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Android fat as a determinant of metabolic syndrome: Sex differences

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ABSTRACT

Objectives: Regional fat accumulation may play an important role in the pathogenesis of metabolic syndrome (MetS) and cardiovascular diseases, yet the results are controversial. The aim of this study was to determine the relationship between regional fat accumulation and MetS as well as the underlying mechanism in Chinese adults.
Methods: We conducted a cross-sectional study of 428 Chinese adults (166 men and 262 women). Android and gynoid fat percentage (AFP and GFP) were measured by dual energy x-ray absorptiometry. Fasting lipid parameters were analyzed by chemistry analyzer COBAS.
Results: Forty-six (28%) men and 34 (13%) women had MetS according to the modified National Cholesterol Education Panel Adult Treatment Panel III definition for South Asia. AFP was strongly correlated with more metabolic risk factors than GFP in men. In women, AFP and GFP showed significant opposite effects on triacylglycerol, high-density lipoprotein cholesterol, and waist circumference. On multivariate regression, AFP was an independent determinant of MetS in men after adjustment for confounding factors. For women, both AFP and the homeostatic model assessment for insulin resistance were predictors for MetS.
Conclusions: Increased android fat may play a direct role in the development of MetS in Chinese adults. However, the associations between android fat, insulin resistance, and MetS are sex-dependent. This is probably due to different effects of sex hormones on adipose tissue or by genetic factors between sexes. Knowing the sex differences in developing MetS may help design sex-specific preventive strategies that will benefit the overall population health.

Introduction

Metabolic syndrome (MetS), a cluster of various risk factors including hypertension, dyslipidemia, dysglycemia, and central obesity [1], has been increasing over the last decades. Several studies support the fact that individuals with MetS have increased risk for type 2 diabetes mellitus (T2DM) and cardiovascular diseases (CVDs) [2]. Although MetS is still a medical controversy due to different definitions and unexplained pathophysiology [3], compelling evidence suggests that excess body fat is associated with an increased risk for MetS [4]. Compared with total body fat, regional body fat distribution, especially in the abdominal region is a stronger correlate of MetS, CVDs, insulin resistance (IR), and morbidity [5–10].

The dual-energy x-ray absorptiometry (DXA) technique allows us to access regional fat deposition and determine the android and gynoid fat accurately [11]. The distinction between individuals with the android and gynoid types of obesity was first proposed by Vague, who substantiated a worse metabolic profile in the android than the gynoid body type [12]. After that, numerous studies, conducted primarily among Westerners, have provided a better understanding of the role of regional fat accumulation in MetS [13,14]. The combination of android and gynoid fat percentage (AFP and GFP, respectively) showed close associations with cardiometabolic risk factors among normal weight U.S. adults [13]. Another study [14] revealed that AFP was significantly associated with high triacylglycerols (TG) and low high-density lipoprotein cholesterol (HDL-C) levels in men and high low-density lipoprotein cholesterol and low HDL-C levels in women. On the other hand, the GFP showed a positive correlation with total cholesterol in men, whereas it had a favorable association with TG and HDL-C in women. This is probably because GFP is controlled by female reproductive hormones (i.e., estrogen) [15]. These results, when

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combined, suggested that evaluation of AFP and GFP may be important in the clinical assessment of cardiometabolic risks and MetS.

Given the different body fat distribution between Westerners and Asians, data from Westerners concerning the link between AFP, GFP, and MetS may not be directly applicable to Asians. To date, only limited studies on regional fat accumulation–related risks have been conducted in Asians. Besides, the respective contribution of AFP and GFP to MetS was not consistent. Kang et al. [16] conducted a community-based cohort study of elderly people to examine the fat distribution–related risks and found that android fat accumulation was significantly associated with clustering of MetS components. Fu et al. [17] reported opposite associations of android and gynoid fat with metabolic risks in Chinese women, but they demonstrated that gynoid fat rather than android fat might be a more important inclusion in metabolic disease risk evaluation. In another study [18], the android/gynoid ratio (A/G ratio) in women was shown to be more significantly correlated with metabolic risk factors than body mass index (BMI), percent body fat, and waist circumference (WC).

Due to the sex differences in body fat distribution and lipid metabolism, the effect of android and gynoid fat accumulation on MetS may differ between men and women. As evidence is still limited regarding the effects of DXA-measured AFP and GFP on MetS among Chinese men and women, the objective of this study was to investigate the sex difference in the association of android and gynoid fat with MetS among healthy Chinese populations living in Singapore. This study provides important sex-specific information about the management of MetS in Chinese population.

Methods

Study design

This study was a cross-sectional analysis of data from 428 healthy Chinese attending a baseline visit from June 17, 2014 to October 20, 2017. Participants were recruited from the general public in Singapore through advertisements in newspapers and on posters that were placed around the National University of Singapore campus, public area, and on the Clinical Nutrition Research Centre (CNRC) website. To be eligible, participants were required to be healthy male or female Singaporeans or individuals who have resided in Singapore for ≥5 y. Participants were excluded if they were pregnant or diagnosed with any major diseases. Before the study, all participants were asked to restrict alcohol and caffeine-containing drinks as well as to refrain from intense physical activity. All procedures involving human subjects were approved by the National Healthcare Group Domain Specific Review Board, Singapore. All hard copies of the data collected will be filed and stored in secure key-access cabinets located at the CNRC. The researchers are the only authorized staff with access-the locked cabinets. Additionally, working data files containing non-identifiable information only will be stored on the computers, which are password protected. Access to the files will be restricted to the research team members.

Anthropometry

Participants arrived at the CNRC laboratory in the morning after a 10-h overnight fast. All participants gave written informed consent before starting. Body weight and height measurements were done in duplicate. Weight (kg) was measured to the nearest 0.1 kg using a digital scale, with participants wearing lightweight clothing and no shoes. Height (cm) was measured using a stadiometer to the nearest millimetre (Seca 763 digital scale, Birmingham, UK). BMI (kg/m^2) was calculated using weight divided by the height squared. The smallest WC above the umbilicus or navel and below the xiphoid process was taken as WC (cm). All measurements were done in duplicate and readings were averaged.

DXA (QDR 4500 A, fan-beam densitometer, Hologic, Waltham, USA, software version 8.21) was used for the measurement of AFP and GFP. DXA is designed to measure bone mineral content, which is calculated from the differential absorption of x-rays of two different energies. Because the calculation requires allowance for overlying soft tissue, values of fat and lean mass can be calculated by using instrument-specific algorithms. The android region is the area between the ribs and the pelvis. It is totally enclosed by the trunk region. The gynoid region includes the hips and upper thighs and overlaps both the leg and trunk regions. The A/G ratio was calculated using the fat mass within the android and gynoid fat regions of interest, as shown in Figure 1. Participants were divided into sex-specific tertiles of AFP as follows: tertile 1: 11.4% to 23.6% men, 16.5% to 30.1% women; tertile 2: 23.7% to 33% men, 30.2% to 37.8% women; and tertile 3: 33.1% to 48.4% men, 37.9% to 57.6% women. Tertiles of GFP were computed as follows: tertile 1: 11.5% to 24.9% men, 27.2% to 38.8% women; tertile 2: 25% to 29.1% men, 38.9% to 43.1% women; and tertile 3: 29.2% to 43.1% men, 43.2% to 53.8% women. Participants in tertile 3 of AFP and GFP were regarded as having elevated AFP and GFP, respectively.

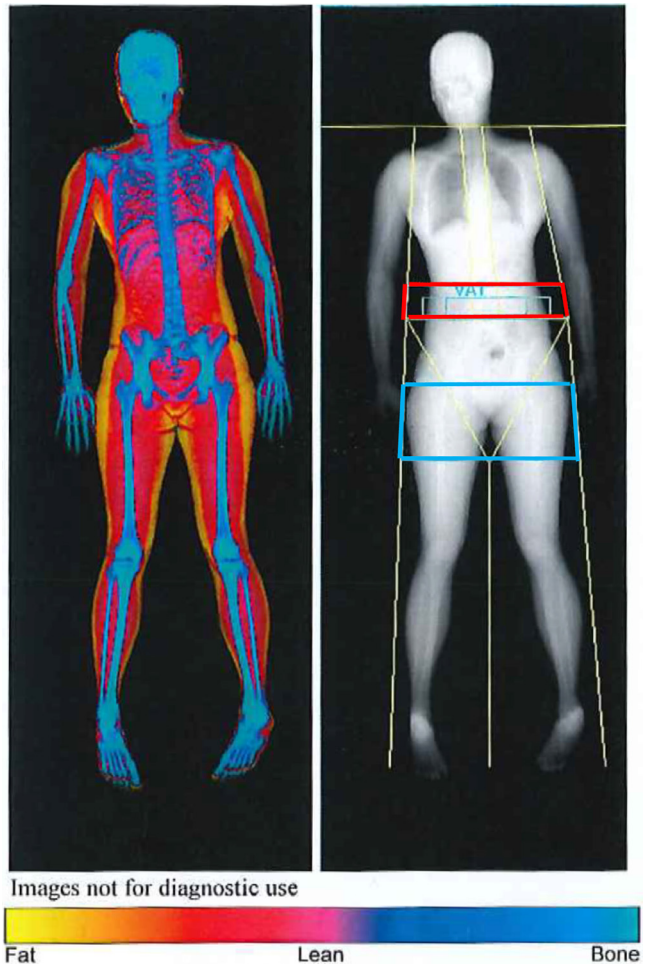

Fig. 1. Dual-energy x-ray absorptiometry (DXA) scan showing demarcations between body regions. A, android; G, gynoid.

Blood measures

Two finger-prick capillary blood samples were obtained for determining fasting blood glucose (FBG; mmol/L concentration using the HemoCue 201+ RT Glucose analyser (HemoCue Ltd, Dronfield, UK). Additionally, 4 mL of venous blood was collected into Vacutainer plastic serum tube 6 mL (Becton Dickinson Diagnostics, Franklin Lakes, NJ, USA). Blood samples were separated by centrifugation at 1500*g* for 10 min at 4°C within 2 h of being drawn and aliquots were stored at −80°C until analysis. Fasting serum insulin (FSI, μU/mL) was measured using the immunochemistry analyzer COBAS e411 (Roche/Hitachi, Indianapolis, IN, USA). Homeostatic model assessment for insulin resistance (HOMA-IR) was calculated from FBG and FSI using HOMA-IR = FBG × FSI/22.5 [19]. Fasting lipid parameters including total cholesterol, HDL-C, low-density lipoprotein cholesterol, and TG were measured using chemistry analyzer COBAS c311 (Roche/HITACHI). Systolic nd diastolic blood pressure (SBP and DBP, respectively) were measured with an Omron blood pressure monitor (model HEM-907, Omron Healthcare Singapore). The measurements were done in duplicate and readings were averaged.

Definition of MetS

Asians with MetS are phenotypically distinct from whites, as they have lower BMI, WC, and muscle mass [20]. In the present study, MetS was diagnosed

according to the modified National Cholesterol Education Panel Adult Treatment Panel III (NCEP ATP III) definition for South Asians [20]. A participant was considered to have MetS if two or more of the following criteria were met:

- WC >87 cm in men or >82 cm in women and/or BMI >23 kg/m^2
- TG ≥1.7 mmol/L
- HDL-C <1 mmol/L in men and <1.3 mmol/L in women
- BP ≥130/85 mmHg
- FBG ≥5.6 mmol/L

Statistical analysis

Statistical analysis was performed using the SPSS version 23 (IBM, Armonk, NY, USA). All data are expressed as means ± SD and checked for normality using Shapiro-Wilk test. Student's *t* tests were used for between-group comparisons. Multivariate linear regression models were used to examine associations between regional fat deposition (i.e., AFP and GFP) with metabolic variables including SBP, DBP, TG, HDL-C, FBG, and WC. Multivariate logistic regression was used to identify the independent determinants for MetS using AFP and GFP, HOMA-IR, age, smoking status, supplementary usage, family disease history, and physical activity as independent variables. Two-sided $P < 0.05$ was considered statistically significant in all cases.

Results

Table 1 depicts the baseline data of the study population. Generally, men (46 of 166, 28%) had a higher prevalence of MetS than women (34 of 262, 13%). As shown in Table 1, participants with MetS had significantly greater AFP and A/G ratio than those without MetS (both $P < 0.001$), but GFP was similar between the two groups ($P = 0.765$). Moreover, participants with MetS were older, heavier, had higher BMI, WC, BP, and worse lipid and glucose profiles than those without MetS. When men and women were analyzed independently, greater AFP and GFP were observed in MetS group for both men (Supplementary Table 1) and women (Supplementary Table 2) than those without MetS.

Prevalence of AFP by the number of MetS components was determined (Fig. 2) using values ≥33.1% and ≥37.9%, whereas GFP was determined using values of ≥29.2% and ≥43.2%, for men and women, respectively (elevated AFP and GFP as defined in the Methods section). For participants with elevated AFP, 3 of 60, 21 of 60, and 31 of 46 men had no, one, and two or more MetS components. In contrast, 24 of 161, 38 of 67, and 25 of 34 women had no, one, and two or more MetS components. Therefore, Figure 2 a shows that the prevalence of AFP for men with no, one, and two or more MetS components were 5%, 35%, and 67.4% compared with 14.9%, 56.7%, and 73.5% in women, respectively (all $P < 0.005$). Similarly, the prevalence of GFP for men with no, one, and two or more 2 MetS components were 11.7%, 38.3%, and 54.3% compared with 22.4%, 52.2%, and 44.1% in women, respectively (all $P < 0.005$).

Table 2 shows the results of multivariate regression models identifying the associations of AFP and GFP with metabolic variables in men and women. After adjusting for age, smoking status, supplementary usage, family disease history, and physical activity (model 1), AFP was significantly associated with all metabolic variables except FBG in men (all $P < 0.005$). GFP showed significant but weaker associations with DBP, TG, HDL-C, and WC compared with AFP. For women, AFP was significantly associated with all metabolic variables, but GFP was only associated with DBP, FBG, and WC. After further adjusting for BMI (model 2), AFP remained significant associations with DBP, TG, HDL-C, and WC in men, whereas GFP was only significantly associated with DBP and WC. The associations between AFP, GFP, and metabolic variables in women were attenuated after BMI was adjusted. When AFP and GFP were simultaneously considered in the models (model 3), AFP showed an adverse effect but GFP showed a favorable effect on metabolic variables for men. AFP was significantly associated with SBP, DBP, TG, HDL-C, and WC, but GFP was only significantly associated with SBP and TG. The results for women were different. AFP and GFP showed significant opposite effects on TG, HDL-C, and WC in model 3 (Table 2).

On multivariate logistic regression, AFP was found to be an independent determinant of MetS for men after adjustment for GFP, HOMA-IR, age, physical activity, dietary supplement use, and family history of disease (Table 3). The odds ratio (OR) of MetS was increased by 1.31-fold (95% confidence interval [CI], 1.12–1.53) for every 1% increase in AFP. Table 4 shows that both AFP ($P = 0.022$) and HOMA-IR ($P = 0.001$) were predictors of MetS for women after adjustment for GFP, age, physical activity, dietary supplement use, and family history of disease. The OR of MetS was increased by 1.16-fold (95% CI, 1.02–1.31) for every 1% increase in AFP.

Table 1
Characteristics of the study population

Variables	Total (N = 428)	No MetS (*n* = 348)	MetS (*n* = 80)	*P*-value*
Age (y)	38.2 ± 14.4	36.1 ± 13.9	47.3 ± 13.2	<0.001
Men, *n* (%)	166 (39)	120 (34)	46 (58)	<0.001
Height (cm)	164.0 ± 8.2	163.8 ± 8.1	164.8 ± 8.5	0.328
Weight (kg)	60.4 ± 11.9	58.1 ± 11.2	70.2 ± 9.4	<0.001
BMI (kg/m^2)	22.3 ± 3.5	21.5 ± 3.1	25.8 ± 2.7	<0.001
WC (cm)	73.4 ± 9.5	71.2 ± 8.4	83.4 ± 7.4	<0.001
AFP (%)	32 ± 8.7	30.5 ± 8.3	38.3 ± 7.6	<0.001
GFP (%)	35.2 ± 8.6	35.3 ± 8.7	35 ± 8	0.765
A/G ratio	0.92 ± 0.20	0.88 ± 0.17	1.12 ± 0.20	<0.001
SBP (mm Hg)	116 ± 15	113 ± 12	132 ± 16	<0.001
DBP (mm Hg)	71 ± 10	68 ± 9	81 ± 10	<0.001
FBG (mmol/L)	4.6 ± 0.5	4.5 ± 0.5	4.7 ± 0.6	<0.001
FSI (mU/L)	8.3 ± 5.4	7.3 ± 4.3	12.7 ± 7.2	<0.001
HOMA-IR	1.7 ± 1.2	1.5 ± 0.9	2.7 ± 1.7	<0.001
TG (mmol/L)	1.0 ± 0.4	0.8 ± 0.3	1.5 ± 0.6	<0.001
TC (mmol/L)	5.3 ± 1.2	5.2 ± 1.2	5.6 ± 1.1	0.012
HDL-C (mmol/L)	1.7 ± 0.4	1.8 ± 0.4	1.4 ± 0.4	<0.001
LDL-C (mmol/L)	3.3 ± 1.1	3.2 ± 1	3.8 ± 1	<0.001

AFP, android fat percentage; A/G, android/gynoid; BMI, body mass index; DBP, diastolic blood pressure; FBG, fasting blood glucose; FSI, fasting serum insulin; GFP, gynoid fat percentage; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostatic model assessment for insulin resistance; LDL-C, low-density lipoprotein cholesterol; SBP, systolic blood pressure; TC, total cholesterol; TG, triacylglycerol; WC, waist circumference.
Values are expressed as mean ± SD.
* Student's *t* test.

Discussion

Despite the discrepancy of definition used to determine MetS and the composition of the population being studied (i.e., sex, age, race and ethnicity), MetS is increasing and constitutes a major public health risk worldwide [21]. Increased calorie intake and sedentary lifestyles have been implicated in the development of MetS. However, it is worth noting that certain population groups have an even greater predisposition to developing MetS [22]. The International Diabetes Federation suggests population-specific cut points for obesity, recognizing increased metabolic risk for some populations (e.g. Japanese and South Asians) despite similar levels of obesity [23]. Using the modified NCEP ATP III criteria for South Asians [20], we found that 28% of men and 13% of women in the present study were diagnosed with MetS.

Obesity is a well-known risk factor for MetS. Previous studies on whites showed that abdominal fat accumulation was strongly associated with increased risks for MetS, CVDs, and T2DM [24–26]. It has been reported that Asians have greater abdominal fat, and thus higher metabolic risks than whites for a given BMI [27,28]. Of the various abdominal measurements, DXA-measured android fat was

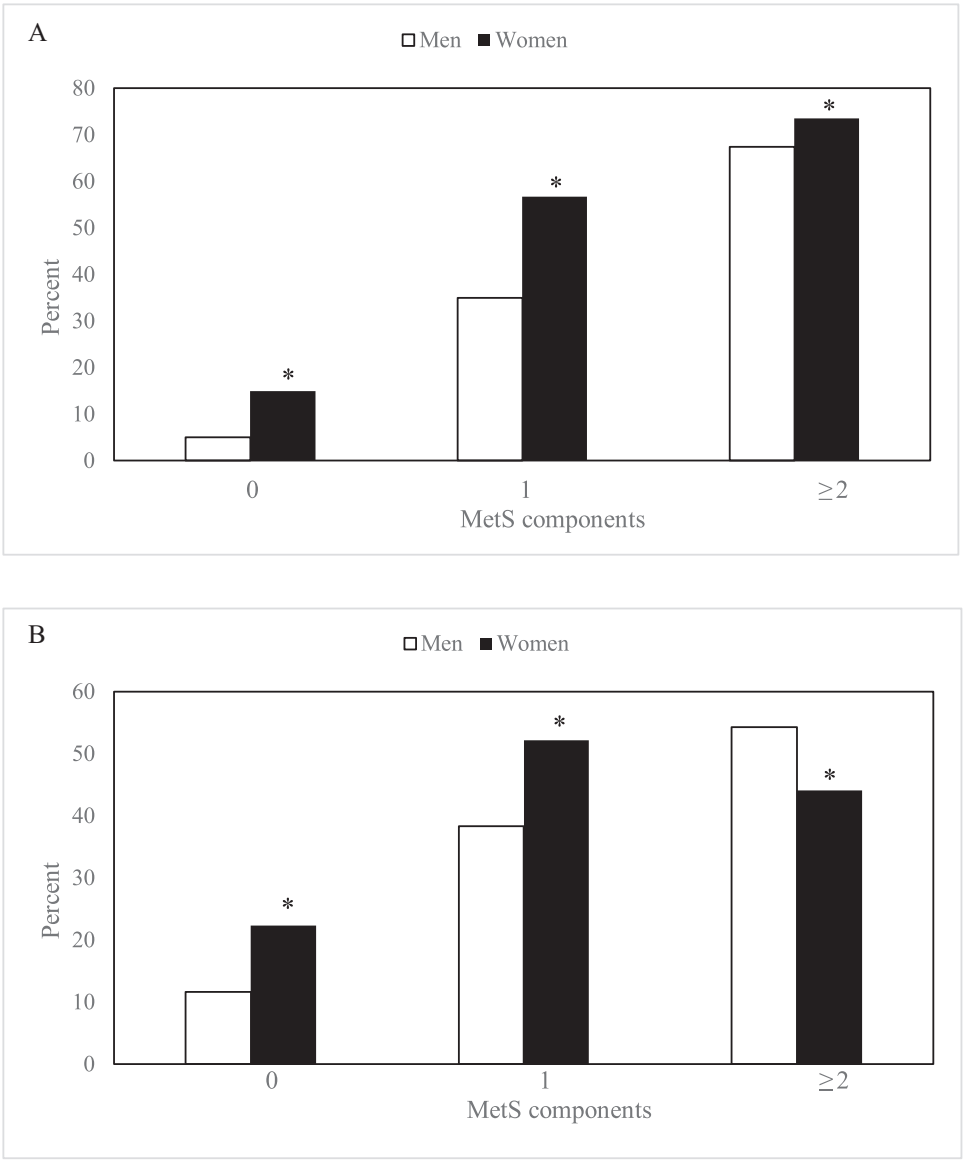

Fig. 2. Prevalence of (A) AFP and (B) GFP by numbers of MetS components in Chinese adults. *$P < 0.005$. AFP, android fat percentage; GFP, gynoid fat percentage; MetS, metabolic syndrome.

found to have deleterious effects on MetS even after accounting for visceral adiposity [14]. However, the respective contribution of the AFP and GFP to cardiovascular risks and MetS remains controversial [29,30]. In the present study, AFP was found to be a good predictor of MetS after adjusting for age, smoking status, supplementary usage, family disease history, physical activity, HOMA-IR, and GFP. This finding suggests that android fat deposition may play a direct role in the development of MetS among Chinese adults. However, the underlying mechanism linking AFP and MetS is not fully understood. A possible explanation is that the android fat accumulation is linked to the increases in size of intra-abdominal visceral adipose tissue. The expansion of adipose tissue produces various bioactive substances known as adipocytokines or adipokines, which leads to the impaired glucose metabolism, lipid disorders, and hypertension [31,32].

Sex differences in the association between body fat distribution and MetS risk have been documented among Chinese population with abdominal obesity previously [33]. To our knowledge, this was the first study to examine the relationship between regional fat depositions and MetS in healthy Chinese men and women. We examined sex differences in the interrelationships between AFP, GFP, and MetS and found that AFP was significantly associated with multiple components of the MetS, even after adjustment for BMI. These results suggest that individuals with elevated level of AFP would suffer from an increased risk for having MetS independent of their BMI. When AFP and GFP were both included in the regression model, AFP remained associated with SBP, DBP, TG, HDL-C, and WC, whereas GFP was only associated with SBP and TG in men, which indicates that android fat is strongly associated with MetS in men. On the other hand, AFP showed adverse effects, whereas GFP showed favorable effects on TG, HDL-C, and WC in women.

As noted in the present study, AFP was found to be an independent determinant of MetS in Chinese men after the adjustment. In women, both AFP and IR were proposed to play critical roles in MetS after adjusting for GFP. The relations between AFP, IR, and the development of MetS may be associated with the sex-associated difference in body fat distribution. At the same level of GFP, Chinese men had

Table 2
Sex-specific multivariable-adjusted regressions analysis for AFP and GFP with individual components of the MetS

	Men (n = 166)		
	Model 1	Model 2	Model 3
SBP	AFP: 0.26 (0.12–0.61)*	AFP: 0.21 (−0.04 to 0.62)	AFP: 0.47 (0.19–1.13)†
	GFP: 0.10 (−0.15 to 0.60)	GFP: −0.02 (−0.49 to 0.40)	GFP: −0.30 (−1.30 to −0.05)†
DBP	AFP: 0.28 (0.13–0.50)*	AFP: 0.35 (0.15–0.65)*	AFP: 0.38 (0.07–0.80)†
	GFP: 0.20 (0.08–0.65)†	GFP: 0.19 (0.01–0.70)†	GFP: −0.03 (−0.55 to 0.43)
TG	AFP: 0.54 (0.02–0.03)*	AFP: 0.51 (0.01–0.03)*	AFP: 0.77 (0.02–0.05)*
	GFP: 0.31 (0.01–0.04)*	GFP: 0.15 (−0.00 to 0.03)	GFP: −0.30 (−0.04 to −0.00)†
HDL-C	AFP: −0.43 (−0.02 to −0.01)*	AFP: −0.44 (−0.03 to −0.01)*	AFP: −0.71 (−0.04 to −0.01)*
	GFP: −0.22 (−0.03 to −0.00)†	GFP: −0.11 (−0.02 to 0.01)	GFP: 0.31 (0.00–0.04)
FBG	AFP: 0.10 (−0.01 to 0.02)	AFP: 0.01 (−0.01 to 0.01)	AFP: 0.22 (−0.01 to 0.03)
	GFP: −0.01 (−0.02 to 0.02)	GFP: −0.11 (−0.03 to 0.01)	GFP: −0.24 (−0.05 to 0.01)
WC	AFP: 0.81 (0.66–0.91)*	AFP: 0.37 (0.25–0.47)*	AFP: 0.43 (0.26–0.58)*
	GFP: 0.59 (0.71–1.17)*	GFP: 0.19 (0.13–0.46)*	GFP: −0.07 (−0.33 to 0.11)
	Women (n = 262)		
SBP	AFP: 0.18 (0.05–0.59)†	AFP: 0.04 (−0.34 to 0.48)	AFP: 0.01 (−0.45 to 0.50)
	GFP: 0.13 (−0.05 to 0.79)	GFP: 0.04 (−0.35 to 0.59)	GFP: 0.04 (−0.43 to 0.65)
DBP	AFP: 0.38 (0.28–0.64)*	AFP: 0.25 (0.02–0.57)†	AFP: 0.23 (−0.04 to 0.59)
	GFP: 0.24 (0.18–0.76)*	GFP: 0.11 (−0.11 to 0.52)	GFP: 0.03 (−0.31 to 0.41)
TG	AFP: 0.41 (0.02–0.03)*	AFP: 0.40 (0.01–0.04)*	AFP: 0.70 (0.03–0.06)*
	GFP: −0.00 (−0.02 to 0.02)	GFP: −0.19 (−0.03 to −0.00)†	GFP: −0.43 (−0.06 to −0.03)*
HDL-C	AFP: −0.48 (−0.04 to −0.02)*	AFP: −0.39 (−0.04 to −0.01)*	AFP: −0.56 (−0.05 to −0.02)*
	GFP: −0.15 (−0.03 to 0.00)	GFP: 0.05 (−0.01 to 0.02)	GFP: 0.25 (0.01–0.04)†
FBG	AFP: 0.33 (0.01–0.03)*	AFP: 0.33 (0.01–0.04)†	AFP: 0.23 (−0.00 to 0.03)
	GFP: 0.28 (0.01–0.05)*	GFP: 0.22 (0.01–0.04)†	GFP: 0.14 (−0.01 to 0.04)
WC	AFP: 0.84 (0.75–0.95)*	AFP: 0.29 (0.19–0.40)*	AFP: 0.40 (0.28–0.52)*
	GFP: 0.41 (0.43–0.89)*	GFP: −0.02 (−0.16 to 0.11)	GFP: −0.16 (−0.39 to −0.12)*

AFP, android fat percentage; DBP, diastolic blood pressure; FBG, fasting blood glucose; GFP, gynoid fat percentage; HDL-C, high-density lipoprotein cholesterol; SBP, systolic blood pressure; TG, triacylglycerol; WC, waist circumference.
Model 1: Adjustment for age, smoking status, supplementary usage, family disease history, physical activity, and menopause status (only in women).
Model 2: Model 1 added adjustment for BMI.
Model 3: Model 2 added adjustment for AFP and GFP.
* $P < 0.005$.
† $P < 0.05$.

Table 3
Multivariate logistic regression analysis to identify independent determinants for MetS (as categorical variable) using AFP and GFP; HOMA-IR; age; smoking status; supplementary usage; family disease history; and physical activity as independent variables in 166 men

Variables	Mean ± SE	*P*-value	Odds ratio (95% CI)
AFP	0.268 ± 0.081	0.001	1.308 (1.116–1.533)
GFP	−0.181 ± 0.102	0.078	0.835 (0.683–1.020)
HOMA-IR	0.010 ± 0.251	0.969	1.010 (0.617–1.653)
Age	0.026 ± 0.024	0.281	1.026 (0.979–1.075)
Smoking status	−0.785 ± 2.105	0.709	0.456 (0.007–28.220)
Family disease history	−0.187 ± 0.740	0.800	0.829 (0.195–3.535)
Supplementary usage	0.538 ± 0.603	0.372	1.713 (0.525–5.585)
Physical activity	0.012 ± 0.010	0.203	1.012 (0.993–1.032)

AFP, android fat percentage; CI, confidence interval; GFP, gynoid fat percentage; HOMA-IR, homeostatic model assessment for insulin resistance; MetS, metabolic syndrome.

Table 4
Multivariate logistic regression analysis to identify independent determinants for MetS (as categorical variable) using AFP and GFP; HOMA-IR; age; smoking status; supplementary usage; family disease history; physical activity; and menopause status as independent variables in 262 women

Variables	Mean ± SE	*P*-value	Odds ratio (95% CI)
AFP	0.144 ± 0.063	0.022	1.155 (1.021–1.307)
GFP	−0.073 ± 0.085	0.387	0.929 (0.787–1.097)
HOMA-IR	0.956 ± 0.288	0.001	2.601 (1.480–4.570)
Age	0.025 ± 0.021	0.222	1.025 (0.984–1.068)
Family disease history	1.972 ± 1.192	0.098	7.182 (0.694–74.322)
Supplementary usage	0.465 ± 0.579	0.422	1.592 (0.512–4.953)
Physical activity	0.010 ± 0.011	0.368	1.010 (0.988–1.033)
Menopause status	0.914 ± 1.049	0.384	2.494 (0.319–19.491)

AFP, android fat percentage; CI, confidence interval; GFP, gynoid fat percentage; HOMA-IR, homeostatic model assessment for insulin resistance; MetS, metabolic syndrome.

more AFP (Supplementary Tables 1 and 2). This is consistent with other studies showing that men were more likely to store fat in the upper body and had a higher risk for developing MetS, T2DM, and CVDs than women [34].

The sex difference in the associations between AFP, IR, and MetS may be associated with different effects of sex hormones on adipose tissue, genetic factors between men and women, or a combination of all [15,35–37]. Moran et al. [38] pointed out that estrogen exerted many physiological effects that might influence CVD risk and IR. In present study, no significant difference in IR was observed between men (1.7 ± 1.3) and women (1.7 ± 1.2), probably due to the method used to measure IR. Nevertheless, the finding that women have better lipid and glucose profiles despite a seemingly paradoxical increase in adiposity suggests that IR is mediated directly or indirectly by estrogen [15].

This study has several limitations. First, although we evaluated a relatively large number of participants, our convenience sample may not have been representative of the general population in Singapore. Participants in this study were apparently healthy and did not suffer from severe chronic diseases. Second, due to the cross-sectional design, it was not possible to explore the causal relationship between body fat distribution and MetS. Third, although HOMA-IR has become

a widely used clinical and epidemiologic tool, it is not a direct measurement of IR. Despite these limitations, the present study had the following strengths. First, the body composition parameters measured with advanced DXA technology and its software were used. Second, to the best of our knowledge, this is the first study investigating the sex differences in the interrelationships between android fat, gynoid fat, and MetS among Chinese adults.

Conclusions

Android fat may play a direct role in the development of MetS among Chinese people living in Singapore. The link between android fat and MetS is sex-dependent. Results from the present study indicated that android fat is an independent determinant of MetS in Chinese men, with an OR of 1.31 for every 1% increase. This is probably due to different effects of sex hormones on adipose tissue or because of genetic factors between men and women. Knowledge of the sex differences in developing MetS may help in designing sex-specific preventative and therapeutic strategies that can be developed into an alternative tool to identify individuals with MetS among Chinese populations. However, the causal relationship between MetS, IR, and android fat among Chinese men and women will need to be further examined in both prospective and interventional studies.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.nut.2018.05.016.

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