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Effects of Exercise and Weight Loss in Older Adults with Obstructive Sleep Apnea

Devon A. Dobrosielski^{1,4}, Susheel Patil², Alan R. Schwartz², Karen Bandeen-Roche³, and Kerry J. Stewart⁴

¹Department of Kinesiology, Towson University, Towson, MD

²Division of Pulmonary and Critical Care Medicine, Johns Hopkins School of Medicine, Baltimore MD

³Department of Biostatistics, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD

⁴Division of Cardiology, Johns Hopkins School of Medicine, Baltimore MD

Abstract

Purpose—Obstructive sleep apnea (OSA) is prevalent among older individuals and is linked to increased cardiovascular disease morbidity. This study examined the change in OSA severity following exercise training and dietary induced weight loss in older adults and the association between the changes in OSA severity, body composition and aerobic capacity with arterial distensibility.

Methods—Obese adults (n=25) with OSA, aged 60 years or older, were instructed to participate in supervised exercise (3 days/week) and follow a calorie-restricted diet. Baseline assessments of OSA parameters, body weight and composition, aerobic capacity and arterial distensibility were repeated at 12 weeks.

Results—Nineteen participants completed the intervention. At 12 weeks, there were reductions in body weight (−9%) and percentage total body fat (−5%) and trunk fat (−8%), while aerobic capacity improved by 20% (all p's<0.01). The apnea-hypopnea index (AHI) decreased by 10 events per hour (p<0.01) and nocturnal SaO₂ (mean SaO₂) improved from 94.9% at baseline to 95.2% post intervention (p=0.01). Arterial distensibility for the group was not different from baseline (p=0.99), yet individual changes in distensibility were associated with the change in nocturnal desaturations (r=−0.49, p=0.03), but not with the change in body weight, AHI or aerobic capacity.

Conclusion—The severity of OSA was reduced following an exercise and weight loss program among older adults, suggesting that this lifestyle approach may be an effective first line non-surgical and non-pharmacological treatment for older patients with OSA.

Address correspondence to: Devon A. Dobrosielski, PhD, Department of Kinesiology, Towson University, 8000 York Road, Towson, MD 21252, ddobrosielski@towson.edu, Fax: (410) 704–3912, Phone: (410) 704–5604.

Conflict of Interest:

The authors report no conflicts of interest. The results of the present study do not constitute endorsement by ACSM.

Keywords

weight loss; mean SaO₂; apnea-hypopnea index; arterial distensibility

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Introduction

Obstructive sleep apnea (OSA) is characterized by repeated episodes of upper airway obstruction that are associated with reductions in ventilation, arousals and/or oxyhemoglobin desaturations during sleep (33). OSA can lead to excessive daytime sleepiness and fatigue, which, in turn, may cause vehicular and industrial accidents (39). In addition to neurocognitive sequelae (5), OSA is associated with increased cardiovascular disease (CVD) morbidity and mortality (35).

While the pathology linking OSA with CVD is complex, it is well accepted that obesity plays an important role in the OSA/CVD interaction. Obesity is the strongest predictor of OSA (34) and lifestyle interventions that promote weight loss are recommended in clinical guidelines as effective treatment strategies (30). The evidence in support of this recommendation has been recently reviewed by Araghi and colleagues (3), who report that lifestyle programs are associated with a decrease in apnea-hypopnea index (AHI) of between 6 events to 12 events per hour of sleep. However, despite these promising findings, there are several gaps in the existing knowledge that warrant further attention.

First, the prevalence of OSA in adults > 60 years is considerably higher compared to middle aged adults (44), yet the abundance of data demonstrating the efficacy of lifestyle interventions for improving OSA severity have been shown in younger to middle aged cohorts (3). Increasing age is correlated with greater pharyngeal collapsibility, independent of body mass index (BMI), and some studies have demonstrated increased airway resistance during sleep in older adults versus younger adults (32). Moreover, compared with weight-matched younger adult control subjects, healthy older adults demonstrate wider oscillations in upper airway resistance during supine sleep that may contribute to greater tendency for periodic breathing (21). Interestingly, exercise, independent of changes in body weight, reduces the severity of OSA (23). These above data suggest that factors beyond obesity contribute to the OSA phenotype in older adults. Given recent trends showing rising rates of obesity among the elderly (13) and evidence associating OSA with increased CVD morbidity in this demographic (42) it would be clinically relevant and of great public health importance to examine the effectiveness of a lifestyle program, consisting of both structured exercise and a weight loss diet on OSA in this vulnerable cohort.

Second, while it is likely that lifestyle change will translate to improved cardiovascular profiles among OSA patients, there have been few studies that have examined intermediary mechanisms of cardiovascular disease (e.g., endothelial function, inflammation, increased sympathetic activity) in the context of an intervention that also reduces obesity and improves aerobic capacity. Since obesity, especially central adiposity, (9) and aerobic capacity (28) also predict CVD risk and mortality, it is unclear whether improvements in these outcomes or reductions in OSA severity are primarily responsible for mitigating cardiovascular disease risk.

Accordingly, the principal aim of this study was to examine the change in OSA severity following a combined exercise and dietary induced weight loss intervention in a group of older men and women. A secondary aim was to examine the association among changes in OSA severity, body weight, body composition and aerobic capacity with arterial distensibility, a marker of vascular wall damage (43) that is highly correlated with cardiovascular outcomes in older adults (40).

Materials and Methods

Participant recruitment and screening

Obese adults (BMI between 30 and 43 kg/m²), aged 60 years and older were eligible for the study. Individuals were excluded if they; 1) were currently being treated for OSA, 2) were engaged in moderate intensity exercise for 90 minutes per week (19), 3) followed a hypocaloric diet for the purpose of weight loss (in last 3 months), 4) had a history of cardiovascular disease as defined by medical history, 5) had untreated hypothyroidism or hyperthyroidism, 6) had moderate to severe hypertension DBP $\geq$ 100 mmHg or SBP $\geq$ 160 mmHg, 7) were diagnosed with central sleep apnea $\geq$ 5 events/hour, 8) had AHI $>$ 60 events/hour and nocturnal oxygen saturation $<$ 85% for $>$ 15% of the record, 9) had diabetes mellitus requiring insulin, 10) had an exercise stress test that was positive for ischemia, complex arrhythmias, or symptoms indicative of ischemia or (11) underlying osteoarthritis that would limit the ability to exercise.

Recruitment occurred through media advertisements. Phone screenings were conducted to determine initial eligibility and to administer the Berlin questionnaire (31) to identify patients at risk for OSA. A score $\geq$ 2 was used to suggest a positive screen for OSA. Those who were previously diagnosed with OSA or who were classified as high risk for OSA were invited to undergo baseline screening. The baseline screening consisted of an orientation to the study and obtaining written informed consent that was approved by the Johns Hopkins University Institutional Review Board. A physician performed a medical history and physical that was followed by a graded exercise test to screen for cardiovascular disease as outlined in 10) above.

Individuals who qualified were scheduled to undergo overnight polysomnography monitoring that served as the baseline measure of OSA severity. Upon waking up the next morning, participants underwent vascular testing, which was immediately followed by body composition assessment. After eating a light breakfast, participants underwent cardiopulmonary exercise testing. Once baseline assessments were completed, participants were enrolled in an exercise and dietary weight loss intervention for 12 weeks. All assessments were repeated in the same order within a week following the end of the intervention.

Polysomnographic assessment

Patients were admitted to the unit at 5 p.m. for the sleep study. Thereafter, a standardized meal was provided for dinner at 6 p.m. Sleep study recording sensors were applied. Standardized recording methods using Remlogic 1.3 (Natus Medical Inc.; Broomfield, CO)

were utilized (22), and included continuous monitoring of left and right electro-oculogram, submental EMG, F3-M2, C3-A2 and O1-M2 electroencephalogram, anterior tibialis electromyogram, oronasal airflow as assessed by both a pressure sensitive nasal cannula and a thermistor, pulse oximetry and thoracic and abdominal movements with respiratory inductive plethysmography, and a modified V5 ECG lead for cardiac rhythm monitoring. The sleep study commenced at 10:00 p.m. (lights out), and ended at 6:00 a.m. the following morning. An apnea was defined as a significant decrease ($>90\%$) in oronasal flow ≥ 10 s, hypopnea as an evident decrease in airflow $>30\%$, but $<90\%$ and associated with either oxygen desaturation of $\geq 3\%$ and/or arousal. The AHI was defined as the sum of apneas and hypopneas per hour of sleep. Mean oxyhemoglobin saturation (mean SaO_2) and average nadir SaO_2 associated with each disordered breathing event (average Low SaO_2) during sleep were retained as markers of OSA severity. Patients were classified as having OSA if the AHI was equal to or exceeded 5 events per hour of sleep.

Arterial distensibility

Beat-by-beat pulse wave amplitude was captured using fingertip peripheral arterial tonometry (PAT) (ENDOPAT 2000, Itamar Medical, Caesarea, Israel) as previously described (7), and used in the determination of arterial distensibility (26). Plethysmographic finger cuffs were placed on the index fingers of both hands while the subjects lay in a supine position. The arterial pressure waveform is a composite of the forward pressure (P1) wave created by ventricular contraction and a wave reflected from the periphery (P2), mainly at branch points or sites of impedance mismatch. From the second derivative of the pulse pressure waveform obtained by the finger plethysmograph, the amplitudes of the second (P2) and first (P1) inflections were obtained (41). The augmentation index (AI) was calculated from the ratio of the difference between P1 and P2 systolic peaks of the waveforms relative to P1 expressed as a percentage $(P2-P1/P1 \times 100)$ (20). An elevated AI derived from PAT is associated with the increased severity of atherosclerosis (41) and abnormal ventricular-vascular coupling (20). This method for calculating AI correlates well ($R=0.68$, $p<0.001$) with radial artery tonometry (18).

Body Composition

Dual Energy X-Ray Absorptiometry (DEXA) was used to measure total and regional (trunk) fat mass in the frontal plane. These data are presented as percentages. Trunk fat was defined from the body of the mandible to the neck of the femur and laterally to the glenohumeral joint. We used a GE Lunar Prodigy (Software Version 13, Milwaukee, WI), which uses advanced fan-beam array mode technology.

Aerobic Capacity

Aerobic capacity testing was done on a treadmill integrated with a Viasys Metabolic/ECG system using a modified Balke protocol, beginning at 3 mph, 0% grade, and increasing 2.5% grade every three minutes until volitional fatigue was reached. A 12-lead ECG was recorded at each stage. Blood pressure was measured during the last 30 seconds and the Rating of Perceived Exertion (RPE) using the Borg 6 to 20 scale (8) was obtained during each stage. Subjects were urged to push themselves to volitional fatigue. An RPE of 18–20 and a

respiratory exchange ratio > 1.1 was used to confirm maximal effort was achieved in every participant. The highest observed 30-second average value of VO_2 was considered maximal.

Exercise training and dietary weight loss intervention

Participants were prescribed cardiorespiratory training and resistance exercise using American College of Sports Medicine guidelines (15). In accordance with these recommendations, cardiorespiratory conditioning consisted of a combination of moderate- and vigorous-intensity exercise on a treadmill, stationary cycle, or stairstepper to achieve a total energy expenditure of $>500\text{--}1000 \text{ MET}\cdot\text{min}\cdot\text{wk}^{-1}$. Participants attended three supervised exercise sessions per week. A gradual progression of exercise duration was employed until each participant could accumulate 45 total minutes of cardiorespiratory conditioning per session, after which intensity was raised incrementally and ultimately varied between 60% and 85% maximal heart rate. Participants wore heart rate monitors (Polar Inc., Lake Success, NY) continuously and were monitored by study staff. American College of Sports Medicine equations were used to estimate $\text{MET}\cdot\text{min}\cdot\text{wk}^{-1}$. On the same day, participants performed two sets of 10–15 repetitions of the following exercises; latissimus dorsi pull down, leg extension, leg curl, bench press, leg press, shoulder press, and seated mid-rowing. An increase in weight was employed once participants could successfully complete two sets of a given resistance for 15 repetitions. Resistance training volume per week was reported as the sum of the total amount of weight lifted (weight x repetitions x sets) per session.

In addition to the exercise intervention, each participant was given dietary advice by a study dietician that was consistent with American Heart Association Diet and Lifestyle Recommendations (29). The overarching goal of the diet intervention was to help the participants achieve weight loss between 8% and 10% baseline body weight in 12 weeks. Participants met with a study dietician once per week for the first four weeks and biweekly thereafter to review food diaries and measure body weight, as this is the most practical outcome to monitor and is the outcome most likely to be of interest to participants. Upon reviewing food records and body weight the dieticians offered counseling and dietary education to help each participant reach his/her goal weight. Three-day food records were completed at baseline and post intervention and were subsequently analyzed using Food Processor software (ESHA Research, Salem, OR).

Statistical Methods

Primary outcomes of interest are presented as median (interquartile range) for continuous variables. Baseline associations between markers of OSA severity, body weight, body composition, aerobic capacity and arterial distensibility were evaluated with Spearman's rank test. Dietary data (baseline and post intervention) and exercise programming data (months 1, 2 and 3) were evaluated for change over time using a dependent t-test and repeated measures ANOVA, respectively. These data are represented as mean (SD). Baseline and post intervention values for the primary outcomes of interest were compared using the Wilcoxon signed-rank test. We calculated Spearman's correlations (ρ) between 12-week changes in measures of body weight, total body and trunk fat percentage, aerobic capacity and OSA parameters with arterial distensibility to examine the weight loss induced

changes in these variables with arterial distensibility. The level of statistical significance was set at $P < 0.05$ (2 tailed). Analyses were performed using STATA version 12 (StataCorp LP, College Station, TX).

Results

Baseline characteristics

One hundred thirty nine individuals responded to advertisements. Eighty-one did not meet inclusion criteria and 18 could not be contacted for subsequent follow-up. Of the remaining 40 individuals who underwent phone screening, one died prior to providing informed consent and four declined future participation. Thirty-five individuals were invited to visit the lab based on the Berlin score, provided informed consent and underwent diagnostic screening on a treadmill. Five individuals were excluded due to EKG abnormalities during the treadmill test suggestive of underlying cardiovascular disease or BMI below 30 kg/m^2 . Of the remaining 30 individuals who underwent polysomnography, five we excluded due to $\text{AHI} < 5$.

Fifteen women and ten men enrolled in the study (mean age of the sample; 67 ± 4 years). None of the participants had been previously diagnosed with OSA. A summary of the baseline associations between markers of OSA severity and body composition and arterial distensibility is provided in Table 1. Of note, lower mean SaO_2 was associated with higher body weight ($r = -0.41$, $p = 0.04$), as well as total body fat percentage ($r = -0.45$, $p = 0.02$) and trunk fatpercentage ($r = -0.54$, $p < -0.01$). The average low SaO_2 was inversely related to body weight ($r = -0.46$, $p = 0.02$) and BMI ($r = -0.42$, $p = 0.04$). Interestingly, more severe AHI was associated with lower total body fat percentage ($r = -0.42$, $p = 0.04$). To explore the potential for confounding by sex, scatterplots and spearman's rho coefficients were produced separately by sex strata. The sex-specific analyses proved similar to each other and the overall analyses, contraindicating substantial sex-related confounding as a concern.

Effects of exercise and dietary weight loss

Of the 25 participants who completed baseline testing, two individuals suffered an injury unrelated to the study and were withdrawn from the intervention, one individual lost a family member to death and withdrew voluntarily and three individuals dropped out of the program due to their inability to adhere to the exercise or diet appointments. The remaining 19 participants completed the exercise and diet intervention, which was followed by post intervention testing. Nutrition data acquired from food diaries are reported in Table 2. As expected, there was a marked reduction in total calories consumed ($p < 0.01$) as well as percentage of total calories derived from fat ($p < 0.01$), whereas the amount of calories derived from dietary protein increased ($p < 0.01$). Exercisers who completed post intervention testing attended a mean (SD) of 34 (2.8) of their prescribed 36 sessions (95% compliance). Table 2 summarizes the exercise training data according to month enrolled in the program. The average $\text{MET} \cdot \text{min} \cdot \text{wk}^{-1}$ and resistance training volume per week increased from Month 1 (weeks 1–4) to Month 3 (weeks 9–12).

Baseline and post intervention data for all completers (12 women; 7 men) are displayed in Table 3. Of note, the intervention resulted in a 9% loss of body weight ($p<0.01$) and reduced AHI by 10 events per hour of sleep ($p=0.03$). Similarly, we observed marked reductions in total body fat percentage (-5%) trunk fat percentage (-8%) and waist circumference (-6%), (all p 's <0.01), while aerobic capacity improved by 20% ($p<0.01$). Also, total sleep time increased by 27 minutes (<0.01) and nocturnal SaO_2 also improved (mean SaO_2) from 94.9% at baseline to 95.2% post intervention ($p=0.02$). The average low SaO_2 at baseline was 89.9% compared to 91.0% post intervention ($p=0.02$). No significant change in AI was observed.

Comparisons between changes in arterial distensibility with changes in OSA severity, body composition and aerobic capacity

The relationship between the change in arterial distensibility and markers of OSA severity, body composition and aerobic capacity were examined and are expressed in Table 4. A reduction in AI following the intervention was associated with improved nocturnal mean SaO_2 ($\rho=-0.47$, $p=0.04$) and average low SaO_2 ($\rho=-0.57$, $p=0.01$), while the relationship with the reduction in total body fat percentage fell short of statistical significance ($\rho=0.45$, $p=0.05$). By contrast, no association was observed for the change in AI and the change in weight, AHI or aerobic capacity. Moreover, the change in body weight was not related to any marker of OSA severity.

Discussion

It is well established that continuous positive airway pressure (CPAP) therapy is an effective first line, non-surgical and non-pharmacological intervention for the management of OSA (25), yet the utility of CPAP is limited by poor patient adherence. We found marked reductions in disordered breathing events and improvements in nocturnal oxyhemoglobin desaturation among older adults with OSA following a 12-week exercise and diet intervention. These positive changes in OSA severity were accompanied by weight loss and reduced total body fat, as well as an increase in aerobic capacity, thus supporting the view that a comprehensive lifestyle approach may be a desirable and effective treatment for patients with OSA, particularly in those with poor adherence to CPAP. In contrast, no significant reduction in mean arterial distensibility was observed following the intervention. However, correlational analysis revealed that positive changes in arterial distensibility were related to improvements in nocturnal desaturations, but not reductions in weight, disordered breathing events or improvements in aerobic capacity.

The present finding of a reduction of 10 apneic events per hour of sleep compares favorably to previous studies that have employed similar therapeutic approaches. Barnes et al. (4) found that four months of supervised exercise, consisting of both aerobic and resistance training, combined with very low energy diet led to a reduction of AHI from 24 to 18 events (-25%) and a 12 kg weight loss among 12 middle aged OSA patients. In the Sleep AHEAD trial (14), older (mean age 61 years) obese adults with type 2 diabetes underwent an intensive lifestyle intervention for one year and lost 8.6% of body weight, which was associated with a decrease in AHI of 10 events per hour of sleep. However, while Sleep

AHEAD encouraged physical activity, this was not closely evaluated. Thus, the implication of the current study is that older adults appear to accrue similar benefits on OSA severity as younger cohorts, when prescribed a regimen of structured exercise and a weight loss diet.

Parceling out the independent contributions of exercise or weight loss for reducing OSA severity is beyond the scope of the present study, although we suspect exercise plays a significant role, due in part to the lack of association between the change in body weight and the change in apneic events. Others (16, 24, 37) have reported improvements in AHI of between 4 and 10 events per hour of sleep, independent of weight loss, in patients who have been prescribed structured exercise for between four and six months. It has been speculated that exercise may improve pharyngeal muscle tone and strength or result in shifts in peripheral fluid accumulation (23). Further, we suspect that improvements in OSA severity are more closely linked to the patterns of regional weight loss, rather than the total amount of weight lost, because abdominal visceral fat elevates mechanical loads on the upper airway and is an abundant source of pro-inflammatory cytokines, which when released may lead to depression of CNS activity and upper airway neuromuscular control (36). That said, we (38) have shown that exercise training alone, independent of weight loss, leads to a significant reduction in visceral fat among older adults. Thus, exercise may mitigate OSA severity by reducing visceral adipose tissue. While changes in OSA severity were not associated with improvement in trunk fat in our sample, our DXA methods lack the sensitivity to detect specific change in the abdominal visceral compartment.

Contrary to other exercise (11) and weight loss (17) studies in non-OSA groups we did not observe a change in arterial distensibility among this group of OSA patients following the intervention. The reason(s) for the lack of change are unclear and we cannot discount the possibility that we made a type 2 error due to our small sample. Further, apart from having OSA, our participants were relatively healthy, as demonstrated by the fact that 1) they had no history of cardiovascular disease and 2) aerobic capacity at baseline for the men and women exceeded predicted normal values by 10% and 70%, respectively (See Table 14; reference (2)). Therefore, there may have been limited room for vascular improvement, although we did not have an appropriate control group to make meaningful comparisons. However, our group-averaged data obscured some interesting observations; namely, that the change in AI was inversely related to the change in nocturnal desaturation, but not to the changes in AHI, body weight or aerobic capacity. While this correlation was observed in a relatively small sample, it suggests that beneficial cardiovascular outcomes accrued through an exercise and diet program may be influenced to a greater extent by improvements in the severity of hypoxemia, rather than the frequency of disordered breathing events or the change in body weight. It also implies that vascular impairment that exists in many patients with OSA may not be the cause or consequence of physical inactivity or cardiovascular deconditioning. Supporting this line of reasoning are data from Drager et al.(10) showing that treatment of OSA with continuous positive airway pressure improves arterial stiffness without affecting body weight. Why the change in AI was more strongly associated with hypoxemia rather than AHI is not immediately clear. Yet, chronic intermittent hypoxia with reoxygenation is thought to be similar to repeated ischemia-reperfusion damage with increased production of reactive oxygen species (27). This increased oxidative stress leads to increased expression of proinflammatory cytokines as well as adhesion molecules that are

believed to activate monocytes, lymphocytes and endothelial cells, resulting in vascular dysfunction. We believe our data could have implications for how we design and implement therapies to reduce CVD risk in OSA, especially with regard to lifestyle programs. While exercising and losing weight will undoubtedly have major implications for cardiovascular morbidity, concomitant use of CPAP to treat underlying OSA (1) may allow for exercise training and weight loss to result in more beneficial cardioprotective outcomes.

This study arose out of an initiative whose ultimate goal is to ameliorate frailty and thereby prolong independent living for older adults. Data from the Cardiovascular Health Study show an independent association between severe sleep disordered breathing and one or more indicators of frailty (12). On the surface our data may seem to add little to this finding, as our cohort consisted of relatively healthy, but overweight, older adults with a history of snoring and daytime sleepiness (as determined by the Berlin questionnaire). However, while the frailty syndrome is typically viewed by lay persons as synonymous with underweight, given the rising prevalence of obesity among older adults (13), and that an obese frail phenotype has already been recognized (6), the most common phenotype of frailty in the future may be that of an obese disabled person. Whether underlying OSA accelerates the onset of frailty and disability remains to be determined, but we argue that the therapeutic approach with the largest clinical impact is one that targets those who are not yet frail but are at high risk for this syndrome.

Several limitations of our study deserve comment. First, we lacked a non-intervention control group. Second, the experimental design did not allow us to compare the effectiveness of diet or exercise alone versus a combined diet and exercise intervention on improvements in OSA. Since this is an understudied cohort our ultimate decision to include a lifestyle group incorporating diet and exercise is based on our hypothesis that we would see the most change in OSA severity following the intervention and therefore we will be able to establish effect sizes that can, in turn, be used to power a larger study. Also, from a clinical application perspective, dietary interventions are most effective for weight loss and maintenance when physical activity/exercise is added. Third, the issue of whether OSA attenuates the reduction in weight or improvements in vascular function is clinically important, but one that we could not explore given the current design. To address whether underlying OSA moderates weight loss or improvements in cardiovascular function will require a non-OSA control. Fourth, we employed very strict selection criteria. Accordingly, our results may not be easily extrapolated to older adults with comorbidities. Fifth, the study was relatively short and we cannot be certain of the physiological effects of a longer trial. Moreover, it is not clear whether individuals' willingness to persevere with this type of intervention extends beyond 12 weeks, although we have reported high compliance rates among older adults who were participating in a similar exercise regimen for six months (38).

Conclusions

The role of lifestyle interventions on OSA severity in older adults has received little attention in the literature. This study has provided two unique findings. First, we observed that OSA severity is improved in a sample of older men and women following a weight loss intervention consisting of structured exercise and dietary change. Second, we found that a

change in arterial distensibility is more closely associated with the change in nocturnal desaturations than changes in apneic events, body weight or aerobic capacity.

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Table 1

Associations between OSA severity, body composition and vascular parameters at baseline (n=25)

	AHI	Mean SaPO ₂	Average Low SaPO ₂
Weight, kg	0.13	-0.41	-0.46*
BMI, kg/m ²	0.18	-0.24	-0.42*
Total body fat, %	-0.42*	-0.45*	0.14
Trunk fat, %	-0.37	-0.54**	0.16
SBP, mmHg	0.19	0.30	0.09
DBP, mmHg	0.15	0.10	-0.12
AI, %	-0.01	-0.01	-0.03

Data are presented as Spearman rank correlations. SBP: systolic blood pressure; DBP: diastolic blood pressure; AI: augmentation index.

* (p<0.05),

** (p<0.01)

Table 2
Dietary and exercise programming data for participants who completed the intervention (n=19)

Dietary Data	Baseline	Post Intervention	P-value
Total Calories, kcal	2062 (683)	- 1439 (431)	<0.01
Calories from fat, %	37 (8)	- 31 (8)	<0.01
Calories from CHO, %	43 (7)	- 46 (7)	0.07
Calories from protein, %	17 (4)	- 20 (4)	<0.01
Calories from alcohol, %	3 (4)	- 3 (3)	0.25

Exercise Data	Month Enrolled			P-value
	1	2	3	
MET•min•wk ⁻¹ ^a	668 (295)	889 (414)	1046 (544) [*]	0.04 ^c
Resistance Volume ^b	21809 (8866)	25442 (8267)	29138 (8592) [*]	0.04 ^c

Data are presented as mean (SD). Significance levels set at p<0.05. CHO: Carbohydrates

^aRepresents the mean of the sum of the metabolic cost during each week for each participant
^bRepresents the mean of the sum of the total weight lifted during each week for each participant
^cANOVA main effect
^{*} P<0.05 vs. Month 1

Table 3

Baseline and post intervention values for primary outcomes among completers

Variable	Baseline	Post Intervention	p-value
Body composition			
Weight, kg	97.5 (82.0 to 114.2)	88.4 (78.4 to 105.3)	<0.01
BMI, kg/m ²	33.8 (32.6 to 36.9)	31.6 (30.3 to 34.7)	<0.01
Waist Circumference, cm	108 (101 to 114)	102 (97 to 113)	<0.01
Total Body Fat, %	42.2 (38.3 to 47.6)	39.9 (34.4 to 46.9)	<0.01
Trunk Fat, %	46.6 (41.9 to 49.4)	43.0 (37.9 to 48.2)	<0.01
Aerobic capacity			
VO _{2max} ml/kg/min	22.3 (18.8 to 25.4)	26.8 (23.1 to 28.6)	<0.01
* VO _{2max} L/min	1.91 (1.79 to 2.80)	2.17 (2.05 to 2.97)	<0.01
Vascular parameters			
SBP, mmHg	129 (114 to 147)	123 (112 to 131)	0.20
DBP, mmHg	69 (65 to 76)	67 (65 to 72)	0.50
AI, AU	36 (22 to 44)	26 (10 to 49)	0.84
Sleep parameters			
Total Sleep Time, min	389 (323 to 401)	416 (395 to 444)	<0.01
Mean SaO ₂ , %	94.9 (94 to 95.4)	95.2 (94.4 to 95.7)	0.02
Average Low SaO ₂ , %	89.9 (88.5 to 91.5)	91.0 (89.4 to 92)	0.02
AHI, events/hour	22 (14 to 44)	12 (5 to 26)	0.03

Data are presented as median (interquartile range)

* Absolute VO_{2max} at baseline for women (mean=1.78 L/min), men (mean=2.89 L/min)

BMI; Body Mass Index, SBP: systolic blood pressure, DBP; diastolic blood pressure, AHI: apnea-hypopnea Index

Table 4

Associations between changes in OSA severity, body composition, aerobic capacity and arterial distensibility

	Mean SaPO ₂	Mean Low SaPO ₂	AHI	Weight	BMI	Total Body Fat	Trunk Fat	VO _{2max}
Average Low SaPO ₂ , %	0.66*	--						
AHI, events/hour	-0.15	-0.53*	--					
Weight, kg	-0.40	-0.49*	0.25	--				
BMI, kg/m ²	-0.26	-0.48*	0.38	0.92*	--			
Total Body Fat, %	-0.36	-0.32	0.11	0.64*	0.41	--		
Trunk Fat, %	-0.26	-0.28	0.08	0.59*	0.38	0.96*	--	
VO _{2max} , ml/kg/min	-0.07	0.25	-0.11	-0.24	0.14	-0.27	-0.25	--
AI, %	-0.47*	-0.57*	0.40	0.20	0.12	0.45	0.34	-0.38

Data are presented as Spearman rank correlations. AHI; apnea-hypopnea index, BMI; Body mass index, AI; augmentation index.

* p<0.05