CLINICAL INVESTIGATION

Effects of Interval Training on Visceral Adipose Tissue in Centrally Obese 70-Year-Old Individuals: A Randomized Controlled Trial

Marcel Ballin, MSc,† Emmy Lundberg, BSc,*† Niklas Sörlén, MSc,*† Peter Nordström, MD, PhD,* Andreas Hult, PhD,† and Anna Nordström, MD, PhD*†‡*

OBJECTIVE: To investigate the effects of 10 weeks of progressive vigorous-intensity interval training as a single intervention on body composition among 70-year-old individuals with central obesity.

DESIGN: Randomized controlled trial (ClinicalTrials.gov registration No. NCT03450655).

SETTING: Community-dwelling 70-year-old men and women living in the Umeå municipality in Sweden.

PARTICIPANTS: Seventy-seven 70-year-old men and women with central obesity (greater than 1 kg visceral adipose tissue [VAT] for women and greater than 2 kg VAT for men).

INTERVENTION: Participants allocated to the intervention group were offered a 10-week progressive concurrent exercise program performed three times per week. All participants in both groups had received tailored lifestyle recommendations focused on diet and physical activity at one occasion within 12 months prior to trial initiation.

MEASUREMENTS: The primary outcome was changes in VAT, and secondary outcomes included changes in total fat mass (FM), total lean body mass (LBM), and body mass index.

RESULTS: Comparing the groups, there were no significant differences in decrease of VAT mass ($P = .10$), although the intervention group significantly decreased FM by 716 g ($P = .01$) and gained LBM by 508 g ($P = .03$), compared to the control group. Furthermore, the effects of the training were significantly greater in the male subcohort ($P < .05$ for interaction), with positive effects also on VAT and FM, where men in the intervention group decreased VAT by 175 g ($P < .05$) and FM by 1364 g ($P = .004$), compared to the male controls.

CONCLUSIONS: The present trial demonstrates that 10 weeks of progressive vigorous interval training is sufficient to significantly decrease FM in older adults with central obesity, with positive effects also on LBM. **J Am Geriatr Soc 00:1-7, 2019.**

Key words: exercise; lean body mass; visceral fat

Today, more than 650 million people are estimated to be obese,[1] and the number of older adults is expected to double by the year 2050.[2] More specifically, obesity has increased also in older people, with more than one-third of adults aged 65 years or older estimated to experience obesity.[3] Each of these trends, accompanied by the decrease in the level of physical activity as people age, has severe impacts on the risk of noncommunicable diseases and all-cause mortality.[4–8]

Aging is known to lead to a gradual decrease in lean body mass (LBM) and to affect total and regional fat mass (FM) distribution.[9,10] In particular, it results in an increased amount of fat in the abdominal region, known as visceral adipose tissue (VAT),[11] also in older people.[12] This factor is of particular interest, as VAT is associated with greater risk for cardiovascular disease (CVD) than general obesity.[13] Consequently, physical activity has shown to improve markers of obesity in overweight and obese populations,[14–16] even in the absence of a hypocaloric diet.[17] However, the effects of more intense exercise on VAT in older adults are not conclusive.[18,19] Therefore, research and consensus on strategies that are likely to be plausible for obese older adults are lacking.

Given that people age differently, exercise programs for older adults would likely have to be developed accordingly, enabling personalized adaptation and progression, which probably is of even greater importance for this population compared to younger people. Therefore, the aim of this trial

From the *Department of Community Medicine and Rehabilitation, Geriatric Medicine, Umeå University, Umeå, Sweden; †Department of Public Health and Clinical Medicine, Occupational and Environmental Medicine, Umeå University, Umeå, Sweden; and the ‡School of Sport Sciences, The Arctic University of Norway, Tromsø, Norway.

Address correspondence to Anna Nordström, MD, PhD, Department of public health and clinical medicine Umeå university, 90187 Umeå, Sweden. E-mail: anna.h.nordstrom@umu.se

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was to investigate the effects of 10 weeks of easy-to-perform, personalized, progressive vigorous-intensity interval training among 70-year-old individuals with central obesity on changes in body composition, including VAT.

METHODS

Study design

This parallel, two-armed, randomized controlled trial with an allocation ratio of 1:1 (ClinicalTrials.gov registration No. NCT03450655) sought to investigate the effects of the current exercise program on measures of body composition. The design, procedures, and informed consent protocol were approved by the regional ethical review board of Umeå, Sweden (Dnr 2017-521-31). The trial was conducted in accordance with the World Medical Association's Declaration of Helsinki and reported according to the Consolidated Standards of Reporting Trials guidelines.[20]

Participants

Participants were recruited between January 2018 and February 2018 from the Healthy Aging Initiative (HAI), an ongoing population-based prevention study conducted in the municipality of Umeå, in northern Sweden. In the HAI, all 70-year-old individuals in Umeå are invited to participate in a free health survey. To date, 84% of the individuals contacted, representing 68% of the eligible population, have chosen to participate. The HAI has been described in detail previously.[21]

Inclusion and exclusion criteria

While central obesity has been defined as waist circumference (WC) greater than 88 cm for women and greater than 102 cm for men,[22] there are, to the best of our knowledge, no reference values for central obesity defined by VAT for this cohort. Thus, based on dual-energy X-ray absorptiometry (DXA) measures from 2675 participants in the HAI study, we determined the mean VAT mass for individuals with a WC of 88 ± 2 cm (1.00 ± 0.34 kg for women; n = 203) and 102 ± 2 cm (2.13 ± 0.56 kg for men; n = 240). These values were then rounded off to 1 and 2 kg for women and men, respectively, and subsequently used as inclusion criteria in the present trial.

Individuals with conditions that contraindicated training or affected the ability to perform the training program were excluded. The exclusion criteria were formalized as: physical disability affecting the ability to perform the exercises within the program; heart failure or severe degenerative condition; myocardial infarction or stroke in the previous 12 months; heart condition that would worsen with aerobic exercise (eg, angina pectoris); and systolic blood pressure higher than 175 mm Hg and diastolic blood pressure higher than 100 mm Hg. In addition, individuals had to pass a resting electrocardiogram (ECG; Schiller Cardiovit CS-6/12; Schiller AG). Any uncertainty that arose during baseline measurement regarding ECG results or contraindicated conditions was discussed with the physicians in charge of the trial (A.N. and P.N.).

Sample size

The sample size for the current trial was estimated to provide 80% power to detect a 20% reduction in VAT mass during the intervention period, with the α level set to .05. Data for the calculation were used from 1200 HAI participants (606 women and 594 men) with central obesity, as defined above. The results showed that a total of 33 men and 45 women would be needed, with a number within that range needed for mixed groups. Statistical power was calculated using G*Power, version 3.0.10.[23]

Randomization

All individuals underwent baseline assessment and were then randomized using 80 preprepared, opaque sealed envelopes containing notes indicating "Training" and "Control" (n = 40 each). Before each participant was given permission to draw an envelope and learn his/her group assignment, all envelopes were shuffled under the supervision from M.B. or E.L.

Intervention

All individuals had previously attended the HAI study sometime during the past 12 months, leading up to the current trial, whereby they had received tailored health recommendations at one occasion focusing on diet and physical activity. Following randomization, individuals allocated to the intervention group participated in a 10-week-long, weekly progressive concurrent exercise program starting in February 2018. The program is described in detail elsewhere (Supplementary Text S1), but in short, supervised training sessions were performed in a group setting three times per week for 10 weeks. The exercises used were personalized, dynamic body-weight exercises initially performed for 18 minutes in terms of circuit-based interval training with a prescribed work/rest ratio of 40:20. Subsequently, there was a gradual increment in duration to a final maximum training duration of 36 minutes. The increment in volume was employed in terms of progressively adding the number of sets and repetitions. Participants were instructed to reach a vigorous intensity, based on a modified version of the Borg CR10 scale,[24] where the participants were encouraged to reach 6 to 7. Control subjects were asked to maintain their daily living and routines throughout the trial.

Assessments

Blinded research personnel performed baseline and outcome assessments between 8 AM and 5 PM. The time of day of the two tests was standardized and matched as much as possible for each participant. All subjects were instructed not to engage in intense physical activity or consume alcohol on the day prior to each assessment and to fast for a minimum of four hours prior to measurement. Outcome assessments were performed for all participants within 10 days of the last exercise session. Blood pressure and resting heart rate were measured using a digital automatic blood pressure device (Omron M6 Comfort HEM-7221-E; Omron Healthcare) after a 15-minute rest with the subject in a supine position. Descriptive data on daily physical activity were retrieved

from the HAI study, where the participants, as part of their health examination, wore a triaxial accelerometer (GT3X+; Actigraph) for 7 consecutive days, as described previously in detail.[21]

Primary outcome measure

The primary outcome measure was the change in VAT mass, measured using a DXA device (Lunar iDXA) and the CoreScan application (GE Healthcare Lunar). The CoreScan application enables objective measurement of VAT mass by a computerized algorithm based on the attenuation of X-ray radiation. By using this method, VAT is distinguished from subcutaneous adipose tissue. Research involving iDXA CoreScan measurement has shown an absolute precision error (root-mean-square SD) of 41.4 g in overweight groups.[25]

Secondary outcome measures

FM, body fat percentage (BFP), and LBM were derived from total-body scans performed with the Lunar iDXA device. The relative precision errors using iDXA have been deemed 1.8% for FM and 0.8% for LBM in overweight groups.[25] Anthropometric data were obtained by measuring height with a gauge (Holtain Limited; Crymych) and weight with a digital scale (HL 120; Avery Berkel). The body mass index (BMI; kg/m^2) was calculated by dividing weight by height squared.

Statistical analysis

Statistical analyses were performed using SPSS software, version 25.0 (IBM Corp). Analyses were conducted on an intention-to-treat basis. Normal distribution was assessed through tests of skewness and kurtosis. For baseline comparison of continuous variables, independent-sample *t*-tests were performed since the data were found to be normal in distribution. For categorical variables, χ^2 tests were performed. Paired *t*-tests were performed for within-group comparisons of measures obtained before and after the 10-week intervention period. Between-group differences for the outcomes of interest were estimated using linear regression models, with the follow-up value as the dependent variable, and adjusting for the baseline value. To evaluate sex differences, a statistical interaction variable in terms of the product of sex and group belonging (both 0 or 1) was created, which was added together with the other covariates (sex, group belonging, and baseline value) in a linear regression model, with the outcomes of the trial as the dependent variable, including VAT. The significance level was set at $P \leq .05$.

RESULTS

Participant recruitment and adherence to the intervention

Among 427 participants in the HAI study during the 12 months prior to the start of the present trial, 193 individuals were identified as meeting the inclusion criterion. Of these individuals, 103 declined participation, did not respond, or were deemed ineligible by application of the exclusion criteria, resulting in a total study sample of 90 individuals. From the 90 individuals included, seven were excluded due to absence during baseline measurements and six were excluded due to failure to pass a resting ECG. Seventy-seven participants completed baseline measurements and were allocated to the intervention (n = 38) and control (n = 39) groups. Two participants in the intervention group and three participants in the control group did not complete the trial due to voluntary termination of participation; thus, 36 participants in each group completed the trial. The median attendance rate in the intervention group was 89% (interquartile range [IQR] = 80%-96%). For men and women separately, the median attendance rate was 96% (IQR = 82%-100%) and 89% (IQR = 73%-95%), respectively, with no significant difference between them. For an outline of the recruitment process and participant flow, please see Supplementary Figure S1.

Participant characteristics

Participant characteristics at baseline are presented in Table 1. Both groups had similar characteristics at baseline. The mean age of the participants was 70.7 ± 0.24 years, with nearly equal proportions of men and women (52% women). At baseline, the mean VAT mass was 2.23 ± 0.92 kg and the mean BMI was 29.2 ± 3.3 kg/m^2 in the total cohort.

Effects of the intervention on body composition

Comparing the groups in the total cohort, there was no significant difference between the intervention group and the control group on the primary outcome, VAT ($P = .10$). However, there were significant differences on secondary outcomes (Table 2, Figure 1). Participants in the intervention group decreased FM by 716 g (95% confidence interval [CI] = 159-1274 g; $P = .01$) and BFP by 0.7% (95% CI = 0.3%-1.2%; $P = .003$), and gained LBM by 508 g (95% CI = 64-951 g; $P = .03$), compared to the control group. No significant difference was seen in BMI ($P = .50$).

Interaction analyses showed significant interactions for sex on VAT and FM ($P < .05$ for both) but not on LBM or BMI. Men in the intervention group lost 175 g of VAT (95% CI = 3-347 g; $P = .047$) and 1364 g of FM (95% CI = 459-2268 g; $P = .004$), compared to men in the control group (Supplementary Figure S2). In contrast, there were no significant effects of the intervention in the female subgroup for these outcomes ($P > .05$ for both).

Potential adverse events and other effects of the training

During the 10-week intervention period, five participants in the intervention group reported adverse events, consisting of lateral epicondylitis, swelling in the metacarpophalangeal joint, muscle strains, knee bursitis, and Achilles tendinitis (n = 1 each). In addition, three participants reported adverse events unrelated to the current intervention, consisting of lumbago, muscle strain, and wrist fracture (n = 1 each). However, none of these conditions lasted longer than the intervention period or affected participants' ability to complete the outcome assessment.

Two participants in the intervention group were unable to complete the trial due to discomfort following training sessions and continuous illness unrelated to the intervention,

Table 1. Participant characteristics at baseline

Characteristics	Total (n = 77)	Intervention (n = 38)	Control (n = 39)	*P* value
Anthropometrics				
Age, y	70.7 ± 0.24	70.7 ± 0.25	70.7 ± 0.24	.9
Women	40 (52)	18 (47)	22 (56)	.6
Height, m	1.70 ± 0.10	1.69 ± 0.09	1.71 ± 0.10	.3
Weight, kg	84.2 ± 11.3	84.7 ± 9.4	83.7 ± 12.9	1.0
Body Composition				
VAT, kg	2.23 ± 0.92	2.30 ± 0.82	2.16 ± 1.01	.6
FM, kg	33.23 ± 5.89	33.36 ± 5.82	33.10 ± 6.04	1.0
BFP, %	39.6 ± 6.2	39.6 ± 6.6	39.6 ± 5.8	1.0
LBM, kg	48.18 ± 9.07	48.56 ± 8.73	47.81 ± 9.48	1.0
BMI, kg/m^2	29.2 ± 3.3	29.7 ± 3.1	28.7 ± 3.5	.3
Daily PA[a]				
Sedentary, %	65.9 ± 9.0	66.0 ± 7.9	65.9 ± 10.2	1.0
Light PA, min	251.2 ± 70.6	252.2 ± 68.9	250.3 ± 73.5	.9
Moderate PA, min	28.2 ± 23.3	27.2 ± 20.1	29.2 ± 26.1	.7
Vigorous PA, min	0.2 ± 0.7	0.2 ± 0.8	0.2 ± 0.7	.7
Total steps	6549 ± 2889	6341 ± 2450	6770 ± 3318	.6
AEE, kcal	369 ± 154	373 ± 159	366 ± 150	.9
SBP, mm Hg	140 ± 15	143 ± 15	137 ± 15	.06
DBP, mm Hg	84 ± 7	84 ± 7	83 ± 7	.7
Resting heart rate, bpm	67 ± 9	67 ± 12	66 ± 7	.8
Variables and Medication				
Lipid-lowering medication	32 (42)	13 (34)	19 (49)	.3
Hypertension medication	47 (61)	23 (61)	24 (62)	.7
Type 2 diabetes	10 (13)	4 (11)	6 (15)	.5
Active smoker	2 (3)	2 (6)	0	.2
Medical History				
Previous stroke	2 (3)	1 (3)	1 (3)	.9
Previous cardiac infarction	6 (8)	2 (5)	4 (10)	.5

Data are presented as group means ± SD or number (percentage).

Abbreviations: AEE, activity energy expenditure; BFP, body fat percentage; BMI, body mass index; bpm, beats per minute; DBP, diastolic blood pressure; FM, fat mass; LBM, lean body mass; PA, physical activity; SBP, systolic blood pressure; VAT, visceral adipose tissue.

[a]Data from the Healthy Aging Initiative study.

respectively. Several participants who had osteoarthritis preceding the start of this trial reported pain relief during the course of the intervention.

DISCUSSION

The present trial showed that 10 weeks of vigorous-intensity interval training effectively improved body composition in older adults with central obesity. It decreased FM by close to threefold relative to the control group, with positive effects also on LBM, in absence of effect on BMI. Moreover, it was shown that the intervention significantly decreased VAT but only in the male participants.

A substantial body of literature shows that total excessive FM and VAT, and loss of LBM, are associated strongly with cardiometabolic risk factors and CVD.[4–6,26–29] Although previous research has systematically shown the importance of exercise,[14–17] consensus on optimal exercise intensity as well

Table 2. Changes in outcomes during the 10-week intervention period

	Within-group differences						Between-group differences		
	Intervention (n = 36)			Control (n = 36)			Intervention difference (n = 36)	Control difference (n = 36)	
Variable	Baseline	At 10 wk	*P* value	Baseline	At 10 wk	*P* value			*P* value
Body Composition									
VAT, g	2339 ± 809	2176 ± 758	<.001	2226 ± 1019	2147 ± 998	.028	−163 ± 204	−78 ± 205	.10
FM, g	33 424 ± 5940	32 353 ± 6004	<.001	33 475 ± 6047	33 120 ± 6109	.054	−1071 ± 1281	−355 ± 1067	.013
BFP, %	39.6 ± 6.6	38.8 ± 6.9	<.001	39.6 ± 5.8	39.5 ± 5.7	.60	−0.8 ± 1.1	−0.1 ± 0.8	.003
LBM, g	48 621 ± 8837	48 900 ± 8918	.08	48 699 ± 9293	48 472 ± 9607	.17	280 ± 929	−227 ± 969	.026
BMI, kg/m^2	29.8 ± 3.1	29.4 ± 3.1	<.001	29.0 ± 3.5	28.7 ± 3.6	.006	−0.4 ± 0.5	−0.3 ± 0.5	.50

Data are presented as group means ± SD.

P values for the between-group differences are derived from linear regression models, adjusted for baseline measurements.

Abbreviations: BFP, body fat percentage; BMI, body mass index; FM, fat mass; LBM, lean body mass; VAT, visceral adipose tissue.

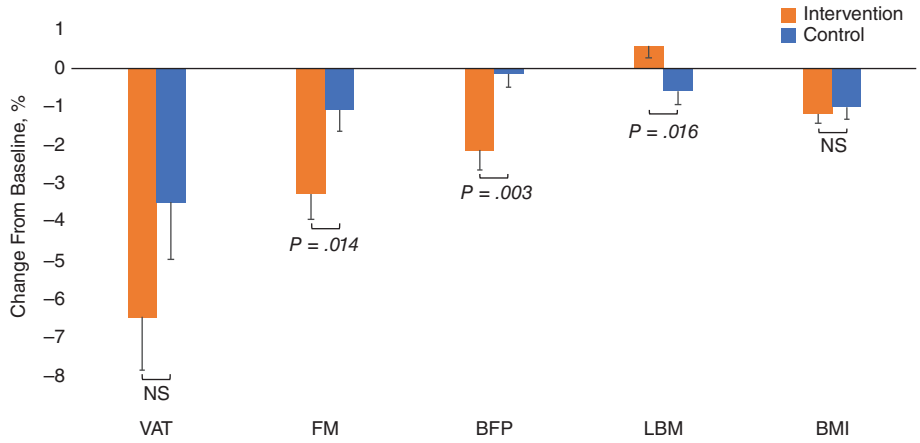

Figure 1. Mean percentage individual changes in body composition in the study groups following the 10-week intervention period. Error bars represent SEMs. *P* values are derived from linear regression models on mean change from baseline in percentage, adjusted for baseline values. Abbreviations: BFP, body fat percentage; BMI, body mass index; FM, fat mass; LBM, lean body mass; NS, not significant; VAT, visceral adipose tissue.

as effective and suitable strategies for decreasing VAT in older adults is lacking.[18,19] This is of importance with respect to the observed prevalence of obesity among older people.[3]

A previous meta-analysis showed that exercise may decrease VAT by 6.1% in absence of weight loss.[30] Although we found a decrease of 6.4% in VAT within the intervention group, this was not significant compared to changes seen in the control group. This may have been caused by a combination of lack of statistical power and the precision error for VAT measurements, making it more difficult to detect small changes.[25] Also, it is not unlikely that the lifestyle consultation provided to the participants in the HAI study prior to the present trial may have contributed as well, since the control group also decreased VAT. While randomized controlled trials on older adults have detected larger decreases in VAT, these included either small samples or dietary interventions, with the aim of keeping the participants in an energy deficit and having them lose weight.[18,19] This impedes evaluation of the isolated effects from exercise.

As for the other measures of body composition, we found a 3% decrease in FM within the intervention group. While another trial on obese older adults found a 5% decrease in FM,[31] our findings are encouraging given that the present intervention lasted only 10 weeks compared to 52 weeks, despite much shorter exercise sessions. Furthermore, aging is known to result in a physiological loss of LBM,[10] and weight loss in general is associated with increased risks of adverse outcomes, including death, in older people.[32] It is therefore of importance that the training did not only result in a net loss of FM, but the intervention group did also gain in LBM compared to the control group. Trials targeting muscle hypertrophy in populations of older people have produced conflicting results,[33,34] and most endurance-focused trials have failed to produce significant effects.[35] In relation to previous research,[36] an exercise-induced energy deficit with capacity also to increase muscle mass, appears to be preferable to a diet-only–induced energy deficit, with resulting loss also of vital LBM.[37] While the present intervention was seemingly efficient for producing favorable effects in a relatively short period of time, these lifestyle changes must be sustained for a longer period of time and evaluated with prospective follow-up assessments to determine their clinical relevance in relation to cardiometabolic health.

In terms of the sex-specific analyses, there were some interesting, albeit preliminary, findings in the male subcohort, where men in the intervention group decreased both VAT and FM significantly more compared to men in the control group. These findings corroborate those of previous studies on overweight adults,[17,38,39] and given that there was no significant difference in adherence between men and women, the hypothesis that there are sex differences in terms of decreasing VAT cannot be ruled out.[40] To that end, it is of interest that we also found sex-specific effects on functional strength from resistance training in a recent randomized study in a similar cohort as the present.[32] Even so, it is critical to note that these are merely exploratory findings, requiring further confirmatory research based on larger study samples before any definitive conclusions can be drawn.

Some limitations of this trial, including the sample size, should be considered. Due to exclusions and dropouts before and during the intervention, the sample was smaller than our initial power calculations suggested would be appropriate. Thus, the results with respect to VAT might have been affected, especially for the sex-specific analyses; hence, the statistical power of the analysis would have been greater with a larger sample. Furthermore, the aim of this trial was to have the participants reach vigorous intensity during exercise. We cannot determine whether they actually reached this level, as we did not objectively measure heart rate. Another limitation is that we did not monitor the participant's diet during the intervention; thus, it is possible that some participants modified their diet, thereby confounding the results.

The primary strengths of the present trial lie in the randomized design and in the use of DXA as an objective measure of changes in body composition. Another strength is the design of the exercise program, which consisted predominantly of a few body weight exercises involving several muscle groups, with feasibility evaluated by potential participants prior to the trial. Moreover, an intriguing finding

from the present trial is the attendance rate, which is high compared to results from a systematic review on adherence to exercise programs for older adults.[41] Based on our experience, we propose that exercise and program design must be considered carefully when involving older people. Also, the exercise program may be performed in a home environment, without expensive gym equipment, which increases its availability for the public at large. This should be noted, since availability, convenience, and affordability have been identified as facilitators for engaging in exercise among older adults.[42] Thus, we believe that the current intervention may be applied in other settings and generalized to other cohorts, including older people.

In conclusion, the main finding of this trial is that 10 weeks of progressive vigorous interval training decreased total FM by almost threefold compared to the control group while increasing muscle mass. These outcomes are previously known to be associated with improved cardiometabolic health and decreased risk of CVDs. The intervention was feasible, with a high attendance rate; was easy to perform; and yet was possible to personalize to help older participants with different physical capacities reach a high intensity. Future research should explore the relative importance of diet and preferred intensity of exercise in terms of improving body composition, including VAT, in older populations, specifically with regards to potential sex differences.

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Lundberg: conception and design; acquisition of data; analysis and interpretation of data; revising the article critically for important intellectual content; final approval.

Sörlén: conception and design; acquisition of data; revising the article critically for important intellectual content; final approval.

P. Nordström: acquisition of data; analysis and interpretation of data; revising the article critically for important intellectual content; final approval.

Hult: conception and design; acquisition of data; analysis and interpretation of data; revising the article critically for important intellectual content; final approval.

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REFERENCES

1. World Health Organization. Overweight and Obesity. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight. Accessed December 10, 2018.
2. United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Ageing 2017 - Highlights* (ST/ESA/SER. A/397).
3. Fakhouri TH, Ogden CL Carroll MD, Kit BK, Flegal KM. Prevalence of obesity among older adults in the United States, 2007-2010. NCHS Data Brief. 2012;(106):1-8.
4. Hossain P, Kawar B, El Nahas M. Obesity and diabetes in the developing world: a growing challenge. N Engl J Med. 2007;356:213-215.
5. Adams KF, Schatzkin A, Harris TB, et al. Overweight, obesity, and mortality in a large prospective cohort of persons 50 to 71 years old. N Engl J Med. 2006;355:763-778.
6. Kopelman PG. Obesity as a medical problem. Nature. 2000;404:635-643.
7. Tanaka H, Dinenno FA, Monahan KD, Clevenger CM, DeSouza CA, Seals DR. Aging, habitual exercise, and dynamic arterial compliance. Circulation. 2000;102:1270-1275.
8. Lee IM, Shiroma EJ, Lobelo F, et al. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. Lancet. 2012;380:219-229.
9. Kuk JL, Saunders TJ, Davidson LE, Ross R. Age-related changes in total and regional fat distribution. Ageing Res Rev. 2009;8:339-348.
10. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, et al. Sarcopenia: European consensus on definition and diagnosis: report of the European Working Group on Sarcopenia in Older People. Age Ageing. 2010;39:412-423.
11. Wajchenberg BL. Subcutaneous and visceral adipose tissue: their relation to the metabolic syndrome. Endocr Rev. 2000;21:697-738.
12. Hunter GR, Gower BA, Kane BL. Age related shift in visceral fat. Int J Body Compos Res. 2010;8:103.
13. Yusuf S, Hawken S, Ounpuu S, et al. Obesity and the risk of myocardial infarction in 27,000 participants from 52 countries: a case-control study. Lancet. 2005;366:1640-1649.
14. Kay SJ, Fiatarone Singh MA. The influence of physical activity on abdominal fat: a systematic review of the literature. Obes Rev. 2006;7:183-200.
15. Ross R, Janssen I. Physical activity, total and regional obesity: dose-response considerations. Med Sci Sports Exerc. 2001;33:S521-S527. discussion S528-S529.
16. Wewege M, van den Berg R, Ward RE, Keech A. The effects of high-intensity interval training vs. moderate-intensity continuous training on body composition in overweight and obese adults: a systematic review and meta-analysis. Obes Rev. 2017;18:635-646.
17. Vissers D, Hens W, Taeymans J, Baeyens JP, Poortmans J, Van Gaal L. The effect of exercise on visceral adipose tissue in overweight adults: a systematic review and meta-analysis. PLoS One. 2013;8:e56415.
18. Coker RH, Williams RH, Kortebein PM, Sullivan DH, Evans WJ. Influence of exercise intensity on abdominal fat and adiponectin in elderly adults. Metab Syndr Relat Disord. 2009;7:363-368.
19. Nicklas BJ, Wang X, You T, et al. Effect of exercise intensity on abdominal fat loss during calorie restriction in overweight and obese postmenopausal women: a randomized, controlled trial. Am J Clin Nutr. 2009;89:1043-1052.
20. Altman DG, Schulz KF, Moher D, et al. The revised CONSORT statement for reporting randomized trials: explanation and elaboration. Ann Intern Med. 2001;134:663-694.
21. Johansson J, Nordstrom A, Nordstrom P. Objectively measured physical activity is associated with parameters of bone in 70-year-old men and women. Bone. 2015;81:72-79.
22. National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III). Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III) final report. Circulation. 2002;106:3143-3421.
23. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods. 2007;39:175-191.
24. Borg G. A category scale with ratio properties for intermodal and interindividual comparisons. In: Geissler HG, Petzold P, ed. Psychophysical judgment and the process of perception. Berlin: VEB Deutscher Verlag der Wissenschaften, 1982:25-34.
25. Meredith-Jones K, Haszard J, Stanger N, Taylor R. Precision of DXA-derived visceral fat measurements in a large sample of adults of varying body size. Obesity. 2018;26:505-512.
26. Fox CS, Massaro JM, Hoffmann U, et al. Abdominal visceral and subcutaneous adipose tissue compartments: association with metabolic risk factors in the Framingham Heart Study. Circulation. 2007;116:39-48.
27. Fontana L, Eagon JC, Trujillo ME, Scherer PE, Klein S. Visceral fat adipokine secretion is associated with systemic inflammation in obese humans. Diabetes. 2007;56:1010-1013.

28. Carr DB, Utzschneider KM, Hull RL, et al. Intra-abdominal fat is a major determinant of the National Cholesterol Education Program Adult Treatment Panel III criteria for the metabolic syndrome. Diabetes. 2004;53:2087-2094.
29. Atkins JL, Whincup PH, Morris RW, Lennon LT, Papacosta O, Wannamethee SG. Sarcopenic obesity and risk of cardiovascular disease and mortality: a population-based cohort study of older men. J Am Geriatr Soc. 2014;62:253-260.
30. Verheggen RJ, Maessen MF, Green DJ, Hermus AR, Hopman MT, Thijssen DH. A systematic review and meta-analysis on the effects of exercise training versus hypocaloric diet: distinct effects on body weight and visceral adipose tissue. Obes Rev. 2016;17:664-690.
31. Villareal DT, Chode S, Parimi N, et al. Weight loss, exercise, or both and physical function in obese older adults. N Engl J Med. 2011;364:1218-1229.
32. Miller SL, Wolfe RR. The danger of weight loss in the elderly. J Nutr Health Aging. 2008;12:487-491.
33. Vikberg S, Sorlen N, Branden L, et al. Effects of resistance training on functional strength and muscle mass in 70-year-old individuals with pre-sarcopenia: a randomized controlled trial. J Am Med Dir Assoc. 2019;20:28-34.
34. Hakkinen K, Alen M, Kallinen M, Newton RU, Kraemer WJ. Neuromuscular adaptation during prolonged strength training, detraining and re-strength-training in middle-aged and elderly people. Eur J Appl Physiol. 2000;83:51-62.
35. Bouaziz W, Vogel T, Schmitt E, Kaltenbach G, Geny B, Lang PO. Health benefits of aerobic training programs in adults aged 70 and over: a systematic review. Arch Gerontol Geriatr. 2017;69:110-127.
36. Weiss EP, Racette SB, Villareal DT, et al. Lower extremity muscle size and strength and aerobic capacity decrease with caloric restriction but not with exercise-induced weight loss. J Appl Physiol. 2007;102:634-640.
37. Beaudart C, Zaaria M, Pasleau F, Reginster JY, Bruyere O. Health outcomes of sarcopenia: a systematic review and meta-analysis. PLoS One. 2017;12:e0169548.
38. Kuk JL, Ross R. Influence of sex on total and regional fat loss in overweight and obese men and women. Int J Obes (Lond). 2009;33:629-634.
39. Donnelly JE, Hill JO, Jacobsen DJ, et al. Effects of a 16-month randomized controlled exercise trial on body weight and composition in young, overweight men and women: the Midwest Exercise Trial. Arch Intern Med. 2003;163:1343-1350.
40. Link JC, Reue K. Genetic basis for sex differences in obesity and lipid metabolism. Annu Rev Nutr. 2017;37:225-245.
41. Picorelli AM, Pereira LS, Pereira DS, Felício D, Sherrington C. Adherence to exercise programs for older people is influenced by program characteristics and personal factors: a systematic review. J Physiother. 2014;60:151-156.
42. Bethancourt HJ, Rosenberg DE, Beatty T, Arterburn DE. Barriers to and facilitators of physical activity program use among older adults. Clin Med Res. 2014;12:10-20.

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article.

Supplementary Text S1. Description of the exercise program.

Supplementary Figure S1. Study flowchart.

Supplementary Figure S2. Mean percentage individual changes in body composition in the intervention group and control group for men (A) and women (B) separately. Error bars represent SEMs. *P* values are derived from linear regression models on mean change from baseline in percentage, adjusted for baseline values. FM indicates fat mass; VAT, visceral adipose tissue.