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Influence of Segmental Body Composition and Adiposity Hormones on Resting Metabolic Rate and Substrate Utilization in Overweight and Obese Adults

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Abstract

Purpose—Low resting metabolic rate (RMR) and high carbohydrate reliance at rest are associated with weight gain, but are highly variable in obese individuals. This study determined the relationship of total and segmental body composition and adiposity hormones with RMR and respiratory exchange ratio (RER) in overweight and obese adults.

Methods—In 49 men (n=23) and premenopausal women (n=26) (Mean $\pm$ SD; Age = 35.0 $\pm$ 8.9 yrs; body mass index [BMI] = 33.6 $\pm$ 5.2 kg·m⁻²; percent body fat [%fat] = 40.0 $\pm$ 8.0%), RMR and RER were evaluated using indirect calorimetry. Total and segmental body composition (fat mass [FM], percent fat [%fat], lean mass [LM], visceral adipose tissue [VAT]), were estimated using dual-energy x-ray absorptiometry. Fasted blood and saliva samples were analyzed for insulin, leptin, estradiol, and cortisol.

Results—In men (M) and women (W), RMR significantly correlated ($p < 0.05$) with FM (M: $R = 0.535$; W: $R = 0.784$) and LM (M: $R = 0.645$; W: $R = 0.867$). Of the segmental measures, trunk LM (M: $R = 0.593$; W: $R = 0.879$; $p < 0.05$) and leg LM (M: $R = 0.664$; W: $R = 0.821$; $p < 0.05$) had the strongest correlations with RMR. In men, but not women, RER significantly correlated with FM ($R = 0.449$; $p = 0.032$), trunk FM ($R = 0.501$; $p = 0.015$), and VAT ($R = 0.456$; $p = 0.029$). In men, RMR positively correlated with cortisol ($R = 0.430$, $p = 0.040$) and estradiol ($R = 0.649$, $p = 0.001$) and RER positively correlated with insulin ($R = 0.525$, $p = 0.010$). In women, RMR positively correlated with insulin ($R = 0.570$, $p = 0.006$), but RER was not significantly correlated with hormones ($p > 0.05$).

Conclusions—Segmental evaluation of body composition, specifically in the lower extremities and abdomen, may be an effective and efficient way to evaluate metabolic status. Sex-specific evaluations are also imperative.

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Conflict of Interest:

The authors declare that they have no conflict of interest.

Key Terms

Lean mass; Visceral Fat; Sex; Metabolism; Leptin; Insulin

Introduction

Metabolic rate and substrate utilization are important factors in maintaining energy balance [1]. Low resting metabolic rate and increased reliance on carbohydrate for energy at rest are both associated with increased weight and fat mass (FM) [1,2]. However, both metabolic rate and substrate utilization are highly variable in obese individuals [3,1]. Individual variability in resting metabolic rate (RMR) is largely attributed to differences in body composition, particularly with respect to lean mass (LM) [4,5]. However, especially in overweight and obese individuals, excess FM has a significant impact on metabolic function, both directly, through altered metabolic rate and substrate oxidation, and indirectly, through chronic changes in hormonal concentrations [6–9].

In a normal weight individual, FM has minimal metabolic activity, accounting for less than 5% of total RMR [10]. However, in overweight and obese individuals, FM has a greater metabolic impact [11,12]. In women with up to 40% body fat, FM was previously associated with an increased metabolic rate, attributable to increased body mass [7]. In contrast, in women with greater than 40% body fat, FM was associated with a significant decrease in metabolic rate [7]. Visceral fat, specifically, has been shown to be more metabolically active than subcutaneous fat and is highly associated with insulin resistance, reduced resting fat oxidation, and poor metabolic flexibility [13–15]. Visceral fat is also associated with higher insulin and cortisol levels, which are important hormones in glucose metabolism [16,17]. Alternatively, subcutaneous fat is associated with higher leptin and estradiol levels, which are associated with greater fat oxidation [16], but the relationship between adiposity-associated hormones and metabolic rate has not been thoroughly investigated. Evaluation of fat distribution and hormonal concentrations are especially important in establishing sex-specific evaluations of metabolic status [18]. Men typically have an android distribution of body fat, with greater visceral fat, while women tend to have a gynoid distribution, with greater subcutaneous fat [18]. Visceral fat in women, however, is consistently associated with metabolic dysfunction and impaired substrate oxidation [18–20]. Evaluation of fat distribution, rather than total body fat, may be an important consideration when evaluating metabolic status.

The importance of LM is less often addressed in the context of obesity [21]. Lean mass, which includes both skeletal muscle and organ tissue, accounts for 20–30% and 60–70% of RMR, respectively [10]. Muscle mass specifically is a primary location for substrate oxidation and is associated with improved health status, including improved glucose and insulin regulation [21–23]. Obese individuals often have greater LM than normal weight individuals, but the functionality of that LM, in terms of contribution to metabolic function, is unclear [11]. Trunk LM, an indirect representation of organ tissue, has previously been shown to be a stronger predictor of RMR than peripheral LM in normal weight individuals and overweight postmenopausal women [24,25]. In contrast, peripheral muscle mass, which

is important in maintaining functionality, is highly associated with positive indicators of metabolic health [26–29]. Thigh muscle size has previously been shown to be negatively associated with mortality risk in both normal weight and overweight elderly populations (66–96 years) [28]. In men, muscle mass, specifically in the lower limbs, was inversely associated with visceral fat [27], but more research on the relationship between LM and metabolic function in women is needed [22,19].

Muscle mass is important in the maintenance of strength, functionality, and improved measures of health and quality of life [28,22,23,21]. Weight loss often results in losses in FM and LM, accompanied by a significant decrease in metabolic rate which may increase risk of weight regain [30]. Skeletal muscle is the most easily manipulated contributor to resting metabolic rate [10] but, the relationship between body composition, specifically lean mass, and metabolic function, is still unclear. Therefore, the purpose of this study was to determine the relationship of total body and segmental body composition with RMR and respiratory exchange ratio (RER) in overweight and obese adults. A secondary purpose was to evaluate the association of adiposity-associated hormones with metabolic rate and substrate utilization.

Methods

Subjects

Sixty-four individuals, out of 114 initially contacted, qualified for in-person qualification review. Forty-nine individuals (males = 23; females = 26) qualified for participation (Mean $\pm$ standard deviation [SD]; Age = 35.0 ± 8.9 yrs; body mass index [BMI] = 33.6 ± 5.2 kg·m⁻²; percent body fat [%fat] = $40.2 \pm 8.0\%$; Ethnicity: White = 32; Black = 13; Hispanic = 2; Asian = 2). All subjects were considered overweight or obese (BMI: women > 25 kg·m⁻²; men > 27 kg·m⁻²; and/or percent body fat > 25%) and healthy, self-reporting no history of metabolic disease. Women were premenopausal, reporting consistent menstruation for three months prior to enrollment. All subjects were weight stable (± 4.5 kg) and had not made significant changes in their macronutrient or caloric intake for three months prior. Subjects were not consuming any dietary supplements that may have influenced metabolism eight months prior to enrollment and were asked to abstain from smoking, caffeine, and alcohol at least eight hours prior to testing. Subject characteristics are presented in Table 1. More detailed descriptions of recruitment and physiological characteristics of this population have previously been described [31].

Experimental Design

All subjects completed one enrollment visit followed by two testing visits. To account for influences of food intake on substrate utilization, a baseline dietary analysis and interpretation of a 4-day dietary log (two weekdays and two weekend days completed prior to the enrollment visit), was completed for each subject. This dietary log was also used to provide subjects with basic dietary recommendations and standardize potential changes in dietary habits that may occur at the beginning of a research trial [32]. A two-week run-in period prior to testing was followed by a brief education session providing standardized dietary information based off the Harvard Healthy Eating Plate [33]. This run-in phase

allowed for any dietary changes to normalization before testing [32]. A 24 hour diet log was completed and analyzed to ensure normalization. Resting metabolic rate, RER, body composition, and blood and saliva samples were completed in the morning following an eight-hour fast. Respiratory exchange ratio during exercise (RER_{ex}) was measured during a steady-state cardiorespiratory test, and used to assess metabolic flexibility. The steady-state cardiorespiratory test was completed an average of 24 hours following resting measures (range = 0–72 hours post) and at least four hours fasted. Informed consent was obtained from all individual participants included in the study. All procedures were performed in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Resting Metabolic Rate and Respiratory Exchange Ratio

Indirect calorimetry with a ventilated hood (TrueOne 2400® Canopy System, ParvoMedics, Inc., Sandy, UT) was used to determine RMR and RER. While lying supine, the ventilated hood was placed over the head and the canopy was tucked around the torso to minimize air penetration. Subjects were asked to relax, but remain awake for the 30-minute duration of the test. Dilution rate was adjusted during the first five minutes of the test so the fraction of expired carbon dioxide was between 1.0 and 1.2%. This portion of the test was excluded to allow breathing and dilution rate to normalize; RMR and RER were averaged over the remaining 25 minutes. Test-retest reliability from our lab produced a RMR intraclass correlation coefficient (ICC) of 0.94, standard error of the measurement (SEM) of 125.6 kcal-day⁻², minimum difference (MD) of 244.3 kcal-day⁻², and coefficient of variation of 5.36%, and a RER ICC of 0.83, SEM of 0.03 arbitrary units (a.u.), and MD of 0.05 a.u.

Sub-maximal Respiratory Exchange Ratio

Respiratory exchange ratio during exercise was evaluated using indirect calorimetry (TrueMax 2400®, Parvo Medics, Salt Lake City, UT) during a submaximal steady-state cardiorespiratory test as previously described by Withers and Gore [34] and Wingfield et al. [35]. After a three-minute warm-up on a cycle ergometer (Lode, Gronigen, The Netherlands) at a self-selected speed and workload of 20 Watts (W), workload was manually increased until heart rate (HR) correlated to 50–60% heart rate reserve (HRR). Once HR was within five beats per minute of the target HRR, subjects continued to exercise for 20 minutes. Respiratory gases were analyzed breath-by-breath via open-circuit spirometry and RER_{ex} was averaged over the 20-minute steady-state portion of the test. Heart rate reserve was calculated using the Karvonen formula ($\text{HRR} = [\text{HR}_{\text{max}} - \text{HR}_{\text{rest}}] \times \% \text{intensity} + \text{HR}_{\text{rest}}$) where HR_{max} was age predicted maximal HR ($\text{HR}_{\text{max}} = 220 - \text{age}$) and HR_{rest} was the lowest HR achieved during the resting metabolic rate test. To assess metabolic flexibility, change in respiratory exchange ratio (RER) was calculated as the difference between RER_{ex} and resting RER.

Body Composition

Total body (FM, %fat, LM) and segmental body composition (arm LM, leg LM, trunk LM, arm FM, leg FM, trunk FM, visceral adipose tissue [VAT]) were estimated from a dual-energy X-ray absorptiometry total body scan (DEXA; GE Lunar iDXA, GE Medical

Systems Ultrasound & Primary Care Diagnostics, Madison, WI, USA) (Figure 1). All scans were performed by a trained DEXA technician and analyzed using default software (enCORE Software Version 16). All subjects were positioned in the center of the scanning table with head at the top, hands at the sides with palms facing the body, and as much separation between the limbs as possible without exceeding the scanning parameter. In accordance with manufacturer guidelines, subjects who were wider than the scanning parameter (n=6) were shifted so that the full right side of the body was within the scanning parameter; left limbs were then estimated from the right limbs per manufacturer guidelines. Left and right arm region-of-interest (ROI) borders bisected the glenohumeral joint at the point of the coracoid process, separating the arms from the trunk. For the left and right leg ROIs, the bottom of the pelvic triangle was raised until the sides of the triangle touched the ischial tuberosity, bisecting the femoral heads and separating the legs from the trunk. Visceral fat was quantified from the pre-defined android ROI set by DEXA software. This region is defined as the region located between the top of the iliac crest and 20% of the distance between the iliac crest and the base of the skull (Figure 1B). The DEXA VAT algorithm then uses x-ray attenuation to estimate the quantity of subcutaneous fat which is subtracted from the total amount of fat in the android region to quantify VAT [36]. Subjects wore lightweight athletic type clothing, removing all metal and heavy plastic items that may disrupt the measure. Test-retest reliability for DEXA measurements from our lab are as follows: FM ICC of 0.998, SEM of 0.462 kg, and MD of 0.905 kg; a %fat ICC of 0.995, SEM of 0.807%, and MD of 1.582%; a LM ICC of 0.998, SEM of 0.806 kg, and MD of 1.580 kg; and a VAT ICC of 0.977, SEM of 0.112 kg, and MD of 0.220 kg.

Hormone Concentrations

A four milliliter sample of blood from the antecubital region of the arm was analyzed for insulin and leptin concentrations. A 1.0–2.0 ml saliva sample, obtained via passive drool, was analyzed for estradiol and cortisol concentrations. Subjects were asked to avoid undergoing dental work 48 hours prior, brushing their teeth 45 minutes prior, and rinsed their mouth immediately upon arrival for testing to avoid sample contamination. All samples were analyzed by the Biobehavioral Lab (Chapel Hill, NC) using commercially available enzymatic assays. Saliva samples were kept frozen at –20°C until analysis. For all assays, the coefficient of variation was below 15%. Mean data for all hormones has previously been reported [31].

Dietary Analysis

All dietary food logs (four-day and 24-hour) were analyzed for average calorie (CAL), carbohydrate (CHO), fat (FAT), and protein (PRO) intake using nutrition analysis software (The Food Processor, version 10.12.0, Esha Research, Salem, OR, USA).

Statistical Analysis

Baseline differences between males and females were evaluated with a t-test. Due to physiological differences found between men and women, all further statistical analyses were performed separately for men and women. Relationships between RMR, RER, RER, and total and segmental body composition variables, as well as adiposity-associated hormones, were evaluated using Pearson product-moment correlations. As diet is a known

confounding variable when evaluating RER, relationships with RER and RER were also evaluated using separate partial correlations controlling for average CHO, FAT, and PRO intake, entered all at once. All analyses were completed using SPSS (Version 21, IBM, Armonk, NY, USA) and an alpha level of 0.05 was considered significant.

Results

Resting Metabolic Rate

Resting metabolic rate was significantly positively correlated with total body FM ($R=0.535$; $p=0.009$) and LM ($R=0.645$; $p=0.001$) for men and women (FM: $R=0.784$; $p<0.001$; LM: $R=0.867$; $p<0.001$) (Figure 2). There was no significant relationship with %fat for either men ($R=0.235$, $p=0.280$) or women ($R=0.299$, $p=0.137$). When evaluating relationships with segmental body composition, RMR was significantly positively ($p<0.05$) correlated with LM in the arms ($R=0.583$), legs ($R=0.664$) (Figure 3), and trunk ($R=0.593$) in men; FM in the arms ($R=0.511$) and trunk ($R=0.573$) were also significantly positively correlated to RMR in men, with no relationship with FM in the legs ($R=0.371$, $p=0.082$) or VAT ($R=0.377$, $p=0.076$). For women, RMR was positively correlated ($p<0.01$) with all LM and FM segments ($R=0.522$ – 0.879), with the strongest relationships presented for LM in the trunk ($R=0.879$; $p<0.001$) and legs ($R=0.821$; $p<0.001$) (Figure 3).

Resting Respiratory Exchange Ratio

Resting RER was significantly positively correlated with total body FM ($R=0.449$; $p=0.032$), but not LM ($R=0.406$; $p=0.054$) or %fat ($R=0.288$; $p=0.183$) in men. Resting RER was not significantly correlated ($p>0.05$) with any total body composition variable in women ($R=-0.138$ – 0.087). When evaluating relationships with segmental body composition in men, RER was significantly correlated with leg LM ($R=0.435$; $p=0.038$), trunk FM ($R=0.501$; $p=0.015$) and VAT ($R=0.456$; $p=0.029$) (Figure 3). In women, RER was not significantly correlated ($p>0.05$) with any segmental body composition variable ($R=-0.078$ – 0.192). When controlling for dietary intake (CHO, FAT, and PRO), RER was not significantly correlated ($p>0.05$) with total body composition in men ($R=0.278$ – 0.386) or women ($R=-0.011$ – 0.109). When controlling for dietary intake, RER was only significantly correlated with trunk FM ($R=0.452$; $p=0.045$) in men; there were no significant correlations with any segmental body composition variable in women ($R=-0.077$ – 0.226).

Change in Respiratory Exchange Ratio

The change in RER from rest to exercise was not significantly correlated ($p>0.05$) with any total ($R=-0.183$ – -0.010) or segmental ($R=-0.224$ – -0.007) body composition variables in men or women (total: $R=0.052$ – 0.102 ; segmental: $R=-0.086$ – 0.227). When controlling for dietary intake, there were still no significant correlations ($p>0.05$) between RER and total ($R=-0.348$ – -0.294) or segmental ($R=-0.376$ – -0.214) body composition variables in men or women (total: $R=-0.024$ – 0.008 ; segmental: $R=-0.109$ – 0.157).

Hormones

In men, insulin ($R=0.623$; $p=0.001$), leptin ($R=0.766$; $p<0.001$), and estradiol ($R=0.602$; $p=0.002$), but not cortisol ($p>0.05$), were positively correlated with FM. In women, insulin

($R=0.646$; $p=0.001$), and leptin ($R=0.590$; $p=0.004$), but not estradiol and cortisol ($p>0.05$), were positively correlated with FM. In men, RMR was positively correlated with cortisol ($R=0.430$, $p=0.040$) and estradiol ($R=0.649$, $p=0.001$), but not leptin ($R=0.286$, $p=0.186$) and insulin ($R=0.367$, $p=0.085$). In women; RMR was positively correlated with insulin ($R=0.570$, $p=0.006$), but not cortisol ($R=-0.082$, $p=0.691$), estradiol ($R=0.298$, $p=0.140$), or leptin ($R=0.379$, $p=0.082$). In men, RER was positively correlated with insulin ($R=0.525$, $p=0.010$), but not with any other adiposity-associated hormones ($R=0.217 - 0.325$, $p>0.05$). In women, RER was not significantly correlated with adiposity-associated hormones ($R=-0.079 - 0.216$, $p>0.05$). Change in RER from rest to exercise was not significantly correlated ($p>0.05$) with adiposity-associated hormones in men ($R=-0.156 - 0.357$) or women ($R=-0.170 - 0.369$). When controlling for dietary intake, RER was significantly correlated with insulin ($R=0.451$; $p=0.046$) in men; no other adiposity-associated hormones significantly correlated with RER in men ($R=0.134 - 0.353$) or women ($R=-0.074 - 0.231$). When controlling for dietary intake, RER was not significantly correlated ($p>0.05$) with adiposity-associated hormones (Men: $R=-0.142 - 0.304$; Women: $R=-0.132 - 0.322$).

Discussion

Results of the current study indicate that while both greater amounts of LM and FM were associated with a higher RMR, LM, especially LM in the trunk and legs, had the strongest relationships with RMR in both men and women. In contrast, trunk FM and VAT were more highly associated with greater resting carbohydrate metabolism than total body FM in men, with no associations in women. Segmental evaluation of body composition, specifically in the lower extremities and abdominal region, may be effective for evaluating metabolic status in overweight and obese adults. The lack of associations between RER, body composition, and adiposity-associated hormones, especially in women, illustrates the importance of sex-specific differentiation when evaluating body composition and metabolism.

Lean mass has previously been shown to account for up to 80% of resting energy expenditure [10], but as adiposity increases, FM has a larger impact on RMR [7]. In the current study, total body LM and FM were significantly correlated with RMR in both men and women. When evaluating segmental body composition, RMR was significantly correlated with almost all segments, but trunk and leg LM specifically had the strongest correlations in both men and women. Leg LM has important implications for maintaining functionality and quality of life and has been previously associated with decreased VAT [27,21]. In contrast, other previous studies involving overweight and obese individuals have found trunk LM to be more strongly associated with RMR than extremity LM, representing a strong contribution of metabolically active organ tissue to metabolic rate [24,25]. These studies, however, did not differentiate between arm and leg LM. Although trunk and leg LM were both significantly correlated with RMR, leg LM may be a more feasible target for intervention than trunk LM and increasing LM in the legs, through resistance training, may have important implications for metabolic health [37]. In the current study, regional distribution of body fat had stronger associations with RMR than total body FM. Specifically, out of the FM variables, trunk FM had the strongest relationship with RMR. A greater abdominal distribution of body fat, represented by trunk FM, is associated with greater disease risk [10]. However, measurements of trunk FM include both subcutaneous

and visceral fat. Visceral fat specifically, is more highly associated with greater disease risk compared to subcutaneous fat, and has previously been shown to be associated with a higher metabolic rate [13,14]. In the current study, a higher RMR was only significantly associated with VAT in women, alluding to potentially greater health consequences of VAT in women as a result of greater lipolytic activity and a proinflammatory response [15,18]. Further, relationships with RMR and total and segmental body composition were stronger in women than in men, supporting overall sex-specific differences in the impact of body composition on metabolic rate.

To date, the relationship between body composition and substrate utilization, or the contribution of carbohydrate and fat to energy production, has been unclear. Obesity and insulin resistance are commonly associated with impaired resting fat utilization, yet RER in obese individuals is highly variable [3]. In the current study, greater carbohydrate oxidation at rest in men was more strongly associated with trunk FM and VAT than total body FM, even when controlling for dietary intake. Greater FM in the trunk and visceral region is associated with an increased circulation of free fatty acids [9]. This can interfere with insulin signaling, impairing glucose uptake and reducing resting fat oxidation [15,9]. In contrast to males in the current study, females demonstrated no significant relationship between total or regional body composition and substrate utilization. In females, VAT is a consistent risk factor for metabolic dysfunction [18], and a higher resting RER has been previously associated with greater FM storage in women [20]. Similar to the results of the current study, a previous study of lean and obese premenopausal women, also reported no correlation between VAT and substrate utilization, despite significant associations with skeletal muscle insulin resistance [15].

As an additional parameter of metabolic function, the change in substrate utilization from rest to exercise was calculated as a potential measure of metabolic flexibility. Metabolic flexibility refers to the ability for skeletal muscle to switch from primarily fat oxidation in a resting state, to greater glucose oxidation following insulin stimulation or the onset of exercise [9]. Results of the current study showed no statistically significant correlations between total or regional body composition and metabolic flexibility in men or women. Few studies have examined metabolic flexibility, especially in relation to regional body composition. In one previous study by Prior et al. [38], older obese adults with impaired glucose tolerance had a smaller increase in RER during submaximal exercise compared to those with normal glucose tolerance, despite no differences in resting RER. Beyond total body composition, muscle quality, which quantifies fat and connective tissue within the muscle, may be a better outcome to identify impaired substrate utilization and metabolic inflexibility, as intramuscular fat accumulation has been shown to interfere with insulin signaling and reduce resting fat oxidation [39,40]. Although the present study did not measure muscle quality, evaluating this relationship in the future would provide additional insight.

There are known differences in substrate metabolism between men and women [41,16]. While the exact contributing factors to these differences are still under debate, differences in hormonal status are likely a strong contributor, especially in premenopausal women. Hormones such as insulin, leptin, estradiol, and cortisol vary with body fat distribution and are

important regulators of energy balance and substrate availability [16,17]. In the current study, a higher RMR was associated with cortisol and estradiol in men, while insulin was associated with RMR in women. It is known that insulin and cortisol are important regulators of glucose metabolism [17], but previous studies have reported weak correlations between insulin, cortisol, and RMR [18,17,6]. Female-specific associations between insulin and RMR have been previously reported by Astrup et al. [6] ($R=0.47$) and Wright et al. [17] ($R=0.35$), but both studies reported little benefit for predicting metabolic rate. Higher insulin levels should also be associated with greater carbohydrate metabolism [6], as was shown in the current study in the association with a higher RER in men. In contrast, women typically have greater concentrations of estradiol and leptin, which show stronger associations with subcutaneous fat and fat oxidation [18,16], although no relationships between adiposity-associated hormones and RER in women were observed in the current study. Obese males have previously been shown to have high estrogen levels, attributed to an increased conversion of androgens to estrogens, which can occur with elevated adiposity [42,43]. Leptin is a hormone produced by adipose tissue that signals long term energy stores [16,43]. In a state of leptin deficiency, exogenous doses of leptin have previously been shown to restore RMR from a weight-loss induced reduction [44], but changes in endogenous leptin concentrations have not been shown to be highly associated with changes in energy expenditure [45]. Although insulin, leptin, estradiol, and cortisol are all considered good markers of adiposity [16,17], further research is needed to determine their influence on metabolic rate and substrate utilization, especially in premenopausal females who experience regular hormonal variation.

Conclusions

Determination of metabolic rate and substrate utilization are important variables to consider when evaluating metabolic health that can serve as early warning signs of impending weight gain and metabolic disease [1,46]. Direct measurements of metabolic rate and substrate utilization are not always clinically feasible, due to time and equipment demands, but evaluation of body composition, specifically evaluating for excess abdominal and visceral fat and adequate lower extremity lean mass, could provide insight into metabolic risk while expediting the evaluation process [28,18]. Prescribing exercise and dietary interventions that not only target fat loss, but also minimize coinciding loss of lean mass, may help minimize metabolic adaptation to weight loss and reduce the chances for weight regain [47]. Exercise interventions such as high-intensity interval training and resistance training have been shown to be especially effective at reducing abdominal fat and increasing leg LM, while also being feasible and enjoyable in obese populations [48,49]. Although current results are limited to overweight and obese individuals, segmental evaluation of body composition could also prove to be insightful in identifying at-risk normal and underweight individuals who often go undetected due to their normal weight status [50]. In conclusion, LM and FM, specifically trunk LM, leg LM, trunk FM, and VAT, were significantly associated with metabolic rate and substrate utilization. Further research is needed to understand sex-specific differences in metabolism and the influence of adiposity-associated hormones on energy regulation, but the evaluation of segmental body composition may help improve

identification of individuals at risk for metabolic dysfunction, as well as help establish individualized exercise interventions.

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Figure 1.
Total body DEXA scan with: A) region of interest cuts for arms and legs and B) region of interest for visceral adipose tissue.

Figure 2.
Relationships between total body FM and LM and resting metabolic rate (RMR) in males (left) and females (right).

Figure 3.

Relationships between leg LM and resting metabolic rate (RMR) males and females.

Relationships between visceral fat mass (VAT) and respiratory exchange ration (RER) for males (left) and females (right).

Table 1Subject characteristics (Mean $\pm$ SD)

	Male (n=23)	Female (n=26)
Age (yrs)	37.4 $\pm$ 10.3	32.8 $\pm$ 6.9
Height (cm)	178.1 $\pm$ 6.4 *	164.1 $\pm$ 7.1 *
Weight (kg)	102.2 $\pm$ 15.1	94.2 $\pm$ 19.3
BMI (kg·m ⁻²)	32.1 $\pm$ 3.3	34.9 $\pm$ 6.2
%fat	33.3 $\pm$ 5.4 *	46.3 $\pm$ 3.9 *
FM (kg)	33.9 $\pm$ 9.4 *	43.2 $\pm$ 11.0 *
LM (kg)	64.5 $\pm$ 7.7 *	47.8 $\pm$ 8.4 *
Arm LM (kg)	8.7 $\pm$ 1.3 *	5.3 $\pm$ 1.2 *
Leg LM (kg)	23.5 $\pm$ 3.0 *	17.5 $\pm$ 3.5 *
Trunk LM (kg)	28.4 $\pm$ 3.6 *	21.7 $\pm$ 3.7 *
Arm FM (kg)	3.4 $\pm$ 1.0 *	4.7 $\pm$ 1.5 *
Leg FM (kg)	9.8 $\pm$ 2.8 *	15.7 $\pm$ 3.7 *
Trunk FM (kg)	19.6 $\pm$ 6.1	21.8 $\pm$ 7.0
VAT (kg)	1.5 $\pm$ 0.8 *	1.0 $\pm$ 0.5 *

* significant difference between males and females (p<0.05)