Original Article

Predictive Ability of Hypertriglyceridemic Waist, Hypertriglyceridemic Waist-to-Height Ratio, and Waist-to-Hip Ratio for Cardiometabolic Risk Factors Clustering Screening among Chinese Children and Adolescents*

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Abstract

Objective Hypertriglyceridemic waist (HW), hypertriglyceridemic waist-to-height ratio (HWHtR), and waist-to-hip ratio (WHR) have been shown to be indicators of cardiometabolic risk factors. However, it is not clear which indicator is more suitable for children and adolescents. We aimed to investigate the relationship between HW, HWHtR, WHR, and cardiovascular risk factors clustering to determine the best screening tools for cardiometabolic risk in children and adolescents.

Methods This was a national cross-sectional study. Anthropometric and biochemical variables were assessed in approximately 70,000 participants aged 6–18 years from seven provinces in China. Demographics, physical activity, dietary intake, and family history of chronic diseases were obtained through questionnaires. ANOVA, χ^2 and logistic regression analysis was conducted.

Results A significant sex difference was observed for HWHtR and WHR, but not for HW phenotype. The risk of cardiometabolic health risk factor clustering with HW phenotype or the HWHtR phenotype was significantly higher than that with the non-HW or non-HWHtR phenotypes among children and adolescents (HW: *OR* = 12.22, 95% *CI*: 9.54-15.67; HWHtR: *OR* = 9.70, 95% *CI*: 6.93-13.58). Compared with the HW and HWHtR phenotypes, the association between risk of cardiometabolic health risk factors (CHRF) clustering and high WHR was much weaker and not significant (WHR: *OR* = 1.14, 95% *CI*: 0.97-1.34).

Conclusion Compared with HWHtR and WHR, the HW phenotype is a more convenient indicator with

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higher applicability to screen children and adolescents for cardiovascular risk factors.

Key words: Hypertriglyceridemic waist; Waist-to-hip ratio; Children and adolescents; China; Hypertriglyceridemic waist-to-height ratio; Cardiovascular risk factors

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INTRODUCTION

Cardiovascular disease (CVD) is one of the leading causes of mortality worldwide[1,2], especially in China, where prevalent cases of cardiovascular diseases reached nearly 94 million in 2016[2], and accounts for more than 40% of all deaths in the country[1]. In the last few decades, the prevalence of cardiometabolic risk factors among Chinese children and adolescents has increased significantly, posing a threat to the health of children and adolescents in China[3,4]. In addition, cardiometabolic risk factors may be more significantly related to visceral adiposity compared with overall adiposity[5].

Some indicators which consider body fat distribution, such as waist-to-height ratio (WHtR), waist circumference (WC), and waist-to-hip ratio (WHR), have been shown to be associated with increased cardiovascular morbidity and mortality[6,7]. A cohort study in China found that the WC of elderly people aged over 65 years showed a significant increasing trend[8]. However, these measures of WC can only identify subcutaneous abdominal fat[9]. Some studies have demonstrated that visceral fat is more strongly associated with CVDs as well as metabolic risk factors than subcutaneous abdominal fat[10,11]. Compared with those without excess visceral fat, patients with excess visceral adiposity face significantly greater risks of metabolic abnormalities, coronary artery disease, and type 2 diabetes[12-14]. However, due to radiation exposure and high cost, measurements of visceral fat, such as Electronic Computed Tomography Instrument (CT) or Magnetic Resonance Imaging (MRI), are not widely available tools for health screening[9]. However, a previous study showed that triglyceride is significantly correlated with visceral fat, suggesting that it could be a good predictor of cardiovascular disease[15].

Several studies have shown that the hypertriglyceridemic waist (HW) phenotype is a cost-effective tool to identity visceral fat for people of all ages, and is associated with an elevated risk of coronary heart disease in youth[16-18]. However, compared with adults, the WC cutoffs are age- and sex-specific for children, and are less available or challenging to use non-professionally[19]. Therefore, a cross-sectional study of Han adolescents indicated that the hypertriglyceridemic waist-to-height ratio (HWHtR) phenotype could be used as a marker to identify the lipid profile of adolescent atherosclerosis[19]. However, it is not known whether the HWHtR phenotype can be used as an alternative to the HW phenotype for children in China. Previous studies on the associations between the WHR phenotype and cardiovascular risk factors clustering are limited, especially in children and adolescents. In addition, a previous study in adults indicated that WHR has a weaker association with cardiovascular risk factors than HW and HWHtR[19]. However, it is not clear whether WHR is a better marker than others among children and adolescents.

Therefore, the purpose of this study was to investigate the relationship between HW, HWHtR, and WHR and cardiovascular risk factors, as well as their potential or predictive ability as screening tools for cardiometabolic risk factor clustering in children and adolescents.

MATERIALS AND METHODS

Study Population

The study was a cross-sectional study which was embedded in the baseline survey of a national multicentered cluster randomized controlled trial (Trial registration date: January 22, 2015; Registration number: NCT02343588) involving about 70,000 Chinese participants aged 6–18 years from seven provinces (including Shanghai, Liaoning, Tianjin, Guangdong, Hunan, Chongqing, and Ningxia)[20]. The trial was approved by the Ethics Committee of Peking University (No. IRB0000105213034). With consent obtained from students, their parents, and the principals of their educational institutions, participants completed the questionnaires, physical examinations, and biochemical assessments. The details of the trial are available in the previously published protocol[21].

Participants who did not have complete baseline data and who were over the age of 18 years were excluded from this analysis. Finally, 62,168 children aged 6–17 years were selected for analysis.

Anthropometric Measurements and Covariates

Anthropometric parameters included weight, height, hip circumference (HC), WC, and body mass index (calculated using the formula of weight divided by square of height, kg/m^2). Weight was measured to the nearest 0.1 kg on a calibrated level type weight scale (model RGT-140, China). Height was measured to an accuracy of 1 mm with Portable stadiometer (model TZG, China). Each participant was measured without shoes and in light clothing. HC and WC were measured using steel tape. HC was defined as the maximum extension of the hip, and WC was defined as the horizontal line between the upper border of the iliac crest and the lowest rib. WHtR was calculated by dividing WC by height, whereas WHR was calculated by dividing WC by HC. Blood pressure (BP) was measured using a mercury sphygmomanometer, (model XJ1ID, China) and a TZ-1 stethophone. Diastolic blood pressure (DBP) and systolic blood pressure (SBP) were recorded twice on the right arm. Potential covariates were investigated by questionnaires, including a children questionnaire and parent questionnaire. Age, sex, area (rural or urban), and family income (< 5,000 CNY, or ≥ 5,000 CNY) were included in the present study as covariates.

Biomedical Assessments

Biochemical variables included Triglycerides (TG), fasting plasma glucose (FPG), total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C). Venous blood samples were taken and collected after a 12-h overnight fast. All biochemical analyses was performed at a biomedical analysis laboratory.

Definitions

WC cut-off values ≥ 90th percentile for age and sex for children and adolescents were classified as high WC[22]. HC was defined as the dimension at the level of the maximum extension of the buttocks. WHR was calculated as WC (cm) divided by HC (cm)[19]. WHtR was calculated as WC (cm) divided by height (cm)[19]. According the National Cholesterol Education Program's (NCEP) Pediatric Panel Report, elevated TG was defined as ≥ 1.24 mmol/L[23]. High SBP and DBP were classified as ≥ 90th percentile for age, sex according to published reference values[24]. Hypercholesterolemia was defined as TC ≥ 200 mg/dL[23]. Low HDL-C was defined as ≤ 1.03 mmol/L and high LDL-C as ≥ 130 mg/dL[25]. The HWHtR phenotype was defined as serum TG concentrations ≥ 1.24 mmol/L and WHtR ≥ 0.50[16]. The HW phenotype was defined as serum TG concentrations ≥ 1.24 mmol/L and WC ≥ 90th percentile for age and sex[23,26]. The WHR phenotype was defined as WHR threshold for age and sex according to lambda-mu-sigma (LMS) curve[27]. Cardiometabolic health risk factor clustering was defined as having at least two of the following cardiometabolic health risk factors: elevated TG, low HDL, elevated LDL, hypercholesterolemia, elevated BP, and impaired FPG[28,29].

Statistical Analysis

We used SPSS version 26.0 for all statistical analyses, considering $P < 0.05$ as statistically significant. Comparisons were conducted based on sex using the ANOVA. Data are described as means ± standard deviation (SD). Chi-square analysis based on sex and category of the phenotype was conducted for categorical variables. Multiple logistic regression models were conducted for modeling relationships among HW, HWHtR, and WHR, and elevated TG, low HDL, elevated LDL, hypercholesterolemia, elevated BP, and impaired FPG. Logistic regression was also used to determine the risk (*OR*, 95% *CI*) of cardiometabolic health risk factor clustering. Participants without the HW and HWHtR phenotypes were considered as the reference groups. Two multivariable logistic regression models with different covariates were fitted for the analysis. Model 1 was adjusted for sex, age, and BMI. In addition to adjusting for the covariates in Model 1, Model 2 was adjusted for area and family income. The stratified analyses were performed by sex (boy and girl) and age (6–9, 10–12, 13–15, and 16–17 years)[30].

RESULTS

Of the 62,168 study participants, 17.5% individuals fulfilled the diagnosis for the cardiometabolic risk factors clustering (18.1% boys and 16.9% girls), and 8.3% were defined as having the HW phenotype, with 8.2% in boys and 8.5% in girls. A total of 6.6% of the participants were classified as having the HWHtR phenotype (8.0% in boys and 5.2% in girls), 34.3% of the participants had high WHR (32.8% in boys and 40.0% in girls). For different cardiometabolic risk factors, 25.7% had

elevated BP, 0.3% had impaired FPG, 12.6% had low HDL, 3.0% had elevated LDL, 26.8% had elevated TG, and 5.4% had hypercholesterolemia. Boys had significantly higher SBP, DBP, and FPG than girls ($P < 0.05$). Girls had significantly higher TG, LDL, and TC than boys ($P < 0.05$) (Table 1 and Supplementary Table S1, available in www.besjournal.com).

Comparisons were conducted between the participants with and without the HW, HWHtR, and WHR phenotypes. As the results in Supplementary Tables S2–S4 (available in www.besjournal.com) showed, the participants with the HW, HWHtR or WHR phenotypes had significantly higher levels of LDL, TG, TC, and BP, as well as higher cardiometabolic health risk. Moreover, the participants had lower HDL levels than those without these phenotypes. Additionally, the difference of the level of FPG between the participants with and without those phenotypes was insignificant.

Multivariate adjusted *OR*s (95% *CI*s) for cardiometabolic health risk factors among the HW, HWHtR, and WHR phenotypes are presented in Table 2. With adjustment of age and sex, and BMI, the risk of cardiometabolic health risk factors in the HW or HWHtR phenotype was significantly higher than those without the phenotype among children (HW: *OR* = 10.79, 95% *CI*: 9.28–12.55; HWHtR: *OR* = 9.21, 95% *CI*: 7.45–11.39). The risks of low HDL, elevated LDL, elevated TC, and high BP were also significantly higher for children with these phenotypes compared with those for children without the HW, HWHtR or WHR phenotype. After adjusting for age, sex, BMI, area, and family income by multivariate logistic regression, the risk of cardiometabolic health risk factors clustering in the HW phenotype was 11.22-fold higher than that in the non-HW group (*OR* = 12.22, 95% *CI*: 9.54–15.67). The risk of cardiometabolic health risk factors clustering in the HWHtR phenotype was also higher that than in the non-HWHtR group (HW: *OR* = 9.70, 95% *CI*: 6.93–13.58). Those with the HW phenotype were more likely to have low HDL, elevated LDL, elevated TC, and high BP compared with non-HW group. Additionally, except for LDL and TC, there was no significant difference between the HWHtR and HW phenotypes in the *OR* of risk factors for cardiometabolic risk factors clustering after

Table 1. General characteristics of the study population by sex

Variables	Total		Boy (*n* = 32,064)		Girl (*n* = 30,104)		*P*
	N	$\bar{x} \pm s$	*n*	$\bar{x} \pm s$	*n*	$\bar{x} \pm s$	
Age (years)	62,168	10.80 ± 3.30	32,064	10.72 ± 3.26	30,104	10.94 ± 3.34	< 0.001
BMI (kg/m^2)	62,168	18.55 ± 3.75	32,064	18.84 ± 3.92	30,104	18.24 ± 3.54	< 0.001
WC (cm)	61,802	64.75 ± 10.79	31,858	65.85 ± 11.50	29,944	63.59 ± 9.86	< 0.001
Hipline (cm)	61,815	77.18 ± 12.00	31,882	77.07 ± 12.07	29,933	77.30 ± 11.92	0.018
CHRF clustering, *n* (%)							
< 2	13,195	82.5	6,675	81.9	6,520	83.1	0.056
≥ 2	2,800	17.5	1,472	18.1	1,328	16.9	
HW, *n* (%)							
0	13,736	91.7	7,050	91.8	6,686	91.5	0.479
1	1,249	8.3	628	8.2	621	8.5	
HWHtR, *n* (%)							
0	9,079	93.4	4,587	92.0	4,492	94.8	< 0.001
1	644	6.6	397	8.0	247	5.2	
WHR, *n* (%)							
0	40,480	65.7	21,373	67.2	19,107	60.0	< 0.001
1	21,153	34.3	10,410	32.8	10,743	40.0	

Note. BMI, body mass index; WC, waist circumference; HW, hypertriglyceridemic waist; HWHtR, hypertriglyceridemic waist-to-height ratio; WHR, waist-to-hip ratio; CHRF clustering, cardiometabolic health risk factors clustering.

adjustment of the covariates. The risk of elevation of LDL with the HWHtR phenotype was significantly higher than that with the HW phenotype (HW: *OR* = 2.96, 95% *CI*: 1.84–4.75; HWHtR: *OR* = 6.87, 95% *CI*: 3.58–13.19). The OR(95%CI) for risk of elevated TC is 3.89 (95%CI: 2.65-5.73) and 4.94 (95%CI: 2.88-8.47) for HW and HWHtR phenotype, respectively. Compared with children with the HW or HWHtR phenotype, the risk of cardiometabolic risk factors clustering in the WHR phenotype was much lower and insignificant.

The results of multivariate logistic regression analysis of cardiometabolic health risk factors of the HW, HWHtR, and WHR phenotypes by sex and age stratified according to model 2 are shown in Supplementary Tables S5–S6 (available in www.besjournal.com) and Figures 1–2. The results after stratification by sex and age were similar to those without stratification. The WHR phenotype had a significantly lower and more insignificant risk of cardiometabolic risk factor aggregation than children with the HW or HWHtR phenotypes.

DISCUSSION

In this cross-sectional study of 62,168 participants, the HW, HWHtR, and WHR phenotypes were used as a marker for cardiometabolic risk factors and their clustering. We found that the HW phenotype was associated with a significantly increased risk of cardiometabolic risk factors clustering among children and adolescents. The increased risk of cardiometabolic risk factors clustering also exists in children and adolescents with the HWHtR phenotype compared with children and adolescents without an HWHtR phenotype. However, compared with the WHR phenotype, the HW and HWHtR phenotypes were superior as screening indicators for cardiometabolic health risk factor clustering.

When body fat capacity exceeds the normal load, the storage capacity of subcutaneous fat will significantly decrease and release excess free fatty acids in the body[15,31]. High concentrations of fatty acids will lead to excess visceral fat, accumulation of

Table 2. *OR* (95% *CI*) of cardiometabolic health risk factors for the HW, HWHtR, and WHR phenotypes

Models	HW			HWHtR			WHR		
	OR	95% *CI*	*P*	*OR*	95% *CI*	*P*	*OR*	95% *CI*	*P*
Model 1									
Elevated TG	NA	NA	NA	NA	NA	NA	0.82	0.75–0.89	< 0.001
Low HDL	2.83	2.42–3.32	< 0.001	2.63	2.13–3.24	< 0.001	1.18	1.05–1.31	0.004
Elevated LDL	2.08	1.55–2.78	< 0.001	3.18	2.13–4.74	< 0.001	1.94	1.59–2.38	< 0.001
Elevated TC	2.58	2.05–3.25	< 0.001	2.85	2.04–3.98	< 0.001	1.64	1.41–1.91	< 0.001
Elevated BP	1.42	1.23–1.63	0.007	1.31	1.08–1.58	0.007	0.92	0.88–0.96	< 0.001
FPG	1.07	0.32–3.53	0.540	0.60	0.12–3.02	0.538	1.14	0.57–2.26	0.720
CHRF clustering	10.79	9.28–12.55	< 0.001	9.21	7.45–11.39	< 0.001	1.05	0.95–1.15	0.350
Model 2									
Elevated TG	NA	NA	NA	NA	NA	NA	1.09	0.95–1.25	0.234
Low HDL	2.45	1.88–3.19	< 0.001	2.71	1.93–3.80	< 0.001	1.30	1.08–1.55	0.005
Elevated LDL	2.96	1.84–4.75	< 0.001	6.87	3.58–13.19	< 0.001	1.64	1.15–2.33	< 0.001
Elevated TC	3.89	2.65–5.73	< 0.001	4.94	2.88–8.47	< 0.001	1.51	1.15–1.98	0.003
Elevated BP	1.32	1.06–1.66	0.015	1.08	0.80–1.47	0.614	1.00	0.93–1.07	0.905
FPG	0.98	0.10–9.63	0.990	1.59	0.13–19.23	0.716	1.89	0.64–5.54	0.247
CHRF clustering	12.22	9.54–15.67	< 0.001	9.70	6.93–13.58	< 0.001	1.14	0.97–1.34	0.115

Note. BP, blood pressure; FPG, fasting plasma glucose; HDL, high-density lipoprotein; LDL, low-density lipoprotein; TG, triglyceride; TC, total cholesterol; CHRF clustering, cardiometabolic health risk factors clustering; HW, hypertriglyceridemic waist; HWHtR, hypertriglyceridemic waist-to-height ratio; WHR, waist-to-hip ratio; NA, data not available. Model 1: adjusted for sex (boy or girl), age (years) and BMI. Model 2: adjusted for variables from model 1, and additionally adjusted by area and family income.

TG, and infiltration of inflammatory cells and fat tissues, leading to increased risk of brain disease[32,33]. Therefore, it is important to find cost-effective, simple, and convenient indexes that can measure subcutaneous and visceral fats for the prevention and control of clustering of cardiometabolic risk factors.

There is a known advantage in adults using the WHtR as a predictor of cardiometabolic risk factors clustering[34]. A previous study conducted in Singapore indicated that a combination of WHtR and BMI could be the best clinical marker in identifying adults with CVD risk factors[19]. Also, a study conducted in Columbia showed that high WHtR was a risk factor for

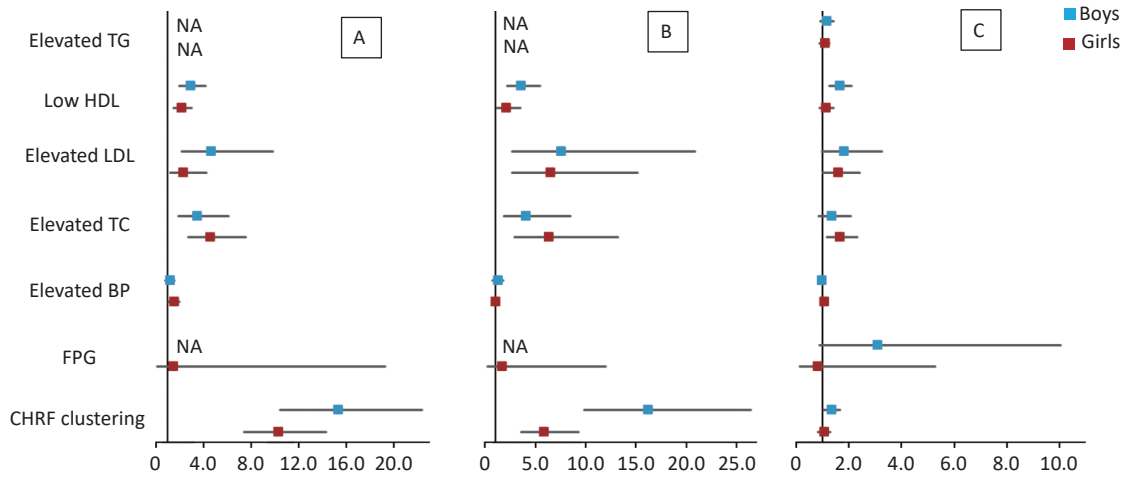

Figure 1. Forest plot of cardiometabolic health risk factors for HW (A), HWHtR (B), and WHR (C) phenotypes stratified by sex. BP, blood pressure; FPG, fasting plasma glucose; HDL, high-density lipoprotein; LDL, low-density lipoprotein; TG, triglyceride; TC, total cholesterol; NA, data not available. CHRF clustering: cardiometabolic health risk factors clustering. Model: adjusted for age (years), BMI, area and family income. HW, hypertriglyceridemic waist; HWHtR, hypertriglyceridemic waist-to-height ratio; WHR, waist-to-hip ratio.

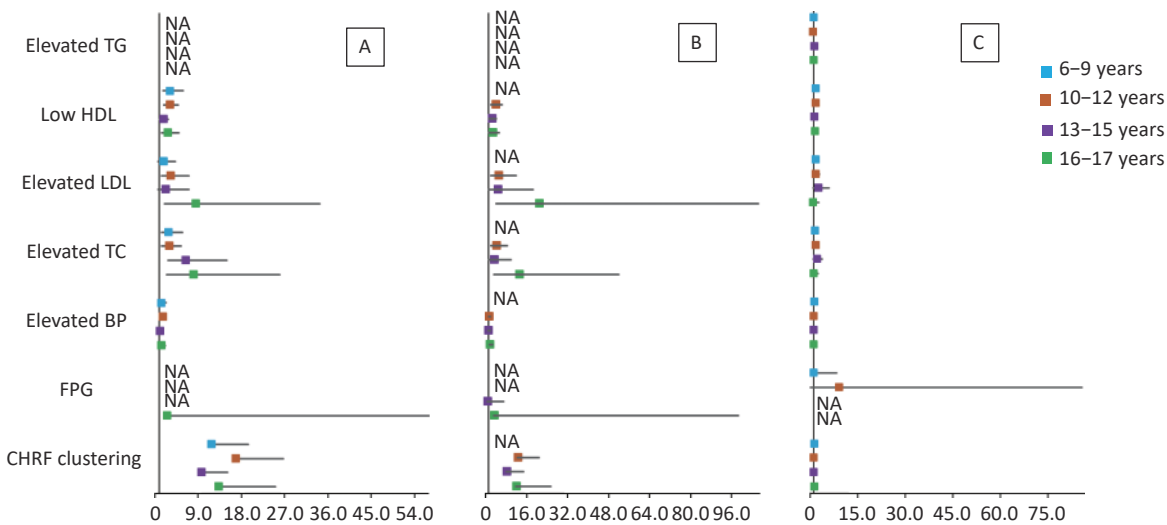

Figure 2. Forest plot of cardiometabolic health risk factors for HW (A), HWHtR (B), and WHR (C) phenotypes stratified by age. BP, blood pressure; FPG, fasting plasma glucose; HDL, high-density lipoprotein; LDL, low-density lipoprotein; TG, triglyceride; TC, total cholesterol; NA, data not available. CHRF clustering: cardiometabolic health risk factors clustering. Model: adjusted for sex, BMI, area and family income. HW, hypertriglyceridemic waist; HWHtR, hypertriglyceridemic waist-to-height ratio; WHR, waist-to-hip ratio.

dyslipidemia for children aged 6–10 years[35]. Similar results have also been reported in a study conducted in Chinese children and adolescents aged 6–17 years[36]. A meta-analysis suggests that WHtR has good and robust performance as a screening tool for identifying cardiometabolic risk in children[37].

The HW phenotype has also been used as a convenient tool to screen the population at high risk of cardiometabolic risk factors clustering. A transversal study including 976 middle-aged Brazilian adults reported that the HW phenotype predicted the incidence of cardiometabolic health risk factors[38]. Similarly, a cohort study including 95,015 Asian adults (18–98 years of age) found that the HW phenotype might be a simple and useful clinical tool to screen individuals who are at risk for future cardiometabolic health risk factors[9]. Among children and adolescents, the HW phenotype was also regarded as a significant marker for cardiometabolic health risk factors. A national study of adolescents in Iran showed that the HW phenotype was associated with cardiometabolic risk factors, particularly elevated cholesterol[39]. A cohort study conducted in Brazil indicated that the HW phenotype could be a good predictor for SBP and glycemia in children and adolescents[40]. Additionally, a study conducted among Chinese adolescents indicated that the HW phenotype was a useful marker for screening adolescents who are at high risk of metabolic syndrome[41]. Overall, the HW phenotype is a convenient and useful tool to identify groups with high risks of cardiometabolic risk factors clustering among both in adults and adolescents.

However, the HWHtR phenotype in children and adolescents has received limited attention. A previous study that enrolled 3,136 Han adolescents indicated that compared with the HW phenotype, the HWHtR phenotype is a better marker of atherogenic lipid profile for adolescents[41]. In addition, the results of the study showed that the HWHtR phenotype is a non-age-dependent index (P = 0.042). Therefore, this study supposed that the HWHtR phenotype is much more applicable for screening adolescents with higher cardiometabolic risk. However, whether the HWHtR phenotype applies to other ethnic groups is unclear[41]. In our study, except for LDL showing a stronger correlation with the HWHtR phenotype than the HW phenotype with the adjustment of potential covariates, there was no significant difference between the two phenotypes (HWHtR and HW) in the *OR* of other risk factors for cardiometabolic health risk factors clustering. In addition, the measurement of WC is more readily available than WHtR[16], and the HW phenotype showed a weaker association with sex than the HWHtR phenotype. Therefore, the HW phenotype may be a better marker than the HWHtR phenotype. Previous studies have indicated that the HW phenotype may be a better marker than WHtR for identifying children and adolescents who are at risk for cardiometabolic disorders[16,40], which is similar to the results of this study.

The majority of adults with high WHR have disproportionate amounts of visceral fat[15]. In a case-control study on acute myocardial infarction, elevated WHR was associated with a higher risk of myocardial infarction[42]. In Europe, it was confirmed that elevated WHR causes higher SBP, higher triglycerides, and two-hour glucose levels[43]. However, a previous study indicated that WHR is more weakly associated with cardiovascular risk factors than HW and HWHtR[19]. Moreover, a large representative observational study in the UK showed that a combination of BMI and the WHR phenotype is more effective in assessing the cardiovascular risk that is associated with obesity[44]. In our study, the WHR phenotype also showed a weak ability to predict cardiometabolic risk factors clustering. The present study did not find an association between the three phenotypes and the risk of hyperglycemia. Hyperglycemia and dyslipidemia are important components of metabolic syndrome and are closely related[45]. A cross-sectional study of a large sample in China (n = 105,922) showed an inverted U-shaped association between the primary glycemic indices and uric acid levels in adults[46]. However, elevated serum uric acid may be associated with the risk of hypertension and dyslipidemia, and the intermediate regulatory mechanism may involve the regulation of FPG[47-50].

Our study has significant strengths. Although it is not the first study to explore indicators for cardiometabolic risk factors clustering among Chinese children and adolescents, the sample size of this study was large and more than 60,000 children and adolescents from different provinces and ethnic groups in China, ranging in age from 6 to 17 years old. A previous study was conducted among Chinese children and adolescents, but only among Han Chinese aged 13 to 17, and the sample size was only approximately 3,000[41]. However, there were some limitations of this study. For example, it was a cross-sectional study, which limited our abilities to infer causality.

CONCLUSION

In conclusion, the HW phenotype is a better

simple marker for identifying children and adolescents with cardiometabolic risk factors clustering. Compared with HWHtR and WHR, the HW phenotype is a non-sex-dependent indicator with higher applicability to screen children and adolescents for cardiovascular risk factors.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

XIAO Tian Li and YUAN Shu Qian drafted the manuscript and performed the statistical analyses. ZHENG Chan Juan, WANG Xi Jie, and YANG Yi De conceived of the study. YANG Yi De, DONG Yan Hui, and ZOU Zhi Yong participated in its design and coordination and helped to draft the manuscript. GAO Jing Yu and Julien S. Baker contributed to the discussion. All authors participated in critically revising and approving the final manuscript.

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ETHICS APPROVAL

The study protocol was approved by the Medical Ethical Committee of Peking University (Number: IRB0000105213034). Informed consent was obtained from all participants and their parents involved in the study.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available from the corresponding author upon request (yangyide@hunnu.edu.cn).

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Supplementary Table S1. General characteristics of the study population by sex

Variables		Total		Boy (*n* = 32,064)		Girl (*n* = 30,104)		*P*
		N	$\bar{x} \pm s$ (%)	*n*	$\bar{x} \pm s$ (%)	*n*	$\bar{x} \pm s$ (%)	
Height		62,168	145.86 ± 17.08	32,064	146.93 ± 18.44	30,104	144.72 ± 15.43	< 0.001
Weight		62,168	40.97 ± 15.53	32,064	42.35 ± 16.88	30,104	39.50 ± 13.79	< 0.001
SBP (mmHg)		62,168	104.33 ± 12.17	32,064	105.72 ± 12.5	30,104	102.85 ± 11.62	< 0.001
DBP (mmHg)		62,168	66.27 ± 8.84	32,064	66.8 ± 8.98	30,104	65.71 ± 8.64	< 0.001
TG (mmol/L)		15,995	1.14 ± 0.81	8,147	1.09 ± 0.80	7,848	1.19 ± 0.83	< 0.001
HDL (mmol/L)		15,998	1.89 ± 1.35	8,149	1.90 ± 1.38	7,849	1.88 ± 1.31	0.476
LDL (mmol/L)		15,998	1.97 ± 0.71	8,149	1.94 ± 0.70	7,849	1.99 ± 0.72	< 0.001
TC (mmol/L)		15,998	3.86 ± 0.90	8,149	3.81 ± 0.90	7,849	3.92 ± 0.90	< 0.001
FPG (mmol/L)		15,990	4.14 ± 1.28	8,143	4.19 ± 1.31	7,847	4.09 ± 1.25	< 0.001
Area	rural	19,753	37.3	10,158	37.5	9,595	37.1	0.359
	urban	33,221	62.7	16,947	62.5	16,274	62.9	
Family income	< 5,000	16,646	63.6	8,234	63.0	8,412	64.2	0.042
(CNY)	≥ 5,000	9529	36.4	4,838	37.0	4,691	35.8	
BP (mmHg)	< P_{90}	42,292	74.3	20,716	70.6	21,576	78.2	< 0.001
	≥ P_{90}	14,642	25.7	8,611	29.4	6,031	21.8	
FPG (mmol/L)	< 6.1	15,945	99.7	8,111	99.6	7,834	99.8	0.007
	≥ 6.1	45	0.3	32	0.4	13	0.2	
HDL (mmol/L)	≥ 1.03	13,987	87.4	7,035	86.3	6,952	88.6	< 0.001
	< 1.03	2,011	12.6	1,114	13.7	897	11.4	
LDL (mmol/L)	< 3.37	15,520	97.0	7,928	97.3	7,592	96.7	0.037
	≥ 3.37	478	3.0	221	2.7	257	3.3	
TG (mmol/L)	< 1.24	11,702	73.2	6,149	75.5	5,553	70.8	< 0.001
	≥ 1.24	4,293	26.8	1,998	24.5	2,295	29.2	
TC (mmol/L)	< 5.17	15,128	94.6	7,745	95.0	7,383	94.1	< 0.001
	≥ 5.17	870	5.4	404	5.0	466	5.9	

Note. BMI, body mass index; WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; BP, blood pressure; FPG, fasting plasma glucose; HDL, high-density lipoprotein; LDL, low-density lipoprotein; TG, triglyceride; TC, total cholesterol; HW, hypertriglyceridemic waist; HWHtR, hypertriglyceridemic waist-to-height ratio; WHR, waist-to-hip ratio; CHRF clustering, cardiometabolic health risk factors clustering.

Supplementary Table S2. Comparisons of cardiometabolic health risk factors between subjects with and without HW phenotype

Variables	Category	non-HW		HW		*P*
		N	Freq. (%)	*N*	Freq. (%)	
Sex	boy	7,050	51.3	628	50.3	0.479
	girl	6,686	48.7	621	49.7	
Area	rural	4,946	41.7	385	36.4	< 0.001
	urban	6,905	58.3	672	63.6	
Family income (CNY)	< 5,000	3,756	64.3	357	62.9	0.494
	≥ 5,000	2,086	35.7	211	37.1	
BP (mmHg)	< P_{90}	10,632	77.4	669	53.6	< 0.001
	≥ P_{90}	3,104	22.6	580	46.4	
FPG (mmol/L)	< 6.1	13,696	99.7	1,242	99.7	0.739
	≥ 6.1	37	0.3	4	0.3	
HDL (mmol/L)	≥ 1.03	12,235	89.1	839	67.2	< 0.001
	< 1.03	1,501	10.9	410	32.8	
LDL (mmol/L)	< 3.37	13,384	97.4	1,159	92.8	< 0.001
	≥ 3.37	352	2.6	90	7.2	
TG (mmol/L)	< 1.24	10,845	79.0	0	0.0	< 0.001
	≥ 1.24	2,891	21.0	1,249	100.0	
TC (mmol/L)	< 5.17	13,075	95.2	1,098	87.9	< 0.001
	≥ 5.17	661	4.8	151	12.1	
CHRF clustering	< 2	11,851	86.3	395	31.6	< 0.001
	≥ 2	1,885	13.7	854	68.4	

Note. BP, blood pressure; FPG, fasting plasma glucose; HDL, high-density lipoprotein; LDL, low-density lipoprotein; TG, triglyceride; TC, total cholesterol; CHRF clustering, cardiometabolic health risk factors clustering; HW, hypertriglyceridemic waist.

Supplementary Table S3. Comparisons of cardiometabolic health risk factors between subjects with and without HWHtR phenotype

Variables	Category	non-HWHtR		HWHtR		*P*
		N	Freq. (%)	*N*	Freq. (%)	
Sex	boy	4,587	50.5	397	61.6	< 0.001
	girl	4,492	49.5	247	38.4	
Area	rural	3,232	41.0	214	36.7	0.041
	urban	4,646	59.0	369	63.3	
Family income (CNY)	< 5,000	2,534	65.4	182	64.3	< 0.001
	≥ 5,000	1,338	34.6	101	35.7	
BP (mmHg)	< P_{90}	6,654	73.3	289	44.9	< 0.004
	≥ P_{90}	2,425	26.7	355	55.1	
FPG (mmol/L)	< 6.1	9,051	99.7	639	99.7	0.907
	≥ 6.1	26	0.3	2	0.3	
HDL (mmol/L)	≥ 1.03	7,857	86.5	398	61.8	< 0.001
	< 1.03	1,222	13.5	246	38.2	
LDL (mmol/L)	< 3.37	8,883	97.8	586	91.0	< 0.001
	≥ 3.37	196	2.2	58	9.0	
TG (mmol/L)	< 1.24	6,617	72.9	0	0.0	< 0.001
	≥ 1.24	2,462	27.1	644	100.0	
TC (mmol/L)	< 5.17	8,700	95.8	567	88.0	< 0.001
	≥ 5.17	379	4.2	77	12.0	
CHRF clustering	< 2	7,481	82.4	165	25.6	< 0.001
	≥ 2	1,598	17.6	479	74.4	

Note. BP, blood pressure; FPG, fasting plasma glucose; HDL, high-density lipoprotein; LDL, low-density lipoprotein; TG, triglyceride; TC, total cholesterol; CHRF clustering, cardiometabolic health risk factors clustering; HWHtR, hypertriglyceridemic waist-to-height ratio.

Supplementary Table S4. Comparisons of cardiometabolic health risk factors between subjects with and without WHR phenotype

Variables	Category	non-WHR		WHR		*P*
		N	Freq. (%)	*N*	Freq. (%)	
Sex	boy	21,373	52.8	10,410	49.2	< 0.001
	girl	19,107	47.2	10,743	50.8	
Area	rural	12,756	37.7	6,877	36.9	0.081
	urban	21,124	62.3	11,770	63.1	
Family income (CNY)	< 5,000	10,914	63.5	5,612	63.9	0.494
	≥ 5,000	6,285	36.5	3,172	36.1	
BP (mmHg)	< P_{90}	27,950	77.1	13,999	69.3	< 0.001
	≥ P_{90}	8,316	22.9	6,206	30.7	
FPG (mmol/L)	< 6.1	10,166	99.7	5,641	99.7	0.683
	≥ 6.1	27	0.3	17	0.3	
HDL (mmol/L)	≥ 1.03	9,131	89.6	4,744	83.8	< 0.001
	< 1.03	1,064	10.4	920	16.2	
LDL (mmol/L)	< 3.37	9,979	97.9	5,408	95.5	< 0.001
	≥ 3.37	216	2.1	256	4.5	
TG (mmol/L)	< 1.24	7,592	74.5	4,013	70.9	< 0.001
	≥ 1.24	2,602	25.5	1,649	29.1	
TC (mmol/L)	< 5.17	9,745	95.6	5,254	92.8	< 0.001
	≥ 5.17	450	4.4	410	7.2	
CHRF clustering	< 2	8,715	85.5	4,372	77.2	< 0.001
	≥ 2	1,479	14.5	1,290	22.8	

Note. BP, blood pressure; FPG, fasting plasma glucose; HDL, high-density lipoprotein; LDL, low-density lipoprotein; TG, triglyceride; TC, total cholesterol; CHRF clustering, cardiometabolic health risk factors clustering; WHR, waist-to-hip ratio.

Supplementary Table S5. *OR* (95% *CI*) of cardiometabolic health risk factors for HW, HWHtR and WHR phenotype stratified by sex

Models	HW			HWHtR			WHR		
	OR	95% *CI*	*P*	*OR*	95% *CI*	*P*	*OR*	95% *CI*	*P*
Boys Model 1									
Elevated TG	NA	NA	NA	NA	NA	NA	0.94	0.83–1.07	0.330
Low HDL	2.93	2.35–3.67	< 0.001	3.05	2.32–4.01	< 0.001	1.39	1.19–1.62	< 0.001
Elevated LDL	2.22	1.47–3.35	< 0.001	3.02	1.77–5.15	< 0.001	2.01	1.46–2.75	< 0.001
Elevated TC	2.48	1.78–3.46	< 0.001	2.59	1.67–4.02	< 0.001	1.54	1.22–1.96	< 0.001
Elevated BP	1.46	1.19–1.78	0.007	1.48	1.14–1.91	0.003	0.86	0.81–0.92	< 0.001
FPG	NA	NA	NA	NA	NA	NA	1.15	0.49–2.69	0.752
CHRF clustering	14.11	11.23–17.72	< 0.001	15.19	11.23–20.55	< 0.001	1.15	1.00–1.33	0.053
Model 2									
Elevated TG	NA	NA	NA	NA	NA	NA	1.12	0.90–1.41	0.304
Low HDL	2.83	1.94–4.15	< 0.001	3.49	2.22–5.48	< 0.001	1.62	1.24–2.11	< 0.001
Elevated LDL	4.58	2.14–9.80	< 0.001	7.47	2.67–20.91	< 0.001	1.78	0.98–3.26	0.060
Elevated TC	3.38	1.88–6.07	< 0.001	3.97	1.85–8.52	< 0.001	1.33	0.86–2.05	0.197
Elevated BP	1.13	0.81–1.58	0.476	1.20	0.78–1.83	0.407	0.93	0.83–1.03	0.152
FPG	NA	NA	NA	NA	NA	NA	3.06	0.89–10.06	0.077
CHRF clustering	15.28	10.44–22.36	< 0.001	16.18	9.91–26.42	< 0.001	1.31	1.02–1.67	0.034
Girls Model 1									
Elevated TG	NA	NA	NA	NA	NA	NA	0.73	0.65–0.82	< 0.001
Low HDL	2.68	2.14–3.36	< 0.001	2.16	1.54–3.02	< 0.001	1.04	0.89–1.21	0.646
Elevated LDL	2.00	1.32–3.04	0.001	3.37	1.86–6.14	< 0.001	1.84	1.41–2.41	< 0.001
Elevated TC	2.82	2.05–3.89	< 0.001	3.11	1.87–5.19	< 0.001	1.66	1.36–2.03	< 0.001
Elevated BP	1.34	1.10–1.64	0.004	1.10	0.81–1.49	0.531	0.96	0.90–1.023	0.205
FPG	2.95	0.70–12.47	0.140	2.18	0.29–16.15	0.447	1.43	0.46–4.47	0.542
CHRF clustering	8.84	7.20–10.85	< 0.001	5.33	3.91–7.26	< 0.001	0.96	0.84–1.09	0.498
Model 2									
Elevated TG	NA	NA	NA	NA	NA	NA	1.05	0.88–1.26	0.568
Low HDL	2.10	1.45–3.03	< 0.001	2.07	1.22–3.49	0.007	1.11	0.87–1.42	0.413
Elevated LDL	2.26	1.21–4.22	0.010	6.44	2.74–15.15	< 0.001	1.56	1.01–2.42	0.045
Elevated TC	4.55	2.74–7.57	< 0.001	6.25	2.95–13.25	< 0.001	1.64	1.16–2.31	0.005
Elevated BP	1.46	1.07–1.98	0.017	0.98	0.78–1.23	0.858	1.03	0.94–1.14	0.506
FPG	1.43	0.11–19.29	0.786	1.63	0.22–11.96	0.631	0.78	0.12–5.28	0.799
CHRF clustering	10.26	7.38–14.27	< 0.001	5.76	3.57–9.29	< 0.001	1.02	0.83–1.27	0.825

Note. BP, blood pressure; FPG, fasting plasma glucose; HDL, high-density lipoprotein; LDL, low−density lipoprotein; TG, triglyceride; TC, total cholesterol. CHRF clustering, cardiometabolic health risk factors clustering; HW, hypertriglyceridemic waist; HWHtR, hypertriglyceridemic waist-to-height ratio; WHR, waist−to−hip ratio; NA, data not available. Model 1: adjusted for age (years) and BMI. Model 2: adjusted for variables from model 1, and additionally adjusted by area and family income.

Supplementary Table S6. *OR* (95% *CI*) of cardiometabolic health risk factors for HW, HWHtR and WHR phenotype stratified by age

Models	HW			HWHtR			WHR		
	OR	95% *CI*	*P*	*OR*	95% *CI*	*P*	*OR*	95% *CI*	*P*
6–9 years Model 1									
Elevated TG	NA	NA	NA	NA	NA	NA	0.70	0.59–0.82	< 0.001
Low HDL	2.97	2.14–4.14	< 0.001	NA	NA	NA	1.45	1.18–1.78	< 0.001
Elevated LDL	1.38	0.81–2.34	0.233	NA	NA	NA	1.94	1.44–2.62	< 0.001
Elevated TC	2.08	1.40–3.07	< 0.001	NA	NA	NA	1.48	1.17–1.86	0.001
Elevated BP	1.54	1.16–2.04	0.003	NA	NA	NA	0.97	0.89–1.05	0.428
FPG	3.11	0.28–34.78	0.356	NA	NA	NA	1.81	0.58–5.65	0.310
CHRF clustering	10.04	7.53–13.38	< 0.001	NA	NA	NA	1.38	1.15–1.66	0.001
Model 2									
Elevated TG	NA	NA	NA	NA	NA	NA	1.10	0.83–1.47	0.508
Low HDL	3.23	1.79–5.85	< 0.001	NA	NA	NA	1.43	1.00–2.04	0.052
Elevated LDL	1.73	0.70–4.28	0.236	NA	NA	NA	1.49	0.86–2.57	0.155
Elevated TC	2.88	1.42–5.82	0.003	NA	NA	NA	1.31	0.87–1.98	0.192
Elevated BP	1.40	0.86–2.28	0.172	NA	NA	NA	1.17	1.03–1.34	0.017
FPG	NA	NA	NA	NA	NA	NA	0.94	0.10–8.86	0.955
CHRF clustering	11.77	7.13–19.44	< 0.001	NA	NA	NA	1.33	0.96–1.85	0.091
10–12 years Model 1									
Elevated TG	NA	NA	NA	NA	NA	NA	0.63	0.54–0.73	< 0.001
Low HDL	3.11	2.32–4.16	< 0.001	3.28	2.37–4.55	< 0.001	1.17	0.93–1.46	0.174
Elevated LDL	2.83	1.73–4.62	< 0.001	3.82	2.25–6.50	< 0.001	2.07	1.42–3.02	< 0.001
Elevated TC	2.91	1.94–4.38	< 0.001	3.56	2.28–5.56	< 0.001	1.83	1.37–2.44	< 0.001
Elevated BP	1.54	1.20–1.98	0.001	1.51	1.14–2.01	0.004	0.87	0.79–0.94	0.001
FPG	1.10	0.11–11.32	0.937	NA	NA	NA	1.59	0.51–4.96	0.428
CHRF clustering	13.00	9.81–17.22	< 0.001	12.36	8.98–17.03	< 0.001	0.01	0.68–0.97	0.022
Model 2									
Elevated TG	NA	NA	NA	NA	NA	NA	0.81	0.64–1.04	0.104
Low HDL	2.85	1.78–4.57	< 0.001	3.50	2.08–5.88	< 0.001	1.57	1.09–2.26	0.016
Elevated LDL	3.71	1.69–8.18	0.001	5.87	2.45–14.02	< 0.001	1.70	0.89–3.25	0.110
Elevated TC	3.37	1.74–6.52	< 0.001	4.84	2.34–10.01	< 0.001	1.87	1.10–3.18	0.021
Elevated BP	1.59	1.07–2.36	0.022	1.12	0.71–1.76	0.634	0.86	0.75–0.99	0.037
FPG	NA	NA	NA	NA	NA	NA	9.05	0.95–85.90	0.055
CHRF clustering	16.73	10.54–26.55	< 0.001	12.69	7.61–21.16	< 0.001	0.96	0.71–1.29	0.776
13–15 years									
Model 1									
Elevated TG	NA	NA	NA	NA	NA	NA	0.88	0.75–1.03	0.109
Low HDL	2.55	1.92–3.38	< 0.001	2.19	1.55–3.10	< 0.001	1.03	0.85–1.25	0.746
Elevated LDL	1.48	0.73–3.01	0.275	1.95	0.86–4.40	0.109	1.28	0.75–2.18	0.361
Elevated TC	2.64	1.58–4.41	< 0.001	1.57	0.80–3.09	0.195	1.57	1.09–2.26	0.016

Continued

Models	HW			HWHtR			WHR		
	OR	95% *CI*	*P*	*OR*	95% *CI*	*P*	*OR*	95% *CI*	*P*
Elevated BP	1.30	0.99−1.69	0.057	1.47	1.05−2.05	0.025	0.90	0.83−0.98	0.019
FPG	NA	NA	NA	NA	NA	NA	0.31	0.05−2.04	0.222
CHRF clustering	10.06	7.55−13.39	< 0.001	8.07	5.62−11.58	< 0.001	0.86	0.72−1.03	0.095
Model 2									
Elevated TG	NA	NA	NA	NA	NA	NA	1.22	0.94−1.57	0.132
Low HDL	1.72	1.08−2.75	0.023	2.29	1.31−4.01	0.004	1.10	0.80−1.51	0.550
Elevated LDL	2.04	0.66−6.35	0.217	4.14	1.07−16.08	0.040	2.46	0.99−6.07	0.052
Elevated TC	5.64	2.45−12.99	< 0.001	3.01	1.02−8.85	0.045	1.94	1.00−3.77	0.050
Elevated BP	1.06	0.69−1.62	0.789	1.03	0.61−1.77	0.903	0.97	0.84−1.11	0.628
FPG	NA	NA	NA	NA	NA	NA	NA	NA	NA
CHRF clustering	9.79	6.21−15.44	< 0.001	8.17	4.60−14.53	< 0.001	1.07	0.80−1.42	0.654
16−17 years									
Model 1									
Elevated TG	NA	NA	NA	NA	NA	NA	0.98	0.77−1.24	0.839
Low HDL	2.57	1.76−3.75	< 0.001	2.52	1.61−3.93	< 0.001	1.22	0.91−1.63	0.184
Elevated LDL	4.50	1.97−10.28	< 0.001	3.83	1.48−9.92	0.006	1.81	0.82−3.97	0.140
Elevated TC	4.26	2.17−8.38	< 0.001	4.01	1.79−9.00	0.001	1.37	0.76−2.44	0.295
Elevated BP	1.20	0.84−1.73	0.322	0.94	0.60−1.45	0.768	0.95	0.83−1.08	0.428
FPG	1.39	0.16−11.81	0.763	1.85	0.19−18.26	0.601	0.59	0.06−5.64	0.644
CHRF clustering	10.02	6.79−14.78	< 0.001	8.77	5.45−14.11	< 0.001	1.23	0.94−1.61	0.124
Model 2									
Elevated TG	NA	NA	NA	NA	NA	NA	0.93	0.63−1.38	0.712
Low HDL	2.56	1.36−4.81	0.004	2.48	1.19−5.14	0.012	1.32	0.80−2.16	0.275
Elevated LDL	8.62	2.17−34.23	0.002	20.95	4.12−106.44	< 0.001	0.70	0.19−2.64	0.597
Elevated TC	7.85	2.45−25.12	0.001	12.90	3.26−51.15	< 0.001	0.83	0.29−2.35	0.723
Elevated BP	1.25	0.70−2.23	0.453	1.34	0.67−2.68	0.408	0.96	0.78−1.19	0.694
FPG	2.56	0.11−60.52	0.561	3.24	0.11−96.18	0.497	NA	NA	NA
CHRF clustering	12.22	6.48−23.04	< 0.001	11.23	5.31−23.76	< 0.001	1.15	0.74−1.81	0.533

Note. BP, blood pressure; FPG, fasting plasma glucose; HDL, high−density lipoprotein; LDL, low−density lipoprotein; TG, triglyceride; TC, total cholesterol; CHRF clustering, cardiometabolic health risk factors clustering; HW, hypertriglyceridemic waist; HWHtR, hypertriglyceridemic waist−to−height ratio; WHR, waist−to−hip ratio. Model 1: adjusted for sex (boy or girl) and BMI. Model 2: adjusted for variables from model 1, and additionally adjusted by area and family income.