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Glucose metabolism among obese and non-obese children of mothers with gestational diabetes

Jun Lu,[1,2] Yuying Gu,[2,3] Leishen Wang,[4] Weiqin Li,[4] Shuang Zhang,[4] Huikun Liu,[4] Junhong Leng ,[4] Jin Liu,[4] Shuo Wang,[4] Andrea A Baccarelli,[5] Lifang Hou,[6] Gang Hu [2]

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For numbered affiliations see end of article.

Correspondence to
Dr Gang Hu; gang.hu@pbrc.edu

ABSTRACT

Objectives Abdominal obesity is more closely associated with diabetes than general obesity in adults, however, it is unknown which kind of obesity is more closely associated with abnormal glucose metabolism in children.

Research design and methods We recruited 973 children (aged 3.08±1.06) of mothers with prior gestational diabetes mellitus (GDM). Children's height, weight, waist circumstance, fasting glucose and insulin were measured using standardized methods. Logistic regression models were used to assess the single and joint associations of general and abdominal obesity with the risks of hyperglycemia (the upper quartile of fasting glucose), insulin resistance (the upper quartile of homeostatic model assessment of insulin resistance (HOMA-IR)), and β-cell dysfunction (the lower quartile of HOMA-%β).

Results Compared with normal weight children, children with general overweight/obesity had higher levels of HOMA-IR and HOMA-%β, higher ORs for hyperglycemia (1.56, 95% CI 1.06 to 2.30) and insulin resistance (3.44, 95% CI 2.32 to 5.09), but a lower OR for β-cell dysfunction (0.65, 95% CI 0.41 to 1.04). Children with abdominal obesity had an increased risk of insulin resistance (2.54, 95% CI 1.71 to 3.76) but not hyperglycemia and β-cell dysfunction compared with children with normal waist circumstance. In the joint analyses, general overweight children with and without abdominal obesity had an increased risk of hyperglycemia and insulin resistance compared with normal weight children.

Conclusions General obesity was more closely associated with abnormal glucose metabolism than abdominal obesity in children of mothers with GDM.

Significance of this study

What is already known about this subject?

- Obesity was associated with childhood insulin resistance, and abdominal obesity was more closely associated with type 2 diabetes than general obesity in adults. It is unknown which kind of obesity is more closely associated with abnormal glucose metabolism in children.

What are the new findings?

- Both general and abdominal obesity were associated with children's insulin resistance, but only general obesity was associated with hyperglycemia in children of mothers with gestational diabetes mellitus. General obesity was more closely associated with abnormal glucose metabolism than abdominal obesity.

How might these results change the focus of research or clinical practice?

- Longitudinal studies are warranted to investigate long-term effects of obesity and weight management on glucose metabolism in children.

INTRODUCTION

The Global Burden of Disease 2015 Obesity Group reported that the prevalence and burden of childhood obesity has increased greatly worldwide from 1980 to 2017.[1] Similar trend has been observed in China, and the prevalence of obesity among children aged 6–11 years has reached 13.2% in 2015.[2 3] Prospective studies showed that overweight and obesity during childhood are major risk factors for adulthood obesity and cardiometabolic diseases such as type 2 diabetes, the metabolic syndrome, and cardiovascular diseases.[4–6] Some studies also indicated that obesity was associated with increased risks of insulin resistance and type 2 diabetes in children.[7–9] Several adiposity indicators have been reported to correlate with glucose metabolism in children. A UK study demonstrated that body mass index (BMI), waist circumference and skinfold thicknesses were positively associated with insulin resistance in all ethnic groups, and correlated with HbA1c levels in South Asian and black African-Caribbean children but not in white Europeans.[7] Another US study reported that both fat mass and waist circumference positively correlated with insulin resistance among children.[9] However, no studies have assessed the association of

various anthropometric obesity indicators with glucose metabolism in Chinese children.

Some studies have found that offspring of mothers with gestational diabetes mellitus (GDM) were more vulnerable to obesity, insulin resistance and diabetes.[10 11] Therefore, it is urgent to investigate the association between adiposity and glucose metabolism in the offspring of mothers with GDM. In the present study, we investigated the effects of general and abdominal obesity on major glucose metabolic measures (hyperglycemia, insulin resistance, and β-cell dysfunction) in children of mothers with GDM in Tianjin, China.

SUBJECTS AND METHODS

GDM screening process

Tianjin is the fourth largest city in China, and there are about 4.3 million residents in six central districts. According to the WHO's criteria, an urban universal screening of GDM was launched in all six central districts in 1999.The screening rate was reported to be >91% between 1999 and 2008.[12] GDM was screened using a two-step method. All pregnant women (at their 26–30 gestational weeks) were first invited to participate in a 1-hour oral glucose tolerance test (OGTT) with 50 g glucose load in their community health centers. Those with glucose reading ≥7.8 mmol/L were referred to the Tianjin Women's and Children's Health Center to undergo a 2-hour OGTT with 75 g glucose load. The pregnant women were classified as having GDM if they met the WHO's criteria of diabetes (fasting glucose ≥7 mmol/L or 2-hour glucose ≥11.1 mmol/L) or impaired glucose tolerance (IGT) (2-hour glucose ≥7.8 and <11.1 mmol/L.[13]

Study population

Totally 76 325 women were under screening of GDM from 2005 to 2009, and 4644 of them were diagnosed with GDM. All 4644 GDM women were invited to participate in the Tianjin Gestational Diabetes Mellitus Prevention Program. A total of 1263 GDM women and their children finished the baseline survey from August 2009 to July 2011. Of them, 973 children had measured fasting glucose and insulin and were included in the present analysis. No differences in 2-hour OGTT concentration, fasting glucose concentration, and the prevalence of IGT and diabetes at 26–30 gestational weeks were observed among women who participated in the postpartum survey and those who did not.[14]Written informed consents were collected from all participants.

Questionnaires and measurements

We collected mothers' information by a self-administered questionnaire, including sociodemographic characteristics, such as age, marital status, education (<13, 13–16, and ≥16 years), family income (<¥5000/month, ¥5000–¥8000/month, and ≥¥8000/month), and occupation; pregnancy outcomes (pre-pregnancy weight, weight gain during pregnancy, gestational age, and the number of births in the index pregnancy); and smoking status (non-smokers, former smokers, and current smokers). Women were classified as having a history of hypertensive disorder of pregnancy (HDP) if they reported doctor-diagnosed hypertension after 20 weeks (including gestational hypertension, pre-eclampsia, severe pre-eclampsia or eclampsia) of gestation on the questionnaire.[15] We collected children's information by another questionnaire completed by their mothers, including children's general information, such as gender, birth date, birth weight, birth length, lactation (exclusive formula, mixed or exclusive breast feeding) and lactation duration; history of diseases and medication; dietary habits (using a validated food frequency questionnaire (FFQ))[16]; and routine activities (indoor and outdoor activities, screen time, and sleep duration).[17]

All children underwent a physical examination. Height and weight were measured while the participants were barefoot and in light indoor clothing by trained research doctors according to the standardized protocol. BMI was calculated as the weight divided by height squared (kg/m^2). Waist circumference was measured mid-way between the lower rib margin and the iliac crest. All mothers' pre-pregnancy BMI was evaluated using their self-reported pre-pregnancy weight in kilos and their measured height in meters. Children's Z scores for BMI for age were calculated according to the WHO growth reference.[18 19] Children's BMI was categorized as normal weight, BMI <85th percentile; overweight, 85th percentile ≤ BMI <95th percentile; and general obesity, BMI ≥95th percentile, according to the WHO age and gender-specific growth reference.[18 19] Abdominal obesity was defined as a waist circumstance ≥90th percentile according to anthropometric reference data for children and adults in the USA, 2007–2010.[20]

Blood samples were drawn from all children after an overnight fasting of at least 6 hours. Fasting plasma glucose was measured using an automatic analyzer (TBA-120FR; Toshiba, Japan), and insulin was measured with chemiluminescence using a Siemens ADVIA Centaur CP Immunoassay System. Homeostatic model assessment (HOMA) was used to estimate β-cell secretory function (HOMA-%β) and insulin resistance (HOMA-IR) as described previously.[14] β-cell dysfunction was defined as the lower quartile of HOMA-%β. Insulin resistance and hyperglycemia were defined as the upper quartile of HOMA-IR and fasting glucose of total sample, respectively.

Statistical analysis

The general characteristics (continuous and categorical variables) of both mothers and children according to children's different statuses of general and abdominal obesity were performed using the χ^2 test or general linear model. Logistic regression models were used to estimate ORs of childhood major abnormal glucose metabolism (hyperglycemia, insulin resistance, and β-cell dysfunction) according to different statuses of general and abdominal obesity. In the joint analyses, children were divided into four groups: normal weight and normal waist

Table 1 Maternal and child characteristics according to children's general and abdominal obesity status

	Normal weight		General overweight/obesity		
	Normal waist circumstance	Abdominal obesity	Normal waist circumstance	Abdominal obesity	P value
Subjects, n	727	75	72	99	
Maternal characteristics					
Age at delivery (years)	31.0±3.45	31.2±3.35	30.9±3.80	31.1±4.23	0.93
Pre-pregnancy BMI (kg/m^2)	22.9±3.23	22.5±3.24	24.8±3.33	24.2±3.42	<0.001
Gestational weight gain (kg)	16.4±5.78	16.5±5.81	18.3±6.82	18.1±6.72	0.005
Gestational age at delivery (weeks)	39.1±1.51	39.1±1.57	38.7±1.34	38.9±1.53	0.13
Education (%)					0.21
<13 years	21.0	21.3	25.0	29.3	
13–16 years	71.5	62.7	72.2	66.7	
≥16 years	7.4	16.0	2.8	4.0	
Smoking status (%)					0.19
Never	96.3	97.3	91.7	92.9	
Past	2.6	1.3	6.9	3.0	
Current	1.1	1.3	1.4	4.0	
Offspring characteristics					
Boy (%)	51.3	60.0	55.6	65.7	0.006
Age (years)	3.11±1.05	2.48±0.70	3.47±1.27	3.00±0.96	<0.001
Birth weight (g)	3497±508	3649±558	3743±543	3638±527	<0.001
Mode of infant feeding (%)					0.59
Exclusive breast feeding	44.6	36	33.3	47.5	
Exclusive formula feeding	41.5	50.7	45.8	41.4	
Mixed feeding	13.9	13.3	20.8	11.1	
Outdoor activity (hours/day)	1.62±0.85	1.80±0.88	1.66±0.84	1.69±0.96	0.34
Screen time (hours/day)	1.23±0.98	1.32±1.12	1.65±1.32	1.51±1.07	0.001
Sleeping time (%)					0.13
≤8 hours/day	1.7	2.7	4.2	2.0	
9–10 hours/day	46.6	29.3	62.5	47.5	
≥11 hours/day	51.7	68.0	33.3	50.5	
Dietary intake					
Energy (kcal/day)	883±231	948±199	946±244	1037±288	<0.001
Protein (% of energy)	16.2±2.77	16.8±3.09	15.6±2.44	17.0±3.14	0.004
Fat (% of energy)	32.4±7.24	33.2±7.15	31.1±6.46	31.0±7.76	0.11
Carbohydrate (%)	52.9±7.58	51.4±7.71	54.7±7.16	53.5±8.13	0.06
Fiber (g/1000 kcal)	3.94±1.02	3.64±1.19	3.85±0.92	3.96±1.03	0.10
Body mass index (kg/m^2)	15.2±0.93	15.8±0.81	17.7±0.74	19.0±2.08	<0.001
BMI for age Z-score	−0.26±0.73	0.15±0.63	1.52±0.41	2.30±1.15	<0.001
Waist circumstance (cm)	49.5±3.11	55.6±3.01	53.8±4.02	59.2±5.62	<0.001
Fasting glucose (mmol/L)	4.35±0.36	4.33±0.37	4.47±0.36	4.44±0.32	0.007
Fasting insulin (mIU/L)	2.44±1.64	2.26±1.94	3.29±1.74	4.23±3.64	<0.001

Overweight or obesity was defined as a body mass index ≥85th percentile according to the WHO age and gender-specific growth reference.
Abdominal obesity was defined as a waist circumstance ≥90th percentile according to anthropometric reference data for children and adults in the USA, 2007–2010.
BMI, body mass index.

circumstance, central obesity only, general obesity only, and general obesity concomitant with central obesity. All analyses were adjusted for children's sex, age, birth weight, and feeding status (model 1); and then children's lifestyles including outdoor physical activity time, screen time, sleep time, daily energy intake, daily fiber intake, energy from carbohydrate, protein, and fat based on FFQ (model 2); and further for maternal delivery age, smoking

Table 2 Childhood major glucose metabolism outcomes according to general and abdominal obesity status

	General obesity status			Abdominal obesity status		
	Normal weight	Overweight/obesity	P value	Normal waist circumstance	Abdominal obesity	P value
Subjects, n	802	171		799	174	
Fasting glucose (mmol/L)	4.35±0.01	4.43±0.03	0.008	4.36±0.01	4.39±0.03	0.28
Fasting insulin (mIU/L)	2.44±0.07	3.75±0.15	<0.001	2.49±0.07	3.51±0.15	<0.001
HOMA-IR*	−0.44±0.01	−0.25±0.03	<0.001	−0.42±0.01	−0.32±0.03	<0.001
HOMA-β*	1.71±0.01	1.82±0.03	<0.001	1.72±0.01	1.80±0.03	0.006
Hyperglycemia						
Cases, n (%)	182 (22.7)	60 (35.1)		191 (23.9)	51 (29.3)	
OR (95% CI)						
Model 1	1	1.74 (1.21 to 2.50)	0.003	1	1.33 (0.91 to 1.93)	0.14
Model 2	1	1.58 (1.09 to 2.30)	0.016	1	1.26 (0.85 to 1.85)	0.25
Model 3	1	1.56 (1.06 to 2.30)	0.024	1	1.24 (0.84 to 1.83)	0.29
Insulin resistance						
Cases, n (%)	163 (20.3)	79 (46.2)		178 (22.3)	64 (36.8)	
OR (95% CI)						
Model 1	1	3.68 (2.55 to 5.30)	<0.001	1	2.75 (1.89 to 4.00)	<0.001
Model 2	1	3.41 (2.34 to 4.97)	<0.001	1	2.59 (1.76 to 3.82)	<0.001
Model 3	1	3.44 (2.32 to 5.09)	<0.001	1	2.54 (1.71 to 3.76)	<0.001
β-cell dysfunction						
Cases, n (%)	199 (24.8)	28 (16.4)		186 (23.3)	41 (23.6)	
OR (95% CI)						
Model 1	1	0.63 (0.40 to 0.98)	0.039	1	0.89 (0.59 to 1.32)	0.55
Model 2	1	0.63 (0.40 to 0.99)	0.047	1	0.85 (0.56 to 1.28)	0.44
Model 3	1	0.65 (0.41 to 1.04)	0.07	1	0.86 (0.57 to 1.31)	0.49

Model 1 adjusted for children's sex, age, birth weight, and feeding status.
Model 2 adjusted for variables in model 1 plus children's screen time, sleep time, outside activity, daily energy intake, fiber, fat, protein and carbohydrate consumption.
Model 3 adjusted for variables in model 2 plus maternal delivery age, smoking status, education, gestational age at delivery, pre-pregnancy body mass index (BMI), weight gain during pregnancy, and hypertensive disorder of pregnancy.
HOMA-β was used to estimate β-cell secretory function.
*Data were log transformed. Differences in fasting glucose, fasting insulin, HOMA-IR and HOMA-β were calculated using general linear model, and adjusted for children's age, sex, birth weight, feeding status, screen-watching time, sleep time, outside activity, daily energy intake, fiber, fat, protein and carbohydrate consumption. Means±SEs were presented.
HOMA-IR, homeostatic model assessment of insulin resistance.

status, education, gestational age, HDP, pre-pregnancy BMI and gestational weight gain (model 3). All the statistical analyses were performed with SPSS statistics V.25.0 for Windows software package (IBM). Two-sided p<0.05 was considered statistically significant.

RESULTS

There were differences in children's gender, age, birth weight, screen-watching time, daily energy intake, fasting plasma glucose and fasting insulin, and maternal pre-pregnancy BMI among children with different statuses of general and abdominal obesity (table 1).

General overweight/obese children had higher levels of fasting insulin, HOMA-IR and HOMA-β compared with normal weight children (table 2). Only general overweight/obese children (4.43 mmol/L vs 4.35 mmol/L, p=0.008) but not abdominal obesity individuals (4.39 mmol/L vs 4.36 mmol/L, p=0.28) had higher levels of fasting glucose compared with normal weight children. Compared with normal weight children, general overweight/obese children had higher multivariable-adjusted (children's sex, age, birth weight, feeding status, outdoor physical activity time, screen time, sleep time, daily energy intake, daily fiber intake, energy from carbohydrate, protein, and fat—model 2) ORs for hyperglycemia (1.58, 95% CI 1.09 to 2.30) and insulin resistance (3.41, 95% CI 2.34 to 4.97), and lower OR for β-cell dysfunction (0.63, 95% CI 0.40 to 0.99). After additional adjustment for maternal delivery age, smoking status, education, gestational age, HDP, pre-pregnancy BMI and gestational weight gain, the positive association of

Table 3 Childhood major glucose metabolism outcomes according to joint status of general and abdominal obesity

	Normal weight		General overweight/obesity		
	Normal waist circumstance	Abdominal obesity	Normal waist circumstance	Abdominal obesity	P value
Subjects, n	727	75	72	99	
Fasting glucose (mmol/L)	4.35±0.01	4.36±0.04	4.45±0.04*	4.43±0.04	0.07
Fasting insulin (mIU/L)	2.43±0.07	2.54±0.22	3.06±0.23*	4.26±0.20*†‡	<0.001
HOMA-IR§	−0.43±0.01	−0.47±0.04	−0.32±0.04*†	−0.21±0.03*†‡	<0.001
HOMA-β§	1.71±0.01	1.70±0.04	1.76±0.04	1.87±0.04*†‡	<0.001
Hyperglycemia					
Cases, n (%)	166 (22.8)	16 (21.3)	25 (34.7)	35 (35.4)	
OR (95% CI)					
Model 1	1	0.96 (0.53 to 1.73)	1.68 (0.99 to 2.85)	1.77 (1.12 to 2.78)	0.005
Model 2	1	0.94 (0.52 to 1.72)	1.51 (0.88 to 2.60)	1.62 (1.01 to 2.60)	0.023
Model 3	1	0.96 (0.52 to 1.75)	1.52 (0.87 to 2.64)	1.58 (0.97 to 2.56)	0.035
Insulin resistance					
Cases, n (%)	149 (20.5)	14 (18.7)	29 (40.3)	50 (50.5)	
OR (95% CI)					
Model 1	1	1.29 (0.69 to 2.42)	2.51 (1.48 to 4.28)	5.03 (3.18 to 7.97)	<0.001
Model 2	1	1.25 (0.66 to 2.36)	2.32 (1.35 to 3.99)	4.73 (2.94 to 7.62)	<0.001
Model 3	1	1.27 (0.67 to 2.42)	2.41 (1.38 to 4.23)	4.61 (2.83 to 7.52)	<0.001
β-cell dysfunction					
Cases, n (%)	175 (24.1)	24 (32)	11 (15.3)	17 (17.2)	
OR (95% CI)					
Model 1	1	1.23 (0.72 to 2.08)	0.68 (0.35 to 1.35)	0.61 (0.35 to 1.08)	0.08
Model 2	1	1.16 (0.67 to 1.98)	0.72 (0.36 to 1.43)	0.60 (0.34 to 1.06)	0.07
Model 3	1	1.13 (0.65 to 1.95)	0.73 (0.36 to 1.47)	0.62 (0.35 to 1.12)	0.11

Model 1 adjusted for children's sex, age, birth weight, and feeding status.
Model 2 adjusted for variables in model 1 plus children's screen time, sleep time, outside activity, daily energy intake, fiber, fat, protein and carbohydrate consumption.
Model 3 adjusted for variables in model 2 plus maternal delivery age, smoking status, education, gestational age at delivery, pre-pregnancy body mass index (BMI), weight gain during pregnancy, and hypertensive disorder of pregnancy.
HOMA-β was used to estimate β-cell secretory function.
*P<0.05 compared with normal weight and normal waist circumstance group.
†P<0.05 compared with abdominal obesity only group.
‡P<0.05 compared with general overweight/obesity only group.
§Data were log transformed. Differences in fasting glucose, HOMA-IR and HOMA-β were calculated using general linear model, and adjusted for children's age, sex, birth weight, feeding status, screen-watching time, sleep time, outside activity, daily energy intake, fiber, fat, protein and carbohydrate consumption. Means±SEs were presented.
HOMA-IR, homeostatic model assessment of insulin resistance.

general overweight with the risks of hyperglycemia (1.56, 95% CI 1.06 to 2.30) and insulin resistance (3.44, 95% CI 2.32 to 5.09) was still significant, but the inverse association between general overweight and β-cell dysfunction became marginally significant. Abdominal obesity children had increased insulin resistance (2.54, 95% CI 1.71 to 3.76; multivariable-adjusted model 3) but not hyperglycemia and β-cell dysfunction compared with normal waist circumstance children.

In the joint analyses, children with general overweight only or with both general and abdominal obesity but not with abdominal obesity only had higher levels of fasting insulin, HOMA-IR and HOMA-β compared with normal weight children (table 3). The multivariable-adjusted ORs among normal weight children, abdominal obesity children only, general overweight/obese children only, and both general overweight/obese and abdominal obesity children were 1.00, 0.96 (95% CI 0.52 to 1.75), 1.52 (95% CI 0.87 to 2.64), and 1.58 (95% CI 0.97 to 2.56) for hyperglycemia (p for trend=0.035), 1.00, 1.27 (95% CI 0.67 to 2.42), 2.41 (95% CI 1.38 to 4.23), and 4.61 (95% CI 2.83 to 7.52) for insulin resistance (p for trend <0.001), and 1.00, 1.13 (95% CI 0.65 to 1.95), 0.73 (95% CI 0.36 to 1.47) and 0.62 (95%CI 0.35 to 1.12) for β-cell dysfunction (p for trend =0.11), respectively.

DISCUSSION

The present study indicated that both general obesity and abdominal obesity were associated with insulin

resistance among children of mothers with GDM. Presence of either general obesity or combined general and abdominal obesity was positively associated with hyperglycemia and insulin resistance, but inversely associated with β-cell dysfunction among children of mothers with GDM.

Obesity is a powerful predictor for insulin resistance and diabetes in adults as well as in children and adolescents.[21–23] However, it remained disputable about which kind of obesity, general or abdominal obesity, was more closely associated with glucose metabolism. Some researchers argued that both general and abdominal obesity strongly predicted type 2 diabetes.[24 25] Other researchers pointed out that abdominal obesity was more strongly associated with diabetes than general obesity.[25–27] In China, both overall and central obesity were associated with diabetes in Chinese adults,[28 29] and abdominal obesity was more closely associated with diabetes than general obesity assessed by BMI.[30] Thus, it has been hypothesized that Asian adults have higher adiposity per unit BMI compared with other racial/ethnic groups, leading to an increased risk of type 2 diabetes at a lower BMI.[31] However, it remained unknown whether general obesity was more closely associated with glucose metabolism than abdominal obesity in children. The present study indicated that both general and central obesity were indicators of childhood insulin resistance, and general obesity but not central obesity alone was positively associated with hyperglycemia among children with GDM mothers. Joint general and abdominal obesity implied the highest risk for hyperglycemia and insulin resistance.

The mechanism of the association between obesity and abnormal glucose metabolism is complicated. First, some studies pointed out that genetic predisposition to central obesity is associated with higher type 2 diabetes risk.[32] Insulin resistance that developed in early-stage childhood obesity was correlated with higher expression of central obesity and type 2 diabetes-associated genes.[33] These findings may in part explain the close relationship of central obesity with insulin resistance and type 2 diabetes. Second, obesity is a state of chronic inflammation. Inflammatory adipokines (eg, progranulin, procalcitonin, interleukin-34) were increased in obese children and associated with insulin resistance.[34–36] Third, malnutrition is very common in obese individuals. Compared with non-obese children, obese children had lower levels of total 25-hydroxy vitamin D, vitamins A, C and E, zinc and magnesium. Such malnutrition was associated with enhanced systemic inflammation and reduced insulin sensitivity in children.[37–39] Additionally, excessive branched-chain amino acids and metabolite in obesity facilitated vascular fatty acid transport and caused insulin resistance.[40 41] Reduced blood supply in both subcutaneous and visceral fats, as well as resting skeletal muscle defect in glucose uptake has also been reported to increase insulin resistance in obesity.[42]

There are some advantages in this study. Our study enrolled a large number of children of mothers with GDM, and is the first report of the different association of general and abdominal obesity with major glucose metabolism in China. Further, a variety of confounding variables, such as the parameters of mothers before and during pregnancy and indices of the children including birth weight and lifestyle factors, were collected and used in the final analysis. There are some limitations in our study. First, this was a cross-sectional study, and the extrapolation of conclusions should be cautious. Second, the underlying mechanisms of the different association have not been investigated in the present study. More pathophysiologic studies are warranted in our future work.

In conclusion, both general obesity and abdominal obesity were associated with insulin resistance among children of mothers with GDM. Presence of either general obesity or combined general and abdominal obesity was positively associated with hyperglycemia and inversely associated with β-cell dysfunction. Our findings suggest that weight management should be given to children with either general or abdominal obesity.

Author affiliations
[1]Department of Endocrinology and Metabolism, Fengxian Hospital Affiliated to Southern Medical University, Shanghai Jiao Tong University Affiliated Sixth People's Hospital South Campus, Shanghai University of Medicine and Health Sciences Affiliated Shanghai Sixth People's Hospital South Campus, Shanghai, China
[2]Chronic Disease Epidemiology, Pennington Biomedical Research Center, Baton Rouge, Louisiana, USA
[3]Department of Mathematics, Shanghai Business School–Fengpu Campus, Shanghai, China
[4]Tianjin Health and Family Planning Commission, Tianjin, China
[5]Columbia University Mailman School of Public Health, New York, New York, USA
[6]Department of Preventive Medicine, Northwestern University Feinberg School of Medicine, Chicago, Illinois, USA

Contributors JLu, YG and GH conceptualized and designed the study, performed statistical analyses, interpreted the results, and drafted, reviewed and revised the manuscript. LW, WL, SZ, HL, JLe, JLi and SW collected the data and revised the manuscript. AAB and LH critically revised the manuscript for important intellectual content. All authors critically reviewed the scientific content and approved the final manuscript. GH is the guarantor of this work, and has full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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Competing interests None declared.

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ORCID iDs
Junhong Leng http://orcid.org/0000-0002-6742-0830
Gang Hu http://orcid.org/0000-0002-6172-8017

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