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The relationship between anthropometry and body composition from computed tomography: The Mediators of Atherosclerosis in South Asians Living in America Study

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ABSTRACT

Objective: Few studies examine the relationships between anthropometry and the body composition measures they approximate, or whether they differ by sex, and no studies have examined these relationships in South Asians living in the US.

Design: We conducted a cross-sectional study of 871 participants in the Mediators of Atherosclerosis in South Asians Living in America (MASALA) Study who had BMI < 40 kg/m^2 and underwent abdominal CT scans for measurement of visceral and subcutaneous fat. Linear regression was used to model the associations between anthropometric measures and naturally log-transformed body composition measures.

Results: All measures of anthropometry, except height, were significantly associated with visceral fat and had a significant non-linear component ($p < .05$). The only associations for visceral fat that exhibited significant heterogeneity by sex were waist circumference (% difference in visceral fat slope: women 1.92, men 2.74, $p = .007$ for interaction) and waist-to-hip ratio (women 25.9, men 717.4, $p < .001$). Except for height, all measures of anthropometry were significantly associated with subcutaneous fat, had a significant quadratic component, and significant heterogeneity by sex (weight (kg): 2.74 for women, 4.08 for men; BMI (kg/m^2): 10.3, 14.0; waist circumference (cm): 1.51, 3.36; hip circumference (cm): 2.53, 4.50) with $p < .001$ for each.

Conclusions: In MASALA participants, the relationships of anthropometric measures with visceral and subcutaneous fat appear similar to other race/ethnic groups, but with weaker non-linearity and heterogeneity by sex. Given these results, researchers should consider separate models by sex for US South Asians when approximating subcutaneous fat or when using waist circumference to approximate visceral fat.

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Abbreviations: BMI: body mass index; CT: computed tomography; MESA: Multi-Ethnic Study of Atherosclerosis, MASALA: Mediators of Atherosclerosis in South Asians Living in America; MIPAV: Medical Image Processing, Analysis, and Visualization

Introduction

Visceral fat is considered a stronger indicator of cardiometabolic risk than subcutaneous fat (Matsuzawa et al. 1995; Rexrode et al. 1998; Rexrode, Buring, and Manson 2001; Lee et al. 2008; Nedungadi and Clegg 2009; Onat et al. 2010) but extensive data on the two fat compartments are lacking due to cost and participant burden of imaging. Similarly, this burden has limited the evidence available to compare the relationships between anthropometrics ubiquitously used as surrogates such as body mass index (BMI) and waist circumference to values of visceral and subcutaneous fat obtained from imaging (Schreiner et al. 1996; Demerath et al. 2007; Carroll et al. 2008; Oka et al. 2009; Camhi et al. 2011; Nazare et al. 2012; Mongraw-Chaffin et al. 2015). Even fewer studies have investigated whether these relationships differ by sex and race/ethnicity (Demerath et al. 2007; Carroll et al. 2008; Nazare et al. 2012; Mongraw-Chaffin et al. 2015). While discussions surrounding the need for different anthropometric cut-points to best estimate risk in different racial/ethnic groups continue (WHO Expert Consultation 2004) to our knowledge, no study has determined the relationship between anthropometric measures and visceral or subcutaneous fat in South Asians in the US.

The Mediators of Atherosclerosis in South Asians Living in America (MASALA) Study provides a rare opportunity to investigate how these anthropometric measures approximate visceral and subcutaneous fat in South Asians, whether they differ by sex, and how they compare to already published estimates in other race/ethnicity groups from the Multi-Ethnic Study of Atherosclerosis (MESA) (Mongraw-Chaffin et al. 2015).

Methods

Study population

The MASALA study is a longitudinal two-site study of 906 participants who self-identify as having South Asian ancestry, with baseline data collected from 2010–2013 (Kanaya et al. 2013). MASALA participants were free of cardiovascular disease at baseline and weighed less than 136 kg to accommodate the computed tomography (CT) scanner limitations. In the current study, we excluded participants with BMI > 40 kg/m^2 ($n = 8$) and those who did not have a readable measurement of CT determined visceral or subcutaneous fat ($n = 27$). The final sample size for this analysis is 871 participants.

Anthropometric indices were measured using standard criteria and instruments (Kanaya et al. 2013). Abdominal computed tomography scans (CT, Philips Medical Systems, Andover, MA, USA; Toshiba Medical Systems, Tustin, CA, USA; Siemens Medical Solution, Malvern, PA, USA) were used to determine abdominal visceral and subcutaneous fat area. A trained radiology technician used a lateral scout image of the spine to establish the correct position (between the L4 and L5 vertebrae) for the abdominal CT using standardized protocols. Visceral and subcutaneous abdominal fat were measured at the L4–L5 level using the Medical Image Processing, Analysis, and Visualization (MIPAV) software at the University of California, San Diego body composition reading center (Center for Information Technology and National Institutes of Health 1999). The subcutaneous compartment was composed of tissue outside the visceral cavity but within the body contour. Visceral fat was defined as those pixels within the appropriate Hounsfield Unit range and within the contour of the visceral cavity.

Other variables including age, sex, race/ethnicity, place of birth, socioeconomic status, menopausal status, health behaviors such as smoking, alcohol use and physical activity, and diagnosed medical conditions such as cancer, diabetes, liver, and kidney disease were assessed by self-report at the baseline interview (Kanaya et al. 2013).

Institutional Review Board approval was obtained at both MASALA study sites (University of California, San Francisco and Northwestern University), and all participants provided written informed consent.

Statistical analysis

We naturally log-transformed visceral and subcutaneous fat distributions and calculated quartiles. We calculated the means and standard deviations of participant characteristics by quartile of naturally log-transformed visceral fat. We centered the anthropometric measures as follows: age − 50 years, height − 160 cm, weight − 50 kg, BMI − 20 kg/m^2, waist circumference − 100 cm, hip circumference − 100 cm, waist to hip ratio − 0.7, and waist to height ratio − 0.4. We used linear regression to determine the relationship between each anthropometric measure separately with visceral and subcutaneous fat. We used likelihood ratio tests and interaction terms to formally test for non-linearity and heterogeneity by sex, respectively. We also ran a series of subgroup analyses to test the sensitivity of our results to age, place of birth, and self-reported history of cancer, liver disease, kidney disease, and diabetes diagnosis as well as current smoking status and diabetes medication use. Finally, we assessed whether adjustment for physical activity influenced our results. Analyses were performed using Stata 11 (StataCorp 2009).

Results

Of the 871 participants included in the current analysis, 47% ($n = 411$) were women, 84% were born in India, 97% had a high school education or greater, and the average age was 55 years (SD = 9.4 years). In general, participants with higher visceral fat were older; less likely to be female, born in India, or be current smokers; but were more likely to have diabetes and to be post-menopausal (Table 1). Participants with a higher quartile of visceral fat were also more likely to have higher mean anthropometric measures, as well as higher mean subcutaneous fat.

All anthropometric measures, except for height, were significantly associated with visceral fat and had a significant quadratic component (Figure 1). For visceral fat only, waist circumference and waist-to-hip ratio exhibited a difference by sex (Table 2).

Similarly, all anthropometric measures, except for height, were significantly associated with subcutaneous fat, and all measures except for height and waist-to-hip ratio had a

Table 1. Baseline clinical and demographic characteristics (mean (SD) or number/percentile (SD)) of 871 adults in MASALA by ln visceral fat quartile.

ln Visceral fat	Total	Quartile 1 (<4.55)	Quartile 2 (4.56–4.84)	Quartile 3 (4.85–5.11)	Quartile 4 (5.12 ≤)	*p* for trend
n	871	217	219	218	217	
ln Visceral fat (cm^2)	4.81 (0.015)	4.22 (0.022)	4.70 (0.005)	4.97 (0.005)	5.33 (0.012)	NA
Sex (% female)	47.1 (1.69)	145/66.8 (3.20)	57.1 (3.35)	40.8 (3.33)	23.5 (2.89)	<.001
Place of birth						
India (%)	83.8 (1.24)	186/85.7 (2.38)	191/87.2 (2.26)	180/82.6 (2.58)	173/79.7 (2.74)	.043
Other (%)	16.2 (1.25)	31/14.3 (2.38)	2812.8 (2.26)	38/17.4 (2.58)	44/20.3 (2.74)	
Age	55.3 (0.32)	54.0 (0.67)	53.8 (0.62)	55.2 (0.60)	58.3 (0.63)	<.001
Total gross family income (% ≥$35,000)	89.3 (1.05)	194/89.4 (2.09)	202/92.2 (1.81)	200/91.7 (1.87)	18283.9 (1.87)	.068
Education (% completed high school)	97.2 (0.55)	212/97.7 (1.02)	213/97.3 (1.11)	213/97.7 (1.02)	20996.3 (1.28)	.46
Smoking (% current smoker)	3.32 (0.61)	21/2.76 (1.12)	17/4.11 (1.34)	29/2.29 (1.02)	50/4.14 (1.36)	<.001
Alcohol (% current drinker)	32.7 (1.59)	67/30.9 (3.14)	63/28.8 (3.07)	66/30.3 (3.12)	89/41.0 (3.35)	.025
Cancer (% dx)	2.41 (0.52)	5/2.30 (1.02)	3/1.37 (0.79)	5/2.29 (1.02)	8/3.70 (1.29)	.27
Exercise (% ≥1314 MET –min/week)	39.2 (1.65)	109/50.2 (3.40)	79/36.1 (3.25)	81/37.2 (3.28)	72/33.2 (3.20)	.001
Diabetes (% fasting glucose ≥ 126)	20.3 (1.37)	25/11.6 (2.18)	33/15.1 (2.42)	47/21.6 (2.79)	71/33.2 (3.23)	<.001
Hypertension (% dx)	40.0 (1.66)	61/28.1 (3.06)	70/32.0 (3.16)	103/47.2 (3.39)	114/52.5 (3.40)	<.001
Cholesterol (% medication use)	29.4 (1.54)	43/19.8 (2.71)	56/25.6 (2.95)	73/33.5 (3.20)	84/38.7 (3.31)	<.001
Kidney disease (% self-report)	3.69 (0.64)	6/2.78 (1.12)	7/3.236 (1.20)	9/4.15 (1.36)	10/4.61 (1.43)	.26
Menopausal status (% post-menopausal)	62.7 (2.43)	77/54.2 (4.20)	77/63.6 (4.39)	55/65.5 (5.22)	40/80.0 (5.71)	.001
Height (cm)	164 (0.3)	161 (0.6)	163 (0.6)	165 (0.6)	167 (0.6)	<.001
Weight (kg)	69.6 (0.41)	60.4 (0.63)	68.4 (0.73)	71.3 (0.6)	78.3 (0.79)	<.001
Body mass index (kg/m^2)	25.8 (0.13)	23.2 (0.19)	25.7 (0.21)	26.2 (0.22)	28.1 (0.26)	<.001
Waist circumference (cm)	92.5 (0.33)	84.3 (0.50)	91.1 (0.54)	93.8 (0.48)	100.9 (0.60)	<.001
Hip circumference (cm)	102.6 (0.27)	98.5 (0.48)	102.6 (0.51)	103.4 (0.47)	106.1 (0.59)	<.001
Waist-to-hip ratio	0.90 (0.002)	0.86 (0.004)	0.89 (0.004)	0.91 (0.004)	0.95 (0.004)	<.001
Waist-to-height ratio	0.56 (0.002)	0.52 (0.003)	0.56 (0.003)	0.57 (0.003)	0.61 (0.004)	<.001
ln Subcutaneous fat (cm^2)	5.39 (0.014)	5.23 (0.033)	5.40 (0.024)	5.41 (0.024)	5.52 (0.026)	<.001

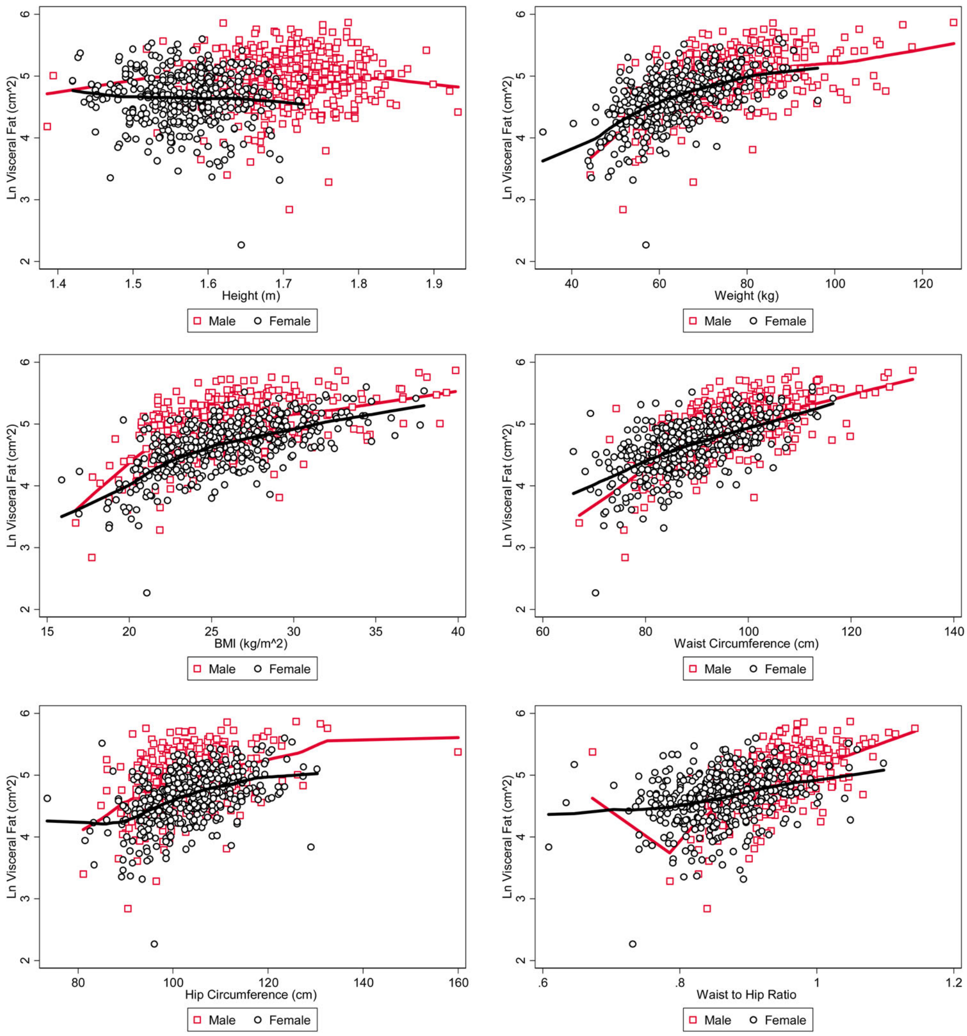

Figure 1. Unadjusted lowess associations between anthropometric measures and ln visceral fat by sex in MASALA.

significant non-linear component (Table 2). All measures, except for height, exhibited heterogeneity by sex with subcutaneous fat (Table 2).

In sensitivity analyses, results were not statistically different by subgroup with the exception of diabetes and diabetes medication use (Table 3). Stratifying by menopausal status and birth control pill use produced similar results (data not shown), with the exception of the estimate for waist circumference and visceral fat in pre-menopausal women which was close to zero and not significant (slope: 0.004 cm^2 95% CI: −0.01,0.02). Intentional exercise (MET-min/week) was significantly and inversely associated with visceral fat and exhibited a significant interaction with BMI and waist circumference ($p < .05$), but inclusion of these variables did not significantly change the results for the main BMI and waist circumference terms or the interaction terms for sex (Table 3).

Table 2. Association between body composition measures and anthropometry by sex in MASALA.

X^a		Intercept +	Linear +	Quadratic	p-Value for sex difference[b]
ln Visceral fat (cm^2)					
Height (cm)	Female	4.64	−0.005	–	.13
	Male	4.91	0.006	–	
Weight (kg)	Female	4.26	0.036	−0.004	.14
	Male	4.25	0.040	−0.004	
BMI (kg/m^2)	Female	4.12	0.121	-0.004	.34
	Male	4.47	0.115	−0.004	
Waist (cm)	Female	4.95	0.019	−0.0003	.007
	Male	5.10	0.027	−0.0003	
Hip (cm)	Female	4.60	0.025	−0.0003	.68
	Male	4.91	0.027	−0.0003	
Waist to hip	Female	3.72	0.230	1.164	<.001
	Male	2.25	2.101	1.164	
Waist to height	Female	0.088	14.27	−9.36	.48
	Male	−0.073	14.55	−9.36	
ln Subcutaneous fat (cm^2)					
Height (cm)	Female	5.48	0.001	–	.45
	Male	5.24	0.006	–	
Weight (kg)	Female	5.18	0.027	−0.0003	.001
	Male	4.52	0.040	−0.0003	
BMI (kg/m^2)	Female	5.07	0.098	−0.003	<.001
	Male	4.72	0.131	−0.003	
Waist (cm)	Female	5.70	0.015	−0.0002	<.001
	Male	5.47	0.033	−0.0002	
Hip (cm)	Female	5.45	0.025	−0.0005	<.001
	Male	5.24	0.044	−0.0005	
Waist to hip	Female	5.88	1.054	–	.003
	Male	4.31	−0.466	–	
Waist to height	Female	2.11	9.85	−6.47	<.001
	Male	0.79	12.04	−6.47	

[a]Anthropometric measures centered as follows: height: 160 cm; weight: 50 kg; BMI: 20 kg/m^2; waist circumference: 100 cm; hip circumference: 100 cm; waist to hip ratio: 0.7 and waist to height ratio: 0.4.
[b]Regression equation for body composition by anthropometry and sex:
ln Body composition: $\beta0_1 + \beta0_2(\text{sex}) + \beta1(X) + \beta2(X^2) + \beta3(\text{sex}*X)$.
Intercept: $\beta0_1 + \beta0_2$; linear: $\beta1 + \beta3$; quadratic: $\beta2$; p-value for difference by sex: p-value for $\beta3$
[c]All reported coefficients are significant, except for the linear component of height.

Discussion

In a cross-sectional analysis of data from the MASALA Study, we found that the relationship between all anthropometric measures and visceral and subcutaneous fat were significantly non-linear, except for the relationship with height. Further, we found that there was significant heterogeneity by sex for the relationship of waist circumference and waist-to-hip ratio with visceral fat. For subcutaneous fat, we found heterogeneity by sex for all measures, except for height. Heterogeneity by sex was characterized by steeper slopes for men than for women. While it has long been recognized that there are sexual dimorphisms in body fat distribution (Vague 1956), and that sex hormones may play an important role in those dimorphisms (Golden 2010), mechanisms for potential differences by race or ethnicity are lacking.

These results are generally consistent with studies done in other racial/ethnic groups, however, to our knowledge there are no prior studies on US South Asians. Our findings are similar to those of Schreiner et al. (1996) and Oka et al. (2009) but different from those of other studies (Carroll et al. 2008; Camhi et al. 2011; Nazare et al. 2012). Specifically, other studies found null results for interaction by sex, found interaction results for

Table 3. Visceral fat[a] linear slopes with body mass index and waist circumference in the MASALA cohort by sensitivity subgroup.

			BMI			Waist circumference		
Estimates	_	*n*	Slope for women	Slope for men	*p*-Value for sex difference	Slope for women	Slope for men	*p*-Value for sex difference
Reported estimates/full group		871	0.121 (0.11, 0.14)	0.115 (0.10, 0.13)	.34	0.019 (0.017, 0.021)	0.027 (0.024, 0.030)	.007
Adjustment for exercise		871	0.097 (0.09, 0.11)	0.103 (0.08, 0.12)	.32	0.017 (0.01, 0.02)	0.023 (0.02, 0.03)	.02
Subgroup analysis								
Age	65+	171	0.131 (0.11, 0.15)	0.151 (0.11, 0.19)	.21	0.014 (0.01, 0.02)	0.032 (0.02, 0.04)	.006
	<65	700	0.119 (0.11, 0.13)	0.108 (0.09, 0.13)	.10	0.020 (0.02, 0.02)	0.025 (0.02, 0.03)	.10
Born in India	N	141	0.120 (0.09, 0.20)	0.117 (0.07, 0.17)	.82	0.023 (0.01, 0.02)	0.027 (0.02, 0.03)	.57
	Y	730	0.125 (0.08, 0.16)	0.117 (0.10, 0.14)	.26	0.018 (0.01, 0.03)	0.027 (0.02, 0.03)	.007
Cancer	N	849	0.122 (0.11, 0.13)	0.117 (0.10, 0.14)	.43	0.019 (0.02, 0.02)	0.027 (0.02, 0.03)	.006
	Y	21	0.100 (0.03, 0.17)	0.053 (−0.10, 0.21)	.22	0.038 (0.03, 0.05)	0.026 (−0.001, 0.05)	.53
Liver disease	N	815	0.115 (0.11, 0.12)	0.106 (0.09, 0.13)	.16	0.020 (0.19, 0.022)	0.026 (0.023, 0.030)	.05
	Y	48	0.208 (0.17, 0.24)	0.235 (0.17, 0.30)	.28	−0.003 (−0.01, 0.01)	0.028 (0.007, 0.048)	.01
Kidney disease	N	835	0.120 (0.11, 0.25)	0.113 (0.09, 0.13)	.28	0.019 (0.02, 0.04)	0.026 (0.02, 0.03)	.02
	Y	32	0.172 (0.12, 0.22)	0.187 (0.08, 0.29)	.68	0.014 (0.006, 0.02)	0.032 (0.02, 0.05)	.17
Diabetes	N	691	**0.119 (0.11, 0.13)**	**0.104 (0.08, 0.12)**	**.04**	0.021 (0.02, 0.02)	0.025 (0.02, 0.03)	.18
	Y	176	**0.097 (0.07, 0.12)**	**0.134 (0.09, 0.18)**	**.02**	**0.007 (0.003, 0.01)**	**0.029 (0.02, 0.04)**	**<.001**
Diabetes medication	N	732	0.119 (0.11, 0.13)	0.105 (0.09, 0.12)	.05	0.020 (0.02, 0.02)	0.025 (0.02, 0.03)	.11
	Y	139	**0.084 (0.06, 0.11)**	**0.135 (0.08, 0.19)**	**.005**	0.008 (0.005, 0.01)	0.031 (0.02, 0.04)	.001
Current smoking	N	842	0.120 (0.11, 0.15)	0.116 (0.10, 0.13)	.55	0.019 (0.01, 0.03)	0.028 (0.02, 0.03)	.005
	Y	29	0.181 (0.10, 0.37)	0.135 (0.05, 0.22)	.34	0.008 (−0.04, 0.01)	0.016 (0.00, 0.03)	.61

Notes: All models include ln visceral fat: sex + BMI + BMI^2 + BMI*sex OR ln visceral fat: sex + waist + $waist^2$ + waist*sex.
Bold values indicate a statistically significant difference between the subgroup and full group estimates.
[a]Naturally log-transformed visceral fat.

different anthropometric measures, or found interactions by race in different subgroups, but did not formally test for interaction by sex. Differences in source population, including differences in racial/ethnic background, between prior studies and this unique cohort may explain discrepancies in findings (Carroll et al. 2008; Camhi et al. 2011; Nazare et al. 2012). For example, compared to participants in the MESA Abdominal Body Composition, Inflammation and Cardiovascular Disease ancillary study (Mongraw-Chaffin et al. 2015), MASALA participants were on average younger, more likely to make more than $35,000 a year, and more likely to have a higher level of education. They also had slightly smaller average anthropometric measures than MESA participants.

The MASALA Study was specifically modeled on the MESA design, and the analysis performed for this study and the study in MESA by Mongraw-Chaffin et al. were identical. Any differences in findings between the two are likely due to race/ethnicity or geographic region of origin. In both cohorts all measures, except height, exhibited some statistically significant non-linearity with visceral fat (Table 2) (Mongraw-Chaffin et al. 2015), and height was not significantly associated with visceral or subcutaneous fat in either cohort (Figure 1) (Mongraw-Chaffin et al. 2015). The relationships between anthropometric measures and visceral fat were similar, with the exception of less heterogeneity and less pronounced non-linearity in MASALA.

In MESA, significant differences in visceral fat by sex existed for weight, waist circumference, waist-to-hip, and waist-to-height ratios, whereas in MASALA, these differences were significant only for waist circumference and waist-to-hip ratio. It is unclear whether these differences in heterogeneity by sex can be explained by the smaller sample size in MASALA and therefore limited power or by true differences in these associations for US South Asians. In general, the relationships for anthropometric measures with visceral and subcutaneous fat appear to be similar for South Asians and other race/ethnicities in the US.

This study has a number of limitations. The primary weaknesses of this study are that the data are cross-sectional and body composition is measured by CT only at the L4/L5 level. Furthermore, due to the small number of participants born in countries other than India, we were unable to further investigate heterogeneity by place of birth. This study also has a number of strengths. To our knowledge, this is the first study to investigate the relationship between anthropometric measures and underlying body composition in US South Asians. Additionally, given that MASALA used the same study design and measurement strategies as MESA, we are able to compare our results to those in other racial/ethnic groups.

This study indicates that the relationship between anthropometry and visceral fat in South Asians is similar to that of other racial/ethnic groups living in the US with significant heterogeneity by sex in the relationship between some anthropometric measures and visceral fat, and between all anthropometric measures and subcutaneous fat. Until validated risk-based cut-points are determined for visceral and subcutaneous fat, the clinical implications of knowing how anthropometric measures are related to underlying body fat composition will be limited. Conversely, using these results to more accurately model adiposity may lead to more efficient discovery of predictors and risks associated with differing body compositions in the future. Investigators should therefore consider using separate models for women and men when using waist circumference as a proxy for visceral fat and when using any anthropometric measure as a proxy for subcutaneous fat.

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Disclosure statement

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Key messages

(1) It has been suggested that different anthropometric cut-points are needed for different racial/ethnic groups; however, little data are available to assess the relationship between anthropometric measures and visceral fat. This study investigated how anthropometric measures are associated with visceral and subcutaneous fat in the the Mediators of Atherosclerosis in South Asians Living in America (MASALA) Study.
(2) Using linear regression for naturally log-transformed visceral and subcutaneous fat and likelihood ratio tests, we found that centered anthropometric measures were significantly and non-linearly associated with visceral and subcutaneous fat, but only the relationship between waist circumference and visceral fat exhibited heterogeneity by sex.
(3) Investigators should consider using separate models for women and men when using waist circumference as a proxy for visceral fat.

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