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Body Fat Distribution, Fat-Free Mass and Cardiovascular Function in the UK Biobank

Ayodipupo S. Oguntade[1*], Ben Lacey[1,2], Hannah Taylor[1] and Sarah Lewington[1,2,3,4]

Abstract

Background We evaluated the independent associations of body composition measures on left ventricular ejection fraction (LVEF) and pulse wave arterial stiffness index (PWASI).

Methods The present analysis included 23,258 individuals (mean age 63 years, 53% women) who participated in the whole body imaging sub-study of the UK Biobank. Associations of body composition measures with each of LVEF and PWASI, after mutual adjustment for one another and potential confounders, were determined using multivariable linear regression.

Results Among regional body fat measures, higher visceral fat (VAT) was associated with lower LVEF ($\beta = -0.45$; 95% CI −0.60, −0.31 per SD) and higher PWASI ($\beta = 0.51$; 95% CI 0.38–0.65 per SD). The association between VAT and LVEF was negatively linear but positively linear for PWASI throughout the range of VAT measured. Other regional fat measures and fat-free mass were not significantly associated with either LVEF or PWASI. Central adiposity measures (waist circumference [WC] and waist–hip ratio [WHR]) showed significant inverse association with LVEF (WC: $\beta = -0.11$; 95% CI −0.21, −0.01 per SD; WHR $\beta = -0.25$; 95% CI −0.38, −0.12 per SD) but positive association with PWASI (WC: $\beta = 0.37$; 95% CI 0.28–0.47 per SD; WHR $\beta = 0.39$; 95% CI 0.27 −0.51 per SD) while BMI was not significantly associated with LVEF ($\beta = 0.05$; 95% CI −0.04, 0.14 per SD) but showed weaker positive association with PWASI ($\beta = 0.27$; 95% CI 0.18–0.35 per SD).

Conclusions Excess visceral fat and central adiposity are associated with impaired LV function and increased arterial stiffness which may predispose to heart failure.

Keywords Body composition, Adiposity, Visceral fat, LV ejection fraction, Arterial stiffness

*Correspondence:
Ayodipupo S. Oguntade
ayodipupooguntade@gmail.com; ayodipupo.oguntade@wolfson.ox.ac.uk
[1] Clinical Trial Service Unit and Epidemiological Studies Unit (CTSU), Nuffield Department of Population Health (NDPH), University of Oxford, Oxford, UK
[2] UK Biobank, Stockport, Greater Manchester, UK
[3] MRC Population Health Research Unit, NDPH, University of Oxford, Oxford, UK
[4] UKM Medical Molecular Biology Institute (UMBI), Universiti Kebangsaan Malaysia, Kuala Lumpur, Malaysia

Clinical Perspective

What is New?

This large cohort shows that excess visceral fat is associated with significant perturbation of cardiovascular function independent of other body fat distribution or fat-free mass.

Excess visceral fat is associated with a linear negative association with LV ejection fraction and a linear positive association with arterial stiffness across all the range measured.

What are the Clinical Implications?

Excess visceral fat appears to be the link between obesity and cardiac dysfunction in the transition to heart failure and preventive health guidance should place more emphasis on optimum waistline for cardiovascular health.

1 Introduction

Adiposity is associated with impairment of cardiac and vascular function in the transition to heart failure [1–3]. Some studies have suggested that abdominal adipose tissue, rather than general adiposity, is primarily responsible for this observation [4, 5]. Until recently, there have been limited number of studies which have investigated the role of body composition (i.e., measures that directly quantify body fat and distribution, as well as fat-free mass) in association with cardiovascular disease risk and it is still unclear if regional body fat measures have added value over conventional anthropometric indices in the general population.

Many insights into the associations between regional fat distribution and cardiac function have come from studies with modest sample sizes (< 5000 individuals) in US populations [1, 5, 6]. In the Dallas Heart Study [1], visceral fat (VAT) was associated with reduced cardiac output and vascular resistance while lower body subcutaneous fat (SAT) was associated with higher cardiac output and reduced vascular resistance. However, in the Multi-ethnic study of atherosclerosis (MESA), only VAT and not SAT was associated with reduced LVEF [5]. van Hout et al. [4] in an analysis of the UK Biobank imaging pilot study have previously reported that higher VAT was associated with LV reduced systolic function while SAT and body fat percent were not significantly associated with LV systolic function.

Vascular aging as measured by arterial stiffness is a consequence of atherosclerosis and is independently associated with risk of incident cardiovascular disease [7, 8]. Increased arterial stiffness increases the LV end-systolic afterload which contributes to myocardial dysfunction and risk of HF [9, 10]. Some studies have also shown that VAT and anthropometric adiposity have strong positive association with arterial stiffness measured using pulse wave velocity [11, 12]. In a retrospective study in South Korea, VAT and waist-hip ratio (WHR) were positively associated with arterial stiffness while both BMI and waist circumference (WC) were not [12]. However, these mentioned studies were limited by their small sample sizes and none examined the independent associations between these measures of body composition when mutually adjusted for one another, especially since regional adipose tissue depots and fat-free mass are often highly correlated.

In this paper, we assessed the independent cross-sectional associations between body composition measures and each of LVEF and pulse wave arterial stiffness index (PWASI) using data from the imaging sub-cohort of the UK Biobank. This provides insight into the potential aetiological role of regional adipose tissue and adiposity measures in cardiovascular function and predisposition to heart failure.

2 Methods

This study followed the followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline [13]. The UK Biobank (www.ukbiobank.ac.uk) has been previously described [14, 15]. Briefly, the UKB is a prospective cohort of 502,000 adults (aged 40–70 years) recruited from the general population of the UK between 2006 and 2010 [15]. All UKB participants have given written informed consent for the use of their data for health research. Participants reported lifestyle exposures, medical history and medications before undergoing standardised assessments including body size measurements at the baseline visit. All UKB participants have their data linked to their NHS records and are followed up by electronic health records linkage. All the authors had full access to all the data in the study and take responsibility for its integrity and the data analysis.

2.1 Imaging Visit Assessment

The UK Biobank whole body imaging sub-study of 100,000 individuals for assessment of body composition and cardiac function started in 2014 and is still ongoing. Participants were measured while wearing light clothing without their shoes. Anthropometric measurements were done as previously described [15–17]. Anthropometric measurements included body weight (using a Tanita BC418MA body composition analyser), standing height (Seca 240 cm height measure), and waist and hip circumference (Seca 200 cm tape measure around the narrowest part of the trunk and the widest part of the hips, respectively) [15–17]. Waist–hip ratio (WHR) is the ratio of the WC to HC (both in cm). Body mass index (BMI) is the ratio of the weight (kg) to the square of the height in metres. Participants had cardiac and abdominal MRI imaging using Siemens 1.5 Tesla MAGNETOM Aera scanner (Siemens Healthcare, Erlangen, Germany) [18]. Abdominal MRI slices

were used to quantify visceral (VAT) and subcutaneous (SAT) fat volumes which were converted to fat mass based on fat density. VAT was defined as the adipose tissue within the abdominal cavity, excluding fat outside the abdominal skeletal muscles and fat within and back of the spine and back muscles. Abdominal SAT was defined as subcutaneous fat in the abdomen from the top of the femoral head to the top of the ninth thoracic vertebrae [19]. Visceral fat was distinguished from subcutaneous fat by following the facial plane defining the internal abdominal wall. Cardiac MRI was used to measure LV volumes, end diastolic pressure and ejection fraction [18].

Total body mass and total body fat were estimated by a GE Lunar iDXA densitometer (GE-Lunar, Madison, WI, USA) and expressed in kilogrammes. Total fat-free mass was obtained by subtracting total fat from total body mass. The sum of MRI-derived visceral fat and abdominal subcutaneous fat was subtracted from total body fat to obtain other body fat. Thus, mutually exclusive compartments of body composition were estimated.

LVEF is the fraction of the total volume of blood in the left ventricle that is pumped out of the LV with each contraction and is expressed in percentage:

$$\text{LVEF} = (\text{Stroke volume/end - diastolic volume}) \times 100.$$

Arterial pulse wave velocity (PWV) was measured using pulse waveforms obtained from an infrared sensor (PulseTrace PCA2, CareFusion, USA) clipped to the index fingertip. The reading was made over 10–15 s. The shape of the waveform is proportional to the time t required for the pulse wave to travel through the arterial tree and be reflected back to the finger. The PWASI is the participant's height (metres) divided by the peak-to-peak time (seconds). This method is a simple and inexpensive technique that has been validated in three independent studies that compared it with carotid-femoral PWV [20–22].

The present analysis include 23,258 individuals who had both whole body MRI and DXA imaging and were free of cardiac and vascular disease and for whom imaging-derived body composition measures were available (see Fig. 1). Socio-demographic and lifestyle variables at imaging visit were expressed in proportions and categorised into groups: age (5-year age-groups); ethnicity (European, others); education (at least college education, below college education and undeclared education attainment); recruitment centres (three regions); smoking (never, past, current); alcohol (abstainer/ex-drinker, occasional, regular); physical activity (0–9.9, 10–49.9, ≥ 50 mET-h/week).

2.2 Statistical Analysis

Normality of the distribution of body composition measures were explored using histogram plots. Socio-demographic and lifestyle variables at the imaging visit were expressed in proportions while body composition measures, LVEF and PWASI were expressed as means (SD). All analyses were adjusted for age (5-year age-groups), sex, ethnicity, region, Townsend deprivation, education, smoking, alcohol and physical activity while analyses for PWASI were additionally adjusted for systolic blood pressure (SBP) since PWASI is strongly influenced by SBP [7]. The inter-relationships between imaging derived measures of body composition measures were determined using Pearson's partial correlation method. Associations of each mutually exclusive imaging-derived body composition measure with each of LV ejection fraction (LVEF) and PWASI, after mutual adjustment for one another and potential confounders, were determined using multivariable linear regression. In mutual adjustment analyses, because of the correlations between the imaging-derived body composition measures, the residuals obtained from a first-step linear regression of each body composition on the rest of the other measures was used. Associations between each anthropometric adiposity measure and each of LVEF and PWASI were also evaluated using multivariable linear regression adjusted for confounders.

Analyses that use values of body composition measures obtained on a single occasion at baseline which do not take into account within-person variability over time, are prone to systematic underestimation of the strength of associations between measured adiposity measures and cardiovascular function ('regression dilution bias') [23, 24]. As such, in this analysis, regression dilution ratios (RDR) of body composition measures were calculated using the age and sex adjusted Pearson partial correlation (r) between body composition measures at baseline imaging visit and imaging resurvey visit approximately 2.3 years later (S1).

For graphical representation of β-coefficient (95% CI) of associations of LVEF and PWASI with increasing fifths of each mutually adjusted body composition measure, β-coefficients per SD were plotted against the mean of each body composition measure at resurvey within groups defined by baseline quintiles of each body composition. The variance of the β-coefficient in each group, including the reference, was calculated (from the variances and co-variances of the β-coefficients in all groups except the reference group) and used to obtain group-specific 95% CIs as previously described [25, 26]. β-Coefficients were estimated for each exposure group with the bottom fifth designated as the reference.

The consistency of associations of the body composition measures with each of LVEF and PWASI across

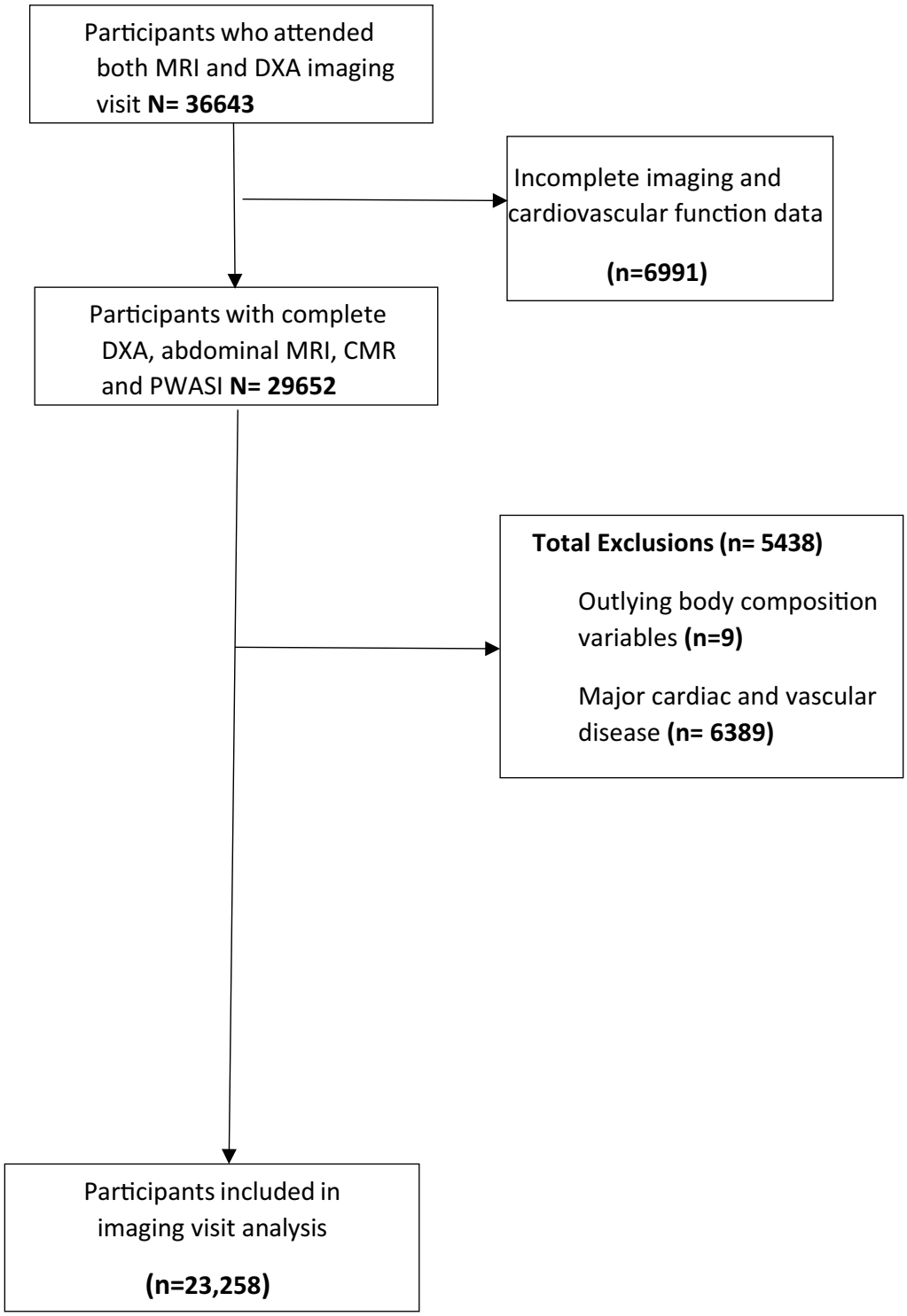

Fig. 1 Flow diagram of UK Biobank study population included in present analysis

the study population was explored by comparing the β-coefficients between subgroups defined by sex, age, smoking, and alcohol. Heterogeneity between subgroups was assessed using Chi-squared tests for heterogeneity and Chi-squared tests for trend was used for ordered subgroups. The linear associations of each body composition

measure with LVEF or PWASI were corrected for regression dilution by dividing the β-coefficient (and standard error) by the RDR as previously described [23, 24]. Associations corrected for regression dilution bias were described as association with 'usual' body composition measure. Also, the usual SD of each body composition measure was obtained by multiplying the measured SD by $\sqrt{R}$DR [15].

Sensitivity analyses was performed to assess the potential for reverse causality by a separate analysis of individuals with major cardiac or vascular diseases at the imaging visit. All analyses were done using Stata version 17 (StataCorp LLC, StataCorp, Texas USA) while plots were made using R version 4.2.3 (R Foundation for Statistical Computing, Vienna, Austria).

Table 1 Characteristics of UK Biobank imaging cohort

Characteristics at imaging visit	Imaging cohort		
	Women *N* = 12,380	Men *N* = 10,878	Total *N* = 23,258
Demographic and lifestyle factors			
Age	62.6 (7.4)	63.4 (7.7)	63.0 (7.5)
European ethnicity	96.8%	96.5%	96.7%
Higher education	63.2%	64.3%	63.7%
Townsend deprivation	−1.9 (2.7)	−2.0 (2.7)	−2.0 (2.7)
Current smoker	2.9%	4.3%	3.6%
Regular drinker	66.8%	79.3%	72.7%
Low physical activity	12.3%	12.2%	12.2%
Hypertension	19.4%	28.3%	23.6%
Diabetes	3.1%	6.5%	4.7%
Anthropometry			
Body mass index (kg/m^2)	25.9 (4.5)	26.8 (3.8)	26.3 (4.2)
Waist circumference (cm)	81.7 (11.4)	93.3 (10.3)	87.1 (12.3)
Hip circumference (cm)	100.4 (9.5)	100.4 (7.1)	100.4 (8.5)
Waist–hip ratio (units)	0.8 (0.1)	0.9 (0.1)	0.9 (0.1)
Vascular function			
Systolic blood pressure (mmHg)	134.7 (18.8)	141.4 (17.1)	137.8 (18.4)
Diastolic blood pressure (mmHg)	76.9 (9.9)	80.8 (9.7)	78.7 (10.0)

Data are presented as % or mean (SD)

3 Results

3.1 Imaging Visit Participants' Characteristics

After exclusions, 23,258 individuals (mean age 63 years, 53.2% women and 96.7% Europeans) from the main cohort were included in this analysis (Table 1). On average, individuals in the imaging cohort were ~12 years older than at the baseline visit. They were also less likely to be smokers and more physically active compared to the baseline cohort. Among men, 4% were current smokers and 79% were regular alcohol drinkers while only 3% women were current smokers and 67% were regular alcohol drinkers. Hypertension and diabetes were more common in men than women.

General adiposity (BMI) was similar in both sexes but men had higher waist circumference than women. As shown in Table 2, men had higher fat-free mass than women (58.3 kg in men vs 41.7 kg in women). There were also sex differences in body fat distribution with men on

Table 2 Imaging-derived body composition, cardiac and vascular function in UK Biobank imaging cohort

Characteristics at imaging visit	Women *N* = 12,380	Men *N* = 10,878	Total *N* = 23,258
Imaging body composition			
Visceral fat volume, Litres	2.5 (1.5)	4.7 (2.2)	3.6 (2.2)
Abdominal subcutaneous fat volume, Litres	7.8 (3.3)	5.7 (2.4)	6.8 (3.1)
Visceral fat mass, kg	2.3 (1.3)	4.3 (2.0)	3.2 (1.9)
Abdominal subcutaneous fat mass, kg	7.0 (3.0)	5.2 (2.2)	6.1 (2.8)
Total body fat mass, kg	26.2 (9.2)	24.3 (8.5)	25.3 (8.9)
Fat-free mass, kg	41.7 (4.8)	58.3 (6.6)	49.4 (10.1)
Cardiac and vascular function			
LV end diastolic volume (mL)	123.1 (58.8)	158.5 (99.9)	139.6 (82.6)
LV end systolic volume (mL)	54.1 (45.6)	73.6 (84.2)	63.2 (67.2)
LV stroke volume (mL)	69.0 (22.0)	84.9 (23.7)	76.4 (24.1)
Cardiac output (L/min)	4.4 (1.6)	5.2 (1.4)	4.7 (1.6)
Cardiac index (L/min/m^2)	2.5 (0.8)	2.6 (0.7)	2.5 (0.8)
LV ejection fraction (%)	56.9 (6.2)	54.5 (6.4)	55.8 (6.4)
Pulse wave arterial stiffness index (m/s)	9.1 (3.0)	10.1 (2.9)	9.6 (3.0)

Data are presented as % or mean (SD)

average having twice as much VAT than women whereas women had more abdominal SAT than men.

As shown in Table 3, body composition measures were highly correlated with one another. BMI was strongly correlated with WC ($r=0.85$ in women; $r=0.86$ in men) but showed weaker correlation with WHR ($r=0.42$ in women; $r=0.58$ in men). Anthropometric adiposity measures were also strongly correlated with regional fat measures. Among regional fat distribution measures, abdominal SAT were strongly correlated with both VAT ($r=0.77$ in women; $r=0.70$ in men) and other body fat ($r=0.90$ in women; $r=0.92$ in men).

3.2 Body Composition, LVEF and Arterial Stiffness

Figure 2 shows the associations of mutually adjusted imaging-derived body composition measures with each of LVEF and PWASI. Visceral fat displayed an inverse association with LVEF (0.45% lower LVEF per usual SD higher visceral fat) but positive association with arterial stiffness (0.51 m/s higher arterial stiffness index per usual SD higher visceral fat). There was no significant association between the other imaging-derived body composition measures and either of LVEF and arterial stiffness index). Throughout the range of VAT measured, there was an inverse association with LVEF but a positive association with PWASI (Fig. 3). There was no evidence of effect modification by sex, age, smoking and alcohol consumption (Figs. 4 and 5). None of the cardiometabolic risk factors explained the observed associations of VAT with each of LVEF and PWASI (S2 and S3).

In Fig. 6, both BMI and hip circumference were not associated with LVEF. However, both WC and WHR showed inverse associations with LVEF. Conversely, all the adiposity measures displayed positive associations with arterial stiffness index which were stronger for both waist circumference and waist-hip ratio than BMI. The strength and direction of associations between the body composition measures and each of LVEF and PWASI were not materially different among individuals with cardiovascular disease at the imaging visit assessment (S4).

4 Discussion

This large imaging study investigates the associations of body composition measures with LVEF and PWASI. VAT was significantly associated with a reduction in LVEF, and with an increase in PWASI, independent of other imaging-derived body composition measures. Also, only WC and WHR (central adiposity measures) were associated with reduction in LVEF while BMI was not associated with LVEF. All the anthropometric measures were associated with an increase in PWASI. This study is perhaps the first to show the linear shape of the association between VAT and each of LVEF and arterial stiffness. The associations for VAT was broadly consistent with the observed associations of central anthropometric adiposity measures with LVEF and PWASI. The associations were similar in those with and without cardiovascular disease and across demographic and lifestyle subgroups. Importantly, there was no evidence of associations with other fat measures or fat-free mass. These results support the evidence for the adverse consequences of excess central adiposity on cardiac and vascular function even in individuals without cardiovascular disease.

In one of the earliest reports on the relationship between body composition measures and cardiac function, Turkbey et al. [27] in the MESA study did not find any association between any of adiposity, fat mass and fat-free mass and VAT. However, the MESA study estimated fat and fat-free mass using bioimpedance which is less precise than whole body imaging. In a recent

Table 3 Correlation between composition variables

		Anthropometric variables					
		Waist circumference	**Waist-hip ratio**	**MRI-visceral fat**	**MRI-abdominal SAT**	**Other fat**	**Fat-free mass**
Body mass index	Women:	0.85	0.42	0.78	0.91	0.91	0.53
	Men:	0.86	0.58	0.78	0.85	0.87	0.53
Waist circumference		Women:	0.74	0.81	0.84	0.80	0.51
		Men:	0.78	0.80	0.83	0.86	0.49
Waist-hip ratio			Women:	0.57	0.41	0.32	0.21
			Men:	0.66	0.54	0.56	0.20
MRI-visceral fat				Women:	0.77	0.75	0.38
				Men:	0.70	0.78	0.34
MRI-abdominal SAT					Women:	0.90	0.45
					Men:	0.92	0.38
Other fat						Women:	0.52
						Men:	0.43

Correlation coefficients were adjusted for age (5-year groups)

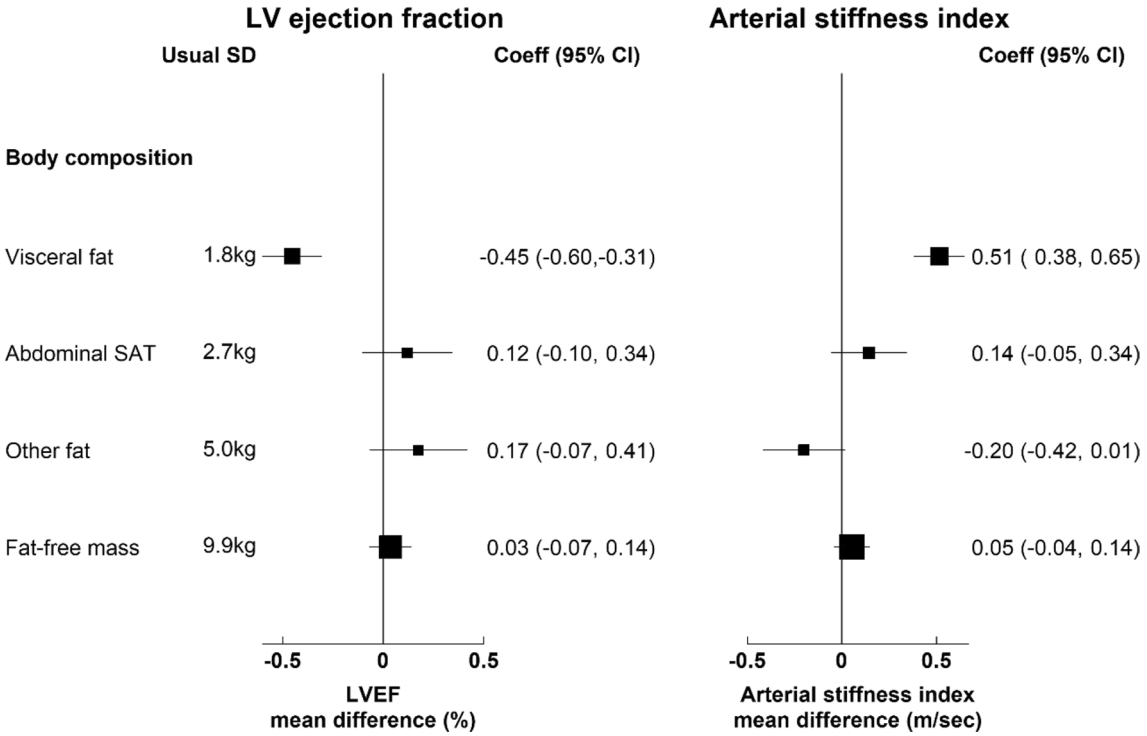

Fig. 2 Associations between body composition measures, left ventricular ejection fraction and pulse wave arterial stiffness index. Body composition measures were mutually adjusted for one another and additionally adjusted for sex, age (5-year groups), region, ethnicity, education, Townsend deprivation, smoking, alcohol and physical activity while pulse wave arterial stiffness index was additionally adjusted for systolic blood pressure. *SAT* subcutaneous fat

post-hoc analysis of the MESA study, VAT above the median distribution was associated with reduction in LVEF while SAT was not [5]. In the preliminary analysis of the UK Biobank imaging pilot study, VAT was also inversely associated with LVEF while both SAT and body fat percent (BF%) were not associated with LVEF [4].

Excess adiposity and fat-free mass have been associated with LV remodelling and eventual systolic dysfunction as the volume and pressure overload increase the stress on the myocardium [1, 2, 6, 28]. In the Dallas Heart study, when regional fat depots and fat-free mass were mutually adjusted for one another, VAT was associated with impairment of LV circumferential strain (a measure of LV systolic function) while the other body composition measures were not [1].

Measures of arterial stiffness have been shown to predict incident cardiovascular events in the general population [29–34]. Higher aortic pulse wave velocity was associated with a 48% higher CVD risk in the Framingham Heart Study independent of socio-demographic, lifestyle and cardiometabolic factors [31]. Reduced ascending aortic distensibility was also an independent predictor of CVD events and HF in the MESA study [33].

Arterial stiffness is an important cardiovascular risk factor that correlates with vascular aging and has been associated with obesity [35–37]. In the Health, Aging, and Body Composition (Health ABC) study, among the body composition measures, VAT showed the strongest positive association with aortic PWV [35]. In a study by Kim et al. [12], VAT and waist-hip ratio were both associated with increased PWASI while BMI was not. Strasser et al. [11] have also reported similar associations between central fat depots and arterial PWV. On the contrary, previous preliminary finding from the UK Biobank imaging pilot study suggested significant positive associations between each of VAT, SAT and BF% and PWASI, albeit stronger for VAT [4].

However, none of these studies mutually adjusted for the whole range of mutually exclusive fat depots and fat-free mass as done in the present analysis which could have confounded the reported findings. Moreover, the small size of these studies precluded precise estimation of the strength of the observed associations.

4.1 Pathophysiologic Mechanisms

Central adiposity especially VAT is a metabolically active tissue and has stronger association with

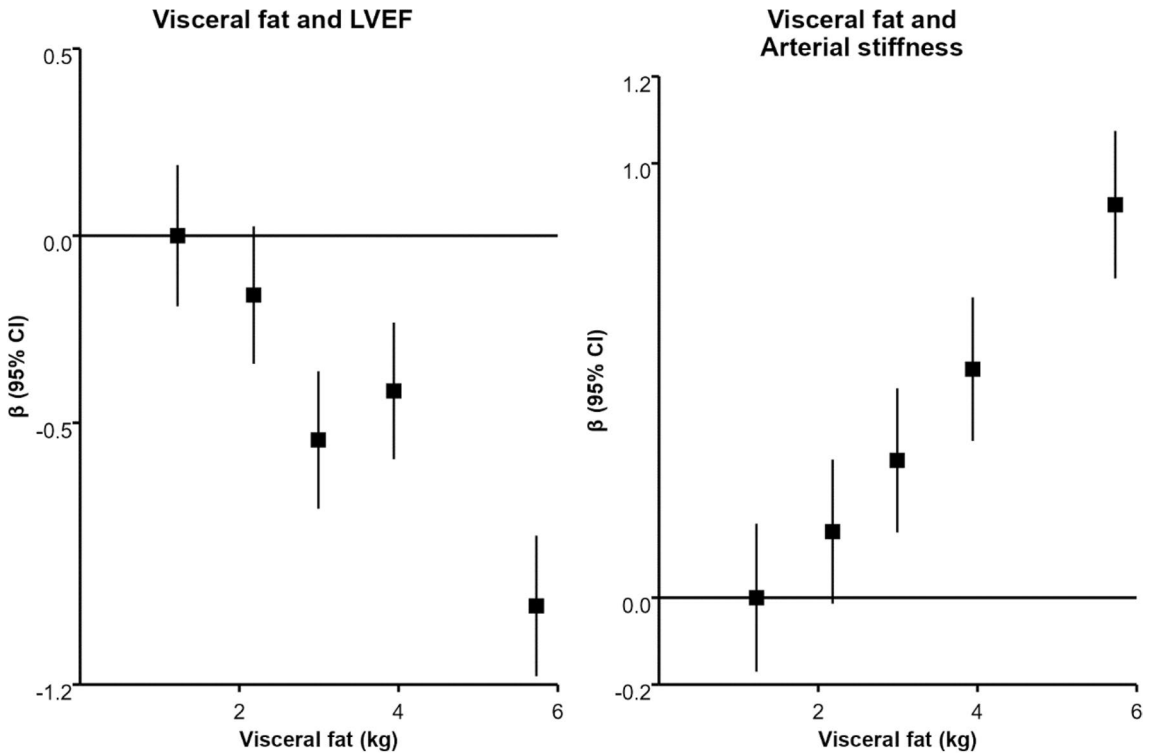

Fig. 3 Associations of increasing fifths of visceral fat with left ventricular ejection fraction and pulse wave arterial stiffness index. Body composition measures were mutually adjusted for one another and additionally adjusted for sex, age (5-year groups), region, ethnicity, education, Townsend deprivation, smoking, alcohol and physical activity while pulse wave arterial stiffness index was additionally adjusted for systolic blood pressure

cardiometabolic factors e.g. lipids, glycaemic profile and blood pressure than other adipose tissue stores and fat-free mass [38–42]. Excess visceral fat has been associated with hyperleptinaemia, hyperinsulinaemia, dysglycaemia and insulin resistance which lead to sympathetic activation, increased activity of renin–angiotensin–aldosterone axis and consequent increased vascular tone and myocardial fibrosis [38, 41, 43].

This leads to chronic elevation of blood pressure, endothelial injury and oxidative stress [44]. These events synergistically contribute to increased arterial stiffness, reduced vascular compliance, reduced cardiac output and consequent afterload mismatch that perpetuate adverse LV hypertrophy, fibrosis and remodelling, the harbinger of LV diastolic and eventual systolic failure [37]. The increased arterial stiffness and vascular load in HF exacerbates the diastolic and systolic dysfunction that is seen in these individuals [45–48]. Studies have reported reversal of cardiac remodelling, improvement in arterial stiffness and reduced risk of heart failure following intentional weight loss from lifestyle interventions and bariatric surgery [28, 49–51].

4.2 Strengths and Limitations

This is the largest contemporary cohort study that has phenotyped body composition and LVEF and PWASI using whole body imaging. Using resurvey values of the different body composition measures to correct for regression dilution and measurement errors, the associations between the long-term usual levels of the different body composition measures and LVEF and PWASI were estimated unlike previous studies. Moreover, by adjusting the different body composition measures for one another, confounding in the strength of the observed associations due to the correlation between the body composition measures was reduced.

Nonetheless, the study has important limitations. First, this is a cross-sectional study and causality of observed association cannot be inferred. Second, the study consists of mainly Europeans and the findings cannot be generalised to other ethnic groups. Third, the influence of weight gain or weight loss over time was not investigated and it was assumed that variations in body composition over time were linear and due to measurement error. Finally, while attempts have been made to reduce potential confounding, the

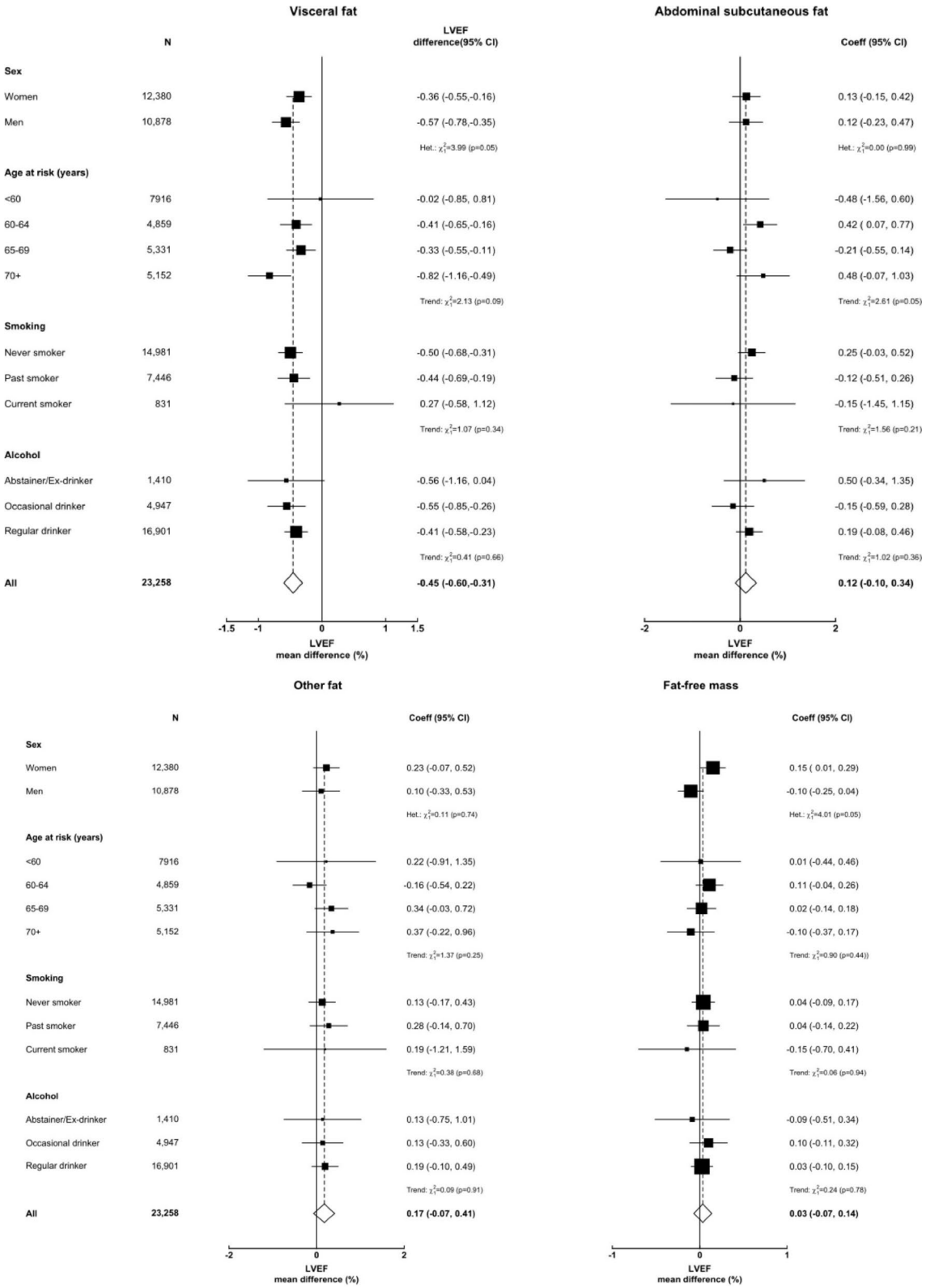

Fig. 4 Associations between body composition measures and left ventricular ejection fraction (LVEF) by levels of confounders. Body composition measures were mutually adjusted for one another and additionally adjusted for sex, age (5-year groups), region, ethnicity, education, Townsend deprivation, smoking, alcohol and physical activity

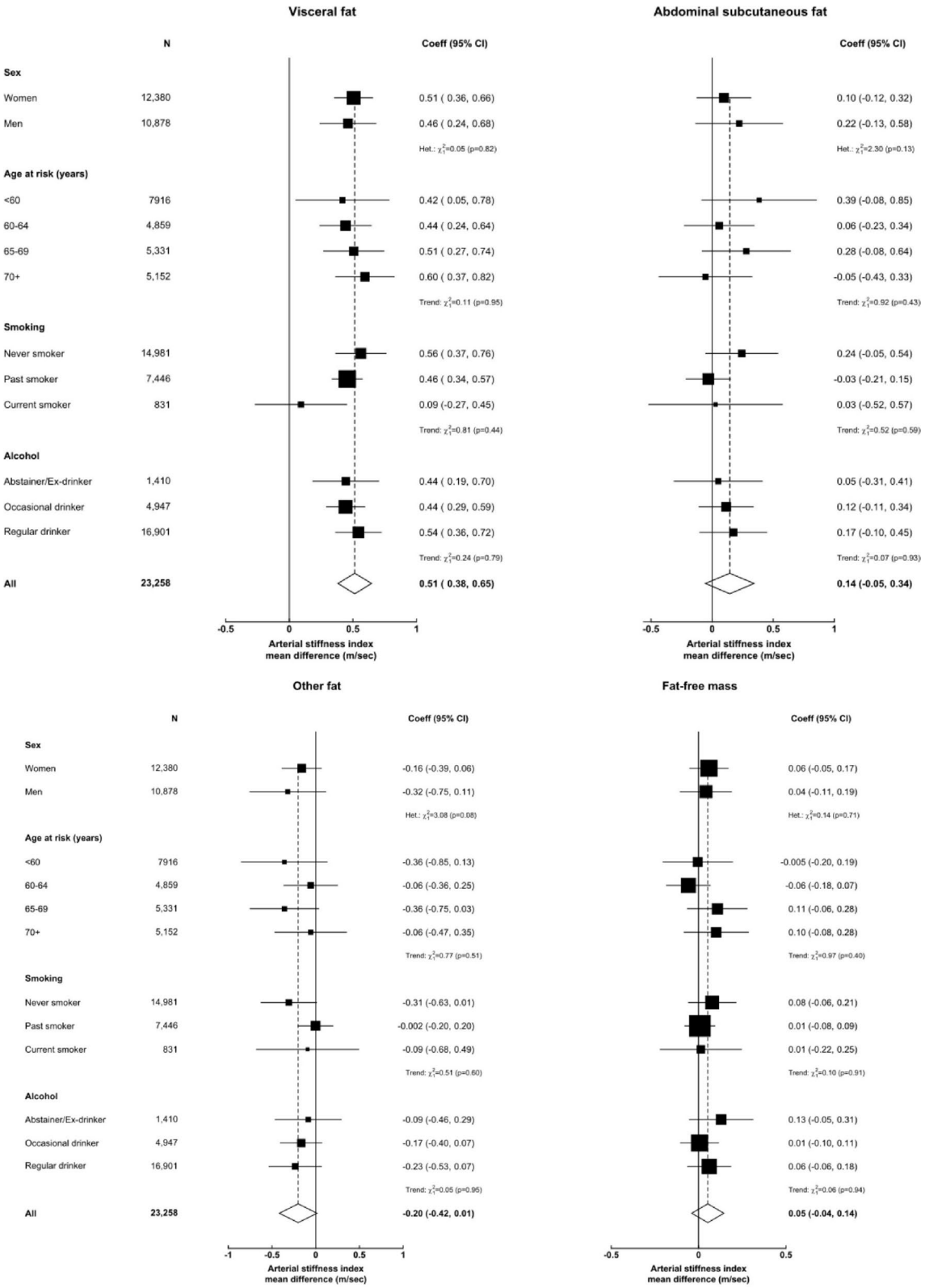

Fig. 5 Associations between body composition measures and pulse wave arterial stiffness index by levels of confounders. Body composition measures were mutually adjusted for one another and additionally adjusted for sex, age (5-year groups), region, ethnicity, education, Townsend deprivation, smoking, alcohol and physical activity while pulse wave arterial stiffness index was additionally adjusted for systolic blood pressure

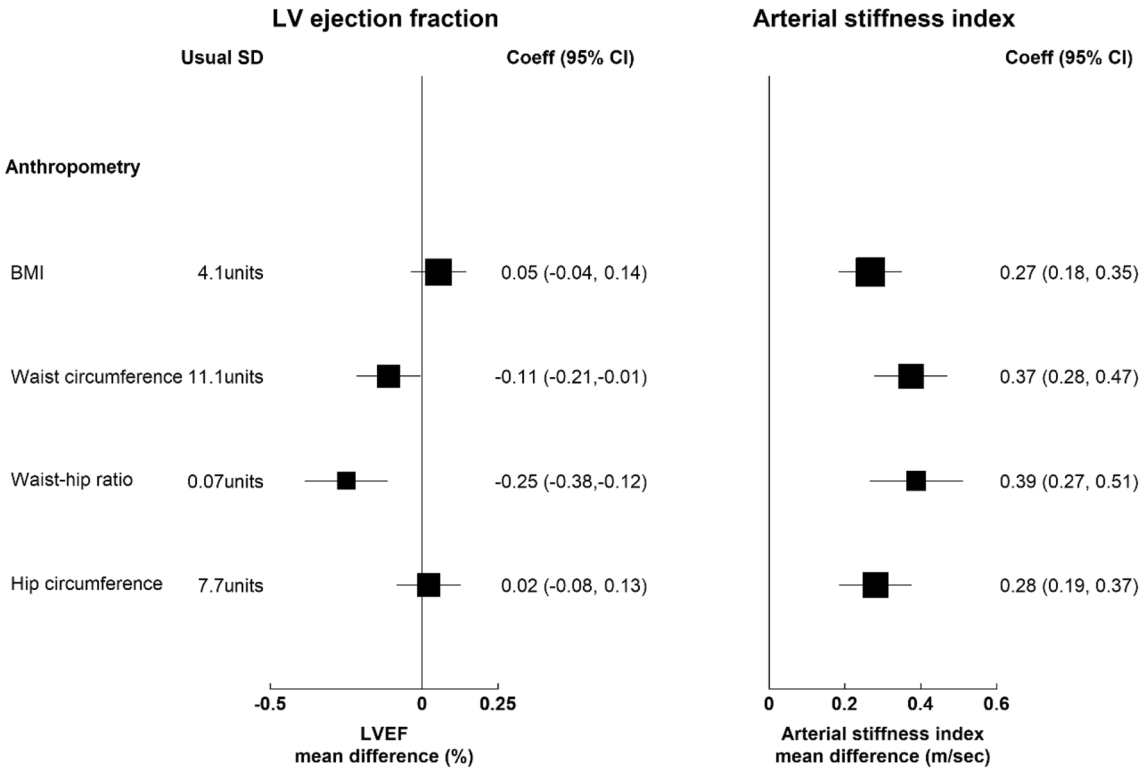

Fig. 6 Associations of usual levels of anthropometric measures with left ventricular ejection fraction (LVEF) and pulse wave arterial stiffness index. The mean difference in each of left ventricular ejection fraction (LVEF) and arterial stiffness index is expressed per usual SD higher level of each anthropometric measure and is adjusted for sex, age (5-year groups), region, ethnicity, education, Townsend deprivation, smoking, alcohol and physical activity while pulse wave arterial stiffness index was additionally adjusted for systolic blood pressure

possibility of unmeasured residual confounding cannot be excluded.

5 Conclusion

This study provides insight into adiposity related systolic and vascular dysfunction. Excess visceral fat and central adiposity independent of other body composition measures were associated with reduced LVEF and increased PWASI which may predispose to heart failure. These findings suggest that excess visceral fat may play a key role in the pathogenesis of adiposity-related heart failure.

Abbreviations

BMI	Body mass index
BFFM	Body fat-free mass
CMR	Cardiac magnetic resonance
DXA	Dual X-ray absorptiometry
EDV	End diastolic volume
LV	Left ventricle
LVEF	Left ventricular ejection fraction
MESA	Multi-ethnic study of atherosclerosis
MRI	Magnetic resonance imaging
SAT	Subcutaneous abdominal fat
VAT	Visceral fat
WC	Waist circumference
WHR	Waist–hip ratio

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1007/s44200-023-00039-z.

Below is the link to the electronic supplementary material.Supplementary file1 (DOCX 429 kb)

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Author Contributions

ASO, BL, HT and SL conceptualised the study. SL and BL secured funding for the study. ASO analysed the data and was responsible for data management. BL, HT and SL supervised the project and provided access to the UKB dataset. ASO drafted the manuscript while all the authors provided intellectual input to the manuscript draft. All authors read and approved the final manuscript.

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independence and has a staff policy of not taking personal payments from industry; further details can be found at https://www.ndph.ox.ac.uk/files/about/ndphindependence-of-research-policy-jun-20.pdf.

Availability of Data and Materials
The data that support the findings of this study are available from the UK Biobank. The UK Biobank will make the data used for this study available to all bonafide researchers for health-related research that is in the public interest.

Declarations

Conflict of interest
SL reports grants from the Medical Research Council (MRC) and research funding from the US Centers for Disease Control and Prevention Foundation (with support from Amgen) during the conduct of the study.

Ethical approval
Ethical approval for UKB is from the National Information Governance Board for Health and Social care, and the National Health Service North west Centre for Research Ethics Committee (Ref: 11/NW/0382) [18].

Consent to participate
UKB participants have given written informed consent for the use of their data for health research and the present research has been conducted using the UK Biobank Resource under Application Number 31461.

Consent for publication
Not applicable.

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