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Effect of Resistance Training and Caloric Restriction on the Metabolic Syndrome

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Abstract

Purpose—The prevalence of metabolic syndrome is greatest in older obese adults and effective evidence-based treatment strategies are lacking. This study determined the efficacy of adding caloric restriction (CR) for weight loss to resistance training (RT) on metabolic syndrome (MetS) and its individual components in older overweight and obese adults.

Methods—We performed a 5-month randomized controlled trial in 126 older (65–79 yrs) overweight and obese (Body Mass Index: 27–35 kg/m²) men and women who were assigned to progressive 3-d/wk, moderate-intensity RT with (RT+CR) or without caloric restriction (RT). MetS components, according to the National Cholesterol Education Program Adult Treatment Panel III, were determined before and immediately after the interventions.

Results—Body mass decreased in RT+CR (–5.67% loss of initial mass) but was unchanged in RT (–0.15%). Compared to RT, RT+CR resulted in reduced very low-density lipoprotein cholesterol (VLDL-chol), triglycerides (TG), and systolic and diastolic blood pressures (*p* between 0.000 and 0.013). The RT group showed no significant within group changes in MetS criteria. Abdominal obesity, hypertension, the number of metabolic abnormalities and the presence of MetS significantly decreased with RT+CR. There were significant group differences for abdominal obesity, hypertension, and number of metabolic abnormalities.

Conclusion—RT+CR is an effective strategy for improving some of the metabolic abnormalities associated with MetS among older overweight and obese adults.

Keywords

metabolic syndrome; obesity; resistance training; caloric restriction; weight loss; older adults

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Introduction

The constellation of metabolic abnormalities known as metabolic syndrome (MetS) is a major risk factor for both cardiovascular disease (CVD) and type II diabetes (5, 21). MetS affects almost one-third of the adult population, including over one-half of adults over 60 years (12), with abdominal obesity being the most prevalent component (12). Thus, the first line of treatment for MetS is dietary-induced weight loss combined with physical activity as these lifestyle changes improve MetS components (35) and lead to reduced risk of CVD and diabetes (13, 25). However, even though the prevalence of MetS is highest in older adults, the majority of prior studies examining effects of weight loss and exercise on MetS were conducted in middle-aged adults (e.g., < 65 yrs). Hence, there is a need for additional research to answer how lifestyle interventions affect MetS criteria in the older segment of the population.

Studies show that aerobic exercise training impacts several of the MetS criteria, and decreases the overall prevalence of MetS among both middle-aged (16), and older (11) adults. Although most randomized controlled trials focus on aerobic training, favorable changes in MetS criteria are also observed after resistance training (RT) (6) or mixed aerobic/RT in middle-aged adults (4, 34). Performing RT is recommended as part of a well-rounded program for older adults to maintain musculoskeletal health and function;(22) however, little is known about the effects of RT on factors constituting MetS in this age group (39). In addition, though one study in older obese adults found that combining aerobic training with caloric restriction (CR) for weight loss improved indices of MetS (41), no study has examined effects of adding CR to RT on cardiometabolic risk in older adults with obesity. Given that the prevalence of MetS increases with age and that aging is associated with an increase in total and abdominal obesity, the effect of adding CR to RT may represent a more effective intervention for older adults. However, aging is also associated with a reduction in muscle strength and mass and the risk-to-benefit ratio of CR for weight loss remains controversial in older adults.

Therefore, the purpose of this study was to determine the effects of adding CR for weight loss to RT on criterion comprising MetS in older overweight and obese adults. We hypothesized that weight loss, achieved by adding CR, would be associated with a greater reduction in the prevalence of MetS and with improvement in individual components of MetS.

Methods

Study design

This article presents data from a randomized clinical trial (clinicaltrials.gov; NCT01049698), designed to determine whether CR enhances improvements in skeletal muscle function in response to RT in 126 older overweight and obese men and women, and these results were previously published (24). Briefly, this was a 5-month study comparing a progressive RT intervention with caloric restriction (RT+CR, n=63) to RT alone (n=63). Participants were recruited and enrolled based on the following criteria: 1) aged 65–79 yrs; 2) sedentary (no RT or purposeful aerobic training in the past 6 mo); 3) BMI of 27 to 35

kg/m²; 4) nonsmoking 1 yr; 5) weight stable (<5% weight change in the past 6 mo); and 6) without insulin-dependent diabetes or evidence of clinical depression, cognitive impairment, heart disease, cancer, liver or renal disease, chronic pulmonary disease, uncontrolled hypertension, physical impairment, or any contraindication for RT or weight loss (e.g., osteoporosis). The study was approved by the Wake Forest School of Medicine Institutional Review Board, and all participants provided written informed consent to participate.

Interventions

The interventions were previously described in detail (23). The RT protocol involved a gradual progression of weight and repetitions during the first month to allow familiarization with the equipment, minimize muscle soreness, and reduce injury potential. The maximal weight that a person could lift with the correct form in a single repetition (1RM) was used to prescribe intensity. The training goal was to complete 3 sets of 10 repetitions for each of 8 exercises at 70% 1RM for that specific exercise. Training loads were adjusted every 4 weeks to be consistent with the 70% 1RM goal.

Participants assigned to RT only were instructed to follow a eucaloric diet, whereas those assigned to RT+CR underwent a dietary weight-loss intervention designed to elicit moderate weight loss (5–10%). This intervention incorporated meal replacements, nutrition education, and dietary behavior modification advice via weekly meetings with the study's registered dietitian (RD) that took place either before or after one of their exercise sessions. Each participant was assigned a daily caloric intake to follow, which was derived from subtracting 600 kcal from his or her estimated daily energy needs for weight maintenance. A maximum of 2 meal replacements per day (shakes and bars; Slim-Fast Inc.) that contained ≈220 kcal with 7–10 g protein, 33–46 g carbohydrates, 1.5–5 g fat, and 2–5 g fiber were provided to participants for breakfast and lunch. Dinner and snack options were recommended by the RD in accordance with each participant's daily caloric goals and tailored to allow for individual preferences for various food items. Participants were asked to keep a diet log of all foods consumed, and the logs were monitored weekly by the RD to verify compliance with the weight-loss intervention.

Assessments

All assessments took place in the Geriatric Research Center of the Wake Forest School of Medicine J Paul Sticht Center on Aging by examiners blinded to participant treatment assignment. Body weight, body composition and MetS components were measured at baseline and immediately after (within 1 week) the 5-month interventions. Height and body mass were measured with shoes and outer garments removed. BMI was calculated as weight in kilograms (kg) divided by the square of height in meters (m). Waist circumference (cm) at the minimal girth was measured in triplicate and values averaged for data analysis. Whole-body fat mass, lean mass, and percentage of body fat were measured by using dual-energy X-ray absorptiometry (Delphi QDR; Hologic). Blood samples were drawn following an overnight fast of at least 8 hours. Triglycerides (TG), total cholesterol (Total chol), very low-density lipoprotein cholesterol (VLDL-chol), low-density lipoprotein cholesterol (LDL-chol), high-density lipoprotein cholesterol (HDL-chol), insulin and glucose were measured in a clinical laboratory (LabCorp, Burlington, NC). Insulin sensitivity was estimated by the

homeostasis model of insulin sensitivity (HOMA-IR) (20). Seated blood pressure was measured using a Dinamap monitor (Johnson & Johnson, XL model 9300). Two readings were taken at 1-min intervals after participants had been seated for 5 min and reported values are the average of these two readings.

Definition of metabolic syndrome

MetS was defined in accordance with the criteria of the National Cholesterol Education Program (Adult Treatment Panel III, NCEP ATP III) (13), which requires that 3 or more of the following conditions be met: 1) abdominal obesity (waist circumference greater than or equal to 102 cm in men and 88 cm in women), 2) serum TG levels greater than or equal to 150 mg/dL or drug treatment for elevated TG, 3) HDL-cholesterol less than 40 mg/dL in men and 50 mg/dL in women or drug treatment for low HDL-cholesterol, 4) fasting glucose greater than or equal to 100 mg/dL or drug treatment for elevated glucose, and 5) systolic blood pressure greater than or equal to 130 mmHg or diastolic blood pressure greater than or equal to 85 mmHg or on antihypertensive drug treatment with a history of hypertension.

Statistical analyses

All statistical analyses were performed with SPSS software (version 21). An α level of <0.05 was used to denote significance and all data were analyzed according to randomly assigned group. Baseline descriptive characteristics are reported as mean ($\pm$ SDs) or frequencies (percentages). Univariate analyses of variance (ANOVAs) were performed to assess between-group statistical differences at baseline. Within-group differences between baseline and follow-up values were determined using a paired t-test. Between-group differences for change values (baseline minus follow-up) were analyzed using ANCOVA with adjustment for baseline age, gender, race and baseline value of the outcome. Analyses were performed using Log values for non-normally distributed data for the following variables: HDL-cholesterol, VLDL-cholesterol, LDL-cholesterol, TG, glucose, insulin and HOMA-IR.

Results

Baseline descriptive characteristics

No significant between group differences were observed for baseline demographic characteristics (Table 1) or for baseline MetS criteria (Table 2 and Figure 1). However, baseline fasting insulin and HOMA-IR were higher in RT vs RT+CR ($p<0.05$; Table 2). The average age of study participants was 69.5 ± 3.7 years, with the majority being white (86.5%) and female (56.3%). Most participants were classified as obese, with mean BMI by treatment group measured as 30.7 ± 2.4 kg/m² and 30.4 ± 2.2 kg/m² for the RT and RT+CR groups, respectively. MetS was present in 28 subjects (44%) in the RT group and 29 subjects (46%) in the RT+CR group at baseline (Figure 1).

Intervention effects on body mass and composition and metabolic syndrome

Adherence to the 3-d/wk RT protocol averaged 86% and 89% in the RT and RT+CR groups, respectively. Weight loss was -5.67% and -0.15% in the RT+CR and RT groups, respectively, and as expected, the RT+CR group lost more weight than the RT group ($p<0.0001$). Intervention effects on body composition have previously been published (23).

Briefly, decreases in total body fat mass, lean mass, and percentage of fat were all greater in the RT+CR group than in the RT group. Within the RT group, there were small but significant declines in total fat mass and percentage of fat but no mean change in total mass or lean mass. Within the RT+CR group, there was a significant loss of both fat and lean mass.

The overall prevalence of MetS significantly ($p<0.05$) decreased in the RT+CR group from 46% to 31% (from 29 subjects at baseline to 17 at follow-up); this was mainly due to a decrease in those with the abdominal obesity and hypertension criteria as the number of subjects with the TG, HDL-chol and fasting glucose criteria did not change (Figure 1). This reduction in MetS prevalence was greater than that found with RT only. There were also between group differences for the change in the total number of MetS components, with the RT+CR group decreasing from 2.3 ± 1.3 to 1.8 ± 1.5 and no change in the RT only group (2.2 ± 1.3 to 2.4 ± 1.4).

Intervention effects on individual/continuous measures of cardiometabolic risk factors

None of the individual components of MetS were significantly improved from baseline to post-intervention in RT group. In fact, fasting glucose significantly increased in the RT group, with a significant between-group difference (Table 2). Fasting insulin decreased within the RT group, but there was no difference between groups. The insulin sensitivity index HOMA-IR did not change significantly in either group (Table 2). Only the RT+CR group experienced a significant reduction in blood pressure (systolic $p<0.0001$, diastolic $p<0.05$), but there was a significant between group difference observed only for systolic blood pressure ($p<0.001$; Table 2). Serum LDL-chol and Total-chol did not change significantly in either group, whereas VLDL-chol and TG decreased significantly more in the RT+CR group compared to the RT group ($p=0.001$ and $p<0.001$ respectively) (Table 2). HDL-chol significantly improved within the RT+CR group without a significant between-group difference.

Discussion

In this study, we investigated the effects of two lifestyle intervention programs on MetS, defined as a cluster of cardiometabolic risk factors. In summary, we demonstrated that a combination of RT+CR, resulting in a modest amount of weight loss (-5.5%), significantly reduced the presence of MetS (from 46% to 31%) in an overweight/obese population of adults older than 65 years. However, RT alone, without weight loss, was not beneficial for improving MetS criteria. Our observations provide strong support for prescribing moderate weight loss to reduce MetS in older adults.

Participants in our study represent the older American population, many of whom are overweight, hypertensive and at risk for CVD and diabetes. At baseline, nearly 50% of participants (44% and 46% in the RT and RT+CR groups, respectively) met the criteria for MetS. Abdominal obesity and hypertension were the primary components that contributed to these percentages. In response to the interventions, the decreases in abdominal obesity and blood pressure in those undergoing RT+CR were the main criteria leading to this group's significantly lower number of metabolic abnormalities. In line with these results, Bateman et

al. (2) concluded that RT was not effective at improving MetS score in overweight and obese adults aged 18–70 years; but that aerobic training was effective for decreasing MetS presence. Importantly, in this previous study, body mass was significantly decreased with aerobic training, but was not changed with RT. Together with our findings, this suggests that MetS risk factor improvements are primarily the result of weight loss, rather than a particular exercise mode. This is in accordance with a review which shows that a dietary-based lifestyle modification is more effective in resolving MetS in adults (40). Given the increased prevalence of MetS in the U.S. population over 60 years of age (12), an intervention that has the potential to improve MetS abnormalities is promising, particularly among those who are overweight or obese.

There has been increased focus on the accumulation of excess fat in the abdominal region, and it has been proposed that waist circumference may be as good as, or even better, than BMI as a measure of excess adiposity and the risk of developing cardiovascular diseases in older adults (15, 36). Increased central adiposity is a key component of MetS (8), and increases in abdominal fat are well described with advancing age (3). Exercise can profoundly change body composition and can preferentially reduce abdominal and visceral obesity (31). Although exercise alone can induce weight loss, a significant reduction in body weight and fat mass requires long exercise sessions (i.e., >60min/day) and programs (>4 months) (27) and maximal benefit for reducing abdominal fat is observed when exercise is combined with dietary CR (17, 31). In the present study, the RT+CR group had a significant reduction in the abdominal obesity criteria for MetS, whereas the RT group did not. In absolute terms, waist circumference decreased by 1.5 cm (1%) and 4.8 cm (5%) in RT and RT+CR groups respectively (results not shown). The minimal decrease in waist circumference in the RT group is similar to results from Stensvold et al. who investigated the effect of RT on the clustering of cardiovascular risk factors and found that waist circumference was decreased significantly, but by only 1.4 cm (33). According to De Koning et al., a 5 cm change in waist circumference could increase CVD risk by 10%(7). By transferring these findings to our results, RT+CR could be associated with an almost 10% reduction in CVD risk compare to no reduction with RT only in older adults.

It is well established that diet-induced weight loss reduces resting blood pressure in overweight adults (28). In older adults with hypertension, the Trial of Non-Pharmacological Intervention in the Elderly (TONE) provides evidence for a beneficial effect of CR on blood pressure (38). However, intervention studies that evaluated the efficacy of CR and RT on blood pressure in older adults are more scarce (41). A smaller study did not show a greater reduction in blood pressure from CR plus aerobic exercise compared to exercise alone (41). In our study, we found a 6% (−8.3 mmHg) reduction in systolic blood pressure and 4% (−3.3 mmHg) reduction in diastolic blood pressure after 5 months of RT+CR. This reduction in blood pressure is of clinical importance, as it has been assumed that ~10 and ~5 mmHg decreases in systolic and diastolic blood pressure, respectively, could decrease the long-term risk of death by ischemic heart diseases by ~40% (19). We did not observe a significant reduction in systolic and diastolic blood pressure in the RT group. Thus, weight loss is the likely factor important for lowering blood pressure. It has been proposed that changes in systolic blood pressure are correlated with reductions in abdominal visceral fat (41, 42). The decrease in visceral fat with weight loss could contribute to a reduction in pro-inflammatory

cytokines such as tumor necrosis factor α and interleukin-6, thereby removing the stimulus for endothelial dysfunction and hypertension (42).

Aerobic and resistance exercise in the absence of weight loss has little or no effect on improving plasma lipid profiles in middle-aged (14) and older adults (4, 41). Previous studies do not show an independent effect of exercise on total chol, LDL-chol, HDL-chol, or TG in older adults (4, 41). Conversely, fat loss through CR or exercise produces comparable changes in lipoprotein concentrations (4, 41). Thus, it appears there is a positive association between exercise-induced changes in lipid profiles and the amount of weight loss induced by the exercise (18). Accordingly, the 5-month intervention of RT without weight loss in this study did not lower HDL-chol, VLDL-chol, LDL-chol, TG or total chol. However, when combining RT with CR, HDL-chol, VLDL-chol and TG were reduced. These results are in agreement with the studies by Dunstan et al. (10) and Oliveira et al. (26) showing that a longer period of training along with changes in body weight may be necessary to promote significant improvement in lipid profiles with RT. As a result, our data indicate that it is the combination of RT and CR that seems to be needed to improve lipid profiles in overweight and obese older adults.

Insulin resistance is considered the central factor that links MetS risk factors (29). Aerobic and resistance training have been proposed as interventions which could normalize skeletal muscle and adipose tissue insulin resistance associated with MetS (30). We did not observe any improvement in insulin sensitivity (HOMA-IR) following RT. Our results are in line with those of Stevensold et al. (33) and Banz et al. who did not report a change in insulin sensitivity following RT only (1). It might be that a reduction in body weight is needed to obtain a change in glucose metabolism; CR interventions resulting in weight loss cause improvements in insulin sensitivity in younger individuals (37). In our study, the addition of CR to RT was successful in generating greater weight loss, but surprisingly, this did not translate to greater improvements in glucose metabolism in this age group. Our results are consistent with results from three trials that assessed insulin sensitivity directly with a euglycemic clamp, which did not show a difference of adding CR to an exercise intervention compared to exercise alone in this age group (9, 32, 41).

Our study has several strengths: 1) We specifically targeted a homogenous community-dwelling group of older overweight and obese adults of 65–79 yr, 2) Covariates such as medication or disease were strictly controlled throughout the study, 3) The study duration of 5 months was long enough to detect relevant changes in MetS risk factors 4) The intensity of the exercise regimen was progressively increased during the interventional period to be consistent with the 70% 1RM goal, and was supervised by certified trainers and 5) Adherence and retention were very high with 88% of participants completing the study and 86% and 89% of participants attending the scheduled sessions for RT group and RT+CR group respectively. However, some limitations are worth mentioning. Insulin sensitivity was evaluated by a rather crude method based on fasting levels of glucose and insulin (HOMA-IR) rather than challenging the system with a glucose load (tolerance test) or with an euglycemic-hyperinsulinemic clamp. The insulin sensitivity outcomes derived from our data should thus be confirmed in future studies using those more accurate measurement

techniques. Another limit is the absence of a non-intervention control group. Thus, the independent effect of each component cannot be isolated with our study.

Research on the effects of RT on MetS management has only recently received greater attention. The present study provide insight that 5 month of a RT program combined with CR results in marked improvement in direct and indirect metabolic risk factors and significantly lowers the severity of MetS in our aging population. Further research about the effect of RT only or in combination with CR is warranted in older adults to ascertain if larger weight loss further reduces risk factors associated with MetS.

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Figure 1.
Effects of interventions on metabolic syndrome criteria

Table 1

Baseline demographic characteristics by treatment group

	RT (n=63)	RT+CR (n=63)
Age, y	69.4 ± 3.6	69.6 ± 3.9
Female, n (%)	34 (54%)	37 (59%)
White, n (%)	54 (86%)	55 (87%)
BMI, kg/m ²	30.7 ± 2.4	30.4 ± 2.2
Height, cm	168 ± 10	167 ± 9
Waist-to-hip ratio	0.89 ± 0.09	0.89 ± 0.09
Self-reported comorbidity, n (%)		
Hypertension	31 (49%)	36 (57%)
Diabetes ¹	9 (14%)	6 (10%)
Sleep apnea	20 (32%)	14 (22%)
Arthritis	37 (59%)	40 (64%)
Chronic back pain	15 (24%)	12 (19%)
Medication use, n (%)		
Antihypertensive	32 (51%)	32 (51%)
Cholesterol-lowering	24 (38%)	33 (52%)
Glucose control	9 (14%)	4 (6%)
Antidepressant/mood	8 (13%)	14 (22%)

All data are Mean ± SD or # (%)

CR, caloric restriction; RT, resistance training

¹Non-insulin-treated diabetes

There were no significant differences between groups by using ANOVA at P<0.05

Table 2

Cardiometabolic variables at baseline and changes with intervention

	RT		RT+CR		P-between groups
	Baseline (n=49-63)	Changes relative to baseline (n=49-55)	Baseline (n=52-63)	Changes relative to baseline (n=52-55)	
Body mass, kg	87.3 ± 13.1	-0.1 ± 2.2	85.4 ± 11.7	-4.9 ± 3.9 [†]	<0.0001
Metabolic variables					
HDL-cholesterol (mg/dl)	53.0 ± 14.9	0.7 ± 8.0	55.3 ± 14.5	1.8 ± 6.8 [*]	0.245
VLDL-cholesterol (mg/dl)	24.3 ± 11.2	1.0 ± 9.3	26.2 ± 12.2	-4.8 ± 9.8 [*]	0.001
LDL-cholesterol (mg/dl)	118.3 ± 34.1	0.8 ± 21.2	105.2 ± 30.6	1.9 ± 21.0	0.596
Total cholesterol (mg/dl)	197.0 ± 39.2	1.9 ± 27.4	186.7 ± 38.2	-0.7 ± 22.0	0.160
TG (mg/dl)	134.6 ± 96.3	2.7 ± 58.1	131.0 ± 61.2	-23.7 ± 49.1 [*]	0.000
Glucose (mg/dl)	99.6 ± 14.7	6.9 ± 21.3 [*]	97.5 ± 10.3	-0.38 ± 8.9	0.009
Fasting insulin (μIU/ml)	17.5 ± 11.3	-3.1 ± 10.0 [*]	14.5 ± 7.6	-1.4 ± 5.6	0.659
HOMA-IR (μIU/ml×mg/dl)	4.4 ± 3.1	-0.5 ± 2.8	3.5 ± 1.9	-0.3 ± 1.5	0.326
Systolic blood pressure (mmHg)	137.3 ± 22.6	0.02 ± 17.9	134 ± 18.3	-8.3 ± 15.9 [†]	0.000
Diastolic blood pressure (mmHg)	76.1 ± 10.9	-0.8 ± 10.2	74.0 ± 10.3	-3.3 ± 8.9 [*]	0.013

All values are mean ± SDs. CR, caloric restriction; RT, resistance training; HOMA, homeostatic model assessment of insulin resistance; HDL-cholesterol, high-density lipoprotein cholesterol; VLDL-cholesterol, very low density lipoprotein cholesterol; TG, triglycerides

Compared to baseline within each group using paired t-test:

[†] P<0.0001,

^{*} P<0.05

Between-group differences for baseline values were analyzed using an ANOVA. There were no significant differences between groups at baseline, except fasting insulin and HOMA were higher in RT vs RT+CR at baseline (p<0.05)