Is the reduction of lower-body subcutaneous adipose tissue associated with elevations in risk factors for diabetes and cardiovascular disease?

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Abstract

Aims/hypothesis Since the accumulation of lower-body subcutaneous adipose tissue (LBSAT) is associated with decreased cardiometabolic risk, we evaluated whether reductions in LBSAT independent of changes in visceral AT (VAT) and abdominal SAT are associated with elevations in diabetes and cardiovascular disease risk factors.

Methods Overweight and obese men ($n=58$) and premenopausal women ($n=49$) with elevated cardiometabolic risk underwent 3 months of diet and/or exercise induced weight-loss treatment; regional body composition assessment by magnetic resonance imaging (MRI); and cardiometabolic risk assessment, including an OGTT.

Results After control for potential confounders, reductions in VAT, abdominal SAT and LBSAT were all associated with improvements in selective cardiometabolic risk factors, including fasting glucose levels, lipid status and OGTT glucose and insulin. Independent of changes in the other AT depots, reductions in VAT and abdominal SAT, but not LBSAT, remained associated with improvement in fasting glucose levels, glucose tolerance and lipid status.

Conclusions/interpretation Among overweight and obese adults with increased cardiometabolic risk, the selective reduction of LBSAT is not associated with elevations in risk factors for diabetes and cardiovascular disease. Thus, the reduction of excess AT conveys health benefit regardless of origin.

Keywords Cardiometabolic risk · Diet · Dyslipidemia · Exercise · Lower-body fat loss · OGTT · Regional body composition · Visceral fat · Weight-loss intervention

Abbreviation

AT	adipose tissue
DEXA	dual-energy x-ray absorptiometry
LBSAT	lower-body subcutaneous adipose tissue
MRI	magnetic resonance imaging
SAT	subcutaneous adipose tissue
VAT	visceral adipose tissue
$\dot{V}O_{2\max}$	maximal rate of oxygen consumption

Introduction

Abdominal adiposity is a strong predictor of type 2 diabetes and cardiovascular disease risk, independent of total obesity [1, 2]. Specifically, visceral adipose tissue (VAT) has emerged as a powerful predictor of type 2 diabetes [3], cardiovascular disease [4] and mortality [5], independent of other fat depots. In accordance with the cross-sectional evidence, the reduction of abdominal obesity and, specifically, VAT through diet and/or exercise is associated with substantial improvements in obesity-related cardiometabolic risk factors [6, 7].

Conversely, lower-body subcutaneous adipose tissue (LBSAT) deposition may actually be protective against cardiometabolic risk [8, 9]. In line with this, several studies report that after control for abdominal AT and/or VAT, greater levels of LBSAT are associated with reduced risk of glucose intolerance, insulin resistance, dyslipidaemia and arterial stiffness [10–16]. However, extrapolation of this notion to suggest that, controlling for changes in abdominal

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adiposity, reductions in LBSAT during weight reduction may lead to deterioration in cardiometabolic profile, and thus increase the risk of type 2 diabetes and cardiovascular disease, counters current knowledge. Indeed, during negative energy balance, SAT throughout the body decreases in mass as a result of a reduction in adipocyte size [17]. This reduction in adipocyte size may lead to improved insulin sensitivity [18], reduced secretion of prothrombotic cytokines [19] and reduced plasma triacylglycerol levels, as well as decreased ectopic fat storage in the liver and VAT [20]. These observations suggest that, rather than being detrimental, reductions in LBSAT stores should actually improve cardiometabolic profile.

Nevertheless, Okura et al. report that, independent of alterations in trunk fat, reductions in leg fat are associated with increased cardiometabolic risk after 14 weeks of weight loss [21]. Unfortunately, in this study (1) trunk fat was represented by the combination of abdominal and gluteal AT—distinct AT depots that may have opposite effects on cardiometabolic risk [22]; (2) measurement of leg fat by dual-energy x-ray absorptiometry (DEXA) did not distinguish between SAT and inter-muscular AT depots, which have independent and possibly opposite effects on cardiometabolic risk [22]; (3) the analyses did not specifically adjust for changes in VAT and abdominal SAT; and (4) the sample consisted of both pre- and postmenopausal women. These limitations confound interpretation of and preclude definitive conclusions from the data reported by this previous study.

Therefore, the aim of the present study was to investigate the independent effects of reductions in VAT, and abdominal SAT and LBSAT on changes in risk factors for type 2 diabetes and cardiovascular disease in response to diet and/or exercise interventions in a sample of overweight or obese men and premenopausal women with elevated cardiometabolic risk.

Methods

Participants The present study is an analysis of previously gathered data on 58 white men and 49 premenopausal women, without overt disease, who were recruited from the general public and had participated in previously published exercise- and/or diet-induced weight loss studies at Queen's University (Kingston, ON, Canada) [7, 23–25]. Briefly, a total of 33 men and 38 women were recruited to participate in a study on the effects of diet and resistance or aerobic exercise on body composition and metabolic status [23, 24]. In this study, for each sex, participants were randomised to a diet only, diet plus resistance exercise or a diet plus aerobic exercise group (see the Interventions section

below for further assignment information). Additionally, a total of 52 men and 54 women participated in two other studies (one for each sex) comparing the effect of diet- and aerobic exercise-induced weight loss on regional body composition and metabolic status (ClinicalTrials.gov registration nos NCT00664547 and NCT00664495) [7, 25]. In these studies, for each sex, participants were randomised to a control, diet-induced weight loss, exercise-induced weight loss, or an exercise without weight loss group (see the Interventions section below for further assignment information). All participants in these prior studies had maintained a stable weight (± 2 kg) for at least 6 months prior to the study, were non-smokers who consumed an average of fewer than two alcoholic beverages per day, had a sedentary lifestyle and were not taking medications known to influence the cardiometabolic risk factors measured. All participants gave informed consent prior to participation, in accordance with the ethical guidelines set by Queen's University.

Participants in the current analysis included 58 men and 49 women from these studies who were overweight or obese ($\text{BMI} \geq 27 \text{ kg/m}^2$) and were at elevated cardiometabolic risk at baseline. Elevated cardiometabolic risk was defined by the presence of one or more of the following: impaired fasting glucose, impaired glucose tolerance, high or borderline high triacylglycerol levels, very high, high or borderline high LDL-cholesterol, low HDL-cholesterol, and high or borderline high total cholesterol, as defined according to current clinical guidelines [26, 27].

Interventions Of the 58 men, 31 were randomly assigned to a diet only (DO; $n=10$), diet plus resistance exercise (DR; $n=10$) or diet plus aerobic exercise (DA; $n=11$) programme designed to induce a daily energy deficit of 4,200–5,200 kJ for 16 weeks, described in detail elsewhere [24]. The remaining 27 men were randomly assigned to a diet ($n=13$) or exercise ($n=14$) programme designed to induce a daily energy deficit of 3,000 kJ for 12 weeks [7].

Of the 49 women, 23 were randomly assigned to a DO ($n=8$), DR ($n=8$) or DA ($n=7$) programme aimed at inducing a daily energy deficit of 4,200–5,000 kJ for 16 weeks [23]. The remaining 26 women were randomly assigned to a diet ($n=13$) or exercise ($n=13$) programme aimed at inducing a daily energy deficit of 2,100 kJ for 14 weeks [25].

Anthropometric measurements Body mass was measured to the nearest 0.1 kg on a calibrated balance. Standing height was measured to the nearest 0.1 cm using a wall-mounted stadiometer. Waist circumference was measured at the level of the last rib to the nearest 0.1 cm after a normal expiration.

Maximal rate of oxygen consumption The maximal rate of oxygen consumption ($\dot{V}O_{2\max}$) was measured by a graded treadmill test using standard open-circuit spirometry techniques (Sensor-Medics, Yorba Linda, CA, USA).

Measurement of total and regional fat and skeletal muscle by magnetic resonance imaging Whole body (41–47 equidistant images) magnetic resonance imaging (MRI) data were obtained with a General Electric 1.5 Tesla magnet, using a procedure described in detail elsewhere [24]. The MRI data were analysed using specially designed image analysis software (Tomovision, Montreal, QC, Canada) using an established protocol [24, 28].

Total AT and skeletal muscle volume were determined using all 41–47 images. The image at 5 cm below L4–L5 was used to divide the upper and lower body. VAT and abdominal SAT were calculated using the five images extending from 5 cm below, to 15 cm above L4–L5. AT and skeletal muscle volumes (l) were converted into mass units (kg) using assumed constant densities (0.92 and 1.04 kg/l, respectively) [29].

Cardiometabolic risk factors Blood samples used to determine fasting lipid and lipoprotein values were obtained in the morning after a 12–14 h overnight fast. Total cholesterol, HDL-cholesterol and triacylglycerol were measured using enzymatic methods on the Roche Modular analytical system (Roche Diagnostics, Indianapolis, IN, USA). The LDL-cholesterol concentration was subsequently determined using the Friedewald equation [30].

Before and approximately 6 days after treatment, a 2 h 75 g OGTT was administered the morning after an overnight fast. Blood samples were collected from the antecubital vein at 0, 60 and 120 min. Glucose was measured using an automated glucose analyser (YSI, Yellow Springs, OH, USA), and insulin was measured by a radioimmunoassay kit (Intermedico, Toronto, ON, Canada). The glucose and insulin AUCs were determined using a trapezoid model [31].

Statistical analyses Baseline differences in anthropometric, MRI and cardiometabolic risk factors between men and women were assessed using a Student's *t* test for independent samples. Changes in variables in response to treatment (collapsed across treatment type) were assessed using paired Student's *t* tests. Linear regression analyses were performed to determine the univariate and multivariate relationships between changes in regional fat depots (abdominal SAT, VAT and LBSAT) and cardiometabolic risk factors, controlling for the following confounders: sex, age, modality of weight-loss treatment and change in $\dot{V}O_{2\max}$. To create the most parsimonious model, non-significant confounder terms were removed from the model. All independent variables were normalised prior to

analysis. All statistical procedures were performed using SPSS 15.0 software (SPSS, Chicago, IL, USA).

Results

Adherence to the diet and exercise protocols Details of exercise and diet adherence are described in detail elsewhere [7, 23–25]. Briefly, the participant attendance rate of the exercise programmes ranged from 92 to 98% for the men and 92 to 96% for the women. Among the men, the calculated average diet-induced energy deficits among the different study groups ranged from 2,770 to 4,800 kJ/day. Among the women, the calculated average diet-induced energy deficits among the different study groups ranged from 1,670 to 5,440 kJ/day.

Comparison of baseline and post-treatment values The pre- and post-treatment values for the anthropometric, body composition, cardiometabolic risk factors, and $\dot{V}O_{2\max}$ in men and women are presented in Table 1. At baseline, the men were older and had higher values for body weight, waist circumference, total and lower-body skeletal muscle, VAT, and $\dot{V}O_{2\max}$, but lower values for total and lower-body total AT and total, lower-body and abdominal SAT ($p<0.05$). The values for all cardiometabolic risk factors were not different between sexes ($p>0.05$), with the exception of lower HDL-cholesterol levels in the men ($p<0.05$). The prevalence of the various cardiometabolic risk factors in the men and women at baseline is presented in Table 2.

Post-treatment, both the men and women showed significant reductions in weight, BMI, waist circumference, whole body, abdominal and lower-body total AT and SAT, VAT and total skeletal muscle mass, but increased $\dot{V}O_{2\max}$ ($p<0.05$). While the men also had less lower-body skeletal muscle mass post-treatment ($p<0.05$), the women showed no change from baseline ($p>0.05$). With the exception of HDL-cholesterol ($p>0.05$ in both sexes), significant improvements in all cardiometabolic risk factors were observed post-treatment in both sexes, including OGTT glucose and insulin, fasting plasma glucose and insulin, triacylglycerol and total and LDL-cholesterol levels ($p<0.05$).

Baseline associations between regional fat deposition and cardiometabolic risk factors As shown in Table 3, after controlling for sex and age, of the three depots (VAT, abdominal and lower-body SAT), only VAT was a significant positive correlate of plasma insulin, triacylglycerol, OGTT glucose ($p<0.05$) and plasma glucose ($p=0.06$) levels, but a negative correlate of HDL-cholesterol levels ($p<0.05$).

Independent of the other AT depots, VAT was a significant positive correlate of plasma glucose and insulin, OGTT

Table 1 Selected anthropometric, body composition, and cardiometabolic risk factors at baseline and post-treatment

	Men (<i>n</i> =58)		Women (<i>n</i> =49)	
	Pretreatment	Post-treatment	Pretreatment	Post-treatment
Age (years)	43.9±9.1		39.9±6.8 ^b	
Anthropometric				
Weight (kg)	101.3±12.0	91.3±11.1 ^a	88.6±13.3 ^b	80.5±12.4 ^a
BMI (kg/m ²)	32.1±3.0	28.9±2.7 ^a	33.1±4.3	30.1±4.1 ^a
Waist circumference (cm)	108.8±7.9	99.5±6.7 ^a	99.4±9.3 ^b	92.9±9.4 ^a
MRI				
Total AT (kg)	35.4±7.9	27.3±7.1 ^a	40.6±9.9 ^b	33.6±8.8 ^a
Total SAT (kg)	27.3±7.1	21.4±6.0 ^a	38.4±10.1 ^b	31.7±9.0 ^a
Total skeletal muscle (kg)	33.4±4.1	31.9±4.2 ^a	21.5±3.0 ^b	21.0±2.7 ^a
Abdominal AT (kg)	9.1±2.1	6.5±1.8 ^a	9.3±2.6	7.5±2.2 ^a
VAT (kg)	3.5±1.3	2.4±1.0 ^a	2.2±0.8 ^b	1.6±0.7 ^a
Abdominal SAT (kg)	5.2±1.7	4.0±1.4 ^a	6.9±2.2 ^b	5.7±1.9 ^a
Lower-body AT (kg)	14.7±3.7	11.7±3.3 ^a	21.3±5.8 ^b	18.0±5.1 ^a
Lower-body SAT (kg)	12.6±3.6	10.0±3.0 ^a	19.1±5.6 ^b	16.1±4.9 ^a
Lower-body skeletal muscle (kg)	18.7±2.3	17.7±2.6 ^a	12.8±2.0 ^b	12.7±1.8
Cardiometabolic risk factors				
2 h OGTT glucose (mmol/l)	30.5±9.8	27.2±8.2 ^a	29.1±6.6	26.6±5.9 ^a
2 h OGTT insulin (pmol/l)	360.9±241.7	219.3±136.0 ^a	349.5±173.3	253.8±135.5 ^a
Fasting glucose level (mmol/l)	5.6±0.7	5.1±0.8 ^a	5.4±0.6	5.1±0.5 ^a
Fasting plasma insulin level (pmol/l)	95.7±70.4	70.6±50.0 ^a	86.6±62.2	58.3±45.5 ^a
Triacylglycerol (mmol/l)	2.3±1.3	1.6±0.7 ^a	1.9±1.2	1.5±0.7 ^a
Total cholesterol (mmol/l)	5.0±1.0	4.6±0.8 ^a	5.3±0.7	4.7±0.8 ^a
HDL-cholesterol (mmol/l)	0.9±0.3	1.0±0.4	1.1±0.2 ^b	1.0±0.2
LDL-cholesterol (mmol/l)	3.4±0.7	3.1±0.7 ^a	3.3±0.7	3.0±0.7 ^a
$\dot{V}O_{2\max}$ (ml kg ⁻¹ min ⁻¹)	34.3±7.0	40.2±7.4 ^a	24.6±3.8 ^b	28.3±5.4 ^a

Data presented as the group means ± SD

^a*p*<0.05 vs baseline; ^b*p*<0.05 vs men**Table 2** Prevalence of cardiometabolic risk factors in the study sample

	Men (<i>n</i> =58)	Women (<i>n</i> =49)
Overweight	14 (24)	12 (25)
Obese	44 (76)	37 (76)
Abdominally obese	47 (81)	43 (88)
Impaired fasting glucose	25 (43)	18 (37)
Impaired glucose tolerance	10 (17)	8 (16)
High/borderline high triacylglycerol	39 (67)	23 (47)
Very high/high/borderline high LDL-cholesterol	30 (52)	23 (47)
Low HDL-cholesterol	28 (48)	16 (33)
High/borderline high total cholesterol	25 (43)	31 (63)
Overweight/obese + one risk factor	9 (16)	15 (31)
Overweight/obese + two risk factors	16 (28)	11 (22)
Overweight/obese + three or more risk factors	33 (57)	23 (47)

Data are presented as *n* (%). Overweight defined as BMI=25–29.9 kg/m²; obese defined as BMI ≥30 kg/m²; abdominally obese defined as waist circumference >102 cm and >88 cm in men and women, respectively; metabolic risk factors defined as per American Diabetes Association and National Cholesterol Education Program guidelines [26, 27]

glucose and insulin (*p*<0.05) and triacylglycerol (*p*=0.06) levels. In the same models, abdominal SAT was a significant negative correlate of HDL-cholesterol (*p*<0.05). Lastly, independent of the abdominal AT depots, greater lower-body SAT was a correlate of lower triacylglycerol and higher HDL-cholesterol levels (*p*<0.05).

Associations between changes in regional fat deposition and changes in cardiometabolic risk factors As shown in Table 4, after controlling for confounders, reductions in VAT were associated with reductions in fasting plasma glucose and OGTT glucose and insulin levels (*p*<0.05). Reductions in abdominal SAT were associated with reductions in total and LDL-cholesterol and OGTT insulin levels (*p*<0.05). Reductions in lower-body SAT were associated with reductions in OGTT insulin levels (*p*<0.05).

After further controlling for changes in abdominal and lower-body SAT, reductions in VAT remained significantly associated with reductions in fasting plasma glucose and OGTT glucose levels (*p*<0.05). Moreover, reductions in abdominal SAT remained independently associated with reductions in total and LDL-cholesterol levels (*p*<0.05). In the same models, reductions in lower-body SAT were not

Table 3 Standardised β -coefficients for associations between baseline regional AT deposition and cardiometabolic risk factors

Parameter	Glucose	Insulin	TG	Cholesterol	LDL-C	HDL-C	OGTT glucose	OGTT insulin
Model 1								
VAT	0.19 ^b	0.25 ^a	0.28 ^a	−0.07	0.00	−0.24 ^a	0.29 ^a	0.19
Abdominal SAT	0.06	0.14	0.03	0.09	−0.01	−0.05	0.11	0.13
Lower-body SAT	0.03	0.07	−0.16	0.07	−0.03	0.14	−0.01	0.09
Model 2								
VAT	0.20 ^a	0.26 ^a	0.20 ^b	−0.08	−0.01	−0.17	0.28 ^a	0.21 ^a
Abdominal SAT	0.04	0.12	0.28	0.12	0.03	−0.30 ^a	0.17	0.09
Lower-body SAT	0.04	0.04	−0.33 ^a	−0.04	−0.05	0.34 ^a	−0.08	0.06

Model 1, controlled for age and sex

Model 2, controlled as model 1 and for other regional AT depots

^a $p \leq 0.05$, ^b $p = 0.06$

HDL-C, HDL-cholesterol; LDL-C, LDL-cholesterol; TG, triacylglycerol

associated with changes in cardiometabolic risk factors ($p > 0.05$).

Discussion

The primary finding of this study is that the reduction of LBSAT consequent to weight loss was not associated with deterioration or an attenuated improvement in risk factors for type 2 diabetes and cardiovascular disease independent of changes in VAT and abdominal SAT. However, independent of changes in LBSAT, reductions in VAT and abdominal SAT were associated with improvements in cardiometabolic risk.

A number of cross-sectional studies have previously shown that, after control for abdominal AT and/or VAT, greater levels of lower-body AT, specifically SAT, are associated with reduced risk of glucose intolerance, insulin resistance, dyslipidaemia and arterial stiffness [10–16]. While we could not corroborate this finding for glucose tolerance, the results of the current report demonstrate that,

independent of VAT and abdominal SAT, greater lower-body SAT is associated with lower triacylglycerol and higher HDL-cholesterol levels. It has been reported that the lower-body (gynoid) obesity phenotype is associated with a hyperplastic expansion of the adipose organ, exemplified by numerous small adipocytes, in contrast to the few, hypertrophied adipocytes of the abdominal obesity phenotype [32, 33]. Enlarged adipocytes that are filled to capacity may predispose to elevations of plasma NEFA levels [34], possibly through poor buffering of NEFA flux in the postprandial state [8], leading to spill-over of lipid into the liver, muscle and VAT [20], and consequent insulin resistance [35, 36]. Additionally, lower-body SAT adipocytes are known to have relatively high rates of lipoprotein lipase activity (enhanced lipogenesis) but diminished rates of lipolysis [37]. Thus, it is suggested that, through the buffering of circulating lipid during periods of energy surplus, the small and sensitive subcutaneous adipocytes of the lower body could decrease cardiometabolic risk by limiting excess lipid deposition within tissues ectopic to LBSAT, all of which are associated with increased health

Table 4 Standardised β -coefficients for associations between changes in regional fat deposition and changes in cardiometabolic risk factors

Parameter	Δ Glucose	Δ Insulin	Δ TG	Δ Cholesterol	Δ LDL-C	Δ HDL-C	Δ 2 h OGTT glucose	Δ 2 h OGTT insulin
Model 1								
Δ VAT	0.21 ^a	0.12	0.09	−0.14	−0.10	−0.09	0.22 ^a	0.23 ^a
Δ Abdominal SAT	−0.04	0.04	−0.01	0.22 ^a	0.24 ^a	−0.11	0.14	0.30 ^a
Δ Lower-body SAT	−0.01	−0.01	−0.06	0.11	0.11	−0.04	0.14	0.23 ^a
Model 2								
Δ VAT	0.22 ^a	−0.13	0.10	−0.17	−0.16	−0.07	0.19 ^a	0.11
Δ Abdominal SAT	−0.08	0.07	0.01	0.23 ^a	0.24 ^a	−0.11	0.07	0.19
Δ Lower-body SAT	−0.01	0.02	−0.07	0.03	0.03	0.05	0.07	0.19

Model 1, controlled for age, sex, treatment group, and change in $\dot{V}O_{2\max}$

Model 2, controlled as model 1 and for changes in other regional AT depots

^a $p \leq 0.05$

HDL-C, HDL-cholesterol; LDL-C, LDL-cholesterol; TG, triacylglycerol

risk [9]. Indeed, clinical examples of subcutaneous adipocyte hypercellularity (i.e. multiple symmetric lipomatosis) are associated with minimal lipid accumulation in the liver, muscle and VAT, and a normal cardiometabolic profile, despite a frank obese state [38], while SAT deficiency (i.e. lipodystrophy) is associated with fat storage in the liver and muscle and an insulin-resistant state [39]. Additionally, implantation of SAT into lipodystrophic rodents has been shown to reverse ectopic fat deposition and associated cardiometabolic risk [40].

While limited lower-body SAT deposition may represent an inadequate buffering capacity of excess energy, predisposing to cardiometabolic dysregulation, our findings suggest that this cross-sectional observation should not be extrapolated to indicate that the reduction of this depot through weight loss is associated with deterioration of cardiometabolic profile. Indeed, during times of negative energy balance, AT decreases in mass because of a reduction in adipocyte size, while the number of adipocytes remains unchanged [17]. Compared with their larger counterparts, small adipocytes are more insulin sensitive [18], secrete less prothrombotic, but more antithrombotic cytokines [19], and are associated with reduced ectopic fat storage [20], while the reduction in size of subcutaneous adipocytes is associated with decreased plasma triacylglycerol levels and VAT storage [20]. Thus, counter to being detrimental, the reduction of lower-body SAT stores may actually improve the function of this tissue, thereby improving the cardiometabolic profile. Indeed, our results revealed that reductions in lower-body SAT are associated with improvement in OGTT insulin, independent of age and sex, but not changes in other fat depots.

Nonetheless, our findings contrast with those of Okura et al. [21] who documented that independent of alterations in trunk fat, reductions in leg fat (as measured by DEXA) are correlated with a worsening of LDL-cholesterol and plasma glucose levels after 14 weeks of diet and exercise, in a mixed sample of pre- and postmenopausal women [21]. A number of key differences between these two studies could explain the discrepant results. First, in the continuous analysis by Okura et al., trunk fat was represented by the combination of abdominal and gluteal AT—distinct AT depots that may have opposite effects on cardiometabolic risk [13]. Second, we distinguished between the different AT depots within the lower-body, namely, SAT and inter-muscular AT, which have independent and possibly opposite effects on cardiometabolic risk [22]. Third, unlike the analyses performed in the current study, those performed by Okura et al. did not adjust for changes in VAT or abdominal SAT. Fourth, our study included only premenopausal women, which eliminates the established confounding effects of menstrual status on regional body composition and cardiometabolic risk [41].

Consistent with prior reports [42, 43], we found that both VAT and abdominal SAT are independent correlates of cardiometabolic risk. This finding was most consistent for VAT, which was independently associated with five of eight cardiometabolic risk factors assessed in this study (fasting glucose and insulin, triacylglycerol and OGTT glucose and insulin levels). Additionally, our results indicate that reductions in VAT and abdominal SAT, controlled for changes in lower-body SAT, are independently associated with improvements in glucose tolerance and dyslipidaemia, respectively. These results are in agreement with previous studies [6, 7], and highlight the importance of decreasing abdominal obesity for reduction of obesity-related cardiometabolic risk.

Our findings are derived from a relatively homogeneous sample of sedentary, obese, middle-aged white men and women who were middle to upper class. This may limit the generalisability of the results of our study, but should not affect the internal validity. Additionally, it is now recognised that adipose tissue acts as an endocrine organ, secreting various cytokines that have numerous effects on cardiometabolic status [44]. As emerging research has noted that the secretion of specific adipokines varies according to location of AT [45], as well as the size of individual adipocytes [46], it is plausible that some of our findings may be explained by changes in depot-specific secretion of these bioactive molecules. These notions require further study.

In summary, our findings confirm that abdominal AT deposition, specifically, excess VAT, is associated with increased cardiometabolic risk, while lower-body SAT deposition may be cardiometabolically protective. However, consequent to weight loss, not only is the selective reduction of lower-body SAT not associated with a deterioration of cardiometabolic profile, it may be beneficial in a manner similar to reductions in VAT and abdominal SAT. Thus, among overweight and obese men and women, the reduction of excess AT is likely to convey health benefit, regardless of origin.

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Duality of interest The authors declare that there is no duality of interest associated with this manuscript.

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