High Body Mass Index Masks Body Composition Differences in Physically Active Versus Sedentary Participants

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Abstract

Background: Despite the benefits of aerobic exercise on body composition, runners with high body mass index (BMI) remain understudied. We examined body composition differences between sedentary insulin-resistant [obese insulin-resistant sedentary (OS-IR)], sedentary insulin-sensitive [obese insulin-sensitive sedentary (OS-IS)], and trained [obese trained (OT)] individuals with high BMI (≥ 25 kg/m²). We hypothesized that after matching for high BMI, OT individuals would have less fat mass (absolute and relative) and greater lean mass than OS-IR or OS-IS individuals.

Methods: This is a retrospective analysis of OS-IR, OS-IS, and OT participants selected for similar age, sex, and BMI. Activity was self-reported. OT participants exercised at least 30 min/day (predominantly running) for 3–5 days/week. OS-IS and OS-IR participants actively exercised <0.5 hr/week. Body composition was measured by dual X-ray absorptiometry.

Results: Thirty-three participants were recruited [$n = 11$ /group, mean age 31.7 years (standard error): (0.9)], 7 females/group, overall BMI [31.6 kg/m² (0.7)]. Insulin resistance, quantified by the homeostatic model assessment for insulin resistance, was higher in the OS-IR [3.3 (0.2)] than the OS-IS [0.9 (0.2): $P < 0.0001$] or OT [1.6 (0.2): $P < 0.0001$] groups. We found the following: (i) Compared to the OS-IR group, the OT group had lower region-specific fat mass as measured by percent fat (trunk) or absolute fat mass (trunk, android region, and abdominal visceral region). (ii) OT and OS-IS groups had similar body composition. (iii) Total fat mass and percent body fat correlated with BMI, (iv) Visceral fat correlated with BMI ($r = 0.80$, $P = 0.003$) only in the OS-IR ($P = 0.03$ for BMI $\times$ group interaction).

Conclusions: Using BMI to classify obesity masks body composition differences in high BMI individuals discrepant for insulin resistance and physical activity status.

Keywords: obesity, exercise, body composition, sedentary

Introduction

THE INCREASING RATES of obesity and sedentary behavior in Americans parallel the increasing rates of incident diabetes.^{1,2} Obesity is defined by body mass index (BMI) ≥ 30 . BMI has been used to define obesity because of its simplicity, availability, and correlation with body fat.^{3,4} BMI, however, is limited in its ability to distinguish between

lean mass and fat mass.⁵ Hence, BMI is suggested as a screening tool, with further evaluation for adiposity-related complications recommended.⁶

Clinically, obesity is disassociated from adiposity-related complications especially for individuals who are obese but metabolically healthy [metabolically healthy obesity (MHO)]⁷ or those who are fit.⁸ In particular, high cardiorespiratory fitness, fitness documented by objective exercise testing, has

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many known benefits even after adjusting for BMI, including lower mortality rates,^{8,9} incident prediabetes,¹⁰ and incident diabetes.¹⁰ Physical activity is not equivalent to cardiorespiratory fitness, as genetics can also significantly influence cardiorespiratory fitness.^{11,12} Since higher physical activity is linked to higher levels of cardiorespiratory fitness,¹³ there is increased interest in the benefits of aerobic training particularly in the obese population.

Aerobic training has established benefits on body composition. Chronic aerobic training (3–9 months) of sedentary obese subjects reduces fat mass and abdominal visceral fat.^{14–16} These studies, however, focused on training subjects from a sedentary baseline.^{14–16} Most studies examining body composition in high BMI athletes involve sports, such as football, where aerobic exercise training is not the primary focus.^{17,18} In women, it has been observed that running is generally associated with lower BMI more than other sports.¹⁹ A knowledge gap remains about difference in body composition between individuals matched for BMI yet discrepant in physical activity. In particular, we were interested in body composition differences between extremes of clinical phenotype [obese insulin-resistant sedentary (OS-IR) vs. obese trained (OT)] given high BMI (BMI ≥ 30 kg/m²) with an intermediate group [obese insulin-sensitive sedentary (OS-IS)] for further comparison matched for age, sex, and BMI. We hypothesized that after matching for high BMI, OT individuals would have less fat mass (absolute and relative) and greater lean mass than OS-IR or OS-IS individuals.

Subjects and Methods

Subject selection

This is a retrospective analysis of obese (BMI ≥ 30 kg/m²) participants previously recruited for TrainMeUpMN. TrainMeUpMN is an ongoing study examining the effects of training in overweight, sedentary, insulin-resistant participants. For the parent TrainMeUpMN study, we recruited overweight participants from the Minneapolis/St. Paul metropolitan area (i) self-reported runners with BMI ≥ 25 (OT); (ii) sedentary, overweight subjects (BMI ≥ 25 kg/m²).

The inclusion criterion for the OT group was that they self-reported regular running exercise (at least 30 min of exercise per day and at least 3–5 sessions/week) and were capable of running for 90 min continuously, as the parent TrainMeUp study required these participants to perform a supervised run for 90 min. We recruited sedentary subjects who self-reported <30 min of active exercise (excluding walking) per week. All subjects were required to be between 18 and 40 years old to exclude the potential influence of sarcopenia on the results.²⁰ Exclusion criteria included self-reported clinically significant medical issues (*e.g.*, diabetes, cardiovascular disease, uncontrolled pulmonary disease), abnormal electrocardiogram (EKG) indicating cardiac disease (study EKG performed at rest before VO₂max), and current pregnancy (a screening pregnancy test was performed).

Insulin resistance in all participants for the retrospective analysis was quantified from fasting glucose and insulin by the homeostatic model assessment for insulin resistance [HOMA-IR: (fasting serum insulin (uU/mL) $\times$ fasting glucose (mmol/L))/22.5].^{21,22} The sedentary subjects were considered insulin resistant (OS-IR) if their HOMA-IR ≥ 2.5 .^{21,22} All recruited subjects (OT, OS-IS, and OS-IR) had their body

composition measured by dual X-ray absorptiometry (DXA). VO₂max was measured in the OT and OS-IR groups to document their cardiorespiratory fitness. However, as identified OS-IS subjects were not eligible for continuation with the TrainMeUpMN, they did not have their VO₂max measured. The University of Minnesota's Institutional Review Board approved the study protocol and methods. All participants provided written informed consent before study participation.

For the current retrospective analysis, we randomly selected obese (BMI ≥ 30 kg/m²) OT, OS-IS, and OS-IR participants with similar age (± 2.5 years), BMI (± 2), and sex. Since we had 11 OT subjects for analysis, for the OS-IS group, we selected from a pool of 81 potential participants from the parent study and for the OS-IR group, we selected from a pool of 59 participants from the parent study. We then compared their body composition, as measured by DXA, between the three groups.

Establishment of baseline cardiorespiratory fitness by VO₂max

Cardiorespiratory fitness, as quantified by VO₂max, was measured at the University of Minnesota Laboratory of Integrative Human Physiology (July 2014 to March 2016) and the Masonic Clinical Research Unit (March 2016 to April 2017). Participants were required to be fasting for 2 hr before testing. Height and weight were measured by a portable stadiometer and digital scale without shoes and wearing light clothing. A 12-lead EKG was obtained and reviewed by a licensed medical professional (physician or physician's assistant) before exercise testing. Resting blood pressure and heart rate were measured using an automatic blood pressure monitor (Colin Press-Mate BP8800C; Colin Medical Instruments Corp., San Antonio, TX), after the subject had been seated quietly for at least 5 min.

Subjects were asked to refrain from intentional exercise for 48 hr before VO₂max testing. A resting EKG was performed before the VO₂ max and reviewed by study personnel. VO₂max was evaluated by indirect calorimetry using one of two metabolic carts, either at the Laboratory of Integrative Human Physiology (Ultima Medgraphics CPX-D; Medical Graphics Corporation, St. Paul, MN) or Masonic Clinical Research Unit [ParvoMedics TrueOne 2400-OUSW 4.3.4 (20160202), Sandy, UT]. A true VO₂max was considered to be attained if at least one of the following three conditions were met: (i) maximal heart rate $>90\%$ of aged-predicted maximum (220-age), (ii) a plateau in oxygen consumption (<200 mL/min change in oxygen consumption), or (iii) respiratory exchange ratio ≥ 1.10 .²³ Testing for OT subjects was done using the Bruce protocol.²⁴ As the OS-IR subjects were sedentary, testing was done using the modified Bruce protocol.²⁵ During VO₂max testing, each subject wore a mask to collect inspired and expired air. A Polar Heart Rate monitor (Polar Electro, Inc., Lake Success, NY) was used to measure heart rate.²⁶ The highest value in the final 30 sec of exercise testing was considered the VO₂max.²⁷

Body composition assessment

Lean mass, bone mineral content, and fat mass were measured by DXA using a GE Healthcare Lunar iDXA (GE Healthcare Lunar, Madison, WI) with enCORE software (version 16.2). The DXA scan was performed in the fasted state

during a separate visit within 1 week from the VO_2max testing. Regional measures of trunk, android, gynoid, abdominal, subcutaneous, and abdominal visceral adipose tissue were also made. Trunk fat mass included fat mass from the chest, abdomen, and pelvis region. The android region was defined as the trunk area approximately between the ribs and the pelvis. The upper boundary was set at 20% of the distance between the iliac crest and the base of the skull. The lower boundary was the top of the iliac crest. The gynoid region included the hips and upper thighs, overlapping both the leg and trunk regions. Visceral [visceral adipose tissue (VAT)] and subcutaneous fat were calculated from the android region. Subcutaneous fat in the android region was determined by examining the X-ray attenuation between the edge of the body and the outer edge of the abdominal cavity²⁸ and visceral fat was calculated by subtracting android subcutaneous fat mass from android total fat mass, as previously described.²⁸ Abdominal VAT was calculated by subtracting subcutaneous fat mass from the android region fat mass.²⁸

Statistical analysis

Descriptive data are expressed as mean and standard error (SE) for continuous measures and N (%) for categorical measures. Comparisons between the OS-IR, OS-IS, and OT groups were performed using analysis of variance with Tukey adjustment for multiple comparisons. The model included BMI, group, and interaction of BMI and group. If the interaction was not significant, it was removed from the model. Correlations between variables were assessed using the Pearson correlation coefficient (r). Statistical significance was defined as $P \leq 0.05$ due to the small sample size and the exploratory nature of this study. Analyses were performed using SAS 9.3 (SAS Institute, Cary, NC).

Results

A total of 33 subjects were recruited ($n=11$ in each group). The subject characteristics are reported in Table 1 [mean (SE)]. Per study design, the OS-IR, OS-IS, and OT groups did not differ significantly on sex, age, or BMI. They

also did not differ significantly according to systolic blood pressure, diastolic blood pressure, or resting heart rate. The sedentary group did not differ in their duration of intentional walking per day [(mean $\pm$ SE) OS-IR: 5.9 (2.2) min/day vs. OS-IS: 18 (8.7) min/day, $P=0.19$]. VO_2max was significantly higher in the OT versus OS-IR group [42.5 (2.4) mL/kg/min vs. 26.7 (1.9) mL/kg/min $P=0.0001$]. The OT group had the highest high-density lipoprotein levels, differing significantly from the OS-IR group ($P=0.0012$) and trending toward significance ($P=0.058$) compared to the OS-IS group. HOMA-IR was highest in the OS-IR group, consistent with insulin resistance. This was significant compared with the OT group ($P<0.0001$) and OS-IS group ($P<0.0001$). HOMA-IR did not differ significantly between the OT and OS-IS groups ($P=0.0816$); all participants in these groups were within the range for insulin sensitivity observed in normal controls.^{21,22}

Fat mass

Body fat is reported in Fig. 1A as a percentage of region-specific tissue total and in Fig. 1B and C as absolute fat mass. Although BMI and overall percent body fat did not differ significantly between groups, percent body fat of the trunk was significantly lower in the OT group [35.0% (3.0), $P=0.0101$] than the OS-IR group [47.4% (1.7)]. Absolute fat mass (Fig. 1B, C) was significantly lower in the OT group than the OS-IR group specifically in these regions: trunk, VAT, and android. The OS-IS and OT groups did not differ significantly in percent body fat or total fat mass in any region (arms, legs, trunk, VAT, android, or gynoid).

BMI correlated with body fat as measured by percent body fat ($r=0.59$ combining the three groups, $P=0.0003$) or by total fat mass ($r=0.83$ combining the three groups, $P \leq 0.0001$). The groups did not differ significantly in these associations. Visceral fat correlated with BMI ($r=0.39$ combining the three groups, $P=0.023$), which was significant for OS-IR ($r=0.80$, $P=0.003$) but not for OS-IS ($r=-0.12$, $P=0.72$) or OT ($r=0.19$, $P=0.58$; $P=0.03$ for the BMI $\times$ group interaction).

TABLE 1. SUBJECT CHARACTERISTICS

Mean (SE)	OS-IR (n=11)	OS-IS (n=11)	OT (n=11)	OS-IR vs. OS-IS	OS-IR vs. OT	OS-IS vs. OT
Female (n, %)	7 (64%)	7 (64%)	7 (64%)			
Age (years)	32.3 (1.8)	30.9 (1.6)	32.0 (1.6)	0.83	0.99	0.88
BMI (kg/m^2)	33.5 (1.0)	30.7(1.0)	30.5(1.5)	0.22	0.19	0.99
SBP (mmHg)	122(2)	123 (3)	128 (7)	0.99	0.55	0.62
DBP (mmHg)	85(9)	76 (2)	74 (3)	0.48	0.32	0.95
Resting pulse (bpm)	72 (3)	65 (3)	66 (3)	0.27	0.34	0.99
Self-report intentional walking per day (min)	5.9 (2.2)	18 (8.7)		0.19		
HDL (mg/dL)	41 (3)	47 (3)	57 (3)	0.28	0.0012	0.0577
TG (mg/dL)	149 (27)	82 (9)	91 (17)	0.0467	0.0958	0.94
LDL (mg/dL)	96 (10)	85 (8)	85 (8)	0.67	0.65	0.99
Fasting glucose (mg/dL)	93 (3)	75 (3)	84 (3)	0.0005	0.0814	0.11
Fasting insulin (mU/L)	14.5 (1.4)	4.8 (0.8)	7.4 (0.9)	<0.0001	0.0001	0.21
HOMA-IR	3.3 (0.2)	0.9 (0.2)	1.6 (0.2)	<0.0001	<0.0001	0.0819
VO_2max (mL/kg/min)	26.7 (1.9)	^a	42.5 (2.4)		0.0001	

^a VO_2max not available.

OS-IR, obese insulin-resistant sedentary; OS-IS, obese insulin-sensitive sedentary; OT, obese trained; SE, standard error; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; HDL, high density lipoprotein; TG, triglyceride; LDL, low density lipoprotein; HOMA-IR, homeostatic model assessment for insulin resistance.

FIG. 1. Comparing body fat content between OS-IR, OS-IS, and OT groups. Body fat mass was measured either by percent body fat (A) or absolute fat mass (B, C). *Indicates significant differences ($P < 0.05$) compared with the OS-IR group. OS-IR, obese insulin-resistant sedentary; OS-IS, obese insulin-sensitive sedentary; OT, obese trained.

Bone mineral content

Bone mineral content is reported as absolute mass (Fig. 2). The groups did not differ significantly in bone mineral content.

Lean mass

Lean mass is reported as absolute mass (Fig. 3). The groups did not differ significantly in lean mass.

Discussion

This study examined whether body composition differed between high BMI populations who are discrepant in their insulin sensitivity or training status. Our key findings include the following: (i) The OT group had lower region-

specific fat mass than the OS-IR group as measured by percent regional fat (Trunk) or absolute fat mass (trunk, android region, abdominal visceral region). (ii) The OT and OS-IS groups had no significant differences in body composition. (iii) Body fat as measured by either percent body fat or total fat mass correlated with BMI. (iv) Visceral fat correlated with BMI in the OS-IR but not the OS-IS or OT groups ($P = 0.03$ for the BMI $\times$ group interaction). These findings support the limitations of BMI in predicting body composition especially in fit, high BMI individuals.

There has been extensive interest in the clinical significance of high BMI. Obesity (BMI ≥ 30) is generally associated with adverse cardiometabolic risk factors, such as diabetes, hypertension, or hyperlipidemia. In the setting of "MHO," which is representative of our OS-IS participants, high BMI is not associated with any adverse cardiometabolic risk factors.⁷ Although the prevalence of MHO is estimated at 10%–25%,⁷ the MHO state may be temporary. Appleton et al. found that $\sim 1/3$ of people who were initially classified as MHO [$n = 281$, mean age 42.3 (0.7)] no longer fit the definition of MHO over 8 years of follow-up.²⁹ In addition, the MHO state may not be entirely benign, depending on follow-up duration. For mortality outcomes, the MHO population [hazard ratio (HR) 0.91, 95% confidence interval (CI) 0.64–1.29] have fewer events over short-term follow-up (up to 7 years) than their metabolically unhealthy obese counterparts (HR 1.79, 95% CI 1.47–2.17) and were similar to their referent metabolically healthy normal weight counterparts.³⁰ With longer follow-up (8 to >10 years), the MHO group trended toward a higher risk for mortality or cardiovascular (CV) events (relative risk [RR] 1.24; 95% CI 1.02–1.55, $P = 0.08$)³¹ and higher risk of developing diabetes (odds ratio: 2.09, 95% CI 0.87–5.03, $P = 0.09$)²⁹ than their metabolically healthy normal weight counterparts.

Another concept similar to MHO is "fat and fit." High cardiorespiratory fitness has many established benefits, including lower mortality rates,^{8,9} incident prediabetes,¹⁰ and incident diabetes¹⁰ even after adjusting for BMI. Chronic aerobic training of sedentary individuals (3–9 months) reduces fat mass, especially abdominal visceral fat^{14,15} and waist circumference.^{14,16} This study adds to the literature by examining high BMI runners. These runners are capable of running for 90 min [mean $\text{VO}_{2\text{max}}$: 42.5 (8.0) mL/kg/min], and have higher cardiorespiratory fitness well above post-training measures from overweight/obese sedentary participants (post-training $\text{VO}_{2\text{max}}$: 16–28 mL/kg/min).^{13,32} We found a strong correlation between BMI and fat mass (0.59–0.83), regardless of training status. This is consistent with previous body composition studies in athletes; BMI is correlated with body fat percentage (0.5–0.9), although the strength of the correlation depended on sex and sport.^{19,18} Although in this study high BMI was correlated with fat mass in all groups, fat mass distribution was influenced by training and metabolic status. Specifically, in the OS-IR group, abdominal visceral fat was higher and significantly correlated with BMI. The lower abdominal visceral fat in high BMI runners is not surprising. Previously, chronic aerobic training has been shown to reduce abdominal visceral fat.^{14,15} The lower abdominal visceral fat in the OS-IS group may be related to differential partitioning between subcutaneous and visceral fat.

We did not find any significant differences in bone mineral content or lean mass between the OS-IR, OS-IS, and OT

FIG. 2. Comparing bone mineral content between OS-IR, OS-IS, and OT groups. There was no significant difference between the groups.

participants. Several explanations are possible. We recruited young adults (age 18–40) to avoid the effects of sarcopenia²⁰ and menopause-related changes in body composition,³³ which could dilute differences between groups. The high cardiorespiratory fitness level of the high BMI runners may be a factor. Although our high BMI runners had a higher $\text{VO}_{2\text{max}}$ than their sedentary counterparts and could run for 90 min continuously, the high BMI runners had lower $\text{VO}_{2\text{max}}$ [42.5 (8.0) mL/kg/min] than previously studied normal weight runners [$\text{VO}_{2\text{max}}$: 49.2 (1.8) mL/kg/min].³⁴ Lastly, bone mineral content and lean mass may be less related to cardiorespiratory fitness and more related to muscle strength. Previous literature reported that neither bone mineral content nor lean mass was associated with performance of a 12 min run.³⁵ Instead, these measures were associated with muscle strength (standing long jump distance, sit-ups, push-ups, pull-ups, and back extensions).³⁵

This article has several clinical implications. BMI is commonly used to classify people according to obesity due to its convenience, low cost, and general association with fat mass. In support of this, our findings show a significant correlation between body fat and BMI, regardless of group. However, our findings also highlight the potential limitations of BMI in high BMI populations who are aerobically fit or insulin sensitive. For instance, visceral fat correlated with BMI only in the OS-

IR population, not the OT or OS-IS population. Also, $\text{VO}_{2\text{max}}$ was inversely correlated with body fat mass, which is supported by previous work.³⁵ Therefore, high cardiorespiratory fitness level is associated with less body fat despite similar BMI level. Lastly, body composition did not differ significantly between the OS-IS and OT groups. Because the metabolic health of the OT participants is in the context of current training, the response of body composition to detraining in this population may provide critical insights into the metabolic benefits of exercise training.

Our article has several strengths. We matched participants for high BMI, sex, and age and in particular, we recruited a unique population—high BMI participants able to run for 90 min in one episode. The study's primary limitation is the small sample size ($n=11/\text{group}$), which limits sex-specific analysis. It has been previously observed that sex-specific differences in body composition exist even within same-sport athletes.³⁶ We matched the sex distribution across groups to address this potential limitation. As this was a retrospective analysis of recruited participants, we acknowledge that a significant study limitation is the unavailability of the $\text{VO}_{2\text{max}}$ measurement in the OS-IS group. The primary role of the $\text{VO}_{2\text{max}}$ measurement, however, was to quantify self-reported physical activity. For the OT group, we required that they self-reported the ability to run 90 min continuously. For

FIG. 3. Comparing lean mass between OS-IR, OS-IS, and OT groups. There was no significant difference between the groups.

the sedentary group, regardless of insulin resistance status, we required that they self-reported less than one half hour per week of active exercise. As previously described in Table 1, the sedentary groups (OS-IR and OS-IS) did not differ in their self-reported intentional walking per day, suggesting similar levels of sedentary behavior. Since we used the same self-report criteria for the OS-IS and OS-IR groups, we anticipate that the VO₂max levels would be similar. The overall theme, regardless, remains the same, recruitment of high BMI participants with discrepant levels of physical activity. Lastly, we acknowledge that our study focused on younger adults, which limits applicability to an older population who would be at higher risk for metabolic abnormalities. Physical activity, as documented by accelerometry or self-report, declines with age, with only ~6.5%–8% of the population ≥50 years old reporting moderate-vigorous physical activity ≥150 min/week as measured by accelerometry.³⁷ Therefore, recruitment of the OT group would be challenging in an older population and the novel comparison between the high BMI participants discrepant for physical activity would not be possible.

Using BMI to classify obesity masks body composition differences in high BMI participants who are discrepant for insulin resistance and physical activity status.

Authors' Contributions

T.A.B., Q.W., and L.S.C.: conception and design of the experiments. A.S., T.A.B., A.E.B., A.A., Q.W., A.S., D.R.D., and L.S.C.: collection, analysis, and interpretation of data. T.A.B., A.E.B., A.A., Q.W., J.S.H., A.S., D.R.D., and L.S.C.: drafting and revising the article. All authors have read and approved the final submission.

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Author Disclosure Statement

T.A.B. and D.R.D. are co-founders of Dexalytics, a company that relates body composition to athletic performance. There is no scientific overlap or scientific conflict of interest with this study. No competing financial interests exist for the other authors.

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