ORIGINAL RESEARCH

Children's Lipid Accumulation Product Combining Visceral Adiposity Index is a Novel Indicator for Predicting Unhealthy Metabolic Phenotype Among Chinese Children and Adolescents

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Purpose: The predictive capacity between children's lipid accumulation product (CLAP) combining visceral adiposity index (VAI), CLAP, and VAI with metabolically unhealthy phenotype remained unclear. This study aimed to compare the ability of CLAP combining VAI, CLAP, VAI and traditional adiposity indicators (body mass index (BMI), waist circumference (WC), waist-to-height ratio (WHtR) and waist-to-hip ratio (WHR)) to predict metabolically unhealthy phenotype among Chinese children and adolescents.

Patients and Methods: In the cross-sectional study, 1714 children and adolescents aged 12 to 18 were selected by random cluster sampling, underwent a questionnaire survey, physical examination, biochemical tests and body composition was measured by bioelectrical impedance analysis (BIA). Participants were divided into four phenotypes according to BMI and metabolic syndrome components. The logarithmic CLAP (LnCLAP), VAI, BMI, WC, WHtR and WHR were standardized for sex and age using the z-score method (standardized variables: LnCLAP-z, VAI-z, BMI-z, WC-z, WHtR-z and WHR-z).

Results: LnCLAP-z $\geq$ 1, VAI-z $\geq$ 1, WC-z $\geq$ 1, and WHR-z $\geq$ 1 increased the risk of metabolically unhealthy normal-weight phenotype (the OR and 95% CI were 4.18 (1.75–10.02), 24.05 (12.79–45.21), 6.17 (1.14–33.51), 2.69 (1.07–6.72), respectively), LnCLAP-z $\geq$ 1, VAI-z $\geq$ 1 and WC-z $\geq$ 1 increased the risk of metabolically unhealthy overweight or obese phenotype (the OR and 95% CI were 2.67 (1.40–5.09), 10.30 (3.03–35.03), 2.19 (1.18–4.09), respectively). The area under the ROC curve (AUC) for CLAP combining VAI in the prediction of the metabolically unhealthy phenotype were 0.837 (0.776–0.899) and 0.876 (0.834–0.918) for boys and girls with normal-weight, 0.853 (0.803–0.903) and 0.794 (0.711–0.878) for boys and girls with overweight and obese (all P < 0.001), which were higher than CLAP, VAI, BMI, WC, WHtR and WHR.

Conclusion: Among Chinese children and adolescents, CLAP combining VAI was a more effective indicator than CLAP, VAI and traditional adiposity indicators in predicting unhealthy metabolic phenotype.

Keywords: children's lipid accumulation product, visceral adiposity index, unhealthy metabolic phenotype, traditional adiposity indicators, children and adolescents

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Introduction

Pediatric obesity has become a serious global public health problem. With the increase in pediatric obesity rate, metabolic syndrome (MetS) was more common in children and adolescents, especially in China.[1,2] Metabolically unhealthy

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obesity was used to define obese individuals with MetS. However, some obese individuals with good metabolic characteristics, which were defined as metabolically healthy obesity,[3] individuals with normal-weight may develop metabolic disorders, which were defined as metabolically unhealthy normal-weight (MUNW).[4] Due to the different criteria used to define the metabolic phenotype, the prevalence of MUNW and metabolically unhealthy obesity ranged from 10.6% to 18.8%[5–7] and 1.3% to 14.3%, respectively,[5,6,8,9] among children and adolescents. Studies reported that unhealthy metabolic phenotype were associated with increased risk of cardiovascular risk factors.[10,11] Therefore, early identification of unhealthy metabolic phenotype in children and adolescents was significant for disease prevention.

At present, the underlying mechanism for the existence of different metabolic phenotypes remains unclear, and increase in visceral adipose tissue (VAT) is the main mechanism.[12] Lipid accumulation product (LAP) and visceral adiposity index (VAI) are novel indicators to measure visceral obesity.[13] LAP, combined waist circumference (WC) and fasting triglycerides (TG) concentration,[14] was associated with MetS in adults.[15] Nevertheless, LAP may not directly reflect lipid accumulation among children and adolescents. The children's lipid accumulation product (CLAP), a novel indicator, was proposed by Zhang et al,[16] which combined WC, abdominal skinfold thickness (AST), and serum triglyceride (TG) concentration, and was related to MetS among Chinese children and adolescents. VAI was a product of body mass index (BMI), WC, TG and high-density lipoprotein cholesterol (HDL-C).[17] In adults, both LAP and VAI performed better in detecting MUNW phenotype than traditional adiposity indicators, including BMI, WC, waist-to-height ratio (WHtR) and waist-to-hip ratio (WHR).[18,19] The combination of LAP and arterial blood pressure measurement might be a useful method for predicting the metabolically healthy obese phenotype in postmenopausal women.[20] However, few studies investigated the predictive ability of CLAP, VAI and the combination of CLAP and VAI in identifying unhealthy metabolic phenotype among children and adolescents. Therefore, the study aimed to explore and compare the ability of CLAP combining VAI, CLAP, VAI and traditional adiposity indicators to predict metabolically unhealthy phenotype among children and adolescents, using data from China.

Methods
Study Population
Chen et al found that the prevalence of MUNW and MUO were 10.6% and 8.9%, respectively, in Chinese children aged 6–17 years.[5] The sample size was determined according to the cross-sectional design, and the calculation formula was $n = \frac{\mu_{\alpha/2}^2 p(1-p)}{\delta^2}$, ($\alpha$=0.05, δ=0.03, and p is the prevalence of MUNW). The sample size should be 404 ($404 = 1.96^2 \times 0.106 \times 0.894/0.03/0.03$), according to the formula of sample size. Considering the sampling error, the sample size needed to be increased by 5%, so the minimum sample size was 424 ($424 = 404 \times (1+5\%)$). In the cross-sectional study, children and adolescents aged 12–18 were randomly selected from 13 classes of 3 Junior Middle Schools and 10 classes of 2 Senior High Schools in Yinchuan city, China, via the cluster random sampling method, from 2017 to 2020. First determined the school, then made a stratification according to the grade level, and finally selected the classes randomly in the cluster. Individuals who were able to engage in various physical exercise activities were included, those with physical disabilities, deformities, congenital genetic diseases, metabolic-related diseases, and missing information were excluded, and a total of 1714 subjects were enrolled in this study. All subjects participated in the questionnaire, physical examination and laboratory examination. Informed consent was signed by all participants and their parents/guardians. This study was approved by the Ethics Committee of Ningxia Medical University (2021-G053) and conducted in accordance with the Declaration of Helsinki.

Questionnaire Investigation
The contents of the questionnaire mainly included the general demographic characteristics of the subjects, such as name, sex, age and birthdate, and so on.

Anthropometrical Data
All anthropometric variables were measured by standardized trained staff after children, and adolescents had removed their shoes and heavy clothing. Height was measured within 0.1 cm using an altimeter (ZH7082), weight was measured within 0.1 kg using a lever scale (RGT-140). WC and hip circumference (HC) were measured within 0.1 cm by nylon tape, WC was measured at the midway between the inferior margin of the last rib and iliac crest at the end of normal exhalation, and HC was

measured at the maximal gluteal protuberance. They were measured twice, the error of two measurements was no more than 0.5 cm or 0.5 kg. The average value of the anthropometric variables was used for analysis. The AST was detected by InBody370 bioelectrical impedance analysis (BIA) produced by Biospace Company of Korea, which used 8-point contact electrode. According to the method recommended by the American Hypertension Education Project working Group, systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured for 3 consecutive times with an Omron HEM-7012 electronic sphygmomanometer, at least 1 min between each time, and the difference between two adjacent measurements was no more than 10 mmHg.[21] The mean value of the last two measurements was used for analysis.

Biochemical Measurements

After 12 hours of overnight fasting, venous blood samples were obtained by direct venipuncture. Fasting plasma glucose (FPG), total cholesterol (TC), TG, low-density lipoprotein cholesterol (LDL-C) and high-density lipoprotein cholesterol (HDL-C) levels were assayed using the American AU480 automatic biochemical analyzer. FPG, TC and TG levels were determined by enzymatic methods. LDL-C and HDL-C were detected by direct method-catalase method.

Calculation of Derivative Indicators

BMI=weight (kg)/height^2(m^2), WHtR=WC (cm)/height (cm), WHR=WC (cm)/HC (cm). CLAP = WC (cm) × AST (mm) × TG (mmol/L)/100.[16] Using the following formula, we calculate VAI with TG and HDL-C levels expressed as mmol/l.[17]

$$\text{Male: VAI} = \frac{WC}{39.68 + 1.88 \times BMI} \times \frac{TG}{1.03} \times \frac{1.31}{HDL-C}$$
$$\text{Female: VAI} = \frac{WC}{36.58 + 1.89 \times BMI} \times \frac{TG}{0.81} \times \frac{1.52}{HDL-C}$$

Definitions

Overweight and obese were defined by BMI, according to the study of body index boundary points of overweight and obesity screening in Chinese children and adolescents.[22] We used the presence of MetS components to define metabolic abnormalities, based on the revised National Cholesterol Education Program Adult Treatment Panel III (ATP III) modified for the pediatric population,[23] as follows: (1) WC ≥ 90th percentile for age and sex;[24] (2) TG levels ≥1.24 mmol/L; (3) HDL-C ≤1.03 mmol/L; (4) SBP and/or DBP ≥ 90th percentile for age, sex and height;[25] (5) FPG levels ≥6.1 mmol/L. Therefore, the

participants were divided into four metabolically phenotypes,[6] as following: (1) metabolically healthy normal-weight (MHNW): normal-weight and ≤1 abnormalities; (2) metabolically unhealthy normal-weight (MUNW): normal-weight and ≥2 abnormalities; (3) metabolically healthy overweight or obesity (MHO): overweight or obese and ≤1 abnormalities; (4) metabolically unhealthy overweight or obesity (MUO): overweight or obese and ≥2 abnormalities.

Statistical Analysis

Epidata 3.1 software and SPSS26.0 were used for data entry and data analysis, respectively. Continuous and categorical variables were described as mean ± standard deviation (SD) or median (25th-75th percentiles), and percentage, respectively. Two-sample t-test or the Wilcoxon rank sum test, and chi-square test were used to compare the differences of the factors above between boys and girls. The logarithmic CLAP (LnCLAP), VAI, BMI, WC, WHtR and WHR were transferred into z scores by sex and age (standardized variables: LnCLAP-z, VAI-z, BMI-z, WC-z, WHtR-z and WHR-z). Z-score = (test value −mean value by age and gender) /SD by age and sex. Multivariate logistic regression was used to explore the relationship between CLAP, VAI, traditional adiposity indicators and unhealthy metabolic phenotype. Receiver operating characteristic (ROC) curve was used to compare the effects of CLAP combining VAI for predicting unhealthy metabolic phenotype. Two-sided $P < 0.05$ was considered to be statistically significant.

Results

Table 1 presents the characteristics of the participants by gender. Compared to girls, boys were older, had higher height, weight, HC, WHtR, FPG and SBP, and lower WHtR, WHR, AST, VAI, TC, TG, HDL-C and DBP (all $P < 0.05$). The overall prevalence of MUNW, MHO and MUO were 9.4%, 7.5% and 16.7%, respectively. Boys showed a lower prevalence of MUNW than girls (6.7% vs 13.8%, $P < 0.001$), no difference was found in the prevalence of MUO between the two groups.

Table 2 provides the associations between CLAP, VAI and anthropometric indices and unhealthy metabolic phenotype. LnCLAP-z ≥ 1, VAI-z ≥ 1, WC-z ≥ 1, and WHR-z ≥ 1 showed higher risk of MUNW phenotype, the OR and 95% CI were 4.18 (1.75–10.02), 24.05 (12.79–45.21), 6.17 (1.14–33.51) and 2.69 (1.07–6.72), respectively (all $P < 0.05$). After gender stratification, the results showed that

Table I Characteristics of the Study Population by Gender

	Total	Boys	Girls	t/F/χ^2	*P* value
N (%)	1714 (100)	1061 (61.9)	653 (38.1)		
Age (years)	15.0±1.6	15.1±1.5	14.7±1.7	5.33	<0.001
Height (cm)	168.1±8.5	171.5±7.9	162.5±6.1	26.48	<0.001
Weight (kg)	58.5±13.0	60.9±13.7	54.6±10.6	10.69	<0.001
BMI (kg/m^2)	20.63±3.74	20.62±3.88	20.65±3.50	−0.18	0.856
WC (cm)	74.4±10.1	74.2±10.8	74.6±8.9	−0.77	0.445
HC (cm)	91.4±6.8	92.1±7.1	90.3±6.1	5.43	<0.001
WHtR	0.44±0.06	0.43±0.06	0.46±0.05	−9.80	<0.001
WHR	0.81±0.06	0.80±0.06	0.82±0.05	−8.06	<0.001
AST (mm)	7.1±3.7	6.1±3.6	8.9±3.2	−15.80	<0.001
LnCLAP	1.5±0.8	1.3±0.9	1.8±0.6	−13.50	<0.001
VAI	0.93 (0.67, 1.33)	0.79 (0.60, 1.10)	1.21 (0.92, 1.66)	−16.53	<0.001
FPG (mmol/L)	4.77±0.68	4.81±0.74	4.72±0.58	2.42	0.016
TC (mmol/L)	3.95±0.94	3.91±0.93	4.01±0.95	−2.09	0.036
TG (mmol/L)	0.92 (0.73, 1.19)	0.91 (0.72, 1.18)	0.93 (0.75, 1.21)	−2.08	0.037
LDL-C(mmol/L)	2.16±0.77	2.18±0.79	2.14±0.73	0.93	0.352
HDL-C(mmol/L)	1.42±0.38	1.39±0.36	1.47±0.41	−4.30	<0.001
SBP (mmHg)	112.1±11.3	113.8±11.5	109.3±10.4	8.39	<0.001
DBP (mmHg)	68.0±8.0	67.3±8.1	69.0±7.7	−4.44	<0.001
MHNW	1137 (66.3)	725 (68.3)	412 (63.1)	23.00	<0.001
MUNW	161 (9.4)	71 (6.7)	90 (13.8)		
MHO	129 (7.5)	85 (8.0)	44 (6.7)	0.39	0.534
MUO	287 (16.7)	180 (17.0)	107 (16.4)		

Abbreviations: BMI, body mass index; WC, waist circumference; HC, hip circumference; WHtR, waist-to-height ratio; WHR, waist-to-hip ratio; AST, abdominal skinfold thickness; lnCLAP, logarithmic children lipid accumulation product; VAI, visceral adiposity index; FPG, fasting plasma glucose; TC, total cholesterol; TG, triacylglycerol; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; SBP, systolic blood pressure; DBP, diastolic blood pressure; MHNW, metabolically healthy normal-weigh; MUNW, metabolically unhealthy normal-weight; MHO, metabolically healthy overweight or obesity; MUO, metabolically unhealthy overweight or obesity.

VAI-z ≥ 1 and WC-z ≥ 1 were the risk factors for boys, and LnCLAP-z ≥ 1 and VAI-z ≥ 1 were the risk factors for girls. LnCLAP-z ≥ 1, VAI-z ≥ 1 and WC-z ≥ 1 increased the risk of MUO phenotype, the OR and 95% CI were 2.67 (1.40–5.09), 10.30 (3.03–35.03) and 2.19 (1.18–4.09), respectively (all *P* < 0.05). After gender stratification, the results showed that LnCLAP-z ≥ 1, VAI-z ≥ 1 and BMI-z were the risk factors for boys, and VAI-z ≥ 1 was the risk factors for girls.

Table 3 reports the result of ROC curve analysis. CLAP combining VAI performed better than other indicators in detecting metabolically unhealthy phenotype in both genders. The AUC was 0.837 (0.776–0.899) for boys in predicting MUNW phenotype, followed by VAI (0.822, 0.759–0.885) and CLAP (0.780, 0.713–0.846), and the AUC was 0.876 (0.834–0.918) for girls, followed by CLAP (0.869, 0.826-0.912) and VAI (0.832, 0.782–0.882) (all *P* < 0.001). Among overweight and obese boys and girls, the AUC of the combination of CLAP and VAI in predicting MUO phenotype were 0.853 (0.803–0.903) and

0.794 (0.711–0.878), respectively, followed by VAI (0.837, 0.789–0.884; 0.779, 0.705–0.852) and CLAP (0.823, 0.762–0.883; 0.748, 0.659–0.838) (all *P* < 0.001). All the traditional obesity indexes could identify MUNW and MUO phenotype, the AUC ranged from 0.675 to 0.711 and 0.706 to 0.731, respectively (all *P* < 0.001).

Discussion

Our study indicated that compared with traditional obesity indicators, CLAP and VAI showed greater power in predicting unhealthy metabolic phenotype among Chinese children and adolescents. However, the combination of CLAP and VAI performed better than the two indicators independently in identifying metabolically unhealthy phenotype.

The prevalence of metabolic phenotypes varied depending on population sources, age ranges, and the definition and classification. Research for Chinese children and adolescents aged 6–18 years indicated that the prevalence of metabolically unhealthy non-obesity and

Table 2 The Associations Between CLAP, VAI, Traditional Adiposity Indicators and Unhealthy Metabolic Phenotype Using Logistic Regressions Among Children and Adolescents

Variables	MUNW					MUO				
	β	SE	Wald	OR(95% CI)	P value	β	SE	Wald	OR(95% CI)	P value
Total										
LnCLAP-z										
<1	0			1.00		0			1.00	
≥ 1	1.43	0.45	10.31	4.18 (1.75–10.02)	0.001	0.98	0.33	8.91	2.67 (1.40–5.09)	0.003
VAI-z										
<1	0			1.00		0			1.00	
≥ 1	3.18	0.32	97.48	24.05 (12.79–45.21)	<0.001	2.33	0.63	13.94	10.30 (3.03–35.03)	<0.001
WC-z										
<1	0			1.00		0			1.00	
≥ 1	1.82	0.86	4.44	6.17 (1.14–33.51)	0.035	0.79	0.32	6.11	2.19 (1.18–4.09)	0.013
WHR-z										
<1	0			1.00						
≥ 1	0.99	0.47	4.46	2.69 (1.07–6.72)	0.035					
Boys										
LnCLAP-z										
<1						0			1.00	
≥ 1						1.23	0.40	9.25	3.41 (1.55–7.50)	0.002
VAI-Z										
<1	0			1.00		0			1.00	
≥ 1	3.59	0.42	72.55	36.22 (15.86–82.74)	<0.001	2.43	0.77	10.11	11.38 (2.54–50.99)	0.001
BMI-z										
<1						0			1.00	
≥ 1						1.03	0.40	6.78	2.80 (1.29–6.09)	0.009
WC-z										
<1	0			1.00						
≥ 1	4.05	1.15	12.38	57.22 (6.00–545.52)	<0.001					
Girls										
LnCLAP-z										
<1	0			1.00						
≥ 1	2.22	0.66	11.25	9.23 (2.52–33.85)	0.001					
VAI-z										
<1	0			1.00		0		1.00		
≥ 1	2.94	0.48	38.26	18.91 (7.45–47.99)	<0.001	2.81	1.04	7.26	16.62 (2.15–128.29)	0.007

Notes: used step forward regression. LnCLAP-z, VAI-z, BMI-z, WC-z, WHtR-z and WHR-z was the standardized logarithmic CLAP, VAI, BMI, WC, WHtR and WHR for sex and age using the z-score method.
Abbreviations: lnCLAP, logarithmic children lipid accumulation product; VAI, visceral adiposity index; BMI, body mass index; WC, waist circumference; WHtR, waist-to-height ratio; WHR, waist-to-hip ratio; MUNW, metabolically unhealthy normal-weight; MUO, metabolically unhealthy overweight or obesity.

metabolically unhealthy obesity were 11.4% and 6.5%, respectively.[6] Another cross-sectional study from China showed that the prevalence of MUNW and MHO in the whole population were 10.6% and 15.3%, and boys had a higher prevalence than girls (MUNW, 11.7% VS 9.5%, MHO, 17.8% VS 12.6%).[5] The prevalence of unhealthy metabolic phenotypes in our results was different from the above studies, and we found that girls had a higher

Table 3 ROC Curve Analysis of the CLAP, VAI and Traditional Adiposity Indicators for Predicting Unhealthy Metabolic Phenotype Among Children and Adolescents

Test Variables	MUNW			MUO		
	AUC±SE	95% CI	*P* value	AUC±SE	95% CI	*P* value
Total						
LnCLAP	0.828±0.020	0.789–0.866	<0.001	0.794±0.025	0.745–0.844	<0.001
VAI	0.829±0.020	0.789–0.868	<0.001	0.813±0.021	0.772–0.853	<0.001
BMI	0.675±0.024	0.628–0.721	<0.001	0.710±0.028	0.654–0.766	<0.001
WC	0.711±0.024	0.665–0.758	<0.001	0.731±0.027	0.677–0.784	<0.001
WHtR	0.683±0.024	0.636–0.731	<0.001	0.706±0.028	0.651–0.761	<0.001
WHR	0.692±0.024	0.645–0.738	<0.001	0.708±0.027	0.655–0.761	<0.001
LnCLAP combining VAI	0.851±0.019	0.813–0.889	<0.001	0.826±0.022	0.782–0.870	<0.001
Boys						
LnCLAP	0.780±0.034	0.713–0.846	<0.001	0.823±0.031	0.762–0.883	<0.001
VAI	0.822±0.032	0.759–0.885	<0.001	0.837±0.024	0.789–0.884	<0.001
BMI	0.617±0.036	0.547–0.686	0.001	0.770±0.032	0.707–0.833	<0.001
WC	0.661±0.035	0.592–0.729	<0.001	0.785±0.031	0.724–0.846	<0.001
WHtR	0.606±0.038	0.532–0.681	0.003	0.764±0.032	0.702–0.826	<0.001
WHR	0.639±0.038	0.565–0.714	<0.001	0.751±0.032	0.687–0.814	<0.001
LnCLAP combining VAI	0.837±0.032	0.776–0.899	<0.001	0.853±0.026	0.803–0.903	<0.001
Girls						
LnCLAP	0.869±0.022	0.826–0.912	<0.001	0.748±0.046	0.659–0.838	<0.001
VAI	0.832±0.025	0.782–0.882	<0.001	0.779±0.038	0.705–0.852	<0.001
BMI	0.723±0.031	0.662–0.784	<0.001	0.598±0.053	0.494–0.701	0.060
WC	0.751±0.031	0.690–0.812	<0.001	0.629±0.051	0.528–0.730	0.013
WHtR	0.741±0.030	0.682–0.800	<0.001	0.593±0.052	0.490–0.695	0.074
WHR	0.720±0.030	0.662–0.778	<0.001	0.638±0.049	0.543–0.733	0.008
LnCLAP combining VAI	0.876±0.021	0.834–0.918	<0.001	0.794±0.043	0.711–0.878	<0.001

Abbreviations: AUC, area under the curve; lnCLAP, logarithmic children lipid accumulation product; VAI, visceral adiposity index; BMI, body mass index; WC, waist circumference; WHtR, waist-to-height ratio; WHR, waist-to-hip ratio; MUNW, metabolically unhealthy normal-weight; MUO, metabolically unhealthy overweight or obesity.

prevalence of MUNW than boys (13.8% VS 6.7%). It could be explained by the different criteria for metabolic phenotypes and age ranges, and overweight children and adolescents were classified as MUO phenotype in our study.

In our study, CLAP and VAI were risk factors for the unhealthy metabolic phenotypes. Cross-sectional studies for Chinese children and adolescents aged 8–15 indicated that with adjustment of age, sex, moderate-to-vigorous physical activity time, risk dietary behaviors and sedentary activity time, CLAP $\geq P_{75}$ increased the risk of MetS, the adjusted OR and 95% CI was 150.75 (20.11–1130.19),[16] and LnCLAP-z ≥ 1 had a higher risk of hypertension, the adjusted OR and 95% CI was 3.70 (2.22–6.16).[26] A study from Riyadh city, Saudi Arabia, showed that VAI was positively associated with insulin resistance among 4–17-year-old children and adolescents.[27] These findings supported our results.

Some research investigated the predictive capacity of LAP, VAI and traditional obesity indicators in detecting metabolically unhealthy phenotype among adults. Results revealed that compared with BMI, WC, WHtR, WHR and neck circumference, VAI showed a stronger association and better predictive capacity, and the AUC for MUNW and MUO were 0.865 and 0.830 for men, 0.847 and 0.903 for women.[19] Data from China Health and Nutrition Survey (CHNS) reported that both LAP and VAI were strongly associated with MUNW phenotypes, and the predictive power of LAP and VAI was superior to that of traditional obesity indicators, even when different criteria were used to define MUNW. Moreover, the AUC of LAP and VAI ranged from 0.606 to 0.807 and 0.611 to 0.835, respectively.[18] Studies for Chinese children and adolescents showed that compared with traditional obesity indicators, CLAP was an effective index in predicting MetS, hypertension and impaired fasting glucose, with AUC and

95% CI of 0.944 (0.913–0.975), 0.668 (0.601–0.735) and 0.637 (0.562–0.712), respectively.[16,26,28] What is more, similar findings were found in adults, where LAP and VAI performed better in predicting MetS than traditional obesity indicators.[15,29] These findings were consistent with ours and supported our findings. CLAP and VAI were more effective at predicting unhealthy metabolic phenotype than traditional obesity indicators, probably because CLAP and VAI could reflect visceral fat accumulation to some extent, while traditional obesity indicators provided some information about fat distribution, but cannot distinguish visceral fat and subcutaneous fat.[30]

Nevertheless, a population-based prospective cohort of adults demonstrated that LAP was an independent predictor of MUNW phenotype, but had no significant superiority over BMI, WC, WHR and WHtR.[31] According to the International Diabetes Federation (IDF) criteria, WHtR was a preferred index in predicting MetS than LAP, BMI, WHR and body Adiposity Index (BAI) among the Kazakh Adult Population in Xinjiang.[32] Liu et al[33] found that WC was the most effective index over LAP, BMI and WHtR for identifying MetS in rural Chinese adults. Wang et al[34] found that compared with LAP, VAI, WC and BAI, BMI was the index that was strongly related to the risk of hypertension in Chinese adults. These results were not consistent with ours, which may be due to differences in the basic characteristics of the population, age range, inconsistent definitions and the different associations between these indicators and MetS components.

Furthermore, we found that the combination of CLAP and VAI showed stronger predictive ability in identifying unhealthy metabolic phenotype than CLAP, VAI and traditional obesity indicators. To a certain extent, CLAP reflected the accumulation of body lipid, VAI showed the accumulation of visceral fat. The excess lipid fuel is eventually manifested as abdominal enlargement or as elevated circulating TG.[14] The effect of CLAP combining VAI for detecting unhealthy metabolic phenotype was higher than that of CLAP and VAI, which may be that the combination of CLAP and VAI reflected the superposition effect of TG and WC. Currently, the underlying mechanisms for CLAP, VAI and unhealthy metabolic phenotype were unclear, the possible mechanisms were as follows. First, the accumulation of ectopic lipids led to insulin resistance (IR) in muscle tissue, which increased liver adipogenesis, and led to liver IR and hyperlipidemia.[35–37] Second, adipose tissue inflammation was involved in the link between obesity and metabolic diseases, macrophages infiltrated the white adipose tissue and increased lipolysis, which stimulated hepatic triglyceride synthesis, thereby promoting hyperlipidemia.[38] Third, compared to abdominal adipose tissue, visceral adipose tissue (VAT) secreted more pro-inflammatory cytokines, such as higher levels of TNF-α, which may be involved in the pathogenesis of hypertension.[39]

Our study provided a reference for understanding the ability of different indicators to predict unhealthy metabolic phenotype. However, there were some limitations in the study should be noted. First, this cross-sectional study limited the causal interpretation of the observed associations. Second, our results may vary depending on the diagnostic criteria of metabolic phenotype. Third, due to the age and race limitations of participants, the results could not be generalized to other populations. Fourth, some confounding factors were not assessed in this study, such as lifestyle and physical activity, which might have influenced our results. Fifth, the application of VAI formula derived from adults to a population under the age of 19 may have an impact on the results. The specific formula for calculating VAI for children and adolescents needed to explore in a larger sample size for future research.

Conclusions

In conclusion, compared with CLAP, VAI and traditional obesity indicators, CLAP combining VAI was the better index for the screening of unhealthy metabolic phenotype in both genders. We suggest that the combination of CLAP and VAI could be considered as an effective index in predicting metabolically unhealthy phenotype among Chinese children and adolescents.

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Disclosure

The authors declare that they have no conflicts of interest.

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