BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2024-095049
Article Type:	Original research
Date Submitted by the Author:	14-Oct-2024
Complete List of Authors:	Wu, Lijun; Capital Institute of Pediatrics, Department of Epidemiology Huang, Yiying; Capital Institute of Pediatrics, Department of Epidemiology Chen, Yiren; Capital Institute of Pediatrics, Department of Epidemiology Liao, Zijun; Capital Institute of Pediatrics, Department of Epidemiology Li, Shaoli; Capital Institute of Pediatrics, Department of Epidemiology Liu, Junting; Capital Institute of Pediatrics, Department of Epidemiology Zong, Xin Nan; Capital Institute of Pediatrics, Department of Epidemiology Chen, Fangfang; Capital Institute of Pediatrics, Department of Epidemiology
Keywords:	Epidemiology < TROPICAL MEDICINE, Obesity, Other metabolic, e.g. iron, porphyria < DIABETES & ENDOCRINOLOGY

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Sex differences in associations between body composition and cardiometabolic indicators in children: a population-based cross-sectional study

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Keywords: fat mass; fat-free mass; body composition; cardiometabolic indicators; sex difference

Running title: sex differences in body composition and cardiometabolic indicators

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Word count:2628

ABSTRACT

Introduction Obesity is a growing global public health problem that increases the risk of cardiovascular disease. The aim of the present study was to assess the effects of body composition on cardiometabolic indicators in children.

Methods This cross-sectional study included 5555 children and adolescents aged 6 to 17 years from 11 kindergartens and schools between 2022 and 2023. We measured body composition using multifrequency bioelectrical impedance analysis, and detected the cardiometabolic indicators, including blood pressure, plasma glucose, and lipids. Linear regression and binary logistic regression were performed to assess the associations between body composition and cardiometabolic abnormalities.

Results In boys, fat mass index (FMI) was positively correlated with total cholesterol (TC) and fasting plasma glucose (FPG), and fat-free mass index (FFMI) was negatively associated with TC only in the normal fat group. However, in girls, FMI was not significantly associated with TC and was positively associated with FPG only in the normal fat-free mass (FFM) group, and FFMI was negatively correlated with TC. Normal FFM-high fat and increased visceral fat region were risk factors for high TC in boys but not in girls.

Conclusion Body composition was significantly associated with cardiometabolic risk factors, and fat stored in different regions has differential influences on cardiometabolic indicators. There were sex differences in the relationships between body composition and cardiometabolic indicators. The findings suggest that body composition is more strongly correlated with cardiometabolic indicators in boys than in girls. Prevention of

obesity and cardiometabolic abnormalities may be more important in boys.

key messages

What is already known on this topic

• Fat mass is associated with adverse cardiometabolic risk markers.

• Fat distribution and location are associated with adverse cardiometabolic risk markers.

• Research among children is still largely lacking.

What this study adds

• Fat-free and fat levels are correlated with cardiometabolic indicators, and fat stored in different regions has differential influences on cardiometabolic indicators in Chinese children.

• The relationships between body composition and cardiometabolic risk factors are influenced by sex in Chinese children.

How this study might affect research, practice or policy

• The findings suggest that body composition is more strongly correlated with cardiometabolic indicators in boys than in girls.

• Prevention of obesity and cardiometabolic abnormalities may be more important in boys.

• Sex differences in obesity-related cardiometabolic abnormalities should be considered in preventive interventions.

INTRODUCTION

Childhood obesity has become a growing public health problem worldwide,[1] and its prevalence is continuously increasing in China.[2] Children with obesity have a greater risk of obesity in adulthood and are predisposed to develop cardiometabolic diseases, including type 2 diabetes, hypertension, and dyslipidemia.[3 4] The early prevention of childhood obesity may be critical to health in childhood and adulthood.

Although body mass index (BMI) is a commonly used measure of obesity, it is limited by the inability to distinguish between different body composition compartments. BMI cannot provide information about fat mass (FM) or fat-free mass (FFM). Studies have shown that FM could be a better predictor of adiposity-related metabolic risk than BMI.[5-7] Children without obesity according to BMI but with obesity based on body fat percentage might have increased cardiometabolic risk factors.[8]

It is well established that excess FM is associated with adverse cardiometabolic risk markers. Increased body FM is related to a progressively worsening risk of hyperglycemia and hyperinsulinemia.[9] FM can also affect blood pressure (BP) and blood lipids.[10 11] In contrast, a higher muscular fitness index is associated with a better cardiometabolic profile.[12] Greater muscle mass (MM) might have a protective impact on cardiometabolic traits, such as hyperglycemia, high low-density lipoprotein cholesterol (LDL-C), and high total cholesterol (TC).[13] However, FM seems more robustly associated with cardiometabolic profiles than MM;[14] thus, FM might be more

important than MM in relation to cardiometabolic profiles.[15]

In recent years, the importance of fat distribution and location in the risk of cardiometabolic diseases has been highlighted. It has been shown that the trunk-to-peripheral fat ratio can predict subsequent BP levels, and the relationship between fat distribution and BP is independent of fat volume.[16] The trunk-to-leg fat ratio was significantly associated with high LDL-C and triglycerides (TG) concentrations, and it seemed to be an independent risk factor for these cardiometabolic indicators.[17] Visceral adiposity has been identified as a cardiometabolic indicator reflecting abdominal fat distribution. Abnormally high deposition of visceral adipose tissue is related to cardiometabolic risk factors, and visceral adiposity does not always depend on BMI.[18]

The influence of different body composition phenotypes on cardiometabolic indicators is very important, but very little research has been conducted in children. The purpose of the present study was to explore the effects of body composition and fat distribution and location on cardiometabolic indicators in Chinese children and adolescents.

METHODS

Study design and participants

We investigated the relationship between body composition and metabolic parameters and the sex differences in these relationships. This study collected baseline data from the Beijing Children and Adolescents Health Cohort Study. The subjects were randomly selected from 11 kindergartens and primary and secondary schools in a district of Beijing between 2022 and 2023. A total of 5555 children and adolescents

aged 6 to 17 years participated in the baseline survey, except those who could not participate in the physical examination due to trauma and physical discomfort. We obtained written informed consent from participants/guardians. The studies involving human participants were reviewed and approved by the ethics committee of Capital Institute of Pediatrics, Beijing, China (SHERLL2022043). This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines for cross-sectional studies.

Patient and public involvement

The subjects were randomly selected from 11 kindergartens and primary and secondary schools in a district of Beijing, China, between 2022 and 2023.

Data collection

Questionnaire

The questionnaires were completed by the participants/guardians to collect information on demographic characteristics, personal and family medical history, and lifestyle factors.

Physical examination data

To address potential sources of bias, all assessments were conducted by trained data collectors, most of whom were nurses and doctors. The quality control of the examinations was performed by the same professional researchers who strictly followed a standardized protocol. All participants fasted after 20:00 the day before the physical examination. The height of the children was measured by trained staff using a Harpenden Portable Stadiometer (UK), and the weight was measured by bioelectrical

impedance analysis (BIA). Then, BMI was calculated as weight in kilograms divided by height in meters squared. All instruments used were the same in the 11 kindergartens and schools during the survey.

BP measurements

Oscillometric sphygmomanometers (HBP-1300, Omron, Kyoto, Japan) were used to measure systolic blood pressure (SBP) and diastolic blood pressure (DBP). The testing was performed in a warm and quiet room. Each participant was seated with their back supported, legs uncrossed, and feet on the floor. The observers measured the circumference at the midpoint of the right arm and selected an appropriate cuff. Three consecutive measurements were performed, and the average value of the last two measurements was recorded as the BP value.

Multifrequency bioelectrical impedance analysis (MFBIA)

MFBIA measurements were conducted using BIA (H-Key350, SeeHigher BAS-H, China), which measured impedance at varying frequencies (1, 5, 50, 250, 500 and 1,000 kHz) across the legs, arms and trunk. Children were required to be on fasting and have an empty bladder. During the measurement, the children in light clothing stood on the platform without shoes and held both hands at a 45-degree angle away from the body; four tactile electrodes were in contact with the palm and thumb of both hands, and the other four were in contact with the anterior and posterior aspects of the sole of both feet. The measurements were collected, and then the FM and FFM were calculated by an undisclosed proprietary algorithm. Fat mass index (FMI) and fat-free mass index (FFMI) were also calculated for each subject as FM and FFM in kilograms divided by

height in meters squared, respectively.

Biochemical measurements

After an overnight fast of at least 12 hours, blood samples were collected by direct venipuncture into ethylene diamine tetraacetic acid anticoagulant tubes. Blood samples were analyzed for concentrations of fasting plasma glucose (FPG), TG, TC, LDL-C, and high-density lipoprotein cholesterol (HDL-C). FPG was determined by the enzyme hexokinase method. Serum TC concentrations were determined using the standard enzymatic method. Serum TG concentrations were determined using the GPO-PAP method. Serum HDL-C and LDL-C were measured using the direct method. The serum lipid levels and plasma glucose levels were assayed using an automatic biochemistry analysis system (Siemens, Germany).

Classification standards and definitions

Elevated BP[19 20]: SBP and/or DBP ≥ 90th percentile for age and sex, 6 years old, reference 19; 7-17 years old, reference 20

High TC[21]: TC ≥ 5.18 mmol/L

Low HDL-C[21]: HDL-C < 1.03 mmol/L

High LDL-C[21]: LDL-C ≥ 3.36 mmol/L

High TG[22]: 6-9 years old, TG ≥ 1.12 mmol/L; 10-18 years old, TG ≥ 1.46 mmol/L

Impaired fasting glucose (IFG)[23]: FPG ≥ 5.6 mmol/L

BMI: weight (kg)/[height (m)]^2

FMI: FM (kg)/[height (m)]^2

Muscle mass index (MMI): MM (kg)/[height (m)]^2

FFMI: FFM (kg)/[height (m)]^2

Fat mass percentage (FMP): FM (kg)/weight (kg) × 100%.

Arm fat mass (mean): [left arm fat mass (kg)+ right arm fat mass (kg)]/2

Leg fat mass (mean): [left leg fat mass (kg)+ right leg fat mass (kg)]/2

High FFM: the FFMI Z score was calculated, and a Z value ≥1 was defined as a high FFM level

High fat: the FMI Z score was calculated, and a Z value ≥1 was defined as a high fat level

Normal FFM: the FFMI Z score was calculated, and a Z value <1 was defined as a normal FFM level

Normal fat: the FMI Z score was calculated, and a Z value <1 was defined as a normal fat level

Normal FFM-normal fat group: both FFM and fat levels were normal

High FFM-normal fat group: FFM level was high, and fat level was normal

Normal FFM-high fat group: FFM level was normal, and fat level was high

High FFM-high fat group: both FFM and fat levels were high

Statistical analysis

Continuous variables were expressed as mean ± standard deviation (SD), and categorical variables were expressed as frequencies with percentages. The independent *t*-test and *Chi-square* analysis were used to compare the differences in basic characteristics between groups. Piecewise regression was used to investigate the associations between high fat or FFM levels and cardiometabolic parameters and

abnormalities. Linear regression and binary logistic regression were used to analyze the associations of FFM-fat composition with cardiometabolic abnormalities and the associations of cardiometabolic parameters with a 1-SD increase in FM. All statistical analyses were performed using SPSS 26.0, and a bilateral $P < 0.05$ was considered statistically significant.

RESULTS

The flow diagram of the study population is shown in Figure S1. A total of 6013 children and adolescents were surveyed at baseline. After children younger than 6 years of age and those without FMI and FFMI values were excluded, 5555 children and adolescents aged 6-17 years were enrolled in the final analysis. A comparison of the basic characteristics of the study sample is reported in Table 1. The study sample was divided into four groups according to fat-free and fat levels: high FFM-high fat group, high FFM-normal fat group, normal FFM-high fat group, and normal FFM-normal fat group. As shown in Table 1, there were differences between the groups in height, weight, and BMI. When fat levels were normal, there were significant differences in SBP, DBP, HDL-C, LDL-C and TG between the high FFM group and the normal FFM group. When fat levels were high, there were significant differences in SBP, DBP, HDL-C and TG between the high FFM group and the normal FFM group.

We quantitatively analyzed the relationships between body composition and cardiometabolic profiles. Table 2 shows the piecewise regression analysis of the associations between the FMI and cardiometabolic indicators stratified by sex and FFM level. Regardless of sex and FFM level, FMI was negatively correlated with HDL-C,

and was positively correlated with SBP, DBP, LDL-C, and TG. In boys, regardless of FFM level, FMI was positively correlated with TC and FPG. However, in girls, FMI was not significantly associated with TC and was positively associated with FPG only in the normal FFM group.

We also analyzed the associations between FFMI and cardiometabolic indicators stratified by sex and fat level. As shown in Table 3, regardless of sex and fat level, FFMI was negatively correlated with HDL-C; positively correlated with SBP, DBP, TG, and FPG; and not linearly correlated with LDL-C. In boys, FFMI was negatively associated with TC only in the normal fat group. However, in girls, regardless of fat level, FFMI was negatively correlated with TC.

To more clearly analyze the sex differences in the relationships between body composition and cardiometabolic indicators, we further performed logistic regression analysis. As shown in Table 4, adjusted for the age of the children, the normal FFM-normal fat group was used as the reference group. Regardless of sex, as long as one of the FFM or fat levels was high, the risk of high BP and low HDL-C increased; the risk of high TG increased in high fat group; and FFM-fat composition was not a risk factor for high IFP. Normal FFM-high fat was a risk factor for high TC in boys but not in girls. In boys, as long as one of the FFM or fat levels was high, the risk of high LDL-C increased. However, in girls, the risk of high LDL-C increased only in the high fat group. We used two models to analyze the influence of fat distribution on cardiometabolic indicators by logistic regression analysis: Model 1, trunk fat mass, arm fat mass, and leg fat mass as independent variables; Model 2, the visceral fat region was used as an

independent variable.

As shown in Table 5, increased visceral fat region was a risk factor for elevated BP, low HDL-C, high LDL-C, high TG and IFG, and increased trunk fat mass was a risk factor for elevated BP, low HDL-C and high TG. However, increased arm fat mass was a protective factor against elevated BP and low HDL-C.

In boys, increased visceral fat region was a risk factor for high TC, increased trunk fat mass was a risk factor for high LDL-C, increased leg fat mass was a risk factor for high TC and high TG, and increased arm fat mass was a protective factor for high TG and a risk factor for IFG (Table 5). However, none of these correlations were detected in girls.

DISCUSSION

In our study, we analyzed the associations of FFM-fat composition with blood pressure, glucose, and lipids. Our results showed that FFM and fat levels were correlated with cardiometabolic indicators, and there were sex differences in the relationships between body composition and cardiometabolic indicators.

Because of the possible differences in the correlations of adiposity with cardiometabolic risk between males and females, sex differences in cardiometabolic abnormalities are commonly observed across the life course. Our results indicated that the associations between body composition and cardiometabolic indicators differed between boys and girls. Some studies have also shown sex differences between fat mass and cardiometabolic risk factors. For instance, Kouda et al. reported that the trunk-to-appendicular fat ratio at baseline was significantly associated with SBP at follow-up in

boys, but there were no significant associations between the trunk-to-appendicular fat ratio and SBP in girls.[16] Duran et al. reported that the trunk-to-leg fat ratio was significantly associated with high LDL-C only in girls.[17] Sex differences have also been shown in the associations between insulin resistance and adiposity indices, and these differences were significantly more evident in middle puberty.[24] The correlations of adiposity with adverse cardiometabolic risk seem to begin earlier in the life course among males than females.[25] Partly consistent with these findings, our results have shown stronger correlations between body composition and cardiometabolic indicators in boys than in girls. Thus, prevention of obesity and cardiometabolic abnormalities may be more important in boys.

It is well known that regional adipose compartments confer different cardiometabolic risks in children. We also found that fat stored in different regions has differential influences on cardiometabolic indicators. However, our results showed that increased arm fat mass was a protective factor against elevated BP and low HDL in children. Previous studies inconsistently reported that arm fat mass was not significantly associated with cardiometabolic risk factors.[26 27]

Our results (Tables 2 and 3) showed that FMI and FFMI were linearly correlated with FPG, but Table 4 showed that FFM-fat composition was not a risk factor for IFG. Further analysis of the relationships between the fat distribution region and cardiometabolic indicators (Table 5) indicated that increased visceral fat region was a risk factor for IFG regardless of sex, suggesting the important influence of visceral fat on glucose metabolism.

In addition, our results showed that high FFM-normal fat was a risk factor for elevated BP, low HDL and high LDL in boys. This finding is inconsistent with a previous study showing that greater muscle mass might have a protective impact on cardiometabolic indicators.[13] There is a need for more high-quality prospective studies to determine these associations.

Limitations

This study is not without limitations. First, this cross-sectional study recruited children from 11 kindergartens and schools in a district in Beijing who might not represent all children and adolescents, likely resulting in selection bias. Second, due to the small number of children with obesity in this study, it is necessary to verify the results in prospective investigations with larger sample sizes. Third, because of the small number of participants stratified by puberty, the study did not analyze the effects of puberty on the relationship between FM or FFM and cardiometabolic risk markers. Finally, although some studies have shown a stronger association between hepatic fat and cardiometabolic indicators than between abdominal fat and cardiometabolic indicators and that these associations are independent of BMI,[28 29] this study lacked an analysis of these associations due to the limited data.

CONCLUSION

Our results indicate that body composition is significantly associated with cardiometabolic risk factors and that fat stored in different regions has differential influences on cardiometabolic indicators. The relationships between body composition and cardiometabolic risk factors are influenced by sex in children and adolescents. This

finding suggested that body composition was more strongly correlated with cardiometabolic indicators in boys than in girls. Sex differences in obesity-related cardiometabolic abnormalities should be considered in preventive interventions.

Acknowledgements

The authors thank the children and their parents for their participation in the study. We also thank all team members who contributed to the study.

Contributors

Fangfang Chen conceptualized and designed the study, carried out the analyses, and reviewed and revised the manuscript. Lijun Wu wrote the initial draft of the manuscript. Yiying Huang and Yiren Chen analyzed the data. Zijun Liao, Shaoli Li, Junting Liu, and Xinnan Zong were involved in data acquisition and data processing. All authors critically reviewed the manuscript for interpretation and intellectual content and approved the final manuscript as submitted. Fangfang Chen is the corresponding authors.

Funding

This research was funded by the public service development and reform pilot project of Beijing Medical Research Institute, grant number BMR2021-3, the Beijing Municipal Administration of Hospitals Incubating Program, grant number Px2022052, and the China Soong Ching Ling Foundation, grant number 2023-24.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the

design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval

We obtained written informed consent from participants/guardians. The studies involving human participants were reviewed and approved by the ethics committee of Capital Institute of Pediatrics, Beijing, China (SHERLL2022043).

Data availability statement

All data relevant to the study are included in the article or uploaded as supplementary information.

Supplemental material

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Table 1 Baseline characteristics of the study subjects stratified by body composition

	N	Normal fat		*P*	High fat		*P*
		Normal FFM	High FFM		Normal FFM	High FFM	
Number (%)							
Boys	2844	2169 (50.61)	179 (51.73)	0.687	269 (61.14)	227 (47.00)	**<0.001**
Girls	2711	2117 (49.39)	167 (48.27)	0.687	171 (38.86)	256 (53.00)	**<0.001**
Demography/anthropometry							
Age (years)	5555	10.56±3.07	10.45±3.03	0.541	10.44±2.99	10.79±2.97	0.077
Height (cm)	5555	146.92±17.49	151.37±17.66	**<0.001**	148.75±15.89	154.02±15.29	**<0.001**
Weight (kg)	5555	41.05±15.38	55.35±20.22	**<0.001**	58.68±19.49	71.78±22.27	**<0.001**
BMI (kg/m^2)	5555	18.29±3.32	23.12±3.76	**<0.001**	25.72±3.64	29.42±4.17	**<0.001**
Cardiometabolic indicators							
SBP (mmHg)	5546	107.83±10.92	115.82±11.88	**<0.001**	117.09±11.43	121.50±10.88	**<0.001**
DBP (mmHg)	5546	59.94±7.29	61.71±7.48	**<0.001**	64.64±7.82	65.66±7.66	**0.046**
TC (mmol/L)	5405	4.12±0.70	4.11±0.79	0.706	4.30±0.72	4.26±0.69	0.395
HDL-C (mmol/L)	5400	1.53±0.34	1.39±0.33	**<0.001**	1.31±0.29	1.23±0.27	**<0.001**
LDL-C (mmol/L)	5405	2.50±0.68	2.63±0.78	**0.001**	2.92±0.76	2.92±0.72	0.992
TG (mmol/L)	5401	0.83±0.37	0.94±0.50	**<0.001**	1.14±0.54	1.32±0.59	**<0.001**
FPG (mmol/L)	5401	4.92±0.52	4.91±0.40	0.665	4.98±0.61	5.00±0.87	0.607
Body composition indicators							
FMP (%)	5555	20.87±8.31	24.98±7.33	**<0.001**	39.39±4.52	39.30±4.67	0.767

FMI (kg/m^2)	5555	4.02±2.16	5.94±2.28	**<0.001**	10.18±2.09	11.65±2.59	**<0.001**
MMI (kg/m^2)	5555	13.43±1.73	16.19±2.20	**<0.001**	14.62±2.01	16.74±2.18	**<0.001**
FFMI (kg/m^2)	5555	14.27±1.83	17.18±2.34	**<0.001**	15.54±2.14	17.79±2.33	**<0.001**
Arm fat mass (kg)	5555	0.66±0.41	0.99±0.53	**<0.001**	1.83±0.84	2.35±1.13	**<0.001**
Leg fat mass (kg)	5555	1.63±0.86	2.32±0.98	**<0.001**	3.65±1.14	4.25±1.26	**<0.001**
Trunk fat mass (kg)	5555	3.75±3.31	6.81±4.11	**<0.001**	11.24±4.24	13.95±4.79	**<0.001**
Visceral fat region (m^2)	5555	40.56±26.99	59.13±33.15	**<0.001**	119.01±42.33	135.91±45.45	**<0.001**
Fat mass (kg)	5555	9.17±5.94	14.39±7.23	**<0.001**	23.29±8.24	28.38±9.62	**<0.001**
Muscle mass (kg)	5555	30.00±10.41	38.54±13.55	**<0.001**	33.45±11.13	40.93±12.91	**<0.001**

Continuous variables shown as mean ± standard deviation.

P values were from tests comparing two groups by independent *t*-tests or *Chi-square* tests. Those highlighted in bold indicate statistical significance (bilateral $P < 0.05$).

FFM, fat-free mass; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; FPG, fasting plasma glucose; FMP, fat mass percentage; FMI, fat mass index; MMI, muscle mass index; FFMI, fat free mass index.

Table 2 Piecewise regression results of the associations between FMI and cardiometabolic indicators stratified by sex and FFM level

	Boys				Girls			
	Normal FFM		High FFM		Normal FFM		High FFM	
Parameters	*β*	95%*CI*	*β*	95%*CI*	*β*	95%*CI*	*β*	95%*CI*
SBP	**1.673**	**(1.536, 1.810)**	**1.136**	**(0.836, 1.436)**	**1.975**	**(1.828, 2.121)**	**1.234**	**(0.988, 1.480)**
DBP	**0.874**	**(0.783, 0.965)**	**0.840**	**(0.655, 1.026)**	**1.038**	**(0.923, 1.152)**	**0.825**	**(0.639, 1.011)**
TC	**0.036**	**(0.027, 0.046)**	**0.034**	**(0.016, 0.051)**	0.001	(-0.010, 0.012)	0.004	(-0.017, 0.024)
HDL-C	**-0.040**	**(-0.045, -0.036)**	**-0.024**	**(-0.032, -0.016)**	**-0.046**	**(-0.051, -0.042)**	**-0.032**	**(-0.039, -0.025)**
LDL-C	**0.077**	**(0.068, 0.086)**	**0.056**	**(0.037, 0.074)**	**0.041**	**(0.030, 0.052)**	**0.026**	**(0.006, 0.047)**
TG	**0.059**	**(0.054, 0.064)**	**0.052**	**(0.039, 0.065)**	**0.050**	**(0.044, 0.055)**	**0.058**	**(0.042, 0.074)**
FPG	**0.019**	**(0.012, 0.026)**	**0.030**	**(0.005, 0.054)**	**0.033**	**(0.024, 0.041)**	0.011	(0.000, 0.022)

P values were from piecewise regression analysis. Those highlighted in bold indicate statistical significance (bilateral $P < 0.05$).

FFM, fat-free mass; CI, confidence interval; FMI, fat mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; FPG, fasting blood glucose.

Table 3 Piecewise regression results of the associations between FFMI and cardiometabolic indicators stratified by sex and fat level

	Boys				Girls			
	Normal fat		High fat		Normal fat		High fat	
Parameters	*β*	95%*CI*	*β*	95%*CI*	*β*	95%*CI*	*β*	95%*CI*
SBP	**3.182**	**(3.024, 3.340)**	**2.319**	**(1.996, 2.643)**	**3.575**	**(3.313, 3.838)**	**2.128**	**(1.683, 2.573)**
DBP	**0.869**	**(0.746, 0.992)**	**0.619**	**(0.374, 0.865)**	**1.439**	**(1.230, 1.647)**	**1.054**	**(0.705, 1.404)**
TC	**-0.047**	**(-0.069, -0.034)**	-0.018	(-0.040, 0.005)	**-0.058**	**(-0.079, -0.038)**	**-0.049**	**(-0.084, -0.015)**
HDL-C	**-0.064**	**(-0.070, -0.059)**	**-0.046**	**(-0.054, -0.037)**	**-0.063**	**(-0.073, -0.054)**	**-0.041**	**(-0.053, -0.029)**
LDL-C	0.004	(-0.009, 0.016)	0.010	(-0.013, 0.034)	-0.011	(-0.031, 0.009)	-0.033	(-0.069, 0.003)
TG	**0.039**	**(0.032, 0.046)**	**0.049**	**(0.031, 0.067)**	**0.054**	**(0.043, 0.065)**	**0.071**	**(0.044, 0.097)**
FPG	**0.025**	**(0.017, 0.034)**	**0.045**	**(0.015, 0.076)**	**0.056**	**(0.041, 0.072)**	**0.036**	**(0.017, 0.055)**

P values were from piecewise regression analysis. Those highlighted in bold indicate statistical significance (bilateral $P < 0.05$).
FFMI, fat-free mass index; CI, confidence interval; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; FPG, fasting blood glucose.

Table 4 Adjusted ORs for the associations of FFM-fat composition with blood pressure, glucose, and lipid metabolic abnormalities stratified by sex

	Boys		Girls	
	OR	95%*CI*	OR	95%*CI*
Elevated BP				
High FFM-normal fat	**2.703**	**(1.835, 3.981)**	**3.612**	**(2.376, 5.491)**
Normal FFM-high fat	**4.476**	**(3.324, 6.027)**	**5.280**	**(3.601, 7.742)**
High FFM-high fat	**6.278**	**(4.625, 8.522)**	**10.364**	**(7.650, 14.043)**
High TC				
High FFM-normal fat	1.357	(0.777, 2.368)	1.080	(0.586, 1.993)
Normal FFM-high fat	**2.065**	**(1.379, 3.091)**	1.187	(0.670, 2.104)
High FFM-high fat	1.343	(0.814, 2.216)	1.344	(0.847, 2.130)
Low HDL-C				
High FFM-normal fat	**2.137**	**(1.309, 3.488)**	**2.669**	**(1.470, 4.846)**
Normal FFM-high fat	**2.794**	**(1.908, 4.089)**	**3.250**	**(1.891, 5.586)**
High FFM-high fat	**4.637**	**(3.234, 6.647)**	**8.892**	**(6.133, 12.894)**
High LDL-C				
High FFM-normal fat	**2.283**	**(1.521, 3.429)**	0.912	(0.526, 1.582)
Normal FFM-high fat	**3.827**	**(2.817, 5.198)**	**2.608**	**(1.775, 3.833)**
High FFM-high fat	**3.607**	**(2.591, 5.020)**	**2.251**	**(1.604, 3.159)**
High TG				
High FFM-normal fat	1.453	(0.923, 2.289)	1.585	(0.967, 2.598)
Normal FFM-high fat	**3.499**	**(2.578, 4.749)**	**3.705**	**(2.535, 5.414)**
High FFM-high fat	**6.686**	**(4.941, 9.048)**	**8.796**	**(6.552, 11.809)**
IFG				
High FFM-normal fat	0.350	(0.110, 1.115)	1.248	(0.491, 3.167)
Normal FFM-high fat	1.642	(0.998, 2.701)	1.156	(0.456, 2.932)
High FFM-high fat	1.442	(0.823, 2.526)	1.760	(0.907, 3.417)

Adjusted for the age of children, normal FFM-normal fat group as the reference group.

P values were from logistic regression analysis. Those highlighted in bold indicate statistical significance (bilateral $P < 0.05$).

OR, odds ratio; FFM, fat-free mass; CI, confidence interval; BP, blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; IFG, impaired fasting glucose.

Table 5 ORs of cardiometabolic risk factors associated with 1-SD increase in fat mass variables

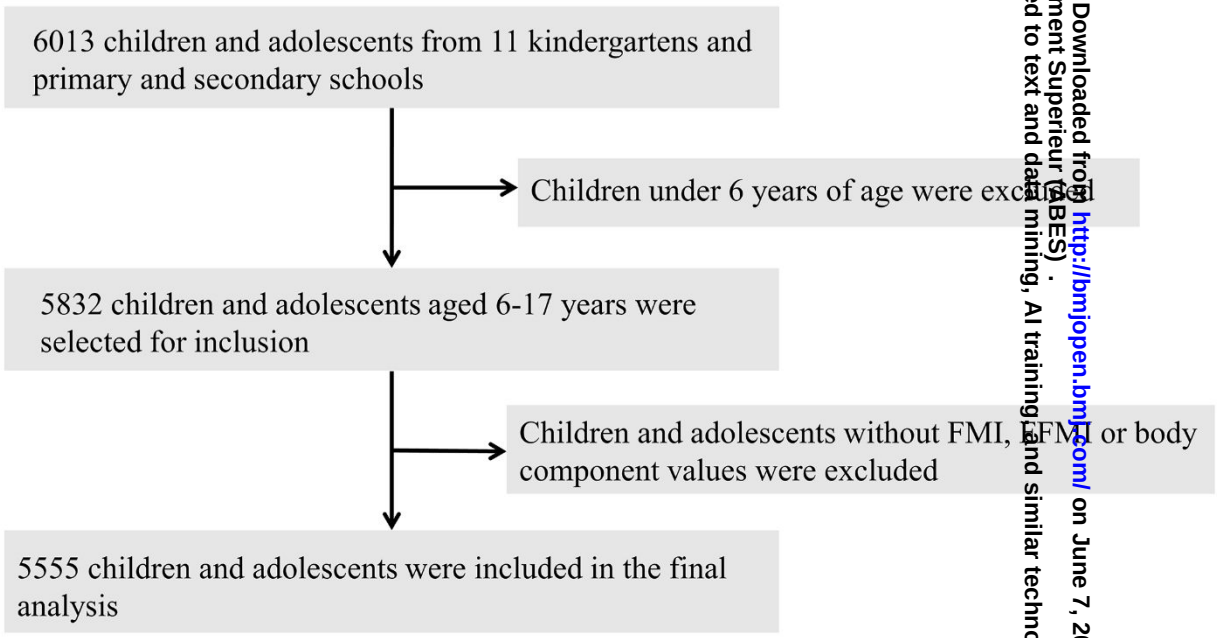
		Boys		Girls	
		OR	95% *CI*	OR	95% *CI*
Elevated BP					
	Trunk fat mass	**7.625**	**(4.184, 13.898)**	**5.153**	**(2.477, 10.717)**
Modle1	Arm fat mass	**0.515**	**(0.367, 0.724)**	**0.545**	**(0.351, 0.847)**
	Leg fat mass	0.616	(0.345, 1.100)	1.200	(0.626, 2.298)
Modle2	Visceral fat region	**2.008**	**(1.822, 2.212)**	**2.583**	**(2.279, 2.929)**
High TC					
	Trunk fat mass	0.510	(0.222, 1.172)	0.984	(0.325, 3.009)
Modle1	Arm fat mass	1.075	(0.711, 1.625)	0.473	(0.210, 1.064)
	Leg fat mass	**2.558**	**(1.120, 5.840)**	2.385	(0.821, 6.931)
Modle2	Visceral fat region	**1.357**	**(1.195, 1.540)**	1.114	(0.946, 1.313)
Low HDL-C					
	Trunk fat mass	**4.255**	**(2.182, 8.295)**	**6.743**	**(2.759, 16.478)**
Modle1	Arm fat mass	**0.518**	**(0.349, 0.700)**	**0.541**	**(0.319, 0.918)**
	Leg fat mass	0.968	(0.486, 1.928)	0.818	(0.381, 1.759)
Modle2	Visceral fat region	**1.788**	**(1.602, 1.995)**	**2.243**	**(1.938, 2.597)**
High LDL-C					
	Trunk fat mass	**1.916**	**(1.043, 3.521)**	1.296	(0.576, 2.916)
Modle1	Arm fat mass	0.747	(0.538, 1.037)	0.651	(0.393, 1.079)
	Leg fat mass	1.430	(0.787, 2.597)	1.863	(0.867, 4.000)
Modle2	Visceral fat region	**1.832**	**(1.659, 2.023)**	**1.473**	**(1.303, 1.665)**
High TG					
	Trunk fat mass	**2.711**	**(1.492, 4.925)**	**2.797**	**(1.353, 5.782)**
Modle1	Arm fat mass	**0.505**	**(0.359, 0.710)**	0.699	(0.456, 1.071)
	Leg fat mass	**1.800**	**(1.005, 3.223)**	1.330	(0.691, 2.560)
Modle2	Visceral fat region	**2.055**	**(1.861, 2.269)**	**2.186**	**(1.939, 2.465)**
IFG					
	Trunk fat mass	1.660	(0.696, 3.963)	0.475	(0.118, 1.910)
Modle1	Arm fat mass	**1.587**	**(1.033, 2.438)**	1.349	(0.675, 2.696)
	Leg fat mass	0.419	(0.167, 1.053)	2.162	(0.617, 7.577)
Modle2	Visceral fat region	**1.242**	**(1.075, 1.436)**	**1.409**	**(1.142, 1.739)**

ORs were expressed in SD units. *P* values were from logistic regression analysis. Those highlighted in bold indicate statistical significance (bilateral $P < 0.05$). Modle1 adjusted for age, trunk fat mass, arm fat mass, and leg fat mass, other than the variable in the model. Modle2 adjusted for age, visceral fat region, other than the variable in the model.

OR, odds ratio; SD, standard deviation; CI, confidence interval; BP, blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; IFG, impaired fasting glucose.

Online supplementary material

Figure S1 Flow chart of participant inclusion and exclusion criteria



Supplementary Figure S1 Flow chart of participant inclusion and exclusion criteria

This study collected baseline data from the Beijing Children and Adolescents Health Cohort Study. We measured body composition and detected the cardiometabolic indicators, including blood pressure, plasma glucose, and lipids.
FMI, fat mass index; FFMI, fat-free mass index.

BMJ Open

Sex differences in associations between body composition and cardiometabolic indicators in Chinese children: a cross-sectional study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2024-095049.R1
Article Type:	Original research
Date Submitted by the Author:	26-Mar-2025
Complete List of Authors:	Wu, Lijun; Capital Institute of Pediatrics, Department of Epidemiology Huang, Yiying; Capital Institute of Pediatrics, Department of Epidemiology Chen, Yiren; Capital Institute of Pediatrics, Department of Epidemiology Liao, Zijun; Capital Institute of Pediatrics, Department of Epidemiology Li, Shaoli; Capital Institute of Pediatrics, Department of Epidemiology Liu, Junting; Capital Institute of Pediatrics, Department of Epidemiology Zong, Xin Nan; Capital Institute of Pediatrics, Department of Epidemiology Chen, Fangfang; Capital Institute of Pediatrics, Department of Epidemiology
Primary Subject Heading:	Paediatrics
Secondary Subject Heading:	Nutrition and metabolism, Epidemiology, Public health
Keywords:	Epidemiology < TROPICAL MEDICINE, Obesity, Other metabolic, e.g. iron, porphyria < DIABETES & ENDOCRINOLOGY

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Sex differences in associations between body composition and cardiometabolic indicators in Chinese children: a cross-sectional study

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Keywords: fat mass; fat-free mass; body composition; cardiometabolic indicators; sex difference

Running title: sex differences in body composition and cardiometabolic indicators

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Word count:3075

ABSTRACT

Objectives Obesity is a growing global public health problem that increases the risk of cardiovascular disease. The aim of the present study was to assess the effects of body composition on cardiometabolic indicators in children.

Design Cross-sectional analysis.

Setting China, the Beijing Children and Adolescents Health Cohort Study between 2022 and 2023.

Participants This cross-sectional study included 5555 children and adolescents aged 6 to 17 years from 11 kindergartens and schools.

Outcome measures We measured body composition using multifrequency bioelectrical impedance analysis, and assessed the cardiometabolic indicators, including blood pressure, plasma glucose, and lipids. Linear regression and binary logistic regression were performed to assess the associations between body composition and cardiometabolic abnormalities.

Results In boys, fat mass index (FMI) was positively correlated with total cholesterol (TC) (in normal fat-free mass (FFM) group, β=0.036, 95% CI: 0.027 to 0.046; in high FFM group, β=0.034, 95% CI: 0.016 to 0.051) and fasting plasma glucose (FPG) (in normal FFM group, β=0.019, 95% CI: 0.012 to 0.026; in high FFM group, β=0.030, 95% CI: 0.005 to 0.054). Fat-free mass index (FFMI) was negatively associated with TC only in the normal fat group (β=-0.047, 95% CI: -0.069 to -0.034) in boys. However, in girls, FMI was not significantly associated with TC and was positively associated with FPG only in the normal FFM group (β=0.033, 95% CI: 0.024 to 0.041), and FFMI was

negatively correlated with TC (in normal fat group, β=-0.058, 95% CI: -0.079 to -0.038; in high fat group, β=-0.049, 95% CI: -0.084 to -0.015). Normal FFM-high fat (OR=2.065, 95% CI: 1.379 to 3.091) and increased visceral fat region (OR=1.357, 95% CI: 1.195 to 1.540) were risk factors for high TC in boys but not in girls.

Conclusions Body composition was significantly associated with cardiometabolic risk factors, and fat stored in different regions has differential influences on cardiometabolic indicators. There were sex differences in the relationships between body composition and cardiometabolic indicators. The findings suggest that body composition is more strongly correlated with cardiometabolic indicators in boys than in girls. Prevention of obesity and cardiometabolic abnormalities may be more important in boys.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ Data were analyzed from the Beijing Children and Adolescents Health Cohort Study, a cross-sectional study.

⇒ The large sample size enhances the statistical strength and generalizability of the results to the Chinese population of children and adolescents.

⇒ The study's cross-sectional design limits our ability to establish causality; further longitudinal studies are necessary.

INTRODUCTION

Childhood obesity has become a growing public health problem worldwide,[1] and its prevalence is continuously increasing in China.[2] Children with obesity have a greater risk of obesity in adulthood and are predisposed to develop cardiometabolic diseases, including type 2 diabetes, hypertension, and dyslipidemia.[3 4] The early prevention of childhood obesity may be critical to health in childhood and adulthood.

Although body mass index (BMI) is a commonly used measure of obesity, it is limited by the inability to distinguish between different body composition compartments. BMI cannot provide information about fat mass (FM) or fat-free mass (FFM). Studies have shown that FM could be a better predictor of adiposity-related metabolic risk than BMI.[5-7] Children without obesity according to BMI but with obesity based on body fat percentage might have increased cardiometabolic risk factors.[8] Moreover, studies have shown that visceral adiposity is an independent risk factor for cardiometabolic diseases and secretes proinflammatory and profibrotic cytokines.[9]

It is well established that excess FM is associated with adverse cardiometabolic risk markers. Increased body FM is related to a progressively worsening risk of hyperglycemia and hyperinsulinemia.[10] FM can also affect blood pressure (BP) and blood lipids.[11 12] In contrast, a higher muscular fitness index and greater muscle mass (MM) may be associated with better cardiometabolic traits, such as blood glucose, low-density lipoprotein cholesterol (LDL-C), and total cholesterol (TC).[13 14] However, FM seems more robustly associated with cardiometabolic profiles than MM;[15] thus, FM might be more important than MM in relation to cardiometabolic profiles.[16]

There are sex-specific contributions of FM and MM to cardiovascular disease risk factors in adults.[17] Higher relative FM showed a stronger association with impaired glucose homeostasis, lipids, and hypertension in males.[18] The associations of adiposity with adverse cardiometabolic risk begin earlier in the life course among males compared with females, particularly for key atherogenic lipids.[19] However, the sex-specific effects of body composition on cardiometabolic indicators in children have been less studied.

In recent years, the importance of fat distribution and location in the risk of cardiometabolic diseases has been highlighted. It has been shown that the trunk-to-peripheral fat ratio can predict subsequent BP levels, and the relationship between fat distribution and BP is independent of fat volume.[20] The trunk-to-leg fat ratio was significantly associated with high LDL-C and triglycerides (TG) concentrations, and it seemed to be an independent risk factor for these cardiometabolic indicators.[21] Visceral adiposity has been identified as a cardiometabolic indicator reflecting abdominal fat distribution. Abnormally high deposition of visceral adipose tissue is related to cardiometabolic risk factors, and visceral adiposity does not always depend on BMI.[22]

The influence of different body composition phenotypes on cardiometabolic indicators is very important, but very little research has been conducted in children. The purpose of the present study was to explore the effects of body composition and fat distribution and location on cardiometabolic indicators in Chinese children and adolescents. Moreover, because of the sex-specific effects of body composition on cardiometabolic profiles in adults, it is important to study the effects of sex differences

in body composition on cardiometabolic indicators in children and adolescents, which can help to prevent obesity in early life.

METHODS

Study design and participants

We investigated the relationship between body composition and metabolic parameters and the sex differences in these relationships. This study collected baseline data from the Beijing Children and Adolescents Health Cohort Study.[23] The subjects were randomly selected from 11 kindergartens and primary and secondary schools in a district of Beijing between 2022 and 2023. A total of 5555 children and adolescents aged 6 to 17 years participated were enrolled in the final analysis, except those who could not participate in the physical examination due to trauma and physical discomfort. We obtained written informed consent from participants/guardians. The study involving human participants was reviewed and approved by the Ethics Committee of the Capital Institute of Pediatrics (Approval No. SHERLL2022043). This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines for cross-sectional studies.

Data collection

Questionnaire

The questionnaires were completed by the participants/guardians to collect information on demographic characteristics, personal and family medical history, and lifestyle factors.

Physical examination data

To address potential sources of bias, all assessments were conducted by trained data collectors, most of whom were nurses and doctors. The quality control of the examinations was performed by the same professional researchers who strictly followed a standardized protocol. All participants fasted after 20:00 the day before the physical examination. The height of the children was measured by trained staff using a Harpenden Portable Stadiometer (UK), and the weight was measured by bioelectrical impedance analysis (BIA). Then, BMI was calculated as weight in kilograms divided by height in meters squared. All instruments used were the same in the 11 kindergartens and schools during the survey.

BP measurements

Oscillometric sphygmomanometers (HBP-1300, Omron, Kyoto, Japan) were used to measure systolic blood pressure (SBP) and diastolic blood pressure (DBP). The observers measured the circumference at the midpoint of the right arm and selected an appropriate cuff. Three consecutive measurements were performed, and the average value of the last two measurements was recorded as the BP value.

Multifrequency bioelectrical impedance analysis (MFBIA)

MFBIA measurements were conducted using BIA (H-Key350, SeeHigher BAS-H, China), which measured impedance at varying frequencies (1, 5, 50, 250, 500 and 1,000 kHz) across the legs, arms and trunk. The MFBIA device is a valid device for evaluating body composition in Chinese children.[24] Children were required to be on fasting and have an empty bladder. The measurements were collected, and then the FM and FFM were calculated by an undisclosed proprietary algorithm. Fat mass index (FMI) and fat-

free mass index (FFMI) were also calculated for each subject as FM and FFM in kilograms divided by height in meters squared, respectively.

Biochemical measurements

After an overnight fast of at least 12 hours, vein blood samples were collected by direct venipuncture into ethylene diamine tetraacetic acid anticoagulant tubes and serum tubes. Blood samples were analyzed for concentrations of fasting plasma glucose (FPG), TG, TC, LDL-C, and high-density lipoprotein cholesterol (HDL-C). FPG was determined by the enzyme hexokinase method. Serum TC concentrations were determined using the standard enzymatic method. Serum TG concentrations were determined using the GPO-PAP method. Serum HDL-C and LDL-C were measured using the direct method. The serum lipid levels and plasma glucose levels were assayed using an automatic biochemistry analysis system (Siemens, Germany).

Classification standards and definitions

The classification standards and definitions are shown in supplementary Table S1.

Statistical analysis

Continuous variables were expressed as mean ± standard deviation (SD), and categorical variables were expressed as frequencies with percentages. The independent *t*-test and *Chi-square* analysis were used to compare the differences in basic characteristics between groups. Piecewise regression was used to investigate the associations between the FMI and cardiometabolic indicators stratified by sex and FFM level and the associations between the FFMI and cardiometabolic indicators stratified by sex and fat level. Linear regression and binary logistic regression were used to

analyze the associations of FFM-fat composition with cardiometabolic abnormalities and the associations of cardiometabolic parameters with a 1-SD increase in FM. All statistical analyses were performed using SPSS 26.0, and a bilateral $P < 0.05$ was considered statistically significant.

Patient and public involvement

None.

RESULTS

The flow diagram of the study population is shown in Figure S1. After children younger than 6 years of age and those without FMI and FFMI values were excluded, 5555 children and adolescents aged 6-17 years were enrolled in the final analysis. A comparison of the basic characteristics of the study sample is reported in Table 1. The study sample was divided into four groups according to fat-free and fat levels: high FFM-high fat group, high FFM-normal fat group, normal FFM-high fat group, and normal FFM-normal fat group. As shown in Table 1, there were differences between the groups in height, weight, and BMI. When fat levels were normal, there were significant differences in SBP, DBP, HDL-C, LDL-C and TG between the high FFM group and the normal FFM group. When fat levels were high, there were significant differences in SBP, DBP, HDL-C and TG between the high FFM group and the normal FFM group.

We quantitatively analyzed the relationships between body composition and cardiometabolic profiles. Table 2 shows the piecewise regression analysis of the associations between the FMI and cardiometabolic indicators stratified by sex and FFM

level. Regardless of sex and FFM level, FMI was negatively correlated with HDL-C, and was positively correlated with SBP, DBP, LDL-C, and TG. In boys, regardless of FFM level, FMI was positively correlated with TC (in normal FFM group, β=0.036, 95% CI: 0.027 to 0.046; in high FFM group, β=0.034, 95% CI: 0.016 to 0.051) and FPG (in normal FFM group, β=0.019, 95% CI: 0.012 to 0.026; in high FFM group, β=0.030, 95% CI: 0.005 to 0.054). However, in girls, FMI was not significantly associated with TC and was positively associated with FPG only in the normal FFM group (β=0.033, 95% CI: 0.024 to 0.041).

We also analyzed the associations between FFMI and cardiometabolic indicators stratified by sex and fat level. As shown in Table 3, regardless of sex and fat level, FFMI was negatively correlated with HDL-C; positively correlated with SBP, DBP, TG, and FPG; and not linearly correlated with LDL-C. In boys, FFMI was negatively associated with TC only in the normal fat group (β=-0.047, 95% CI: -0.069 to -0.034). However, in girls, regardless of fat level, FFMI was negatively correlated with TC (in normal fat group, β=-0.058, 95% CI: -0.079 to -0.038; in high fat group, β=-0.049, 95% CI: -0.084 to -0.015).

To more clearly analyze the sex differences in the relationships between body composition and cardiometabolic indicators, we further performed logistic regression analysis. As shown in Table 4, adjusted for the age of the children, the normal FFM-normal fat group was used as the reference group. Regardless of sex, as long as one of the FFM or fat levels was high, the risk of high BP and low HDL-C increased; the risk of high TG increased in high fat group; and FFM-fat composition was not a risk factor

for high IFP. Normal FFM-high fat was a risk factor for high TC in boys (OR=2.065, 95% CI: 1.379 to 3.091) but not in girls. In boys, as long as one of the FFM or fat levels was high, the risk of high LDL-C increased. However, in girls, the risk of high LDL-C increased only in the high fat group. The protective effect of high FFM against high LDL-C was not obvious in the high fat group regardless of sex, and high FFM-normal fat was a risk factor for high LDL-C in boys (OR=2.283, 95% CI: 1.521 to 3.429).

We used two models to analyze the influence of fat distribution on cardiometabolic indicators by logistic regression analysis: Model 1, trunk fat mass, arm fat mass, and leg fat mass as independent variables; Model 2, the visceral fat region was used as an independent variable.

As shown in Table 5, increased visceral fat region was a risk factor for elevated BP, low HDL-C, high LDL-C, high TG and impaired fasting glucose (IFG), and increased trunk fat mass was a risk factor for elevated BP, low HDL-C and high TG. However, increased arm fat mass was a protective factor against elevated BP and low HDL-C.

In boys, increased visceral fat region was a risk factor for high TC, increased trunk fat mass was a risk factor for high LDL-C, increased leg fat mass was a risk factor for high TC and high TG, and increased arm fat mass was a protective factor for high TG and a risk factor for IFG (Table 5). However, none of these correlations were detected in girls.

DISCUSSION

In our study, we analyzed the associations of FFM-fat composition with blood pressure, glucose, and lipids. Our results showed that FFM and fat levels were correlated with

cardiometabolic indicators, and there were sex differences in the relationships between body composition and cardiometabolic indicators. The data were analyzed from the Beijing Children and Adolescents Health Cohort Study, a population-based cross-sectional study. The large sample size enhances the statistical strength and generalizability of the results to the Chinese population of children and adolescents.

Because of the possible differences in the correlations of adiposity with cardiometabolic risk between males and females, sex differences in cardiometabolic abnormalities are commonly observed across the life course. Our results indicated that the associations between body composition and cardiometabolic indicators differed between boys and girls. Some studies have also shown sex differences between fat mass and cardiometabolic risk factors. For instance, Kouda et al. reported that the trunk-to-appendicular fat ratio at baseline was significantly associated with SBP at follow-up in boys, but there were no significant associations between the trunk-to-appendicular fat ratio and SBP in girls.[20] Duran et al. reported that the trunk-to-leg fat ratio was significantly associated with high LDL-C only in girls.[21] Sex differences have also been shown in the associations between insulin resistance and adiposity indices, and these differences were significantly more evident in middle puberty.[25] The correlations of adiposity with adverse cardiometabolic risk seem to begin earlier in the life course among males than females.[19] Partly consistent with these findings, our results have shown stronger correlations between body composition and cardiometabolic indicators in boys than in girls. Thus, prevention of obesity and cardiometabolic abnormalities may be more important in boys.

It is well known that regional adipose compartments confer different cardiometabolic risks in children. We also found that fat stored in different regions has differential influences on cardiometabolic indicators. However, our results showed that increased arm fat mass was a protective factor against elevated BP and low HDL in children. Previous studies inconsistently reported that arm fat mass was not significantly associated with cardiometabolic risk factors.[26 27]

Our results showed that FMI and FFMI were linearly correlated with FPG, but FFM-fat composition was not a risk factor for IFG. Further analysis of the relationships between the fat distribution region and cardiometabolic indicators indicated that increased visceral fat region was a risk factor for IFG regardless of sex, suggesting the important influence of visceral fat on glucose metabolism.

In addition, our results showed that high FFM-normal fat was a risk factor for elevated BP, low HDL and high LDL in boys. This finding is inconsistent with a previous study showing that greater muscle mass might be associated with better cardiometabolic traits.[14] There is a need for more high-quality prospective studies to determine these associations.

Recognized as a global health problem, obesity is associated with multiple cardiometabolic disorders.[28] Adiposity results in chronic low-grade inflammation and an imbalance in adipokine secretion, and ultimately alters the physiological state of adipose tissue communication with target organs.[29] Excess adipose tissue also enhances and disturbs the generation of reactive oxygen species and increases oxidative stress, which contributes to the pathogenesis and outcomes of cardiometabolic diseases.[30]

Visceral adiposity is an independent risk factor for cardiometabolic diseases and secretes proinflammatory and profibrotic cytokines, which in turn cause systemic metabolic disorders.[9]

Limitations

Our study has several limitations. First, this cross-sectional study recruited children from 11 kindergartens and schools in a district in Beijing who might not represent all children and adolescents, likely resulting in selection bias. Second, due to the small number of children with obesity in this study, it is necessary to verify the results in prospective investigations with larger sample sizes. Third, because of the small number of participants stratified by puberty, the study did not analyze the effects of puberty on the relationship between FM or FFM and cardiometabolic risk markers. Fourth, although some studies have shown a stronger association between hepatic fat and cardiometabolic indicators than between abdominal fat and cardiometabolic indicators and that these associations are independent of BMI,[31 32] this study lacked an analysis of these associations due to the limited data. Fifth, we did not analyze the effect of socioeconomic status on the results of this study because of the limited data. Finally, the study's cross-sectional design limits our ability to establish causality; further longitudinal studies are necessary.

CONCLUSION

Our results indicate that body composition is significantly associated with cardiometabolic risk factors and that fat stored in different regions has differential influences on cardiometabolic indicators. The relationships between body composition

and cardiometabolic risk factors are influenced by sex in children and adolescents. This finding suggested that body composition was more strongly correlated with cardiometabolic indicators in boys than in girls. Sex-specific interventions may be warranted.

Acknowledgements

The authors thank the children and their parents for their participation in the study. We also thank all team members who contributed to the study.

Contributors

Fangfang Chen conceptualized and designed the study, carried out the analyses, and reviewed and revised the manuscript. Lijun Wu wrote the initial draft of the manuscript. Yiying Huang and Yiren Chen analyzed the data. Zijun Liao, Shaoli Li, Junting Liu, and Xinnan Zong were involved in data acquisition and data processing. All authors critically reviewed the manuscript for interpretation and intellectual content and approved the final manuscript as submitted. Fangfang Chen is the corresponding authors and the guarantor.

Funding

This research was funded by the public service development and reform pilot project of Beijing Medical Research Institute, grant number BMR2021-3, the Beijing Municipal Administration of Hospitals Incubating Program, grant number Px2022052, and the China Soong Ching Ling Foundation, grant number 2023-24.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval

We obtained written informed consent from participants/guardians. The studies involving human participants were reviewed and approved by the ethics committee of Capital Institute of Pediatrics, Beijing, China (SHERLL2022043).

Data availability statement

All data relevant to the study are included in the article or uploaded as supplementary information.

Supplemental material

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Table 1 Baseline characteristics of the study subjects stratified by body composition

	N	Normal fat		*P*	High fat		*P*
		Normal FFM	High FFM		Normal FFM	High FFM	
Sex							
Boys	2844	2169 (50.61)	179 (51.73)	0.687	269 (61.14)	227 (47.00)	**<0.001**
Girls	2711	2117 (49.39)	167 (48.27)	0.687	171 (38.86)	256 (53.00)	**<0.001**
Demography/anthropometry							
Age (years)	5555	10.56±3.07	10.45±3.03	0.541	10.44±2.99	10.79±2.97	0.077
Height (cm)	5555	146.92±17.49	151.37±17.66	**<0.001**	148.75±15.89	154.02±15.29	**<0.001**
Weight (kg)	5555	41.05±15.38	55.35±20.22	**<0.001**	58.68±19.49	71.78±22.27	**<0.001**
BMI (kg/m^2)	5555	18.29±3.32	23.12±3.76	**<0.001**	25.72±3.64	29.42±4.17	**<0.001**
Cardiometabolic indicators							
SBP (mmHg)	5546	107.83±10.92	115.82±11.88	**<0.001**	117.09±11.41	121.50±10.88	**<0.001**
DBP (mmHg)	5546	59.94±7.29	61.71±7.48	**<0.001**	64.64±7.82	65.66±7.66	**0.046**
TC (mmol/L)	5405	4.12±0.70	4.11±0.79	0.706	4.30±0.72	4.26±0.69	0.395
HDL-C (mmol/L)	5400	1.53±0.34	1.39±0.33	**<0.001**	1.31±0.29	1.23±0.27	**<0.001**
LDL-C (mmol/L)	5405	2.50±0.68	2.63±0.78	**0.001**	2.92±0.76	2.92±0.72	0.992
TG (mmol/L)	5401	0.83±0.37	0.94±0.50	**<0.001**	1.14±0.54	1.32±0.59	**<0.001**
FPG (mmol/L)	5401	4.92±0.52	4.91±0.40	0.665	4.98±0.61	5.00±0.87	0.607
Body composition indicators							
FMP (%)	5555	20.87±8.31	24.98±7.33	**<0.001**	39.39±4.52	39.30±4.67	0.767

FMI (kg/m^2)	5555	4.02±2.16	5.94±2.28	**<0.001**	10.18±2.09	11.65±2.59	**<0.001**
MMI (kg/m^2)	5555	13.43±1.73	16.19±2.20	**<0.001**	14.62±2.01	16.74±2.18	**<0.001**
FFMI (kg/m^2)	5555	14.27±1.83	17.18±2.34	**<0.001**	15.54±2.14	17.79±2.33	**<0.001**
Arm fat mass (kg)	5555	0.66±0.41	0.99±0.53	**<0.001**	1.83±0.84	2.35±1.13	**<0.001**
Leg fat mass (kg)	5555	1.63±0.86	2.32±0.98	**<0.001**	3.65±1.14	4.25±1.26	**<0.001**
Trunk fat mass (kg)	5555	3.75±3.31	6.81±4.11	**<0.001**	11.24±4.24	13.95±4.79	**<0.001**
Visceral fat region (m^2)	5555	40.56±26.99	59.13±33.15	**<0.001**	119.01±42.33	135.91±45.45	**<0.001**
Fat mass (kg)	5555	9.17±5.94	14.39±7.23	**<0.001**	23.29±8.24	28.38±9.62	**<0.001**
Muscle mass (kg)	5555	30.00±10.41	38.54±13.55	**<0.001**	33.45±11.13	40.93±12.91	**<0.001**

Continuous variables shown as mean ± standard deviation.

P values were from tests comparing two groups by independent *t*-tests or *Chi-square* tests. Those highlighted in bold indicate statistical significance (bilateral $P < 0.05$).

FFM, fat-free mass; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; FPG, fasting plasma glucose; FMP, fat mass percentage; FMI, fat mass index; MMI, muscle mass index; FFMI, fat free mass index.

Table 2 Piecewise regression results of the associations between FMI and cardiometabolic indicators stratified by sex and FFM level

	Boys				Girls			
	Normal FFM		High FFM		Normal FFM		High FFM	
Parameters	*β*	95%*CI*	*β*	95%*CI*	*β*	95%*CI*	*β*	95%*CI*
SBP	**1.673**	**(1.536, 1.810)**	**1.136**	**(0.836, 1.436)**	**1.975**	**(1.828, 2.121)**	**1.234**	**(0.988, 1.480)**
DBP	**0.874**	**(0.783, 0.965)**	**0.840**	**(0.655, 1.026)**	**1.038**	**(0.923, 1.152)**	**0.825**	**(0.639, 1.011)**
TC	**0.036**	**(0.027, 0.046)**	**0.034**	**(0.016, 0.051)**	0.001	(-0.010, 0.012)	0.004	(-0.017, 0.024)
HDL-C	**-0.040**	**(-0.045, -0.036)**	**-0.024**	**(-0.032, -0.016)**	**-0.046**	**(-0.051, -0.041)**	**-0.032**	**(-0.039, -0.025)**
LDL-C	**0.077**	**(0.068, 0.086)**	**0.056**	**(0.037, 0.074)**	**0.041**	**(0.030, 0.052)**	**0.026**	**(0.006, 0.047)**
TG	**0.059**	**(0.054, 0.064)**	**0.052**	**(0.039, 0.065)**	**0.050**	**(0.044, 0.055)**	**0.058**	**(0.042, 0.074)**
FPG	**0.019**	**(0.012, 0.026)**	**0.030**	**(0.005, 0.054)**	**0.033**	**(0.024, 0.041)**	0.011	(0.000, 0.022)

Adjusted for the age of children. *P* values were from piecewise regression analysis. Those highlighted in bold indicate statistical significance (bilateral $P < 0.05$).

FFM, fat-free mass; CI, confidence interval; FMI, fat mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; FPG, fasting blood glucose.

Table 3 Piecewise regression results of the associations between FFMI and cardiometabolic indicators stratified by sex and fat level

	Boys				Girls			
	Normal fat		High fat		Normal fat		High fat	
Parameters	*β*	95%*CI*	*β*	95%*CI*	*β*	95%*CI*	*β*	95%*CI*
SBP	**3.182**	**(3.024, 3.340)**	**2.319**	**(1.996, 2.643)**	**3.575**	**(3.313, 3.838)**	**2.128**	**(1.683, 2.573)**
DBP	**0.869**	**(0.746, 0.992)**	**0.619**	**(0.374, 0.865)**	**1.439**	**(1.230, 1.647)**	**1.054**	**(0.705, 1.404)**
TC	**-0.047**	**(-0.069, -0.034)**	-0.018	(-0.040, 0.005)	**-0.058**	**(-0.079, -0.038)**	**-0.049**	**(-0.084, -0.015)**
HDL-C	**-0.064**	**(-0.070, -0.059)**	**-0.046**	**(-0.054, -0.037)**	**-0.063**	**(-0.073, -0.054)**	**-0.041**	**(-0.053, -0.029)**
LDL-C	0.004	(-0.009, 0.016)	0.010	(-0.013, 0.034)	-0.011	(-0.031, 0.009)	-0.033	(-0.069, 0.003)
TG	**0.039**	**(0.032, 0.046)**	**0.049**	**(0.031, 0.067)**	**0.054**	**(0.043, 0.065)**	**0.071**	**(0.044, 0.097)**
FPG	**0.025**	**(0.017, 0.034)**	**0.045**	**(0.015, 0.076)**	**0.056**	**(0.041, 0.072)**	**0.036**	**(0.017, 0.055)**

Adjusted for the age of children. *P* values were from piecewise regression analysis. Those highlighted in bold indicate statistical significance (bilateral $P < 0.05$).

FFMI, fat-free mass index; CI, confidence interval; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; FPG, fasting blood glucose.

Table 4 Adjusted ORs for the associations of FFM-fat composition with blood pressure, glucose, and lipid metabolic abnormalities stratified by sex

	Boys		Girls	
	OR	95%*CI*	OR	95%*CI*
Elevated BP				
High FFM-normal fat	**2.703**	**(1.835, 3.981)**	**3.612**	**(2.376, 5.491)**
Normal FFM-high fat	**4.476**	**(3.324, 6.027)**	**5.280**	**(3.601, 7.742)**
High FFM-high fat	**6.278**	**(4.625, 8.522)**	**10.364**	**(7.650, 14.043)**
High TC				
High FFM-normal fat	1.357	(0.777, 2.368)	1.080	(0.586, 1.993)
Normal FFM-high fat	**2.065**	**(1.379, 3.091)**	1.187	(0.670, 2.104)
High FFM-high fat	1.343	(0.814, 2.216)	1.344	(0.847, 2.130)
Low HDL-C				
High FFM-normal fat	**2.137**	**(1.309, 3.488)**	**2.669**	**(1.470, 4.846)**
Normal FFM-high fat	**2.794**	**(1.908, 4.089)**	**3.250**	**(1.891, 5.586)**
High FFM-high fat	**4.637**	**(3.234, 6.647)**	**8.892**	**(6.133, 12.894)**
High LDL-C				
High FFM-normal fat	**2.283**	**(1.521, 3.429)**	0.912	(0.526, 1.582)
Normal FFM-high fat	**3.827**	**(2.817, 5.198)**	**2.608**	**(1.775, 3.833)**
High FFM-high fat	**3.607**	**(2.591, 5.020)**	**2.251**	**(1.604, 3.159)**
High TG				
High FFM-normal fat	1.453	(0.923, 2.289)	1.585	(0.967, 2.598)
Normal FFM-high fat	**3.499**	**(2.578, 4.749)**	**3.705**	**(2.535, 5.414)**
High FFM-high fat	**6.686**	**(4.941, 9.048)**	**8.796**	**(6.552, 11.809)**
IFG				
High FFM-normal fat	0.350	(0.110, 1.115)	1.248	(0.491, 3.167)
Normal FFM-high fat	1.642	(0.998, 2.701)	1.156	(0.456, 2.932)
High FFM-high fat	1.442	(0.823, 2.526)	1.760	(0.907, 3.417)

Adjusted for the age of children, normal FFM-normal fat group as the reference group.

P values were from logistic regression analysis. Those highlighted in bold indicate statistical significance (bilateral $P < 0.05$).

OR, odds ratio; FFM, fat-free mass; CI, confidence interval; BP, blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; IFG, impaired fasting glucose.

Table 5 ORs of cardiometabolic risk factors associated with 1-SD increase in fat mass variables

		Boys		Girls	
		OR	95% *CI*	OR	95% *CI*
Elevated BP					
	Trunk fat mass	**7.625**	**(4.184, 13.898)**	**5.153**	**(2.477, 10.717)**
Modle1	Arm fat mass	**0.515**	**(0.367, 0.724)**	**0.545**	**(0.351, 0.847)**
	Leg fat mass	0.616	(0.345, 1.100)	1.200	(0.626, 2.298)
Modle2	Visceral fat region	**2.008**	**(1.822, 2.212)**	**2.583**	**(2.279, 2.929)**
High TC					
	Trunk fat mass	0.510	(0.222, 1.172)	0.984	(0.325, 3.009)
Modle1	Arm fat mass	1.075	(0.711, 1.625)	0.473	(0.210, 1.064)
	Leg fat mass	**2.558**	**(1.120, 5.840)**	2.385	(0.821, 6.931)
Modle2	Visceral fat region	**1.357**	**(1.195, 1.540)**	1.114	(0.946, 1.313)
Low HDL-C					
	Trunk fat mass	**4.255**	**(2.182, 8.295)**	**6.743**	**(2.759, 16.478)**
Modle1	Arm fat mass	**0.518**	**(0.349, 0.700)**	**0.541**	**(0.319, 0.918)**
	Leg fat mass	0.968	(0.486, 1.928)	0.818	(0.381, 1.759)
Modle2	Visceral fat region	**1.788**	**(1.602, 1.995)**	**2.243**	**(1.938, 2.597)**
High LDL-C					
	Trunk fat mass	**1.916**	**(1.043, 3.521)**	1.296	(0.576, 2.916)
Modle1	Arm fat mass	0.747	(0.538, 1.037)	0.651	(0.393, 1.079)
	Leg fat mass	1.430	(0.787, 2.597)	1.863	(0.867, 4.000)
Modle2	Visceral fat region	**1.832**	**(1.659, 2.023)**	**1.473**	**(1.303, 1.665)**
High TG					
	Trunk fat mass	**2.711**	**(1.492, 4.925)**	**2.797**	**(1.353, 5.782)**
Modle1	Arm fat mass	**0.505**	**(0.359, 0.710)**	0.699	(0.456, 1.071)
	Leg fat mass	**1.800**	**(1.005, 3.223)**	1.330	(0.691, 2.560)
Modle2	Visceral fat region	**2.055**	**(1.861, 2.269)**	**2.186**	**(1.939, 2.465)**
IFG					
	Trunk fat mass	1.660	(0.696, 3.963)	0.475	(0.118, 1.910)
Modle1	Arm fat mass	**1.587**	**(1.033, 2.438)**	1.349	(0.675, 2.696)
	Leg fat mass	0.419	(0.167, 1.053)	2.162	(0.617, 7.577)
Modle2	Visceral fat region	**1.242**	**(1.075, 1.436)**	**1.409**	**(1.142, 1.739)**

ORs were expressed in SD units. *P* values were from logistic regression analysis. Those highlighted in bold indicate statistical significance (bilateral $P < 0.05$). Modle1 adjusted for age, trunk fat mass, arm fat mass, and leg fat mass, other than the variable in the model. Modle2 adjusted for age, visceral fat region, other than the variable in the model.

OR, odds ratio; SD, standard deviation; CI, confidence interval; BP, blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; IFG, impaired fasting glucose.

Online supplementary material

Supplementary Table S1. Classification standards and definitions

Metrics	Standards or definition	References
Elevated BP (6 years old)	SBP and/or DBP ⩾ 90th percentile for age and sex	Fan H, Yan Y, Mi J. Updating blood pressure references for Chinese children aged 3-17 years. Chinese Journal of Hypertension 2017;25:28-35.
Elevated BP (7-17 years old)	SBP and/or DBP ⩾ 90th percentile for age and sex	Reference of screening for elevated blood pressure among children and adolescents aged 7～18 years: WS/T 610-2018[S]. 2018.
High TC	TC ≥ 5.18 mmol/L	Subspecialty Group of Rare Diseases, the Society of Pediatrics, Chinese Medical Associationet al. Expert consensus on diagnosis and management of dyslipidemia in children (2022) [in Chinese]. *Chinese Journal of Pediatrics* 2022;60:633-9.
Low HDL-C	HDL-C < 1.03 mmol/L	Subspecialty Group of Rare Diseases, the Society of Pediatrics, Chinese Medical Associationet al. Expert consensus on diagnosis and management of dyslipidemia in children (2022) [in Chinese]. *Chinese Journal of Pediatrics* 2022;60:633-9.
High LDL-C	LDL-C ≥ 3.36 mmol/L	Subspecialty Group of Rare Diseases, the Society of Pediatrics, Chinese Medical Associationet al. Expert consensus on diagnosis and management of dyslipidemia in children (2022) [in Chinese]. *Chinese Journal of Pediatrics* 2022;60:633-9.

High TG	6-9 years old, TG ≥ 1.12 mmol/L; 10-18 years old, TG ≥ 1.46 mmol/L
IFG	FPG ≥ 5.6 mmol/L
BMI	weight (kg)/[height (m)]^2
FMI	FM (kg)/[height (m)]^2
MMI	MM (kg)/[height (m)]^2
FFMI	FFM (kg)/[height (m)]^2
FMP	FM (kg)/weight (kg) × 100%.
Arm fat mass (mean)	[left arm fat mass (kg)+ right arm fat mass (kg)]/2
Leg fat mass (mean)	[left leg fat mass (kg)+ right leg fat mass (kg)]/2
High FFM	the FFMI Z score was calculated, and a Z value ⩾ 1 was defined as a high FFM level
High fat	the FMI Z score was calculated, and a Z value ⩾1 was defined as a high fat level
Normal FFM	the FFMI Z score was calculated, and a Z value <1 was defined as a normal FFM level

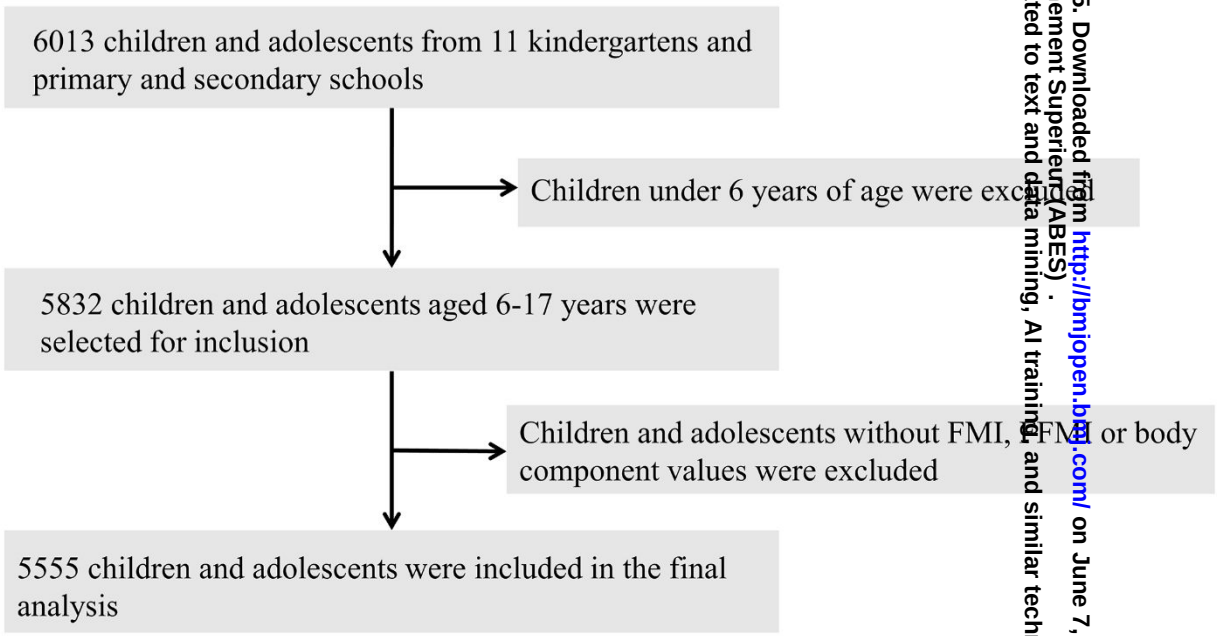
Group of Rare Diseases, Group of Cardiovascular Diseases, Group of Child Health Care, et al. Lipid abnormalities in children: disease diagnosis and expert consensus (2022) [J]. *Chinese journal of pediatrics* 2022;60:633-9.

American Diabetes Association. 2. Classification and Diagnosis of Diabetes: Standards of Medical Care in Diabetes-2020. *Diabetes Care* 2020;43:S14-S31.

Normal fat	the FMI Z score was calculated, and a Z value <1 was defined as a normal fat level
Normal FFM-normal fat group	both FFM and fat levels were normal
High FFM-normal fat group	FFM level was high, and fat level was normal
Normal FFM-high fat group	FFM level was normal, and fat level was high
High FFM-high fat group	both FFM and fat levels were high

Abbreviations: BMI, body mass index; BP, blood pressure; DBP: diastolic blood pressure; FFM, fat-free mass; FFMI, fat-free mass index; FMI, fat mass index; FMP, fat mass percentage;FPG, fasting plasma glucose; HDL-C, high-density lipoprotein cholesterol; IFG, impaired fasting glucose; LDL-C, low-density lipoprotein cholesterol; MMI, muscle mass index; SBP, systolic blood pressure;TC, total cholesterol; TG, triglycerides.

Figure S1 Flow chart of participant inclusion and exclusion criteria



Supplementary Figure S1 Flow chart of participant inclusion and exclusion criteria

This study collected baseline data from the Beijing Children and Adolescents Health Cohort Study. We measured body composition and detected the cardiometabolic indicators, including blood pressure, plasma glucose, and lipids.
FMI, fat mass index; FFMI, fat-free mass index.

BMJ Open

Sex differences in associations between body composition and cardiometabolic indicators in Chinese children: a cross-sectional study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2024-095049.R2
Article Type:	Original research
Date Submitted by the Author:	16-Apr-2025
Complete List of Authors:	Wu, Lijun; Capital Institute of Pediatrics, Department of Epidemiology Huang, Yiying; Capital Institute of Pediatrics, Department of Epidemiology Chen, Yiren; Capital Institute of Pediatrics, Department of Epidemiology Liao, Zijun; Capital Institute of Pediatrics, Department of Epidemiology Li, Shaoli; Capital Institute of Pediatrics, Department of Epidemiology Liu, Junting; Capital Institute of Pediatrics, Department of Epidemiology Zong, Xin Nan; Capital Institute of Pediatrics, Department of Epidemiology Chen, Fangfang; Capital Institute of Pediatrics, Department of Epidemiology
Primary Subject Heading:	Paediatrics
Secondary Subject Heading:	Nutrition and metabolism, Epidemiology, Public health
Keywords:	Epidemiology < TROPICAL MEDICINE, Obesity, Other metabolic, e.g. iron, porphyria < DIABETES & ENDOCRINOLOGY

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Sex differences in associations between body composition and cardiometabolic indicators in Chinese children: a cross-sectional study

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Keywords: fat mass; fat-free mass; body composition; cardiometabolic indicators; sex difference

Running title: sex differences in body composition and cardiometabolic indicators

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Word count:3390

ABSTRACT

Objectives Obesity is a growing global public health problem that increases the risk of cardiovascular disease. The aim of the present study was to assess the effects of body composition on cardiometabolic indicators in children.

Design Cross-sectional analysis.

Setting China, the Beijing Children and Adolescents Health Cohort Study between 2022 and 2023.

Participants This cross-sectional study included 5555 children and adolescents aged 6 to 17 years from 11 kindergartens and schools.

Outcome measures We measured body composition using multifrequency bioelectrical impedance analysis, and assessed the cardiometabolic indicators, including blood pressure, plasma glucose, and lipids. Linear regression and binary logistic regression were performed to assess the associations between body composition and cardiometabolic abnormalities.

Results In boys, fat mass index (FMI) was positively correlated with total cholesterol (TC) (in normal fat-free mass (FFM) group, β=0.036, 95% CI: 0.027 to 0.046; in high FFM group, β=0.034, 95% CI: 0.016 to 0.051) and fasting plasma glucose (FPG) (in normal FFM group, β=0.019, 95% CI: 0.012 to 0.026; in high FFM group, β=0.030, 95% CI: 0.005 to 0.054). Fat-free mass index (FFMI) was negatively associated with TC only in the normal fat group (β=-0.047, 95% CI: -0.069 to -0.034) in boys. However, in girls, FMI was not significantly associated with TC and was positively associated with FPG only in the normal FFM group (β=0.033, 95% CI: 0.024 to 0.041), and FFMI was

negatively correlated with TC (in normal fat group, β=-0.058, 95% CI: -0.079 to -0.038; in high fat group, β=-0.049, 95% CI: -0.084 to -0.015). Normal FFM-high fat (OR=2.065, 95% CI: 1.379 to 3.091) and increased visceral fat region (OR=1.357, 95% CI: 1.195 to 1.540) were risk factors for high TC in boys but not in girls.

Conclusions Body composition was significantly associated with cardiometabolic risk factors, and fat stored in different regions has differential influences on cardiometabolic indicators. There were sex differences in the relationships between body composition and cardiometabolic indicators. The findings suggest that body composition is more strongly correlated with cardiometabolic indicators in boys than in girls. Prevention of obesity and cardiometabolic abnormalities may be more important in boys.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ Data were analyzed from the Beijing Children and Adolescents Health Cohort Study, a cross-sectional study.

⇒ The large sample size enhances the statistical strength and generalizability of the results to the Chinese population of children and adolescents.

⇒ The study's cross-sectional design limits our ability to establish causality; further longitudinal studies are necessary.

INTRODUCTION

Childhood obesity has become a growing public health problem worldwide,[1] and its prevalence is continuously increasing in China.[2] Children with obesity have a greater risk of obesity in adulthood and are predisposed to develop cardiometabolic diseases, including type 2 diabetes, hypertension, and dyslipidemia.[3 4] The early prevention of childhood obesity may be critical to health in childhood and adulthood.

Although body mass index (BMI) is a commonly used measure of obesity, it is limited by the inability to distinguish between different body composition compartments. BMI cannot provide information about fat mass (FM) or fat-free mass (FFM). Studies have shown that FM could be a better predictor of adiposity-related metabolic risk than BMI.[5-7] Children without obesity according to BMI but with obesity based on body fat percentage might have increased cardiometabolic risk factors.[8] Moreover, studies have shown that visceral adiposity is an independent risk factor for cardiometabolic diseases and secretes proinflammatory and profibrotic cytokines.[9]

It is well established that excess FM is associated with adverse cardiometabolic risk markers. Increased body FM is related to a progressively worsening risk of hyperglycemia and hyperinsulinemia.[10] FM can also affect blood pressure (BP) and blood lipids.[11 12] In contrast, a higher muscular fitness index and greater muscle mass (MM) may be associated with better cardiometabolic traits, such as blood glucose, low-density lipoprotein cholesterol (LDL-C), and total cholesterol (TC).[13 14] However, FM seems more robustly associated with cardiometabolic profiles than MM;[15] thus, FM might be more important than MM in relation to cardiometabolic profiles.[16]

There are sex-specific contributions of FM and MM to cardiovascular disease risk factors in adults.[17] Higher relative FM showed a stronger association with impaired glucose homeostasis, lipids, and hypertension in males.[18] The associations of adiposity with adverse cardiometabolic risk begin earlier in the life course among males compared with females, particularly for key atherogenic lipids.[19] However, the sex-specific effects of body composition on cardiometabolic indicators in children have been less studied.

In recent years, the importance of fat distribution and location in the risk of cardiometabolic diseases has been highlighted. It has been shown that the trunk-to-peripheral fat ratio can predict subsequent BP levels, and the relationship between fat distribution and BP is independent of fat volume.[20] The trunk-to-leg fat ratio was significantly associated with high LDL-C and triglycerides (TG) concentrations, and it seemed to be an independent risk factor for these cardiometabolic indicators.[21] Visceral adiposity has been identified as a cardiometabolic indicator reflecting abdominal fat distribution. Abnormally high deposition of visceral adipose tissue is related to cardiometabolic risk factors, and visceral adiposity does not always depend on BMI.[22]

The influence of different body composition phenotypes on cardiometabolic indicators is very important, but very little research has been conducted in children. The purpose of the present study was to explore the effects of body composition and fat distribution and location on cardiometabolic indicators in Chinese children and adolescents. Moreover, because of the sex-specific effects of body composition on cardiometabolic profiles in adults, it is important to study the effects of sex differences

in body composition on cardiometabolic indicators in children and adolescents, which can help to prevent obesity in early life.

METHODS

Study design and participants

We investigated the relationship between body composition and metabolic parameters and the sex differences in these relationships. This study collected baseline data from the Beijing Children and Adolescents Health Cohort Study.[23] The subjects were randomly selected from 11 kindergartens and primary and secondary schools in a district of Beijing between 2022 and 2023. A total of 5555 children and adolescents aged 6 to 17 years participated were enrolled in the final analysis, except those who could not participate in the physical examination due to trauma and physical discomfort. We obtained written informed consent from participants/guardians. The study involving human participants was reviewed and approved by the Ethics Committee of the Capital Institute of Pediatrics (Approval No. SHERLL2022043). This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines for cross-sectional studies.

Data collection

Questionnaire

The questionnaire is not a known questionnaire; it is a unified standardized questionnaire that needs to be developed according to the research. The questionnaire included basic information, family history of disease, birth and feeding, exercise, behavior and lifestyle, diet, allergies, adolescent development, sleep and other related

content. These questionnaires were issued one week before the onsite investigation and were filled out jointly by parents/guardians and students. The quality of the questionnaires was reviewed by the class teachers and the staff of the cooperation group at two levels.

Physical examination data

To address potential sources of bias, all assessments were conducted by trained data collectors, most of whom were nurses and doctors. The quality control of the examinations was performed by the same professional researchers who strictly followed a standardized protocol. All participants fasted after 20:00 the day before the physical examination. The height of the children was measured by trained staff using a Harpenden Portable Stadiometer (UK), and the weight was measured by bioelectrical impedance analysis (BIA). Then, BMI was calculated as weight in kilograms divided by height in meters squared. All instruments used were the same in the 11 kindergartens and schools during the survey.

BP measurements

Oscillometric sphygmomanometers (HBP-1300, Omron, Kyoto, Japan) were used to measure systolic blood pressure (SBP) and diastolic blood pressure (DBP). The observers measured the circumference at the midpoint of the right arm and selected an appropriate cuff. Three consecutive measurements were performed, and the average value of the last two measurements was recorded as the BP value.

Multifrequency bioelectrical impedance analysis (MFBIA)

MFBIA measurements were conducted using BIA (H-Key350, SeeHigher BAS-H,

China), which measured impedance at varying frequencies (1, 5, 50, 250, 500 and 1,000 kHz) across the legs, arms and trunk. The MFBIA device is a valid device for evaluating body composition in Chinese children.[24] The agreement between FM and FFM measured by BIA and air displacement plethysmography was strong (Lin's concordance correlation coefficient (CCC) > 0.80). Children were required to be on fasting and have an empty bladder. The measurements were collected, and then the FM and FFM were calculated by an undisclosed proprietary algorithm. Fat mass index (FMI) and fat-free mass index (FFMI) were also calculated for each subject as FM and FFM in kilograms divided by height in meters squared, respectively.

Biochemical measurements

After an overnight fast of at least 12 hours, vein blood samples were collected by direct venipuncture into ethylene diamine tetraacetic acid anticoagulant tubes and serum tubes. Blood samples were analyzed for concentrations of fasting plasma glucose (FPG), TG, TC, LDL-C, and high-density lipoprotein cholesterol (HDL-C). FPG was determined by the enzyme hexokinase method. Serum TC concentrations were determined using the standard enzymatic method. Serum TG concentrations were determined using the GPO-PAP method. Serum HDL-C and LDL-C were measured using the direct method. The serum lipid levels and plasma glucose levels were assayed using an automatic biochemistry analysis system (Siemens, Germany).

Classification standards and definitions

The classification standards and definitions are shown in supplementary Table S1.

Statistical analysis

Continuous variables were expressed as mean ± standard deviation (SD), and categorical variables were expressed as frequencies with percentages. The independent *t*-test and *Chi-square* analysis were used to compare the differences in basic characteristics between groups. Piecewise regression was used to investigate the associations between the FMI and cardiometabolic indicators stratified by sex and FFM level and the associations between the FFMI and cardiometabolic indicators stratified by sex and fat level. Linear regression and binary logistic regression were used to analyze the associations of FFM-fat composition with cardiometabolic abnormalities and the associations of cardiometabolic parameters with a 1-SD increase in FM. All statistical analyses were performed using SPSS 26.0, and a bilateral $P < 0.05$ was considered statistically significant.

Patient and public involvement

None.

RESULTS

The flow diagram of the study population is shown in Figure S1. After children younger than 6 years of age and those without FMI and FFMI values were excluded, 5555 children and adolescents aged 6-17 years were enrolled in the final analysis. A comparison of the basic characteristics of the study sample is reported in Table 1. The study sample was divided into four groups according to fat-free and fat levels: high FFM-high fat group, high FFM-normal fat group, normal FFM-high fat group, and normal FFM-normal fat group. As shown in Table 1, there were differences between the groups in height, weight, and BMI. When fat levels were normal, there were

significant differences in SBP, DBP, HDL-C, LDL-C and TG between the high FFM group and the normal FFM group. When fat levels were high, there were significant differences in SBP, DBP, HDL-C and TG between the high FFM group and the normal FFM group.

We quantitatively analyzed the relationships between body composition and cardiometabolic profiles. Table 2 shows the piecewise regression analysis of the associations between the FMI and cardiometabolic indicators stratified by sex and FFM level. Regardless of sex and FFM level, FMI was negatively correlated with HDL-C, and was positively correlated with SBP, DBP, LDL-C, and TG. In boys, regardless of FFM level, FMI was positively correlated with TC (in normal FFM group, β=0.036, 95% CI: 0.027 to 0.046; in high FFM group, β=0.034, 95% CI: 0.016 to 0.051) and FPG (in normal FFM group, β=0.019, 95% CI: 0.012 to 0.026; in high FFM group, β=0.030, 95% CI: 0.005 to 0.054). However, in girls, FMI was not significantly associated with TC and was positively associated with FPG only in the normal FFM group (β=0.033, 95% CI: 0.024 to 0.041).

We also analyzed the associations between FFMI and cardiometabolic indicators stratified by sex and fat level. As shown in Table 3, regardless of sex and fat level, FFMI was negatively correlated with HDL-C; positively correlated with SBP, DBP, TG, and FPG; and not linearly correlated with LDL-C. In boys, FFMI was negatively associated with TC only in the normal fat group (β=-0.047, 95% CI: -0.069 to -0.034). However, in girls, regardless of fat level, FFMI was negatively correlated with TC (in normal fat group, β=-0.058, 95% CI: -0.079 to -0.038; in high fat group, β=-0.049, 95% CI: -0.084

to -0.015).

To more clearly analyze the sex differences in the relationships between body composition and cardiometabolic indicators, we further performed logistic regression analysis. As shown in Table 4, adjusted for the age of the children, the normal FFM-normal fat group was used as the reference group. Regardless of sex, as long as one of the FFM or fat levels was high, the risk of high BP and low HDL-C increased; the risk of high TG increased in high fat group; and FFM-fat composition was not a risk factor for high IFP. Normal FFM-high fat was a risk factor for high TC in boys (OR=2.065, 95% CI: 1.379 to 3.091) but not in girls. In boys, as long as one of the FFM or fat levels was high, the risk of high LDL-C increased. However, in girls, the risk of high LDL-C increased only in the high fat group. The protective effect of high FFM against high LDL-C was not obvious in the high fat group regardless of sex, and high FFM-normal fat was a risk factor for high LDL-C in boys (OR=2.283, 95% CI: 1.521 to 3.429).

We used two models to analyze the influence of fat distribution on cardiometabolic indicators by logistic regression analysis: Model 1, trunk fat mass, arm fat mass, and leg fat mass as independent variables; Model 2, the visceral fat region was used as an independent variable.

As shown in Table 5, increased visceral fat region was a risk factor for elevated BP, low HDL-C, high LDL-C, high TG and impaired fasting glucose (IFG), and increased trunk fat mass was a risk factor for elevated BP, low HDL-C and high TG. However, increased arm fat mass was a protective factor against elevated BP and low HDL-C.

In boys, increased visceral fat region was a risk factor for high TC, increased trunk fat mass was a risk factor for high LDL-C, increased leg fat mass was a risk factor for high TC and high TG, and increased arm fat mass was a protective factor for high TG and a risk factor for IFG (Table 5). However, none of these correlations were detected in girls.

DISCUSSION

In our study, we analyzed the associations of FFM-fat composition with blood pressure, glucose, and lipids. Our results showed that FFM and fat levels were correlated with cardiometabolic indicators, and there were sex differences in the relationships between body composition and cardiometabolic indicators. The data were analyzed from the Beijing Children and Adolescents Health Cohort Study, a population-based cross-sectional study. The large sample size enhances the statistical strength and generalizability of the results to the Chinese population of children and adolescents.

Because of the possible differences in the correlations of adiposity with cardiometabolic risk between males and females, sex differences in cardiometabolic abnormalities are commonly observed across the life course. Our results indicated that the associations between body composition and cardiometabolic indicators differed between boys and girls. Some studies have also shown sex differences between fat mass and cardiometabolic risk factors. For instance, Kouda et al. reported that the trunk-to-appendicular fat ratio at baseline was significantly associated with SBP at follow-up in boys, but there were no significant associations between the trunk-to-appendicular fat ratio and SBP in girls.[20] Duran et al. reported that the trunk-to-leg fat ratio was

significantly associated with high LDL-C only in girls.[21] Sex differences have also been shown in the associations between insulin resistance and adiposity indices, and these differences were significantly more evident in middle puberty.[25] The correlations of adiposity with adverse cardiometabolic risk seem to begin earlier in the life course among males than females.[19] Partly consistent with these findings, our results have shown stronger correlations between body composition and cardiometabolic indicators in boys than in girls. Thus, prevention of obesity and cardiometabolic abnormalities may be more important in boys.

It is well known that regional adipose compartments confer different cardiometabolic risks in children. We also found that fat stored in different regions has differential influences on cardiometabolic indicators. However, our results showed that increased arm fat mass was a protective factor against elevated BP and low HDL in children. Previous studies inconsistently reported that arm fat mass was not significantly associated with cardiometabolic risk factors.[26 27]

Our results showed that FMI and FFMI were linearly correlated with FPG, but FFM-fat composition was not a risk factor for IFG. Further analysis of the relationships between the fat distribution region and cardiometabolic indicators indicated that increased visceral fat region was a risk factor for IFG regardless of sex, suggesting the important influence of visceral fat on glucose metabolism.

In addition, our results showed that high FFM-normal fat was a risk factor for elevated BP, low HDL and high LDL in boys. The protective effect of high FFM against high LDL-C was not obvious in the high fat group regardless of sex. This finding is

inconsistent with a previous study showing that greater muscle mass might be associated with better cardiometabolic traits.[14] This may be due to a lack of adjustment for confounding factors, such as puberty, diet, physical activity, and socioeconomic status. There is a need for more high-quality prospective studies to determine these associations.

Recognized as a global health problem, obesity is associated with multiple cardiometabolic disorders.[28] Adiposity results in chronic low-grade inflammation and an imbalance in adipokine secretion, and ultimately alters the physiological state of adipose tissue communication with target organs.[29] Excess adipose tissue also enhances and disturbs the generation of reactive oxygen species and increases oxidative stress, which contributes to the pathogenesis and outcomes of cardiometabolic diseases.[30] Visceral adiposity is an independent risk factor for cardiometabolic diseases and secretes proinflammatory and profibrotic cytokines, which in turn cause systemic metabolic disorders.[9]

Limitations

Our study has several limitations. First, this cross-sectional study recruited children from 11 kindergartens and schools in a district in Beijing who might not represent all children and adolescents, likely resulting in selection bias. Second, due to the small number of children with obesity in this study, it is necessary to verify the results in prospective investigations with larger sample sizes. Third, because of the small number of participants stratified by puberty, the study did not analyze the effects of puberty on the relationship between FM or FFM and cardiometabolic risk markers. Fourth,

although some studies have shown a stronger association between hepatic fat and cardiometabolic indicators than between abdominal fat and cardiometabolic indicators and that these associations are independent of BMI,[31 32] this study lacked an analysis of these associations due to the limited data. Fifth, dietary and physical activity adjustments were omitted because of data limitations. Students' diet and exercise during the day are almost uniformly conducted at school, and the analysis of the collected questionnaires on diet and exercise shows that the distribution at all levels was relatively uniform. However, it cannot be ruled out that diet and physical activity had substantial impacts on the results. We have taken this issue into account in the follow-up research plan, but this questionnaire is not accurate enough to collect such information; thus, we will design a more detailed structured questionnaire to collect diet and exercise data, further validate our current research conclusions, and further explore the role of diet and exercise. Sixth, we did not analyze the effect of socioeconomic status on the results of this study because of the limited data. Socioeconomic status can significantly predict cardiometabolic disease outcomes.[33] Socioeconomic status is inversely associated with the risk for cardiometabolic diseases, type 2 diabetes, and total mortality.[34] However, the protective effects of socioeconomic status are more pronounced in women than in men.[35] In future studies, we will collect socioeconomic status data and analyze the effects of socioeconomic status on the relationships between body composition and cardiometabolic indicators. Finally, the study's cross-sectional design limits our ability to establish causality; further longitudinal studies are necessary.

CONCLUSION

Our results indicate that body composition is significantly associated with cardiometabolic risk factors and that fat stored in different regions has differential influences on cardiometabolic indicators. The relationships between body composition and cardiometabolic risk factors are influenced by sex in children and adolescents. This finding suggested that body composition was more strongly correlated with cardiometabolic indicators in boys than in girls. Sex-specific interventions may be warranted.

Acknowledgements

The authors thank the children and their parents for their participation in the study. We also thank all team members who contributed to the study.

Contributors

Fangfang Chen conceptualized and designed the study, carried out the analyses, and reviewed and revised the manuscript. Lijun Wu wrote the initial draft of the manuscript. Yiying Huang and Yiren Chen analyzed the data. Zijun Liao, Shaoli Li, Junting Liu, and Xinnan Zong were involved in data acquisition and data processing. All authors critically reviewed the manuscript for interpretation and intellectual content and approved the final manuscript as submitted. Fangfang Chen is the corresponding authors and the guarantor.

Funding

This research was funded by the public service development and reform pilot project of Beijing Medical Research Institute, grant number BMR2021-3, the Beijing

Municipal Administration of Hospitals Incubating Program, grant number Px2022052, and the China Soong Ching Ling Foundation, grant number 2023-24.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval

We obtained written informed consent from participants/guardians. The studies involving human participants were reviewed and approved by the ethics committee of Capital Institute of Pediatrics, Beijing, China (SHERLL2022043).

Data availability statement

All data relevant to the study are included in the article or uploaded as supplementary information.

Supplemental material

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Table 1 Baseline characteristics of the study subjects stratified by body composition

	N	Normal fat		*P*	High fat		*P*
		Normal FFM	High FFM		Normal FFM	High FFM	
Sex							
Boys	2844	2169 (50.61)	179 (51.73)	0.687	269 (61.14)	227 (47.00)	**<0.001**
Girls	2711	2117 (49.39)	167 (48.27)	0.687	171 (38.86)	256 (53.00)	**<0.001**
Demography/anthropometry							
Age (years)	5555	10.56±3.07	10.45±3.03	0.541	10.44±2.99	10.79±2.97	0.077
Height (cm)	5555	146.92±17.49	151.37±17.66	**<0.001**	148.75±15.89	154.02±15.29	**<0.001**
Weight (kg)	5555	41.05±15.38	55.35±20.22	**<0.001**	58.68±19.49	71.78±22.27	**<0.001**
BMI (kg/m^2)	5555	18.29±3.32	23.12±3.76	**<0.001**	25.72±3.64	29.42±4.17	**<0.001**
Cardiometabolic indicators							
SBP (mmHg)	5546	107.83±10.92	115.82±11.88	**<0.001**	117.09±11.41	121.50±10.88	**<0.001**
DBP (mmHg)	5546	59.94±7.29	61.71±7.48	**<0.001**	64.64±7.82	65.66±7.66	**0.046**
TC (mmol/L)	5405	4.12±0.70	4.11±0.79	0.706	4.30±0.72	4.26±0.69	0.395
HDL-C (mmol/L)	5400	1.53±0.34	1.39±0.33	**<0.001**	1.31±0.29	1.23±0.27	**<0.001**
LDL-C (mmol/L)	5405	2.50±0.68	2.63±0.78	**0.001**	2.92±0.76	2.92±0.72	0.992
TG (mmol/L)	5401	0.83±0.37	0.94±0.50	**<0.001**	1.14±0.54	1.32±0.59	**<0.001**
FPG (mmol/L)	5401	4.92±0.52	4.91±0.40	0.665	4.98±0.61	5.00±0.87	0.607
Body composition indicators							
FMP (%)	5555	20.87±8.31	24.98±7.33	**<0.001**	39.39±4.52	39.30±4.67	0.767

FMI (kg/m^2)	5555	4.02±2.16	5.94±2.28	**<0.001**	10.18±2.09	11.65±2.59	**<0.001**
MMI (kg/m^2)	5555	13.43±1.73	16.19±2.20	**<0.001**	14.62±2.01	16.74±2.18	**<0.001**
FFMI (kg/m^2)	5555	14.27±1.83	17.18±2.34	**<0.001**	15.54±2.14	17.79±2.33	**<0.001**
Arm fat mass (kg)	5555	0.66±0.41	0.99±0.53	**<0.001**	1.83±0.84	2.35±1.13	**<0.001**
Leg fat mass (kg)	5555	1.63±0.86	2.32±0.98	**<0.001**	3.65±1.14	4.25±1.26	**<0.001**
Trunk fat mass (kg)	5555	3.75±3.31	6.81±4.11	**<0.001**	11.24±4.24	13.95±4.79	**<0.001**
Visceral fat region (m^2)	5555	40.56±26.99	59.13±33.15	**<0.001**	119.01±42.33	135.91±45.45	**<0.001**
Fat mass (kg)	5555	9.17±5.94	14.39±7.23	**<0.001**	23.29±8.24	28.38±9.62	**<0.001**
Muscle mass (kg)	5555	30.00±10.41	38.54±13.55	**<0.001**	33.45±11.13	40.93±12.91	**<0.001**

Continuous variables shown as mean ± standard deviation.

P values were from tests comparing two groups by independent *t*-tests or *Chi-square* tests. Those highlighted in bold indicate statistical significance (bilateral $P < 0.05$).

FFM, fat-free mass; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; FPG, fasting plasma glucose; FMP, fat mass percentage; FMI, fat mass index; MMI, muscle mass index; FFMI, fat free mass index.

Table 2 Piecewise regression results of the associations between FMI and cardiometabolic indicators stratified by sex and FFM level

	Boys				Girls			
	Normal FFM		High FFM		Normal FFM		High FFM	
Parameters	*β*	95%*CI*	*β*	95%*CI*	*β*	95%*CI*	*β*	95%*CI*
SBP	**1.673**	**(1.536, 1.810)**	**1.136**	**(0.836, 1.436)**	**1.975**	**(1.828, 2.121)**	**1.234**	**(0.988, 1.480)**
DBP	**0.874**	**(0.783, 0.965)**	**0.840**	**(0.655, 1.026)**	**1.038**	**(0.923, 1.152)**	**0.825**	**(0.639, 1.011)**
TC	**0.036**	**(0.027, 0.046)**	**0.034**	**(0.016, 0.051)**	0.001	(-0.010, 0.012)	0.004	(-0.017, 0.024)
HDL-C	**-0.040**	**(-0.045, -0.036)**	**-0.024**	**(-0.032, -0.016)**	**-0.046**	**(-0.051, -0.041)**	**-0.032**	**(-0.039, -0.025)**
LDL-C	**0.077**	**(0.068, 0.086)**	**0.056**	**(0.037, 0.074)**	**0.041**	**(0.030, 0.052)**	**0.026**	**(0.006, 0.047)**
TG	**0.059**	**(0.054, 0.064)**	**0.052**	**(0.039, 0.065)**	**0.050**	**(0.044, 0.055)**	**0.058**	**(0.042, 0.074)**
FPG	**0.019**	**(0.012, 0.026)**	**0.030**	**(0.005, 0.054)**	**0.033**	**(0.024, 0.041)**	0.011	(0.000, 0.022)

Adjusted for the age of children. *P* values were from piecewise regression analysis. Those highlighted in bold indicate statistical significance (bilateral $P < 0.05$).

FFM, fat-free mass; CI, confidence interval; FMI, fat mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; FPG, fasting blood glucose.

Table 3 Piecewise regression results of the associations between FFMI and cardiometabolic indicators stratified by sex and fat level

	Boys				Girls			
	Normal fat		High fat		Normal fat		High fat	
Parameters	*β*	95%*CI*	*β*	95%*CI*	*β*	95%*CI*	*β*	95%*CI*
SBP	**3.182**	**(3.024, 3.340)**	**2.319**	**(1.996, 2.643)**	**3.575**	**(3.313, 3.838)**	**2.128**	**(1.683, 2.573)**
DBP	**0.869**	**(0.746, 0.992)**	**0.619**	**(0.374, 0.865)**	**1.439**	**(1.230, 1.647)**	**1.054**	**(0.705, 1.404)**
TC	**-0.047**	**(-0.069, -0.034)**	-0.018	(-0.040, 0.005)	**-0.058**	**(-0.079, -0.038)**	**-0.049**	**(-0.084, -0.015)**
HDL-C	**-0.064**	**(-0.070, -0.059)**	**-0.046**	**(-0.054, -0.037)**	**-0.063**	**(-0.073, -0.054)**	**-0.041**	**(-0.053, -0.029)**
LDL-C	0.004	(-0.009, 0.016)	0.010	(-0.013, 0.034)	-0.011	(-0.031, 0.009)	-0.033	(-0.069, 0.003)
TG	**0.039**	**(0.032, 0.046)**	**0.049**	**(0.031, 0.067)**	**0.054**	**(0.043, 0.065)**	**0.071**	**(0.044, 0.097)**
FPG	**0.025**	**(0.017, 0.034)**	**0.045**	**(0.015, 0.076)**	**0.056**	**(0.041, 0.072)**	**0.036**	**(0.017, 0.055)**

Adjusted for the age of children. *P* values were from piecewise regression analysis. Those highlighted in bold indicate statistical significance (bilateral $P < 0.05$).

FFMI, fat-free mass index; CI, confidence interval; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; FPG, fasting blood glucose.

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Table 4 Adjusted ORs for the associations of FFM-fat composition with blood pressure, glucose, and lipid metabolic abnormalities stratified by sex

	Boys		Girls	
	OR	95%*CI*	OR	95%*CI*
Elevated BP				
High FFM-normal fat	**2.703**	**(1.835, 3.981)**	**3.612**	**(2.376, 5.491)**
Normal FFM-high fat	**4.476**	**(3.324, 6.027)**	**5.280**	**(3.601, 7.742)**
High FFM-high fat	**6.278**	**(4.625, 8.522)**	**10.364**	**(7.650, 14.043)**
High TC				
High FFM-normal fat	1.357	(0.777, 2.368)	1.080	(0.586, 1.993)
Normal FFM-high fat	**2.065**	**(1.379, 3.091)**	1.187	(0.670, 2.104)
High FFM-high fat	1.343	(0.814, 2.216)	1.344	(0.847, 2.130)
Low HDL-C				
High FFM-normal fat	**2.137**	**(1.309, 3.488)**	**2.669**	**(1.470, 4.846)**
Normal FFM-high fat	**2.794**	**(1.908, 4.089)**	**3.250**	**(1.891, 5.586)**
High FFM-high fat	**4.637**	**(3.234, 6.647)**	**8.892**	**(6.133, 12.894)**
High LDL-C				
High FFM-normal fat	**2.283**	**(1.521, 3.429)**	0.912	(0.526, 1.582)
Normal FFM-high fat	**3.827**	**(2.817, 5.198)**	**2.608**	**(1.775, 3.833)**
High FFM-high fat	**3.607**	**(2.591, 5.020)**	**2.251**	**(1.604, 3.159)**
High TG				
High FFM-normal fat	1.453	(0.923, 2.289)	1.585	(0.967, 2.598)
Normal FFM-high fat	**3.499**	**(2.578, 4.749)**	**3.705**	**(2.535, 5.414)**
High FFM-high fat	**6.686**	**(4.941, 9.048)**	**8.796**	**(6.552, 11.809)**
IFG				
High FFM-normal fat	0.350	(0.110, 1.115)	1.248	(0.491, 3.167)
Normal FFM-high fat	1.642	(0.998, 2.701)	1.156	(0.456, 2.932)
High FFM-high fat	1.442	(0.823, 2.526)	1.760	(0.907, 3.417)

Adjusted for the age of children, normal FFM-normal fat group as the reference group.

P values were from logistic regression analysis. Those highlighted in bold indicate statistical significance (bilateral $P < 0.05$).

OR, odds ratio; FFM, fat-free mass; CI, confidence interval; BP, blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; IFG, impaired fasting glucose.

Table 5 ORs of cardiometabolic risk factors associated with 1-SD increase in fat mass variables

		Boys		Girls	
		OR	95% *CI*	OR	95% *CI*
Elevated BP					
	Trunk fat mass	**7.625**	**(4.184, 13.898)**	**5.153**	**(2.477, 10.717)**
Modle1	Arm fat mass	**0.515**	**(0.367, 0.724)**	**0.545**	**(0.351, 0.847)**
	Leg fat mass	0.616	(0.345, 1.100)	1.200	(0.626, 2.298)
Modle2	Visceral fat region	**2.008**	**(1.822, 2.212)**	**2.583**	**(2.279, 2.929)**
High TC					
	Trunk fat mass	0.510	(0.222, 1.172)	0.984	(0.325, 3.009)
Modle1	Arm fat mass	1.075	(0.711, 1.625)	0.473	(0.210, 1.064)
	Leg fat mass	**2.558**	**(1.120, 5.840)**	2.385	(0.821, 6.931)
Modle2	Visceral fat region	**1.357**	**(1.195, 1.540)**	1.114	(0.946, 1.313)
Low HDL-C					
	Trunk fat mass	**4.255**	**(2.182, 8.295)**	**6.743**	**(2.759, 16.478)**
Modle1	Arm fat mass	**0.518**	**(0.349, 0.700)**	**0.541**	**(0.319, 0.918)**
	Leg fat mass	0.968	(0.486, 1.928)	0.818	(0.381, 1.759)
Modle2	Visceral fat region	**1.788**	**(1.602, 1.995)**	**2.243**	**(1.938, 2.597)**
High LDL-C					
	Trunk fat mass	**1.916**	**(1.043, 3.521)**	1.296	(0.576, 2.916)
Modle1	Arm fat mass	0.747	(0.538, 1.037)	0.651	(0.393, 1.079)
	Leg fat mass	1.430	(0.787, 2.597)	1.863	(0.867, 4.000)
Modle2	Visceral fat region	**1.832**	**(1.659, 2.023)**	**1.473**	**(1.303, 1.665)**
High TG					
	Trunk fat mass	**2.711**	**(1.492, 4.925)**	**2.797**	**(1.353, 5.782)**
Modle1	Arm fat mass	**0.505**	**(0.359, 0.710)**	0.699	(0.456, 1.071)
	Leg fat mass	**1.800**	**(1.005, 3.223)**	1.330	(0.691, 2.560)
Modle2	Visceral fat region	**2.055**	**(1.861, 2.269)**	**2.186**	**(1.939, 2.465)**
IFG					
	Trunk fat mass	1.660	(0.696, 3.963)	0.475	(0.118, 1.910)
Modle1	Arm fat mass	**1.587**	**(1.033, 2.438)**	1.349	(0.675, 2.696)
	Leg fat mass	0.419	(0.167, 1.053)	2.162	(0.617, 7.577)
Modle2	Visceral fat region	**1.242**	**(1.075, 1.436)**	**1.409**	**(1.142, 1.739)**

ORs were expressed in SD units. *P* values were from logistic regression analysis. Those highlighted in bold indicate statistical significance (bilateral $P < 0.05$). Modle1 adjusted for age, trunk fat mass, arm fat mass, and leg fat mass, other than the variable in the model. Modle2 adjusted for age, visceral fat region, other than the variable in the model.

OR, odds ratio; SD, standard deviation; CI, confidence interval; BP, blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; IFG, impaired fasting glucose.

Online supplementary material

Supplementary Table S1. Classification standards and definitions

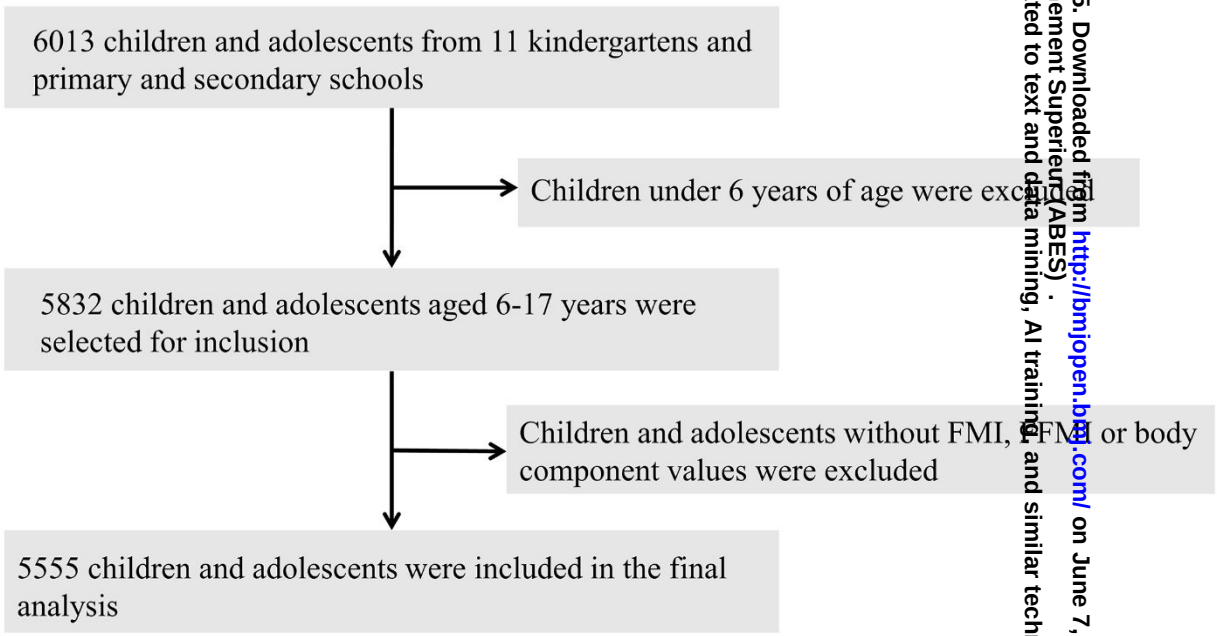
Metrics	Standards or definition	References
Elevated BP (6 years old)	SBP and/or DBP ⩾ 90th percentile for age and sex	Fan H, Yan Y, Mi J. Updating blood pressure references for Chinese children aged 3-17 years. Chinese Journal of Hypertension 2017;25:28-35.
Elevated BP (7-17 years old)	SBP and/or DBP ⩾ 90th percentile for age and sex	Reference of screening for elevated blood pressure among children and adolescents aged 7～18 years: WS/T 610-2018[S]. 2018.
High TC	TC ≥ 5.18 mmol/L	Subspecialty Group of Rare Diseases, the Society of Pediatrics, Chinese Medical Associationet al. Expert consensus on diagnosis and management of dyslipidemia in children (2022) [in Chinese]. *Chinese Journal of Pediatrics* 2022;60:633-9.
Low HDL-C	HDL-C < 1.03 mmol/L	Subspecialty Group of Rare Diseases, the Society of Pediatrics, Chinese Medical Associationet al. Expert consensus on diagnosis and management of dyslipidemia in children (2022) [in Chinese]. *Chinese Journal of Pediatrics* 2022;60:633-9.
High LDL-C	LDL-C ≥ 3.36 mmol/L	Subspecialty Group of Rare Diseases, the Society of Pediatrics, Chinese Medical Associationet al. Expert consensus on diagnosis and management of dyslipidemia in children (2022) [in Chinese]. *Chinese Journal of Pediatrics* 2022;60:633-9.

High TG	6-9 years old, TG ≥ 1.12 mmol/L; 10-18 years old, TG ≥ 1.46 mmol/L	Group of Rare Diseases, Group of Cardiovascular Diseases, Group of Child Health Care, et al. Lipid abnormalities in children: disease diagnosis and expert consensus (2022) [J]. *Chinese journal of pediatrics* 2022;60:633-9.
IFG	FPG ≥ 5.6 mmol/L	American Diabetes Association. 2. Classification and Diagnosis of Diabetes: Standards of Medical Care in Diabetes-2020. *Diabetes Care* 2020;43:S14-S31.
BMI	weight (kg)/[height (m)]^2	
FMI	FM (kg)/[height (m)]^2	
MMI	MM (kg)/[height (m)]^2	
FFMI	FFM (kg)/[height (m)]^2	
FMP	FM (kg)/weight (kg) × 100%.	
Arm fat mass (mean)	[left arm fat mass (kg)+ right arm fat mass (kg)]/2	
Leg fat mass (mean)	[left leg fat mass (kg)+ right leg fat mass (kg)]/2	
High FFM	the FFMI Z score was calculated, and a Z value ⩾ 1 was defined as a high FFM level	
High fat	the FMI Z score was calculated, and a Z value ⩾1 was defined as a high fat level	
Normal FFM	the FFMI Z score was calculated, and a Z value <1 was defined as a normal FFM level	

Normal fat	the FMI Z score was calculated, and a Z value <1 was defined as a normal fat level
Normal FFM-normal fat group	both FFM and fat levels were normal
High FFM-normal fat group	FFM level was high, and fat level was normal
Normal FFM-high fat group	FFM level was normal, and fat level was high
High FFM-high fat group	both FFM and fat levels were high

Abbreviations: BMI, body mass index; BP, blood pressure; DBP: diastolic blood pressure; FFM, fat-free mass; FFMI, fat-free mass index; FMI, fat mass index; FMP, fat mass percentage;FPG, fasting plasma glucose; HDL-C, high-density lipoprotein cholesterol; IFG, impaired fasting glucose; LDL-C, low-density lipoprotein cholesterol; MMI, muscle mass index; SBP, systolic blood pressure;TC, total cholesterol; TG, triglycerides.

Figure S1 Flow chart of participant inclusion and exclusion criteria



Supplementary Figure S1 Flow chart of participant inclusion and exclusion criteria

This study collected baseline data from the Beijing Children and Adolescents Health Cohort Study. We measured body composition and detected the cardiometabolic indicators, including blood pressure, plasma glucose, and lipids.
FMI, fat mass index; FFMI, fat-free mass index.