reactive oxidative species) [35], while lower ROS levels are correlated with a reduction in the production of superoxide anion (O2-), resulting in increased NO bioavailability [36]. Third, PA can improve autonomic function and neurovascular stress response among CHD patients, and it also affects microvascular function [37]. Consistent with these results, FINS, TC and GLU exhibited statistically significant mediating effects in the PA-CHD association in this cross-sectional sample. This finding suggests that PA can influence the development of CHD by influencing FINS, TC and GLU. This finding not only echoes previous research, but also deepens our understanding of the causes of disease from new perspectives, while also providing a precise focus for the development of targeted interventions. Currently, the global burden of cardiovascular disease is increasing. These findings have important practical implications for guiding public health policymaking, optimizing the allocation of medical resources, and promoting health promotion activities at the community [38, 39].

Sensitivity analysis was performed to assess the potential impact of unmeasured confounders on study outcomes. The E-value was 1.064 without adjusting for confounders, and increased to 1.167 after adjusting for age and gender, suggesting that the robustness of the results for unmeasured confounders was enhanced after adjusting for known confounders. After further adjustment of the high-fat and high-salt variables, the E-value decreased slightly to 1.165, indicating that the high-fat and high-salt diets had a certain impact on the robustness of the Model, but the impact was small. Overall, the E-value is still high, suggesting that the results are robust even in the presence of unmeasured confounders. Sensitivity analyses further confirmed the benefits of PA in controlling CHD [40]. The protective effect of PA is significantly enhanced in people on high-fat diets, possibly because high-fat diets increase the risk of cardiovascular disease, so PA exerts a stronger protective effect in people on high-fat diets. The protective effect of PA was weak and not significant in people on low-fat diets. This may be because the low-fat diet itself has cardiovascular health benefits, reducing the relative protective effect of PA. The high—salt diet showed no marked protective effect on PA, which implies that it may play a little moderating role in the context of PA and CHD. The low-salt diet marginally enhanced PA's cardioprotective effect ($P=0.043$). The interaction between PA and diet showed that the protective function of PA was stronger in the high-fat diet population. This finding underscores the importance of promoting PA among people on high-fat diets. The high- salt diet didn't have a significant protective effect on PA, indicating that a high salt diet may not be an important regulatory factor for PA and CHD. Despite this, the high-salt diet, in itself, constitutes a crucial risk factor for cardiovascular disease, so it is important to reduce salt intake.

In rural populations, this cross-sectional study found that the association between PA and CHD may be mediated by FINS, TC and GLU, but that SBP, DBP, HDL and TG did not show significant mediating effects. Although clinical evidence supports that PA improves cardiovascular outcomes by regulating blood pressure and lipids, cross-sectional design may differ in outcomes due to the inability to capture dynamic

causal timing. In addition, the living environment, genetic background, and potential confounding factors of rural populations may also influence the mediation pathway. In the future, it is necessary to combine long-term follow-up or intervention experiments to further verify the dynamic effect of PA on metabolic indexes in different populations.

There were several limitations of this study that should be recognized. First, although our mediation analysis provided insights into potential pathways, cross-sectional studies cannot establish causal relationships, so our findings should be seen as correlates rather than causal. Second, despite the relatively large overall sample size ($n = 9004$), the number of participants diagnosed with CHD was limited, reducing the statistical power to detect subtle associations. In addition, the sample of this study was from the rural area of Xinxiang. As this study was limited to rural residents, urban residents were poorly represented, which limited the generalizability of the findings to a wider population. Third, our exclusion criteria focused on individuals without severe heart disease, while patients with severe heart disease and mobility impairments were excluded, which could lead to an underestimation of disease severity and its interaction with PA. Longitudinal studies that include different populations and clinically confirmed endpoints are needed to validate these findings. Fourth, in this cross-sectional sample, FINS, TC and GLU showed statistically significant mediating effects in the PA-CHD association. Although this mediation model was mechanistically plausible, longitudinal studies are required to confirm these findings. This is a limitation of our study, which we will consider for further validation in subsequent studies. Finally, while the robustness of the results was validated by sensitivity analysis, we recognized that there may be unmeasured or uncontrolled confounders that could have a significant impact on the results. For example, factors such as socioeconomic status and drug use have not been included in the analysis and may influence the association between PA and CHD. In addition, the completeness of the dietary data in this study reached 99.3%, indicating that most of the data were complete. However, 0.7% of the data were still missing, which may have an impact on the robustness of the findings. Nonetheless, given the low proportion of missing data, its impact on the overall study conclusions may be limited. Therefore, we will further explore and control these potential confounders in future studies, and minimize missing data to ensure the stability of the results, so as to provide an important reliable basis for public health policies and interventions.

Conclusions

This study showed the occurrence of CHD was closely related to lifestyle, and the benefit of PA in the control of CHD was further confirmed by sensitivity analysis. This study innovatively revealed the mediating role of FINS, TC and GLU in the relationship between PA and CHD in rural residents, enriched the theoretical framework of the pathogenesis of CHD, and provided a basis for the formulation of targeted interventions. These findings were of great significance for guiding public health policy formulation and optimizing the allocation of medical resources, especially for improving the lifestyle of rural residents and reducing the incidence and mortality of CHD. Future research should further explore other potential mediating and confounding factors to contribute more solutions to the global prevention and control of cardiovascular diseases.

Supplementary Information

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Below is the link to the electronic supplementary material.Supplementary Material 1.

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Authors' contributions

Data Curation, X.G.C., M.J.J. and T.Y.J.; Funding Acquisition, W.W.D.; Investigation, X.G.C., Z.Y.Z. and W.H.; Methodology,W.Y.B.; Project Administration, W.W.D.; Writing – Original Draft, X.G.C. and M.J.J.; Writing – Review & Editing, W.W.D.; Article submission, F.T..

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Data availability

The research data supporting this study are subject to restricted access under institutional confidentiality protocols; however, datasets can be obtained by contacting the corresponding author through the formal request process.

Declarations

Ethics approval and consent to participate

The study is in line with the ethical norms of human research. All methods of the study were carried out in accordance with the Declaration of Helsinki and relevant regulations. The study was approved by Xinxiang Medical University's Ethics Committee for Human Study (No: XYLL-2016176). Informed consent was obtained from all participants before inclusion in the study.

Consent for publication

Not applicable. This manuscript does not contain any individual person's data (e.g., images, videos, or clinical details) that require consent for publication.

Competing interests

The authors declare no competing interests.

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References

1. Mendis S, Davis S, Norrving B. Organizational update: the world health organization global status report on noncommunicable diseases 2014; one more landmark step in the combat against stroke and vascular disease. Stroke. 2015;46(5):e121-122.
2. Reiner Ž. The importance of smoking cessation in patients with coronary heart disease. Int J Cardiol. 2018;258:26–7.
3. Rigotti NA, McDermott MM. Smoking Cessation and Cardiovascular Disease: It's Never Too Early or Too Late for Action. J Am Coll Cardiol. 2019;74(4):508–11.
4. Satija A, Bhupathiraju SN, Spiegelman D, et al. Healthful and Unhealthful Plant-Based Diets and the Risk of Coronary Heart Disease in US. Adults J Am Coll Cardiol. 2017;70(4):411–22.
5. Sisti LG, Dajko M, Campanella P, et al. The effect of multifactorial lifestyle interventions on cardiovascular risk factors: a systematic review and meta-analysis of trials conducted in the general population and high risk groups. Prev Med. 2018;109:82–97.
6. Centers for Disease C, Prevention. Vital signs: avoidable deaths from heart disease, stroke, and hypertensive disease - United States, 2001–2010. MMWR Morb Mortal Wkly Rep. 2013;62(35):721–727.
7. Stewart RAH, Held C, Hadziosmanovic N, et al. Physical Activity and Mortality in Patients With Stable Coronary Heart Disease. J Am Coll Cardiol. 2017;70(14):1689–700.
8. Legrand FD, Albinet C, Canivet A, et al. Brief aerobic exercise immediately enhances visual attentional control and perceptual speed. Testing the mediating role of feelings of energy. Acta Psychol (Amst). 2018;191:25–31.
9. Chow CK, Redfern J, Hillis GS, et al. Effect of Lifestyle-Focused Text Messaging on Risk Factor Modification in Patients With Coronary Heart Disease: A Randomized Clinical Trial. JAMA. 2015;314(12):1255–63.
10. Liu X, Mao Z, Li Y, et al. Cohort Profile: The Henan Rural Cohort: a prospective study of chronic non-communicable diseases. Int J Epidemiol. 2019;48(6):1756–1756j.
11. Li H, Liu B, Song J, et al. Characteristics of Gut Microbiota in Patients with Hypertension and/or Hyperlipidemia: A Cross-Sectional Study on Rural Residents in Xinxiang County, Henan Province. Microorganisms. 2019;7(10):399.
12. Korsiak J, Tranmer J, Day A, et al. Sleep duration as a mediator between an alternating day and night shift work schedule and metabolic syndrome among female hospital employees. Occup Environ Med. 2018;75(2):132–8.
13. Despres JP. Physical Activity, Sedentary Behaviours, and Cardiovascular Health: When Will Cardiorespiratory Fitness Become a Vital Sign? Can J Cardiol. 2016;32(4):505–13.
14. Rubattu S, Volpe M. Natriuretic Peptides in the Cardiovascular System: Multifaceted Roles in Physiology, Pathology and Therapeutics. Int J Mol Sci. 2019;20(16):3991.
15. Schuler G, Hambrecht R, Schlierf G, et al. Regular physical exercise and low-fat diet Effects on progression of coronary artery disease. Circulation. 1992;86(1):1–11.
16. Clark AM, Haykowsky M, Kryworuchko J, et al. A meta-analysis of randomized control trials of home-based secondary prevention programs for coronary artery disease. Eur J Cardiovasc Prev Rehabil. 2010;17(3):261–70.
17. Dziedzic M, Jozefczuk E, Guzik T J, et al. Interplay between plasma glycine and branched-chain amino acids contributes to the development of hypertension and coronary heart disease. Hypertension. 2024;81(6):1320–31.
18. Baird TA, Parsons MW, Barber PA, et al. The influence of diabetes mellitus and hyperglycaemia on stroke incidence and outcome. J Clin Neurosci. 2002;9(6):618–26.
19. Khan HA, Sobki SH, Khan SA. Association between glycaemic control and serum lipids profile in type 2 diabetic patients: HbA1c predicts dyslipidaemia. Clin Exp Med. 2007;7(1):24–9.
20. Festa A, D'Agostino R Jr, Howard G, et al. Chronic subclinical inflammation as part of the insulin resistance syndrome: the Insulin Resistance Atherosclerosis Study (IRAS). Circulation. 2000;102(1):42–7.
21. Streese L, Guerini C, Buhlmayer L, et al. Physical activity and exercise improve retinal microvascular health as a biomarker of cardiovascular risk: A systematic review. Atherosclerosis. 2020;315:33–42.
22. Ismail H, McFarlane JR, Nojoumian AH, et al. Clinical outcomes and cardiovascular responses to different exercise training intensities in patients with heart failure: a systematic review and meta-analysis. JACC Heart Fail. 2013;1(6):514–22.
23. Nishida C, Uauy R, Kumanyika S, et al. The joint WHO/FAO expert consultation on diet, nutrition and the prevention of chronic diseases: process, product and policy implications. Public Health Nutr. 2004;7(1A):245–50.
24. Kim K, Choi S, Hwang SE, et al. Changes in exercise frequency and cardiovascular outcomes in older adults. Eur Heart J. 2020;41(15):1490–9.
25. Hotta K, Chen B, Behnke BJ, et al. Exercise training reverses age-induced diastolic dysfunction and restores coronary microvascular function. J Physiol. 2017;595(12):3703–19.
26. Gunthner R, Hanssen H, Hauser C, et al. Impaired retinal vessel dilation predicts mortality in end-stage renal disease. Circ Res. 2019:1796–807.
27. Siegrist M, Hanssen H, Lammel C, et al. Effects of a cluster-randomized school-based prevention program on physical activity and microvascular function (JuvenTUM 3). Atherosclerosis. 2018;278:73–81.
28. Ludyga S, Kochli S, Puhse U, et al. Effects of a school-based physical activity program on retinal microcirculation and cognitive function in adolescents. J Sci Med Sport. 2019;22(6):672–6.
29. Hanssen H, Nickel T, Drexel V, et al. Exercise-induced alterations of retinal vessel diameters and cardiovascular risk reduction in obesity. Atherosclerosis. 2011;216(2):433–9.
30. Streese L, Khan AW, Deiseroth A, et al. High-intensity interval training modulates retinal microvascular phenotype and DNA methylation of p66Shc gene: a randomized controlled trial (EXAMIN AGE). Eur Heart J. 2020;41(15):1514–9.
31. Hanssen H, Minghetti A, Magon S, et al. Effects of different endurance exercise modalities on migraine days and cerebrovascular health in episodic migraineurs: A randomized controlled trial. Scand J Med Sci Sports. 2018;28(3):1103–12.
32. Hanssen H, Minghetti A, Faude O, et al. Effects of different endurance exercise modalities on retinal vessel diameters in unipolar depression. Microvasc Res. 2018;120:111–6.
33. Deiseroth A, Streese L, Kochli S, et al. Exercise and Arterial Stiffness in the Elderly: A Combined Cross-Sectional and Randomized Controlled Trial (EXAMIN AGE). Front Physiol. 2019;10:1119.
34. Tikellis G, Anuradha S, Klein R, et al. Association between physical activity and retinal microvascular signs: the Atherosclerosis Risk in Communities (ARIC) Study. Microcirculation. 2010;17(5):381–93.
35. Paneni F, Costantino S, Cosentino F. Molecular pathways of arterial aging. Clin Sci (Lond). 2015;128(2):69–79.
36. Francia P, delli Gatti C, Bachschmid M, et al. Deletion of p66shc gene protects against age-related endothelial dysfunction. Circulation. 2004;110(18):2889–2895.
37. Badrov MB, Wood KN, Lalande S, et al. Effects of 6 Months of Exercise-Based Cardiac Rehabilitation on Autonomic Function and Neuro-Cardiovascular Stress Reactivity in Coronary Artery Disease Patients. J Am Heart Assoc. 2019;8(17):e012257.
38. Chen Y, You Y, Wang Y, et al. Global Insights Into Rural Health Workers' Job Satisfaction: A Scientometric Perspective. Front Public Health. 2022;10:895659.
39. Chen Y, You Y, He J, et al. Comment on: Predictive value of pretreatment circulating inflammatory response markers in the neoadjuvant treatment of breast cancer: meta-analysis. Br J Surg. 2024;111(7):znae187.
40. Chen Y, You Y, Wei M, et al. Exploration of physical activity, sedentary behavior and insulin level among short sleepers. Front Endocrinol (Lausanne). 2024;15:1371682.

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