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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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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). 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 analysed from the Beijing Children and Adolescents Health Cohort Study, a cross-sectional study.
⇒ The large sample size enhances the statistical strength and generalisability 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 dyslipidaemia.[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 hyperglycaemia and hyperinsulinaemia.[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 reporting guidelines for cross-sectional studies.

Data collection

Questionnaire

The questionnaire is not a known questionnaire; it is a unified standardised questionnaire that needs to be developed according to the research. The questionnaire included basic information, family history of disease, birth and feeding, exercise, behaviour and lifestyle, diet, allergies, adolescent development, sleep and other related content. These questionnaires were issued 1 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 standardised 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 metres squared. All instruments used were the same in the 11 kindergartens and schools during the survey.

Blood pressure (BP) measurements

Oscillometric sphygmomanometers (HBP-1300, Omron, Kyoto, Japan) were used to measure systolic BP (SBP) and diastolic BP (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 1000 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. FMI and FFMI were also calculated for each subject as FM and FFM in kilograms divided by height in metres squared, respectively.

Biochemical measurements

After an overnight fast of at least 12 hours, vein blood samples were collected by direct venipuncture into EDTA anti-coagulant tubes and serum tubes. Blood samples were analysed 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 online supplemental table S1.

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

		Normal fat			High fat		
	N	Normal FFM	High FFM	P	Normal FFM	High FFM	P
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±15.80	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 (mm Hg)	5546	107.83±10.92	115.82±11.88	**<0.001**	117.09±11.44	121.50±10.88	**<0.001**
DBP (mm Hg)	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±42.32	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±SD.
P values were from tests comparing two groups by independent *t*-tests or $\chi 2$ tests. Those highlighted in bold indicate statistical significance (bilateral p<0.05).
BMI, body mass index; 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; LDL-C, low-density lipoprotein cholesterol; MMI, muscle mass index; SBP, systolic blood pressure; TC, total cholesterol; TG, triglycerides.

Statistical analysis

Continuous variables were expressed as mean±SD, and categorical variables were expressed as frequencies with percentages. The independent *t*-test and $\chi 2$ 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 analyse 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 online supplemental 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 analysed 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 analysed the associations between FFMI and cardiometabolic indicators stratified by sex and fat level. As shown in table 3, regardless of sex and fat level,

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 to 1.810)**	**1.136**	**(0.836 to 1.436)**	**1.975**	**(1.828 to 2.121)**	**1.234**	**(0.988 to 1.480)**
DBP	**0.874**	**(0.783 to 0.965)**	**0.840**	**(0.655 to 1.026)**	**1.038**	**(0.923 to 1.152)**	**0.825**	**(0.639 to 1.011)**
TC	**0.036**	**(0.027 to 0.046)**	**0.034**	**(0.016 to 0.051)**	0.001	(−0.010 to 0.012)	0.004	(−0.017 to 0.024)
HDL-C	**−0.040**	**(−0.045 to 0.036)**	**−0.024**	**(−0.032 to 0.016)**	**−0.046**	**(−0.051 to 0.041)**	**−0.032**	**(−0.039 to 0.025)**
LDL-C	**0.077**	**(0.068 to 0.086)**	**0.056**	**(0.037 to 0.074)**	**0.041**	**(0.030 to 0.052)**	**0.026**	**(0.006 to 0.047)**
TG	**0.059**	**(0.054 to 0.064)**	**0.052**	**(0.039 to 0.065)**	**0.050**	**(0.044 to 0.055)**	**0.058**	**(0.042 to 0.074)**
FPG	**0.019**	**(0.012 to 0.026)**	**0.030**	**(0.005 to 0.054)**	**0.033**	**(0.024 to 0.041)**	0.011	(0.000 t 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).
DBP, diastolic blood pressure; FFM, fat-free mass; FMI, fat mass index; FPG, fasting blood glucose; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; SBP, systolic blood pressure; TC, total cholesterol; TG, triglycerides.

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 to 3.340)**	**2.319**	**(1.996 to 2.643)**	**3.575**	**(3.313 to 3.838)**	**2.128**	**(1.683 to 2.573)**
DBP	**0.869**	**(0.746 to 0.992)**	**0.619**	**(0.374 to 0.865)**	**1.439**	**(1.230 to 1.647)**	**1.054**	**(0.705 to 1.404)**
TC	**−0.047**	**(−0.069 to 0.034)**	−0.018	(−0.040 to 0.005)	**−0.058**	**(−0.079 to 0.038)**	**−0.049**	**(−0.084 to 0.015)**
HDL-C	**−0.064**	**(−0.070 to 0.059)**	**−0.046**	**(−0.054 to 0.037)**	**−0.063**	**(−0.073 to 0.054)**	**−0.041**	**(−0.053 to 0.029)**
LDL-C	0.004	(−0.009 to 0.016)	0.010	(−0.013 to 0.034)	−0.011	(−0.031 to 0.009)	−0.033	(−0.069 to 0.003)
TG	**0.039**	**(0.032 to 0.046)**	**0.049**	**(0.031 to 0.067)**	**0.054**	**(0.043 to 0.065)**	**0.071**	**(0.044 to 0.097)**
FPG	**0.025**	**(0.017 to 0.034)**	**0.045**	**(0.015 to 0.076)**	**0.056**	**(0.041 to 0.072)**	**0.036**	**(0.017 to 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).
DBP, diastolic blood pressure; FFMI, fat-free mass index; FPG, fasting blood glucose; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; SBP, systolic blood pressure; TC, total cholesterol; TG, triglycerides.

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 analyse 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 the 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 analyse 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) and 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 analysed the associations of FFM-fat composition with BP, 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 analysed from the Beijing Children and Adolescents Health Cohort Study, a population-based cross-sectional study. The large sample size enhances the statistical strength and

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

generalisability 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, the 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]

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					
Model 1	Trunk fat mass	**7.625**	(**4.184 to 13.898**)	**5.153**	(**2.477 to 10.717**)
	Arm fat mass	**0.515**	(**0.367 to 0.724**)	**0.545**	(**0.351 to 0.847**)
	Leg fat mass	0.616	(0.345 to 1.100)	1.200	(0.626 to 2.298)
Model 2	Visceral fat region	**2.008**	(**1.822 to 2.212**)	**2.583**	(**2.279 to 2.929**)
High TC					
Model 1	Trunk fat mass	0.510	(0.222 to 1.172)	0.984	(0.325 to 3.009)
	Arm fat mass	1.075	(0.711 to 1.625)	0.473	(0.210 to 1.064)
	Leg fat mass	**2.558**	(**1.120 to 5.840**)	2.385	(0.821 to 6.931)
Model 2	Visceral fat region	**1.357**	(**1.195 to 1.540**)	1.114	(0.946 to 1.313)
Low HDL-C					
Model 1	Trunk fat mass	**4.255**	(**2.182 to 8.295**)	**6.743**	(**2.759 to 16.478**)
	Arm fat mass	**0.518**	(**0.349 to 0.700**)	**0.541**	(**0.319 to 0.918**)
	Leg fat mass	0.968	(0.486 to 1.928)	0.818	(0.381 to 1.759)
Model 2	Visceral fat region	**1.788**	(**1.602 to 1.995**)	**2.243**	(**1.938 to 2.597**)
High LDL-C					
Model 1	Trunk fat mass	**1.916**	(**1.043 to 3.521**)	1.296	(0.576 to 2.916)
	Arm fat mass	0.747	(0.538 to 1.037)	0.651	(0.393 to 1.079)
	Leg fat mass	1.430	(0.787 to 2.597)	1.863	(0.867 to 4.000)
Model 2	Visceral fat region	**1.832**	(**1.659 to 2.023**)	**1.473**	(**1.303 to 1.665**)
High TG					
Model 1	Trunk fat mass	**2.711**	(**1.492 to 4.925**)	**2.797**	(**1.353 to 5.782**)
	Arm fat mass	**0.505**	(**0.359 to 0.710**)	0.699	(0.456 to 1.071)
	Leg fat mass	**1.800**	(**1.005 to 3.223**)	1.330	(0.691 to 2.560)
Model 2	Visceral fat region	**2.055**	(**1.861 to 2.269**)	**2.186**	(**1.939 to 2.465**)
IFG					
Model 1	Trunk fat mass	1.660	(0.696 to 3.963)	0.475	(0.118 to 1.910)
	Arm fat mass	**1.587**	(**1.033 to 2.438**)	1.349	(0.675 to 2.696)
	Leg fat mass	0.419	(0.167 to 1.053)	2.162	(0.617 to 7.577)
Model 2	Visceral fat region	**1.242**	(**1.075 to 1.436**)	**1.409**	(**1.142 to 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). Model 1 adjusted for age, trunk fat mass, arm fat mass and leg fat mass, other than the variable in the model. Model 2 adjusted for age and visceral fat region, other than the variable in the model.
BP, blood pressure; HDL-C, high-density lipoprotein cholesterol; IFG, impaired fasting glucose; LDL-C, low-density lipoprotein cholesterol; TC, total cholesterol; TG, triglycerides.

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 MM 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.

Recognised 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 analyse 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 analyse 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 analyse 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.

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