Racial Differences in Relative Skeletal Muscle Mass Loss During Diet-Induced Weight Loss in Women

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Objective: It is unclear whether there are race-specific differences in the maintenance of skeletal muscle during energy restriction. Changes in relative skeletal muscle index (RSMI; limb lean tissue divided by height squared) were compared following (1) diet alone, (2) diet + aerobic training, or (3) diet + resistance training.

Methods: Overweight, sedentary African American (AA; n = 72) and European American (EA; n = 68) women were provided an 800-kcal/d diet to reduce BMI < 25 kg/m². Regional fat-free mass was measured with dual-energy x-ray absorptiometry. Steady-state VO₂ and heart rate responses during walking were measured.

Results: AA women had greater RSMI and preserved RSMI during diet alone, while RSMI was significantly reduced among EA women (EA women −3.6% vs. AA women + 1.1%; P < 0.05). Diet + resistance training subjects retained RSMI (EA women + 0.2% vs. AA women + 1.4%; P = 0.05), whereas diet + aerobic training subjects decreased RSMI (EA women −1.4% vs. AA women −1.5%; P < 0.05). Maintenance of RSMI was related to delta walking ease and economy.

Conclusions: Compared with AA women, EA women are less muscular and lose more muscle during weight loss without resistance training. During diet-induced weight loss, resistance training preserves skeletal muscle, especially among premenopausal EA women. Maintenance of muscle during weight loss associates with better ease and economy of walking.

Introduction

Weight loss is usually associated with the loss of fat-free mass (FFM). Although organ mass and bone mass may be lost, the majority of FFM loss is likely skeletal muscle (1). Decreased skeletal muscle can impair locomotion economy and ease (2) and contribute to reduced nonexercise activity thermogenesis (NEAT) (2,3). Exercise training, especially resistance training, has been shown to be successful in increasing skeletal muscle mass and NEAT (4-6). In addition, the loss of FFM has been shown to be retained for individuals who resistance train during diet-induced weight loss (7,8).

Sarcopenia refers to a progressive, age-related loss in skeletal muscle mass. Decreased skeletal muscle mass accelerates with age (6), as 13% to 24% of individuals less than 70 years old are sarcopenic, whereas more than 50% of individuals over 80 years old are sarcopenic (9,10). Normally, sarcopenia refers to older individuals, although it can occur in relatively young individuals. Because loss of muscle is an ongoing process as we age, the identification of individuals who are vulnerable to sarcopenia before it becomes problematic may be important. Because of the inherent risk of skeletal muscle loss during energy restriction, this may be essential when individuals are undergoing weight loss. Identifying individuals who are sarcopenic or “presarcopenic” is not possible unless stature as well as skeletal muscle mass is considered. Baumgartner et al. (9) suggested a simple measure that can be used to objectively quantitate muscle relative to height, thus offering a measure that can be used to identify sarcopenia. This measure is obtained by dividing limb lean tissue by height squared (defined as relative skeletal muscle index [RSMI]). Different researchers have proposed RSMI sarcopenic cut points varying from 5.14 to 7.36 kg/m² (9,11,12).

Low relative skeletal muscle mass can lead to loss of function, decreased physical activity, and potentially weight gain in older populations (9). Decreased function is apparent even in relatively young individuals, especially women (13,14), when relative skeletal muscle...
mass is low, but it can be improved when individuals resistance train (2,5,15). FFM (8) and relative skeletal muscle mass have been reported to be greater in African Americans (AAs) than European Americans (EAs) (6). Although AAs may lose less FFM following weight loss (8), no one has compared the losses of RSMI between different weight-loss interventions. In addition, it is not clear how the loss of RSMI may affect ease and economy during locomotion.

Therefore, the purpose of the paper is to compare the loss of RSMI following diet-induced weight loss, diet-induced weight loss with aerobic training, and diet-induced weight loss with resistance training in a cohort of AA and EA women. We hypothesize that AA women will have higher RSMI and will lose less RSMI than EA women during weight loss, but there will be no interaction difference by ethnic group (EA and AA women will respond similarly to the three interventions) in change of RSMI. Walking ease and economy have been associated with increased free-living activity and reduced weight gain following weight loss (3,4,16,17), suggesting that factors that may impact walking ease and economy may be important for weight maintenance and metabolic health. Therefore, a secondary aim was to observe the relationship between change in RSMI and change in walking economy after weight loss. We also hypothesize that decreased RSMI change will be positively associated with ease of walking on a flat and graded treadmill but negatively related to change in net oxygen uptake (increase in walking economy).

Methods

This study is a secondary analysis from a study designed to identify metabolic factors that predispose women to weight gain (exercise training in black and white women who no longer have obesity) (18). Women with overweight (BMI > 27 and < 30 kg/m²; 72 AA and 68 EA women) between the ages of 20 and 44 years who had not exercise trained during the prior year served as subjects. Race designation was self-selected. The women had a family history of obesity, experienced regular menstrual cycles, did not have a history of diabetes and had normal glucose tolerance, were sedentary, and did not take metabolism-altering medication. All were tested at baseline after a 4-week weight-stabilization period during which the subjects were weighed three times per week with food provided during the last 2 weeks. After evaluation, they were randomly group assigned by race, age, and BMI to one of the following three groups: (1) weight loss with aerobic exercise training three times per week, (2) weight loss with resistance exercise training three times per week, and (3) weight loss without exercise training. During weight loss, the subjects were provided an 800-kcal/d diet until BMI < 25 was reached. For 4 weeks after weight loss, food was provided and subjects remained weight stable. The macronutrient content furnished by the General Clinical Research Center (GCRC) kitchen was 20% to 22% fat, 20% to 22% protein, and 56% to 58% carbohydrate during both weight-loss and weight-stable time periods. Women were admitted to the GCRC 2 days prior to all testing to ensure that physical activity and diet were standardized. Testing was done in a fasted state in the morning after spending the night in the GCRC. The study was approved by the University of Alabama at Birmingham Institutional Review Board, and informed consent was obtained from all subjects.

Exercise training

Exercise training occurred in a 1,600-square-foot exercise training facility devoted to research. All training was supervised by an exercise physiologist and was scheduled to occur three times each week. Both aerobic and resistance trainers warmed up with 5 minutes of walking and 3 to 5 minutes of stretching.

Aerobic training

Continuous treadmill walking and/or jogging was used as the mode for aerobic training. Subjects did 20 minutes of continuous exercise at 67% maximum heart rate (HR) during the first week of training. Duration and intensity increased each week so that by the beginning of the eighth week, subjects exercised continuously at 80% maximum HR for 40 minutes. Subjects were encouraged to increase intensity (either speed or grade) when the average exercise HR was consistently below 80% maximum HR. After the exercise session, subjects cooled down for 3 to 5 minutes with gradually decreasing exercise intensity.

Resistance training

The resistance training consisted of squats, leg extensions, leg curls, elbow flexions, triceps extensions, lateral pull-downs, bench presses, military presses, lower back extensions, and bent-leg sit-ups. After 1 week of familiarization (training with a light weight), the one-repetition maximum (1-RM) was measured. The first week following the 1-RM tests, one set of 10 repetitions was performed at 65% 1-RM, with percent of 1-RM increasing in subsequent weeks until week 4 intensity was at 80% 1-RM. Starting at week 5, two sets of 10 repetitions were attempted at 80% 1-RM for each exercise, with a 2-minute rest between sets. Strength was evaluated every 5 weeks, and adjustments in training resistance were made based on the most current 1-RM.

Resting oxygen uptake and energy expenditure

Prior to weight loss and after weight loss, on three consecutive mornings in a fasted state after an overnight stay in the GCRC, resting oxygen uptake and resting energy expenditure were determined between 6:00 and 6:50 AM. Subjects remained awake in a quiet, softly lit, well-ventilated room in which temperature was maintained between 22°C and 24°C. Subjects laid supine on a comfortable bed, and oxygen uptake was measured using a ventilated hood system. After resting for 15 minutes, oxygen uptake was measured for 30 minutes with a computerized, open-circuit indirect calorimetry system (Deltatrac II; SensorMedics, Yorba, California). The last 20 minutes were used for analysis. Oxygen uptake values used in the determination of exercise net VO₂ (i.e., exercise VO₂ – resting VO₂) were means of the three morning values. The coefficient of variation for repeat VO₂ measures is < 4% in our lab.

VO₂max

A maximal modified Bruce protocol was used to determine maximal oxygen uptake (VO₂max) (19). HR was measured using a Polar Vantage XL HR monitor (Gays Mills, Wisconsin). Oxygen uptake and carbon dioxide production were measured continuously using a MAX-II metabolic cart (Physiodyne Instrument Corporation, Quogue, New York). Gas analyzers were calibrated with certified gases of known concentrations. Standard criteria for HR (HR within 10 beats/min of estimated maximum), respiratory exchange ratio (value above 1.2), and
plateauing were used to ensure achievement of VO\textsubscript{2max}. The coefficient of variation for repeat measures of VO\textsubscript{2max} are less than 3% in our lab.

**Ease and economy of physical activity**

HR and oxygen uptake (VO\textsubscript{2}) were obtained during a flat (4.8 km/h) and 2.5% grade (4.8 km/h) treadmill walk. The duration of each task was between 4 and 5 minutes, and steady state was obtained. Oxygen uptake and carbon dioxide production were also measured using a MAX-II metabolic cart. Net oxygen uptake (work steady-state VO\textsubscript{2} – resting VO\textsubscript{2}) is reported in milliliters of oxygen per kilogram per minute and is considered exercise economy for walking and stair climbing. HR increases as the intensity of exercise increases. Therefore, HR is considered an index of exercise difficulty.

**Dual-energy x-ray absorptiometry**

The Lunar DPX-L densitometer (LUNAR Radiation, Madison, Wisconsin) was used to determine total fat and FFM as well as arm and leg lean tissue according to the manufacturer’s instructions. Adult Software version 1.33 (LUNAR Radiation) was used to analyze the scans. RSMI was calculated by dividing limb (arm + leg) lean tissue by height squared.

**Socioeconomic status**

The Hollingshead four-factor index of social class (20) was used to assess socioeconomic status (SES). This questionnaire derives SES from the occupational status and educational attainment of the participant and her spouse, if applicable, with higher scores reflecting greater SES.

**Statistics**

A three (group) by two (race) analysis of variance (ANOVA) was run for all the descriptive variables to identify any differences between groups and race. Two (time) by three (group) by two (race) ANOVA was run for RSMI with repeated measures on time.

Multiple regression models for estimation of delta net VO\textsubscript{2} and HR during the flat and graded walking tests (mean ± SE, with delta VO\textsubscript{2max}, delta RSMI, and race serving as independent variables) were used. Bonferroni-corrected post hoc t tests were run on contrasts of interest. SPSS software version 25 (IBM Corp., Armonk, New York) was used for the analyses, and \(\alpha\) was set at 0.05.

**Results**

Baseline descriptive variables are in Table 1. No race or group differences were observed for any variable except VO\textsubscript{2max}, for which there was a race difference (EA women higher than AA women). During the weight-loss intervention, subjects decreased in weight significantly (12.1 ± 2.5 kg), but there were no group or race differences in weight loss.

Table 2 shows the changes in RSMI with weight loss. There was a race and group effect, a time by race interaction, and a time by group by race interaction. Post hoc analysis revealed that AA women had larger RSMI (were more muscular) and lost less RSMI during the diet-only intervention than EA women. In addition, resistance training resulted in a retention of RSMI in both AA and EA women, but aerobic training resulted in decreased RSMI in both races.

Figure 1 shows the percentage change for RSMI, with post hoc analysis revealing a significant difference between the AA women (1.1% increase) and EA women (3.6% decrease) for the diet-only group.

In order to identify the independent contributions to changes in walking economy (delta steady-state net VO\textsubscript{2}) and ease (delta steady-state HR), four multiple regression models were evaluated (Table 3). The models for both delta flat and grade net VO\textsubscript{2} showed that both delta RSMI and delta VO\textsubscript{2max} were independent correlates with the two walking tasks. The models for the submaximal flat and graded walks showed that delta RSMI was an independent correlate of delta HR during the two submaximal walking tasks, but delta

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**TABLE 1 Descriptive variables for subjects (mean ± SD)**

|                    | Diet only          | Diet + aerobic training | Diet + resistance training |
|--------------------|--------------------|-------------------------|---------------------------|
|                    | EA, n = 17  | AA, n = 17             | EA, n = 22 | AA, n = 23         | EA, n = 29  | AA, n = 32 |
| Age (y)            | 36.6 ± 4.8  | 34.6 ± 6.0             | 35.0 ± 7.4  | 33.8 ± 6.7         | 35.6 ± 6.7 | 34.0 ± 5.6 |
| SES\(^*\)          | 44.6 ± 13   | 47.0 ± 9.2             | 48.8 ± 11.7 | 49.8 ± 5.8         | 47.0 ± 10.8 | 46.4 ± 11.2 |
| Height (cm)        | 165.9 ± 7.0 | 165.8 ± 5.1            | 164.0 ± 5.8 | 164.8 ± 7.2        | 168.0 ± 7.8 | 164.4 ± 5.6 |
| Body weight (kg)   | 78.5 ± 8.5  | 77.7 ± 5.6             | 76.3 ± 6.8  | 77.3 ± 6.8         | 79.8 ± 9.3  | 75.8 ± 5.4  |
| BMI (kg/m\(^2\))   | 28.3 ± 1.4  | 28.2 ± 1.4             | 28.3 ± 1.6  | 28.5 ± 1.3         | 28.1 ± 1.3  | 28.0 ± 1.0  |
| VO\textsubscript{2max} (mL/kg/min) | 27.7 ± 3.8 | 27.7 ± 3.9            | 30.1 ± 4.1  | 26.1 ± 3.0         | 29.3 ± 3.9  | 28.7 ± 3.3  |
| FW\textsubscript{N2O} | 8.9 ± 1.5   | 9.6 ± 1.5              | 9.8 ± 1.2   | 9.0 ± 0.8          | 9.4 ± 1.1   | 9.3 ± 1.2   |
| FW\textsubscript{HR} (beats/min) | 119.6 ± 16.2 | 116.6 ± 14.4         | 116.6 ± 10.8 | 126.0 ± 15.4      | 120.2 ± 12.7 | 120.4 ± 12.8 |
| GW\textsubscript{N2O} | 11.6 ± 1.6  | 12.3 ± 1.4             | 12.4 ± 1.6  | 12.1 ± 1.2         | 12.3 ± 1.2  | 12.1 ± 1.5  |
| GW\textsubscript{HR} (beats/min) | 134.1 ± 18.6 | 134.5 ± 16.6         | 130.3 ± 9.8 | 143.2 ± 16.4      | 133.3 ± 13.6 | 135.8 ± 15.1 |

\(^*\)SES calculated from the Hollingshead four-factor index of social class, wherein higher scores reflect greater SES.

|                    | Diet only          | Diet + aerobic training | Diet + resistance training |
|--------------------|--------------------|-------------------------|---------------------------|

No significant differences detected between groups or race (all comparisons; \(P > 0.20\), with the exception of race for VO\textsubscript{2max}.
**TABLE 2** Descriptive analysis of RSMI (mean ± SD)

|                  | RSMI (kg/m²) | Diet only | Diet + aerobic training | Diet + resistance training | Significant effect |
|------------------|--------------|-----------|-------------------------|---------------------------|-------------------|
|                  |              | Time | n  | EA | n  | AA | n  | EA | n  | AA | n  | EA | n  | AA | n  | EA | n  | AA | r | P  |
| G (baseline)     |              | 0   | 17 | 6.66 ± 0.56 | 17 | 7.07 ± 0.63 | 22 | 6.56 ± 0.69 | 23 | 7.12 ± 0.43 | 29 | 6.63 ± 0.40 | 32 | 7.28 ± 0.53 | R, G |
| G (weight loss)  |              | 1   | 17 | 6.42 ± 0.53 | 17 | 7.15 ± 0.68 | 22 | 6.47 ± 0.63 | 23 | 7.01 ± 0.48 | 29 | 6.64 ± 0.38 | 32 | 7.38 ± 0.60 | T × R |
| Δ (change)       |              | -0.24 | - | 0.08 | - | -0.09 | - | -0.11 | - | 0.01 | - | 0.10 | T × G × R |

Post hoc analysis revealed that AA women had higher RSMI and lost less RSMI during diet-only condition. Post hoc analysis also revealed that both AA and EA women maintained RSMI when resistance training was combined with diet, but both AA and EA women lost RSMI when aerobic training was combined with diet (mean ± SD). Δ (change) = weight loss – baseline. Significant effect, P < 0.05; AA, African American; EA, European American; G, group effect; R, race effect; RSMI, relative skeletal muscle index; T, time effect; T0, baseline; T1, weight loss.

VO_{2\text{max}} was not a significant correlate in any of the models. To ensure that a race by RSMI interaction was not affecting the models, we performed an additional multiple regression model that included an interaction term between race and RSMI. The interaction term was not a significant correlate in any of the models (data not shown).

**Discussion**

Consistent with our hypothesis, we found that AA women had higher RSMI and lost less RSMI than EA women during weight loss. Not consistent with our hypothesis, we found that there were major racial differences in RSMI loss between groups, with the AA and EA women responding similarly to the two weight-loss regimens that included exercise training but with major differences in RSMI loss for the women who underwent energy restriction without exercise training. The EA women who did not exercise train lost 3.6% of their RSMI, while AA women who did not train gained 1.1% RSMI. Also consistent with our hypothesis, we found that decreased RSMI was negatively associated with decreased HR (increased ease of walking) and net VO_{2} (increase in walking economy) while walking on the flat and graded treadmill. In other words, maintenance of RSMI with weight loss was related with better walking economy and ease. Because resistance training was associated with maintenance of RSMI in both AA and EA women, these results further support the inclusion of resistance training during energy-restriction-driven weight loss, especially for EA women.

Previous research has shown that AAs have more FFM and limb skeletal muscle than EAs even after adjusting for height and/or limb

**TABLE 3** Multiple linear regression models for estimation change (Δ, delta) in net oxygen uptake and HR during flat and graded walking test after weight loss (mean ± SE)

| Model | Model | ΔFW_{ Vox2 } | Intercept | Slope | Partial | r | P  |
|-------|-------|--------------|-----------|-------|---------|---|----|
|       |       | ΔRSMI  | -1.34 ± 4.5 | 0.27* | 0.002  | 0.002 | 0.001 |
|       |       | ΔVO_{2\text{max}} | 0.16 ± 0.1 | 0.001 | 0.001  | 0.001 |
|       |       | Race  | -0.03 ± 0.3 | 0.01 | 0.913  | 0.913 |
|       |       | ΔFW_{ HR } | -8.1 ± 1.9 | 0.05 | 0.035  | 0.035 |
|       |       | ΔRSMI  | -8.94 ± 3.7 | 0.05 | 0.016  | 0.016 |
|       |       | ΔVO_{2\text{max}} | -0.59 ± 0.3 | 0.01 | 0.888  | 0.888 |
|       |       | Race  | 0.42 ± 2.1 | 0.02 | 0.850  | 0.850 |
|       |       | ΔGW_{ Vox2 } | -1.3 ± 0.2 | 0.001 | 0.001  | 0.001 |
|       |       | ΔRSMI  | -1.69 ± 0.5 | 0.001 | 0.001  | 0.001 |
|       |       | ΔVO_{2\text{max}} | 0.2 ± 0.1 | 0.001 | 0.001  | 0.001 |
|       |       | Race  | 0.1 ± 0.3 | 0.03 | 0.722  | 0.722 |
|       |       | ΔGW_{ HR } | -9.9 ± 2.2 | 0.007 | 0.007  | 0.007 |
|       |       | ΔRSMI  | -11.1 ± 3.5 | 0.001 | 0.001  | 0.001 |
|       |       | ΔVO_{2\text{max}} | -0.5 ± 0.3 | 0.175 | 0.175  | 0.175 |
|       |       | Race  | -0.3 ± 2.1 | 0.902 | 0.902  | 0.902 |

**Figure 1** Percentage change of RSMI of AA and EA women for diet + aerobic, diet + resistance, and diet only groups. **Denotes significant decrease in RSMI.

Race coded 0 EAs and 1 AA.
*P < 0.05.
AA, African American; EA, European American; HR, heart rate; ΔFW_{ Vox2 }, delta heart rate during flat walking; ΔFW_{ HR }, delta heart rate during grade walking; ΔGW_{ Vox2 }, delta net oxygen uptake during flat walking (walking steady-state VO_{2} – resting VO_{2}); ΔGW_{ HR }, delta net oxygen uptake during grade walking (walking steady-state VO_{2} – resting VO_{2}); ΔRSMI, delta relative skeletal muscle index; ΔVO_{2\text{max}}, delta maximal oxygen uptake.
Our results support this finding. Little has been written concerning potential reasons for this difference or to explain the ability of the AA women to maintain RSMI during weight loss even when not exercise training. The differences were not associated with diet macronutrient content because we fed all the subjects the same macronutrient diet (20%-22% fat, 20%-22% protein, and 56%-58% carbohydrate). The differences were probably not mediated by a more active lifestyle for the AA women because we previously showed that AA women had lower activity-related energy expenditure than EA women (21) and that the difference persisted following weight loss and exercise training (8). Hormone environment certainly may be playing a role. Recently, it has been reported that postmenopausal women taking hormone-replacement therapy had higher FFM than either premenopausal women or postmenopausal women not on hormone-replacement therapy (22). In addition, premenopausal AA women have higher blood estradiol than EA premenopausal women (23,24), at least suggesting that sex hormones may be playing a role in racial differences in FFM and possibly muscle. Of course, genetic contributions may be playing a role in racial differences in RSMI. For example, we previously reported that insulinlike growth factor I (IGF-I) polymorphism is associated with lean mass in women, with the IGF-I<sub>189</sub> polymorphism associating with reduced lean tissue (25). Interestingly, more than 47% of the AA women in this study were noncarriers, but less than 7% of the EA women were noncarriers of the IGF-I<sub>189</sub> polymorphism.

Consistent with previous work (16), ease of locomotion (reduced HR while walking) was increased with weight loss. This is particularly important because ease of locomotion probably plays a role in participation in free-living physical activity. We previously showed that resistance-training-induced increases in strength and muscle are associated with increased ease of locomotion (4,15,17), while ease of locomotion is related to NEAT (3,5,21). These relationships further support the potential importance of maintaining RSMI during weight-loss programs.

Further supporting the importance of maintaining RSMI, differences in RSMI were related to differences in walking economy and differences in walking ease while walking at a moderate speed (4.8 km/h) on a flat and 2.5% grade at the same speed (Table 3), even after adjusting for aerobic capacity (VO<sub>2</sub>max). Because, as indicated above, ease and economy of locomotion probably contribute to the likelihood of being physically active, and because participation in physical activity is not only important for maintenance of weight but also metabolic health (25), maintenance of locomotion ease is an important goal.

Because there is considerable range in RMSI (varying from 5.45 to 7.36 kg/m<sup>2</sup>) for identification of cut points for individuals with sarcopenia (9,11,12), we selected a conservative cut point of 6.29 kg/m<sup>2</sup> proposed by Bouchard et al. (11). We identified eighteen EA women and three AA women below this cut point prior to weight loss. Of the two AA women and five EA women who were sarcopenic prior to weight loss in the diet plus resistance training group, both AA women and one EA woman increased muscle enough to no longer be sarcopenic after weight loss. The number of sarcopenic women remained constant in the no-exercise group, and the number of sarcopenic women in the aerobic group increased from seven to eight.

We used dual-energy x-ray absorptiometry (DXA) to measure limb lean tissue and calculate RSMI. Magnetic resonance imaging and computed tomography (CT) may be more precise methods for measuring limb lean tissue and thus RSMI than DXA. Both magnetic resonance imaging and CT are very expensive, and whole-body CT adds significant radiation exposure to subjects. Therefore, neither technique is suitable for most studies. We feel that DXA is very reliable. The coefficient of variation for repeat scans in our lab is 1.1%. In addition, only one technician analyzed all scans and was blinded to the race and group of the subjects, so we are confident that no group or racial biasing occurred with the analysis.

Conclusion

Premenopausal EA women are not only less muscular than AA women, but they also lose significant amounts of muscle during weight loss that does not include resistance training, while AA women do not. Maintenance of muscle during diet-induced weight-loss programs is important for maintaining ease of locomotion, which may have a positive effect on participation in physical activity. As shown in previous studies, resistance training during diet-induced weight-loss help losses to help maintain muscle, especially in EA premenopausal women.

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