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EFFECTS OF WHOLE-BODY ELECTROMYOSTIMULATION EXERCISE AND CALORIC RESTRICTION ON CARDIOMETABOLIC RISK PROFILE AND MUSCLE STRENGTH IN OBESE WOMEN WITH THE METABOLIC SYNDROME: A PILOT STUDY

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Obesity, particularly in conjunction with further cardiometabolic risk factors, is associated with an increased risk of cardiovascular disease and mortality. Increased physical activity and dietary modifications are cornerstones of therapeutic interventions to treat obesity and related risk factors. Whole-body electromyostimulation (WB-EMS) has emerged as an innovative, time-efficient type of exercise that can provide positive effects on body composition and muscle strength. However, the impact of WB-EMS on cardiometabolic health in obese individuals with metabolic syndrome (MetS) has yet to be determined. The aim of this pilot study was, therefore, to investigate the feasibility and effects of WB-EMS on cardiometabolic risk markers and muscle strength in obese women diagnosed with MetS. Twenty-nine obese women (56.0 ± 10.9 years, BMI: 36.7 ± 4.6 kg/m^2) with the clinical diagnosis of MetS were randomized to either 12 weeks of WB-EMS (n = 15) or an inactive control group (CON, n = 14). Both groups received nutritional counseling (aim: –500 kcal energy deficit/day). WB-EMS was performed 2×/week (20 min/session). Body composition, maximum strength (F_{max}) of major muscle groups, selected cardiometabolic risk indices and the metabolic syndrome Z-score (MetS-Z) were determined baseline and after the intervention. WB-EMS was well tolerated and no adverse events occurred. Body weight was significantly reduced in both groups by an average of ~3 kg ($P < 0.01$). The body fat percentage was only decreased in the WB-EMS group ($P = 0.018$). Total cholesterol concentrations decreased in the WB-EMS group ($P = 0.018$) and in CON ($P = 0.027$). Only the WB-EMS group increased F_{max} significantly in all major muscle groups ($P < 0.05$) and improved the overall cardiometabolic risk score (MetS-Z, $P = 0.029$). This pilot study indicates that WB-EMS can be considered as a feasible and time-efficient exercise option for improving body composition, muscle strength and cardiometabolic health in obese women with MetS. Moreover, these findings underpin the crucial role of exercise during weight loss interventions in improving health outcomes.

Key words: *obesity, cardiometabolic disorders, physical activity, whole-body electromyostimulation, resistance training, calorie-reduced diet, weight loss, body composition*

INTRODUCTION

The prevalence of obesity has steadily increased globally over the last decades (1). Excessive body weight has been shown to be associated with numerous health-related conditions, including cardiovascular disease, type 2 diabetes, some forms of cancer, musculoskeletal disorders, and an increased risk of mortality (2, 3). The clustering of obesity-related cardiometabolic risk factors, such as large waist circumference (excess abdominal fat), hypertension, dyslipidemia, hyperglycemia or insulin resistance (also referred to as the metabolic syndrome) increases the risk of cardiovascular disease by three-fold and of premature mortality by 50%, respectively (4). Thus, the rising prevalence of obesity is a significant public health concern throughout the world and there is an urgent need for effective therapy concepts. Adequate changes in diet and an increase in physical activity are cornerstones in the treatment of obesity and related comorbidities. Recently, it has been concluded that exercise training and a higher level of physical fitness improve risk factors that underlie the metabolic syndrome, regardless of body mass index (BMI) (5). In addition to aerobic exercise, it is recommended that obese individuals should regularly perform resistance training in order to counteract an inactivity-related loss of muscle mass and strength (6). Given that skeletal muscle mass is the largest metabolically active tissue in the body, muscular training can also have meaningful effects on glucose regulation, insulin sensitivity and resting metabolic rate (7, 8). The beneficial impact of resistance training on muscle functionality, body composition and various cardiometabolic risk markers in overweight and obese individuals has already been demonstrated in several studies (9). However, with increasing body weight, traditional resistance training programs, commonly consisting of several muscle exercises performed on weight machines or with free weights, become increasingly difficult due to the poor fitness level or physical complaints such as joint pains or intensified sensation of breathlessness that typically come along with severe obesity (10, 11).

Recently, whole-body electromyostimulation (WB-EMS) has emerged as a joint-friendly, potentially less exhausting and time-efficient alternative to traditional resistance training (12, 13). The WB-EMS technology allows a simultaneous activation of all major muscle groups through the application of an electrical current by means of specific suits with built-in electrodes. Studies have shown that WB-EMS can improve body composition, muscular strength and certain cardiometabolic risk markers in lean individuals (14), premenopausal overweight women (15) and older adults with sarcopenic obesity (16-18). However, data on the effects of WB-EMS on the cardiometabolic risk profile in obese metabolic syndrome patients, whose health risks are substantially higher than of individuals with overweight or milder obesity without clustering of cardiometabolic abnormalities, are still lacking. The aim of the present pilot study was, therefore, to investigate the feasibility and preliminary efficacy of WB-EMS for improving cardiometabolic health and muscle strength in obese women diagnosed with metabolic syndrome receiving standard nutritional counseling aimed at reducing body weight. Based on reports from previous studies in overweight and moderately obese individuals (15-18), we hypothesized that WB-EMS would be a safe and tolerable exercise option for obese metabolic syndrome patients and, that WB-EMS combined with caloric restriction would lead to greater improvements in the cardiometabolic risk profile than caloric restriction alone.

MATERIALS AND METHODS

Ethics statement

The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the ethical committee of the Friedrich-Alexander University Erlangen-Nuernberg (approval number: 203_17B). All participants were fully informed about the objectives and methods of the study and provided a written consent before participation.

Participants

Participants were recruited through newspaper advertisements and flyers posted in surrounding medical practices. Inclusion criteria were: minimum age of 18 years, BMI ≥ 30 kg/m^2 and central obesity (waist circumference > 80 cm) plus at least two additional cardiometabolic risk factors, including hypertension (≥ 130 mmHg systolic or ≥ 85 mmHg diastolic) or pharmacologic treatment of previously diagnosed hypertension, dyslipidemia (HDL-cholesterol < 50 mg/dL, triglycerides ≥ 150 mg/dL) or pharmacologic treatment of blood lipid abnormalities, fasting blood glucose ≥ 100 mg/dL or pharmacologic treatment of hyperglycemia, and homeostatic model assessment of insulin resistance (HOMA-IR) ≥ 2.0) (19, 20), a self-reported sedentary lifestyle (defined as no specific sports training and engaging in less than 30 min of moderate physical activity three times per week) over at least one year prior to the study and reporting a goal of weight loss. Exclusion criteria were: clinical diagnosis of heart disease, cancer, epilepsy, severe orthopaedic conditions or other major health problems that might preclude safe participation in the study, pregnancy and participation in other weight reduction programs within the last six months.

Experimental design

One week before the start of the intervention, participants completed the baseline examination. The baseline examination also included a routine medical check-up (including resting and exercise electrocardiography and measurement of blood pressure) to ensure a safe participation in the exercise program. All procedures were carried out under stable laboratory conditions at our Research-Center and were strictly standardized as outlined below. Outcome reassessment was repeated within the first week after completion of the intervention. All assessments were made in a single-blinded fashion, meaning that the personnel who collected the data were not aware of the participants' group assignment. Participants were instructed to refrain from alcohol and vigorous physical effort for at least 24 hours prior to the examinations. Participants were asked to maintain their usual lifestyle patterns throughout the study to minimize the potential confounding effects of changes in daily physical activity. After the baseline examination, participants were randomly assigned to either the WB-EMS group or an inactive control group (CON). Random assignment was achieved using the software MinimPy (GNU GPL v3), which was designed for automatic, computerized allocation of subjects to treatment groups in clinical trials. Randomization was performed independent of the researchers involved in data collection.

Procedures

1. Blood pressure measurements

Participants reported in the morning after an overnight fast to the laboratory. After resting for five minutes in a seated position in a quiet room, systolic and diastolic blood pressure values were measured using an automatic upper-arm blood pressure monitor (M5 professional, Omron, Mannheim, Germany). In total, three consecutive measurements were obtained at 60-second intervals and their averaged values were used in the analysis.

2. Blood sampling

A total of ~25 mL blood samples were drawn *via* venipuncture from an antecubital arm vein into different collection tubes using a disposable cannula (S-Monovette®, Sarstedt, Nurmbrecht, Germany). All blood samples were analyzed by the diagnostic laboratories of the University Hospital Erlangen. Serum values of glucose, triglycerides, total cholesterol, low density lipoprotein cholesterol (LDL-C) and high density lipoprotein cholesterol (HDL-C) were measured photometrically (Clinical Chemistry Analyzer AU700 or AU5800, Beckman Coulter, Brea, CA, USA). Serum glycosylated hemoglobin A_{1c} (HbA_{1c}) was determined using an turbidimetric immuneassay (Integra 400, Roche Diagnostics, Mannheim, Germany). Serum insulin concentration was assessed using a chemiluminescent immunoassay (Liaison XL, DiaSorin, Dietzenbach, Germany). HOMA-IR was calculated as follows (21):

$$HOMA-IR = \frac{fasting\ glucose\ (\text{mg/dl}) \times fasting\ insulin\ (\mu\text{U/ml})}{405}$$

Additionally, creatine kinase (CK) and creatinine levels (Clinical Chemistry Analyzer AU700 or AU5800, Beckman Coulter, Brea, CA, USA) were measured baseline, after 6 weeks and at the final examination to monitor muscular stress and potential effects on renal function.

3. Anthropometric and body composition measurements

Body height was obtained using a stadiometer (seca 274, Seca, Hamburg, Germany). Waist circumference was measured at the approximate midpoint between the lower margin of the last palpable rib and the upper iliac crest along the midaxillary line with a measuring tape while participants were in a standing position. Body composition measurements were performed using a segmental multi-frequency bioelectrical impedance analysis device (seca mBCA 515, Seca, Hamburg, Germany). All bioimpedance measurements were conducted according to the manufacturer's instructions and as previously described in detail (22).

4. Assessment of overall cardiometabolic risk

Participants' overall cardiometabolic risk was assessed using the metabolic syndrome Z-score (MetS-Z). MetS-Z combines several cardiometabolic risk factors into a single continuous score and allows determining the severity of cardiometabolic risk compared to others. A score below zero reflects a lower degree of cardiometabolic risk than the average population, whereas scores above zero are associated with higher risk for future health complications. MetS-Z was calculated according to the formula suggested by Johnson *et al*. (23), based on waist circumference (WC), mean arterial blood pressure (MAP), serum concentrations of fasting serum glucose (GLU), triglycerides (TG), and HDL-C, as follows:

$$[(50\text{-}HDL)/14.1] + [(TG\text{-}150)/81.0] + [(GLU\text{-}100)/11.3] + [(WC\text{-}88)/9.0] + [(MAP\text{-}100)/9.1]$$

5. Muscle strength testing

Maximum strength (F_{max}) of the major muscle groups (chest, upper back, lower back, abdominals and legs) was estimated through submaximal tests, based on the performance of multiple repetitions. Compared to the one repetition maximum (1-RM) test, which is considered the gold standard for assessing muscle strength in athletes and trained individuals (24), multiple repetition maximum strength tests involve less risk to induce injuries of the musculoskeletal system and are therefore recommended for untrained individuals and patients with pre-existing medical conditions (25-27). After a brief warm-up, initial instructions and familiarization with the test devices and the correct exercise techniques, participants performed the strength tests on the following five exercise devices: chest press, lat pulldown machine, lower back machine, abdominal crunch and leg press (TechnoGym, Neu-Isenburg, Germany). All tests were instructed and supervised by certified physiotherapists or sports therapists. The initial load was estimated based on the therapist's experience and feedback on questions regarding participants' training history. Subsequently, participants were instructed to perform as many repetitions as possible with the given load until concentric movement failure. The number of repetitions was not supposed to exceed six repetitions, which has been shown to be an appropriate number to accurately predict 1-RM (25). If the repetition number was more than six, the load was increased and a new attempt was performed after 3 min of rest. The detection of the respective weight was typically achieved within a maximum of three attempts. To avoid negative impacts of circadian rhythm on the test results, the baseline test and the retest were performed at approximately the same time of the day. Maximum strength (1-RM) was calculated according to the Brzycki equation (28), as follows:

$$1\text{-}RM = \frac{100 \times load\ rep}{102.78 - 2.78 \times rep}$$

6. Nutritional counselling

Participants received nutritional counseling at the baseline examination and at subsequent follow-up meetings every four weeks by a registered dietitian. Dietary advices to promote weight loss were given by face-to-face conversation at every meeting. As recommended by national and international guidelines for the prevention and treatment of obesity (29, 30), participants were advised to achieve a daily energy deficit of 500 kcal. To achieve this, individual nutritional advices were given based on the participants' dietary behavior prior to entering the study. Nutritional intake was monitored by 24 h-dietary records (Freiburger Ernaehrungsprotokoll; Nutri-Science, Freiburg, Germany) assessed on three days in a row at study entry and within the last week of the study intervention. Computer-based analysis of mean caloric and nutrient intake was done by the software Prodi®6 expert (Nutri-Science, Freiburg, Germany).

7. Whole-body electromyostimulation

All WB-EMS sessions were supervised and instructed one-to-one by certified physiotherapist and sports therapists, who were trained in implementing the specific WB-EMS protocol prior to the study. The training sessions were conducted twice a week for 20 min per session with at least two days rest between sessions. Each participant performed the training over a period of twelve weeks (a total of 24 sessions). The WB-EMS exercise was performed using devices and equipment from miha bodytec (Gersthofen, Germany), including a vest, a hip belt and upper-arm and thigh cuffs with integrated electrodes to induce the electrical muscle stimulation. The electrical muscle stimulation was applied by bipolar impulses at a frequency of 85 Hz and a pulse width of 350 µs inducing an intermittent stimulation of a 6 s impulse phase followed by 4 s rest as described in previous studies (14, 17, 31). In total, eight muscle groups were addressed by the WB-EMS application (upper arms, chest, upper back, latissimus, abdomen, lower back, buttocks and thighs). The current intensity was set to trigger a noticeable muscle contraction. During the impulse phase, participants performed two sets of light dynamic movements, each repeated for ten times, including trunk flexion and extension, moderate squats, butterfly movements and lat pull-down movements to support the activation of the mentioned muscle groups. The current intensity was individually adapted in each session and, where appropriate, increased accordingly to ensure training load progression.

Statistical analysis

Formal sample size calculations were not performed prior to this pilot study. However, it has been suggested that n = 12 per group is a good rule of thumb for estimating key outcomes with sufficient precision in pilot studies (32). The distribution of all data was checked using the Kolmogorov-Smirnov test. Initially, baseline comparisons between groups were performed by independent t-tests. Paired t-tests were performed to determine differences between baseline and follow-up in each group. In case of non-normally distributed data, non-parametric Wilcoxon's matched pair tests were conducted. For all analyses, the significance level was set at $P < 0.05$. All data are presented as means ± standard deviation (SD). In addition, effect sizes (Cohen's d) are included, where appropriate. Cohen's *d* effect sizes were interpreted as: small effect = 0.20 – 0.49, medium effect = 0.50 – 0.79 and large effect ≥ 0.80 (33). To investigate the relationship between selected parameters, Pearson or Spearman correlation analyses were calculated. All statistical analyses were performed using SPSS version 24.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

Study flow and training adherence

A total of 43 participants were screened for eligibility. Forty participants who met the eligibility criteria were enrolled in the study and randomly assigned to either the WB-EMS group or CON. Overall, eleven participants dropped out during the intervention period. The reasons for dropout are displayed in *Fig. 1* (study flow chart). Thus, a total of 29 participants completed the study and were included in the final data analysis. The adherence rate (the percentage of the scheduled training sessions that the participants completed) in the WB-EMS group was 92.8 ± 8.2%. No adverse events occurred at any point during the training sessions.

Anthropometric characteristics and body composition

There were no significant baseline group differences in anthropometric and body composition variables. Both groups reduced body weight significantly after 12 weeks of intervention (WB-EMS group: –3.1 ± 3.0 kg, P = 0.001, *d* = –0.20; CON: –3.1 ± 3.3 kg, P = 0.004, *d* = –0.21). Fat free mass and body water remained stable in both groups. Only in the WB-EMS group, the percentage of body fat was significantly reduced after the intervention (–0.9 ± 1.3 %, P = 0.018, *d* = –0.269) (*Table 1*).

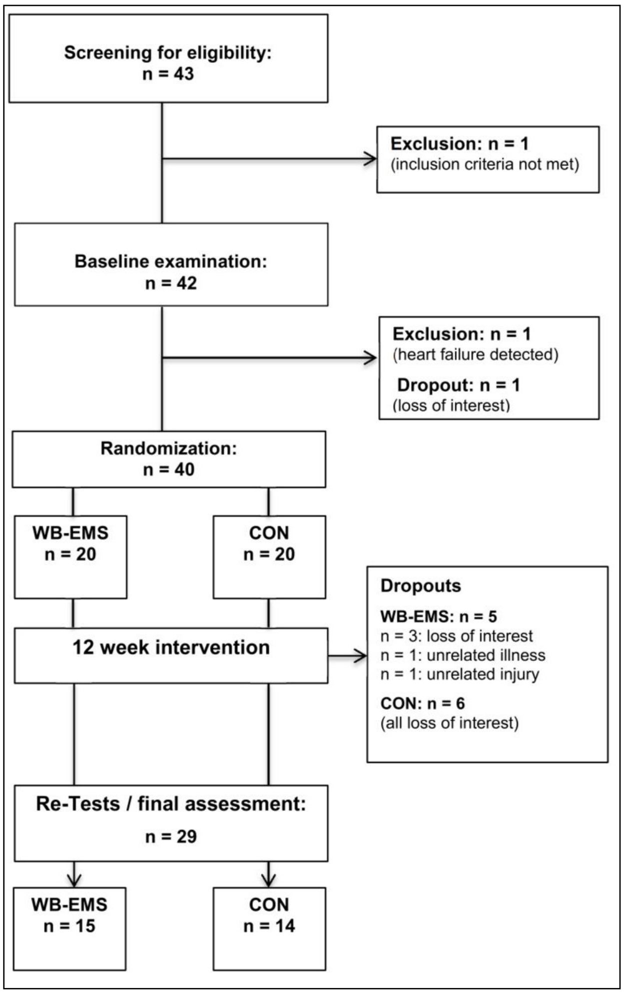

Fig. 1. Study flow chart.

Nutritional analysis

The WB-EMS group and CON did not differ significantly in total energy and macronutrient intake. Two participants (one each from WB-EMS and CON) missed to provide a complete follow-up dietary record and were thus not included in the nutritional evaluation. Nutritional analyses revealed that the average total daily energy intake per day decreased significantly in both groups from baseline to follow-up (WB-EMS group: –336 ± 497 kcal, P = 0.025, *d* = –0.56; CON: –587 ± 826 kcal, P = 0.025, *d* = –0.65), which was mainly achieved through a reduction in fat and carbohydrates (*Table 2*). There was a significant correlation between caloric restriction and the amount of weight loss (P = 0.011; ρ = 0.48).

Cardiometabolic risk markers

The two groups did not differ significantly on any blood marker of cardiometabolic risk at baseline. Paired t-tests revealed a significant reduction in total-cholesterol in the WB-EMS group (–8.3 ± 11.9 mg/dL, P = 0.018, *d* = –0.23) as well as in CON (–14.8 ± 22.2 mg/dL, P = 0.027, *d* = –0.35). The reduction in total-cholesterol was mainly due to a reduction LDL-C, which, however, only reached statistical significance in CON (–9.8 ± 16.6 mg/dL, P = 0.046, *d* = –0.31). Overall cardiometabolic risk score (MetS-Z) was only significantly reduced in the WB-EMS group after the intervention (–1.2 ± 1.9 units, P = 0.029, *d* = –0.46) (*Table 3*).

Blood markers of muscle status and renal function

The blood markers of muscle status and renal function in the two groups did not differ significantly at the three time points except for the mean CK-values measured at the final examination, which were significantly higher in the WB-EMS group compared to CON (P = 0.028, *d* = 0.86). There were no significant within-group changes over time in CK and creatinine levels (*Table 4*).

Muscle strength

There were no significant baseline differences between the two groups in F_{max} of the assessed muscle groups. The WB-EMS group improved muscle strength significantly after the 12-week intervention (abdominals: +21.6 ± 33.1%, P = 0.039, *d* = 0.28; lower back: +57.9 ± 57.8%, P = 0.002, *d* = 0.94; chest: +35.4 ± 40.8%, P = 0.002, *d* = 0.78; upper back: +27.8 ± 20.1%, P < 0.001, *d* = 1.15; legs: +21.8 ± 29.8, P = 0.019, *d* = 0.74). In CON, no significant differences were found in muscle strength before and after the intervention (*Table 5*).

DISCUSSION

The present pilot study aimed to evaluate the feasibility and efficacy of WB-EMS training in obese women diagnosed with metabolic syndrome. The main findings are that: (i) WB-EMS was well tolerated by obese women with metabolic syndrome and appears to be a feasible and safe exercise option in the treatment of obesity and cardiometabolic disorders, (ii) the

Table 1. Anthropometric characteristics and body composition pre- and post-intervention.

Variables	WB-EMS		CON	
	pre	**post**	**pre**	**post**
Height (cm)	166.0 ± 6.8	–	165.4 ± 5.9	–
Body mass (kg)	99.7 ± 16.4	96.6 ± 15.1**	102.5 ± 14.7	99.4 ± 15.3**
Body mass index (kg/m²)	36.1 ± 4.5	35.0 ± 4.1 *	37.4 ± 4.8	36.3 ± 4.9**
Waist circumference (cm)	107.2 ± 7.3	104.9 ± 9.6	109.6 ± 8.6	108.6 ± 9.9
Fat free mass (kg)	52.3 ± 6.7	51.7 ± 6.1	52.6 ± 7.2	51.8 ± 7.0
Body fat (%)	47.0 ± 3.4	46.1 ± 3.6*	48.5 ± 4.2	47.6 ± 4.8
Total body water (L)	39.6 ± 5.1	39.1 ± 4.6	39.9 ± 5.3	39.1 ± 5.1
Extracellular water (L)	18.3 ± 2.5	18.1 ± 2.3	18.7 ± 2.4	18.5 ± 2.3

CON, control group; WB-EMS, whole-body electromyostimulation group. Data are presented as mean values ± SD; $P < 0.05$ and $^{**}P < 0.01$ - significantly different from pre-intervention.

Table 2. Average daily nutritional intake pre- and post-intervention.

Variables	WB-EMS		CON	
	pre	**post**	**pre**	**post**
Energy intake (kcal)	2314 ± 649	1978 ± 546*	2571 ± 927	1983 ± 893*
Protein intake (g)	92 ± 32	97 ± 62	103 ± 30	84 ± 36
Relative protein intake (%)	17 ± 4	19 ± 6	17 ± 3	18 ± 3
Fat intake (g)	92 ± 29	80 ± 22	122 ± 67	86 ± 61*
Relative fat intake (%)	37 ± 7	38 ± 4	42 ± 9	37 ± 12
Carbohydrate intake (g)	248 ± 77	190 ± 43**	231 ± 77	185 ± 93*
Relative carbohydrate intake (%)	44 ± 7	40 ± 6	38 ± 10	40 ± 15

CON, control group; WB-EMS, whole-body electromyostimulation group. Nutritional intake was assessed by 24 h-dietary records on 3 consecutive days. Data are presented as mean values ± SD; $^{*}P < 0.05$ and $^{**}P < 0.01$ - significantly different from pre-intervention.

Table 3. Cardiometabolic risk markers pre- and post-intervention.

Variables	WB-EMS		CON	
	pre	**post**	**pre**	**post**
Systolic blood pressure (mmHg)	135 ± 14	130 ± 13	136 ± 14	137 ± 14
Diastolic blood pressure (mmHg)	89 ± 16	86 ± 12	88 ± 10	88 ± 9
MAB (mmHg)	107 ± 21	100 ± 11	104 ± 10	105 ± 10
Glucose (mg/dL)	104 ± 10	102 ± 14	103 ± 14	98 ± 15
HbA1c (%)	5.6 ± 0.6	5.5 ± 0.5	5.8 ± 0.7	5.8 ± 1.0
Triglycerides (mg/dL)	118 ± 32	112 ± 27	150 ± 80	120 ± 61
Total cholesterol (mg/dL)	218 ± 37	210 ± 33*	242 ± 41	228 ± 40*
HDL-C (mg/dL)	58 ± 14	57 ± 13	54 ± 9	54 ± 12
LDL-C (mg/dL)	139 ± 29	134 ± 25	161 ± 33	151 ± 31*
LDL/HDL ratio	2.5 ± 0.8	2.5 ± 0.8	3.0 ± 0.6	2.9 ± 0.6
Insuline (mg/dL)	18 ± 7.0	15 ± 6	17 ± 9	14 ± 9
HOMA-IR	4.6 ± 2.1	3.9 ± 2.0	4.3 ± 2.5	3.7 ± 2.7
MetS-Z-Score	2.3 ± 3.0	1.1 ± 2.2*	2.8 ± 2.9	2.0 ± 2.6

CON, control group; HbA$_{1c}$, glycosylated hemoglobin A$_{1c}$; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostatic model assessment of insulin resistance; LDL-C, low-density lipoprotein cholesterol; MAB, mean arterial blood pressure; MetS-Z-Score, metabolic syndrome Z-score; WB-EMS, whole-body electromyostimulation group. Data are presented as mean values ± SD; $^{*}P < 0.05$ - significantly different from pre-intervention.

application of WB-EMS in combination with a calorie-reduced nutrition improved cardiometabolic health status to a greater extent than caloric restriction alone, despite similar weight loss, and (iii) as little as two 20-min sessions of WB-EMS per week significantly increased muscle strength within 12 weeks in previously physically unfit metabolic syndrome patients.

Several studies have demonstrated that regular resistance training is a potent stimulus to improve muscle mass, strength,

Table 4. Blood markers of muscle status and renal function.

Variables	WB-EMS			CON		
	pre	**week 6**	**post**	**post**	**week 6**	**post**
Creatine kinase (U/L)	140 ± 80 (35 – 353)	195 ± 215 (35 – 09)	135 ± 49# (34 – 208)	100 ± 34 (54 – 68)	102 ± 57 (50 – 52)	97 ± 40 (48 – 174)
Creatinine (mg/dL)	0.8 ± 0.1 (0.5 – 1.1)	0.8 ± 0.2 (0.5 – 1.1)	0.7 ± 0.2 (0.5 – 1.1)	0.8 ± 0.3 (0.6 – 1.7)	0.8 ± 0.2 (0.5 – 1.4)	0.8 ± 0.2 (0.5 – 1.4)

CON, control group; WB-EMS, whole-body electromyostimulation group. Data are presented as mean values ± SD and ranges; #P < 0.05 - significant difference between WB-EMS and CON.

Table 5. Muscular strength pre- and post-intervention.

Variables	WB-EMS		CON	
	pre	**post**	**pre**	**post**
$\mathbf{F_{max}}$ **abdominal crunch** (kg)	26.5 ± 13.6	29.9 ± 10.2*	25.1 ± 9.7	23.6 ± 9.8
$\mathbf{F_{max}}$ **lower back machine** (kg)	48.1 ± 21.2	68.8 ± 22.7**	50.2 ± 21.1	53.2 ± 21.7
$\mathbf{F_{max}}$ **chest press** (kg)	21.6 ± 7.2	28.4 ± 10.0**	21.8 ± 11.1	21.4 ± 11.4
$\mathbf{F_{max}}$ **lat pulldown machine** (kg)	35.0 ± 7.4	44.0 ± 8.2***	32.6 ± 7.9	34.3 ± 8.5
$\mathbf{F_{max}}$ **leg press** (kg)	138.6 ± 30.1	165.4 ± 41.4*	126.3 ± 35.2	128.3 ± 29.9

CON, control group; F_{max}, maximum strength - estimated one repetition maximum (1-RM), assessed through multiple repetitions and calculated according to the Brzycki equation; WB-EMS, whole-body electromyostimulation group. Data are presented as mean values ± SD; *P < 0.05, **P < 0.01 and ***P < 0.001 - significantly different from pre-intervention.

body composition and various cardiometabolic risk markers in overweight and obese individuals (6, 9). Schjerve *et al*., (34), for example, reported significant improvements in maximum leg-strength, endothelial function and LDL-C concentrations in obese men and women without significant weight loss after a 12-week strength training program consisting of three weekly sessions of high-intensity leg press training (4 – 5 repetitions at 90% 1-RM) plus additional abdominal and back exercises. Normandin *et al*. (35) observed a significant reduction in body weight and improvements in cardiometabolic risk markers including waist circumference, blood pressure and triglycerides in older overweight and obese individuals after a 5-month combined intervention of progressive resistance training (8 exercises, 3 sets of 10 repetitions) and caloric restriction. Another recent study observed significant increases in muscle strength and muscle mass as well as significant improvements in inflammatory biomarkers and the MetS-Z-Score after a 12-week progressive resistance training program (consisting of eight exercises, three sets of 10 – 15 repetitions, performed with weight machines) in older, slightly overweight women (36). Most traditional resistance training programs commonly consist of multiple-set muscle exercises using weight machines or free weights. Multiple-set resistance training programs have been shown to be particularly effective to elicit various beneficial physiological adaptations (37, 38). However, higher-volume resistance training may be perceived as too strenuous and difficult to complete by individuals with very low fitness levels or contra-indicated in certain musculoskeletal disorders (10, 39). Furthermore, as in the general population, perceived "lack of time" is stated by obese individuals as a major reason for insufficient physical activity and premature dropout from exercise programs (40, 41). In this context, a recent meta-analysis of interventions applying high-intensity interval training (HIIT), a specific type of cardiovascular exercise, has demonstrated that longer session duration and higher weekly time effort for exercise are associated with greater dropout rates in previously sedentary individuals (42).

WB-EMS training is a rather novel, joint-friendlier and time-saving exercise modality, which is considered as a reasonable alternative for individuals who either are unable (*e.g.* due to physical limitations) or not willing to participate in strenuous, more time-consuming conventional resistance training programs (12). To date, most studies evaluating the efficacy of WB-EMS have included athletes, moderately trained or untrained (but otherwise healthy) subjects and mainly focused on the effects on muscle mass, muscle strength and functionality, body composition and low back pain, which have been thoroughly summarized in systematic reviews (12, 13, 43). However, there is increasing evidence that WB-EMS may also be a promising exercise option in different clinical settings. Studies with cardiac patients, for instance, have reported that two 20-min WB-EMS sessions per week performed over periods of six months (44) and ten weeks (45), respectively, induced positive effects on oxygen uptake and cardiac function. Studies on overweight women and older adults with sarcopenic obesity that have applied 1 – 2 weekly 20 min WB-EMS sessions over periods of 16 – 26 weeks observed beneficial changes in muscle mass and body composition (15-18), significant muscle strength increments (16, 17) and improvements in the cardiometabolic risk profile (16, 18). Recent studies from our laboratory have demonstrated that the application of WB-EMS (two 20-min sessions per week for 12 weeks combined with nutritional support) in cancer patients with advanced solid tumors and hematological malignancies appears to be safe and feasible, with clinically relevant positive effects on muscle mass, physical functions and performance status (46-48). However, it has been highlighted that the impact of WB-EMS on cardiometabolic risk factors has not yet been properly evaluated (12, 13). Thus, the present study provides important new insights to expand the knowledge in this field of research.

In contrast to previous studies that have examined the effects of WB-EMS in individuals who were overweight or moderately obese but otherwise free of severe comorbidities (15-18), the present investigation included multi-morbid severely obese metabolic syndrome patients with an increased potential risk of developing complications during exercise (49, 50). In this context, it is important to note that no adverse events occurred during the exercise sessions, suggesting that WB-EMS may be safely administered in obese patients with metabolic syndrome. In view of current debates on the potential risks of WB-EMS-induced muscle damage (51), it should furthermore be pointed out that none of the participants reported severe muscle discomfort, nor, in particular, displayed clinically relevant disturbances in CK and creatinine levels after 6 and 12 weeks of WB-EMS exercise, respectively. These observations are further supported by the high adherence rate (~93%) in the WB-EMS group and the relative low dropout rate (25%) when compared to those typically reported for exercise interventions (30 – 50%) (53-55), indicating that WB-EMS is well tolerated and accepted by obese patients with cardiometabolic disorders. Given that lack of time is one of the most frequently mentioned reasons for not participating in regular physical activity among many obese individuals (40), the time-saving character of WB-EMS could be helpful in overcoming perceived time barriers to uptake and maintenance of physical activity, although the longer-term adherence to this type of exercise and/or potential changes in physical activity behavior remain to be explored. Moreover, given that aerobic exercise is another crucial component of a well-rounded exercise regime for obese individuals (6), the time-efficient WB-EMS protocol may allow sufficient time for implementation of a combined exercise program to improve all aspects of physical fitness. Future studies may wish to examine the effects of such combined exercise programs on overall fitness and cardiometabolic health.

The average weight loss of ~3% achieved in both groups corresponds to the mean amounts of weight loss reported in the majority of lifestyle weight management programs (56). Although a weight loss of at least 5% has been suggested as clinically meaningful and a criterion to define a "successful" treatment for weight reduction, respectively, it has been reported that even lesser amounts of weight loss may provide beneficial effects on some risk markers (57-59). In line with this, we observed significant average reductions in total cholesterol levels of ~3% in the WB-EMS group and ~5% in CON, respectively. Given that for every percent reduction in total cholesterol, an average 2% reduction in the incidence risk of coronary heart disease has been estimated (60), the observed effect can be considered clinically meaningful. The significant reduction in LDL-C, which was only observed in CON, could potentially be attributed to the greater reduction in fat intake compared to the WB-EMS, but this remains speculative. As expected, the amount of weight loss correlated with the energy deficit achieved through caloric restriction, emphasizing the crucial role of adequate dietary changes to cause significant weight loss (61). Given that both groups achieved a similar mean weight loss, it is reasonable to assume that the two weekly sessions of WB-EMS contributed only marginally to promote a greater negative energy balance through greater energy expenditure. Accordingly, it has been estimated that the energy turnover of a 20-min WB-EMS exercise session corresponds to approximately 120 kcal (62). However, although weight loss is typically the primary goal in interventions to treat obesity, it has been well demonstrated that exercise provides multiple health benefits irrespective of weight loss in obese individuals (63). Moreover, it has been shown that an improvement in physical fitness had a significantly greater impact on all-cause and cardiovascular disease mortality risk than changes in BMI (64, 65). In line with this, we observed that WB-EMS combined with caloric restriction had a greater impact on lowering overall cardiometabolic risk (MetS-Z) than caloric restriction alone, despite similar weight loss in both groups. The greater reduction in MetS-Z in the WB-EMS group was mainly due to a more favorable (although not statistically significant) decrease in waist circumference. Furthermore, it is important to point out that only the WB-EMS group experienced significant improvements in muscle strength of all major muscle groups, ranging from ~13% (abdominals) to ~43% (lower back). This finding is of major importance given that greater muscular strength was found to be associated with a lower risk of musculoskeletal disorders (66-68), better cardiometabolic health (69) and higher health-related quality of life (70). Moreover, large prospective cohort studies have shown that muscular strength is associated with lower mortality in the general population (71, 72) and in clinical cohorts (73), independent of BMI and cardiorespiratory fitness.

There are some limitations in our study that should be considered when interpreting the results. First, the present study is a pilot study with a relatively small sample size. Therefore, the findings related to the efficacy of WB-EMS in obese metabolic syndrome patients should be confirmed in further studies. The preliminary data from this study, however, provide important estimates to support the planning of future studies, which are necessary to draw more definitive conclusions. Second, it is to note that self-reported food records, as applied in this study, may be associated with potential sources of error. It has been reported, for example, that individuals commonly tend to underestimate their food intake and that the recording per se may (unconsciously) influence the eating behavior (74, 75). However, we assume that the careful briefing and monitoring throughout the recording period should have minimized the extent of potential errors. Furthermore, the reported changes in energy intake agree quite well with the objectively measured participants' weight loss. Third, we note that the present study was conducted in a controlled setting with a carful one-to-one supervision of all exercise sessions. The safe application of WB-EMS in individuals with distinctive health risk factors in commercial settings (*e.g.* fitness centers), however, is still under debate and remains to be critically evaluated. In view of the reported potential risks for muscle overload/damage as a result of improper use of WB-EMS (due to excess impulse intensity) and several mentioned contraindications, such as cardiac pacemakers/implanted electronic devices, cardiac arrhythmia or epilepsy (51), it is important to expressly highlight that individuals with health restrictions intending to use WB-EMS should undergo a careful medical examination and that WB-EMS should only be performed under the supervision of a qualified instructor. Fourth, direct comparisons between WB-EMS and conventional resistance training (the standard exercise modality to improve muscle strength and muscle mass) have only scarcely been investigated. One study examining the effects of WB-EMS versus high-intensity resistance exercise found that both modalities were similar effective at improving body composition and strength in healthy untrained individuals (76). However, comparable studies in individuals with pre-existing health conditions, such as obese metabolic syndrome patients, are still lacking and will be needed to establish more tailored exercise programs in clinical settings. Fifth, given that we initially only examined female participants, it remains to be clarified in future investigations whether the results of this pilot study can be transferred to men. Lastly, given that the present study lasted only 12 weeks, long-term effects and adherence to WB-EMS in obese metabolic syndrome patients remain unclear. Hence, future studies involving longer intervention and follow-up periods will be needed to answer such questions.

The results of the present pilot study indicate that WB-EMS can feasibly be implemented in obese metabolic syndrome patients. According to the preliminary data obtained in this study, WB-EMS combined with caloric restriction seems to be more effective for improving the cardiometabolic risk profile in obese patients with metabolic syndrome than caloric restriction alone, despite similar effects on body weight loss. Additionally, WB-EMS induced with as little as two 20-min sessions per week significant improvements in muscle strength of all major muscle groups. Nonetheless, further studies are needed to clarify the role of WB-EMS as a viable exercise option in the treatment of obesity, cardiometabolic disorders and other chronic diseases.

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REFERENCES

1. NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. *Lancet* 2017; 390: 2627-2642.
2. Berrington de Gonzalez AB, Hartge P, Cerhan JR, *et al*. Body-mass index and mortality among 1.46 million white adults. *N Engl J Med* 2010; 263: 2211-2219.
3. Prospective Studies Collaboration, Whitlock G, Lewington S, *et al*. Body-mass index and cause-specific mortality in 900000 adults: collaborative analyses of 57 prospective studies. *Lancet* 2009; 373: 1083-1096.
4. Wu SH, Liu W, Ho SC. Metabolic syndrome and all-cause mortality: a meta-analysis of prospective cohort studies. *Eur J Epidemiol* 2010; 25: 375-384.
5. Myers J, Kokkinos P, Nyelin E. Physical activity, cardiorespiratory fitness, and the metabolic syndrome. *Nutrients* 2019; 1: E1652. doi: 10.3390/nu11071652
6. Donnelly JE, Blair SN, Jakicic JM, *et al*. Appropriate physical activity intervention strategies for weight loss and prevention of weight regain for adults. *Med Sci Sports Exerc* 2009; 41: 459-471.
7. Hamasaki H, Kawashima Y, Adachi H, *et al*. Associations between lower extremity muscle mass and metabolic parameters related to obesity in Japanese obese patients with type 2 diabetes. *Peer J* 2015; 3: e942. doi: 10.7717/peerj.942
8. Sinha I, Sakthivel D, Varon DE. Systematic regulators of skeletal muscle regeneration in obesity. *Front Endocrinol* 2017; 8: 29. doi: 10.3389/fendo.2017.00029.
9. Strasser B, Schobersberger W. Evidence for resistance training as a treatment therapy in obesity. *J Obes* 2011; 2011: 482564. doi: 10.1155/2011/482564
10. Okifuji A, Hare BD. The association between chronic pain and obesity. *J Pain Res* 2015; 8: 399-408.
11. Parameswaran K, Todd DC, Soth M. Altered respiratory physiology in obesity. *Can Respir J* 2006; 13: 203-210.
12. Kemmler W, Weissenfels A, Willert S, *et al*. Efficacy and safety of low frequency whole-body electromyostimulation (WB-EMS) to improve health-related outcomes in non-athletic adults. A systematic review. *Front Physiol* 2018; 9: 573. doi: 10.3389/fphys.2018.00573
13. Pano-Rodriguez A, Beltran-Garrido JV, Hernandez-Gonzalez V, Reverter-Masia J. Effects of whole-body electromyostimulation on health and performance: a systematic review. *BMC Complement Altern Med* 2019; 19: 87. doi: 10.1186/s12906-019-2485-2489.
14. Kemmler W, von Stengel S. Whole-body electromyostimulation as a means to impact muscle mass and abdominal body fat in lean, sedentary, older female adults: subanalysis of the TEST-III trial. *Clin Interv Aging* 2013; 8: 1353-1364.
15. Willert S, Weissenfels A, Kohl M, *et al*. Effects of whole-body electromyostimulation on the energy-restriction-induced reduction of muscle mass during intended weight loss. *Front Physiol* 2019; 10: 1012. doi: 10.3389/fphys.2019.01012
16. Kemmler W, Teschler M, Weissenfels A, *et al*. Whole-body electromyostimulation to fight sarcopenic obesity in community-dwelling older women at risk. Results of the randomized controlled FORMOsA-sarcopenic obesity study. *Osteoporos Int* 2016; 27: 3261-3270.
17. Kemmler W, Weissenfels A, Teschler M, *et al*. Whole-body electromyostimulation and protein supplementation favorably affect sarcopenic obesity in community-dwelling older men at risk: the randomized controlled FranSO study. *Clin Interv Aging* 2017; 12: 1503-1513.
18. Wittmann K, Sieber C, von Stengel S, *et al*. Impact of whole body electromyostimulation on cardiometabolic risk factors in older women with sarcopenic obesity: the randomized controlled FORMOsA-sarcopenic obesity study. *Clin Interv Aging* 2016; 11: 1697-1706.
19. Gayoso-Diz P, Otero-Gonzalez A, Rodriguez-Alvarez MX, *et al*. Insulin resistance (HOMA-IR) cut-off values and the metabolic syndrome in a general adult population: effect of gender and age: EPIRCE cross-sectional study. *BMC Endocr Disord* 2013; 13: 47. doi: 10.1186/1472-6823-13-47
20. Huang PL. A comprehensive definition for metabolic syndrome. *Dis Model Mech* 2009; 2: 231-237.
21. Matthews DR, Hosker JP, Rudenski AS, Naylor BA, Treacher DF, Turner RC. Homeostasis model assessment: insulin resistance and beta-cell function from fasting plasma glucose and insulin concentrations in man. *Diabetologia* 1985; 28: 412-419.
22. Bosy-Westphal A, Schautz B, Later W, Kehayias JJ, Gallagher D, Muller MJ. What makes a BIA equation unique? Validity of eightelectrode multifrequency BIA to estimate body compo-sition in a healthy adult population. *Eur J Clin Nutr* 2013; 67 (Suppl. 1): S14-S21.
23. Johnson JL, Slentz CA, Houmard JA, *et al*. Exercise training amount and intensity effects on metabolic syndrome (from studies of a targeted risk reduction intervention through defined exercise). *Am J Cardiol* 2007; 100: 1759-1766.
24. NSCA. NSCA's Guide to Test and Assessment's. Champaign, Human Kinetics, 2012.
25. Dohoney P, Chromiak JA, Lemire D, Abadie BR, Kovacs C. Prediction of one repetition maximum (1-RM) strength from a 4-6 RM and a7-10 RM submaximal strength test in healthy young adult males. *J Exerc Physiol Online* 2002; 5: 54-59.
26. Nascimento MA, Cyrino ES, Nakamura FY, Romanzini M, Cardoso Pianca HJ, Queiroga MR. Validation of the Brzycki equation for the estimation of 1-RM in the bench press. *Braz J Sports Med* 2007; 13: 40-42.
27. Reynolds JM, Gordon TJ, Robergs RA. Prediction of one repetition maximum strength from multiple repetition maximum testing and anthropometry. *J Strength Cond Res* 2006; 20: 584-592.
28. Brzycki M. Strength testing: predicting a one-rep max from repetitions to fatigue. *J Phys Educ Recreat Dance* 1993; 64: 88-90.
29. Carels RA, Young KM, Coit C, Clayton AM, Spencer A, Hobbs M. Can following the caloric restriction

recommendations from the Dietary Guidelines for Americans help individuals lose weight? *Eat Behav* 2008; 9: 328-335.
30. Wirth A, Wabitsch M, Hauner H. The prevention and treatment of obesity. *Dtsch Arztebl Int* 2014; 111: 705-713.
31. Kemmler W, Schliffka R, Mayhew JL, von Stengel S. Effects of whole-body electromyostimulation on resting metabolic rate, body composition, and maximum strength in postmenopausal women: the training and electrostimulation trial. *J Strength Cond Res* 2010; 24: 1880-1887.
32. Julious SA. Sample size of 12 per group rule of thumb for a pilot study. *Pharm Stat* 2005; 4: 287-291.
33. Cohen J. Statistical power analysis for the behavioral sciences. Hoboken, Taylor and Francis 1988.
34. Schjerve IE, Tyldum GA, Tjonna AE, *et al*. 2008. Both aerobic endurance and strength training programmes improve cardiovascular health in obese adults. *Clin Sci* 2008; 115: 283-293.
35. Normandin E, Chmelo E, Lyles MF, Marsh AP, Nicklas BJ. Effect of resistance training and caloric restriction on the metabolic syndrome. *Med Sci Sports Exerc* 2017; 49: 413-419.
36. Tomeleri CM, Souza MF, Burini RC, *et al*. Resistance training reduces metabolic syndrome and inflammatory markers in older women: a randomized controlled trial. *J Diabetes* 2018; 10: 328-337. doi: 10.1111/1753-0407.12614.
37. Galvao DA, Taaffe DR. Single- vs. multiple-set resistance training: recent developments in the controversy. *J Strength Cond Res* 2004; 18: 660-667.
38. Krieger JW. Single vs. multiple sets of resistance exercise for muscle hypertrophy: a meta-analysis. *J Strength Cond Res* 2010; 24: 1150-1159.
39. Sabharwal S, Root MZ. Impact of obesity on orthopaedics. *J Bone Joint Surg* 2012; 94: 1045-1052.
40. Andersen RE, Jakicic JM. Interpreting the physical activity guidelines for health and weight management. *J Phys Act Health* 2009; 6: 651-656.
41. Reichert FF, Barros AJ, Domingues MR, Hallal PC. The role of perceived personal barriers to engagement in leisure-time physical activity. *Am J Public Health* 2007; 97: 515-519.
42. Reljic D, Lampe D, Wolf F, Zopf Y, Herrmann HJ, Fischer J. Prevalence and predictors of dropout from high-intensity interval training in sedentary individuals: a meta-analysis. *Scand J Med Sci Sports* 2019; 29: 1288-1304.
43. Wirtz N, Dormann U, Micke F, Filipovic A, Kleinoder H, Donath L. Effects of whole-body electromyostimulation on strength-, sprint-, and jump performance in moderately trained young adults: a mini-meta-analysis of five homogenous RCTs of our work group. *Front Physiol* 2019; 10: 1336. doi: 10.3389/fphys.2019.01336
44. Fritzsche D, Fruend A, Schenk S, *et al*. Electromyostimulation (EMS) in cardiac patients. Will EMS training be helpful in secondary prevention? *Herz* 2010; 35: 34-40.
45. Van Buuren F, Mellwig KP, Prinz C, *et al*. Electrical myostimulation improves left ventricular function and peak oxygen consumption in patients with chronic heart failure: results from the exEMS study comparing different stimulation strategies. *Clin Res Cardiol* 2013; 102: 523-534.
46. Schink K, Gassner H, Reljic D, *et al*. Assessment of gait parameters and physi-cal function in patients with advanced cancer participating in a 12-week exercise and nutrition programme: a controlled clinical trial. *Eur J Cancer Care* 2019; 12: e13199. doi: 10.1111/ecc.13199
47. Schink K, Herrmann HJ, Schwappacher R, *et al*. Effects of whole-body electromyostimulation combined with individualized nutritional support on body composition in patients with advanced cancer: a controlled pilot trial. *BMC Cancer* 2018; 18: 886. doi: 10.1186/s12885-018-4790-y
48. Schink K, Reljic D, Herrmann HJ, *et al*. Whole-body electromyostimulation combined with individualized nutritional support improves body composition in patients with hematological malignancies - a pilot study. *Front Physiol* 2018; 9: 1808. doi: 10.3389/fphys.2018.01808.
49. Hess PL, Al-Khalidi HR, Friedman DJ, *et al*. The metabolic syndrome and risk of sudden cardiac death: the atherosclerosis risk in communities study. *J Am Heart Assoc* 2017; 6: e006103. doi: 10.1161/JAHA.117.006103.
50. Pedersen BK, Saltin B. Exercise as medicine - evidence for prescribing exercise as therapy in 26 different chronic diseases. *Scand J Med Sci Sports* 2015; 25 (Suppl. 3): 1-72. doi: 10.1111/sms.12581.
51. Stollberger C, Finsterer J. Side effects of and contraindications for whole-body electromyostimulation: a viewpoint. *BMJ Open Sport Exerc Med* 2019; 5: e000619. doi: 10.1136/bmjsem-2019-000619
52. Kenney K, Landau ME, Gonzalez RS, Hundertmark J, O'Brien K, Campbell WW. Serum creatine kinase after exercise: drawing the line between physiological response and exertional rhabdomyolysis. *Muscle Nerve* 2012; 45: 356-362.
53. Buckworth J, Dishman RK. Exercise Psychology. Champaign, Human Kinetics 2002.
54. Kelley GA, Kelley KS. Dropouts and compliance in exercise interventions targeting bone mineral density in adults: a meta-analysis of randomized controlled trials. *J Osteoporos* 2013; 2013: 250423. doi: 10.1155/2013/250423.
55. Nam S, Dobrosielski DA, Steward KJ. Predictors of exercise intervention dropout in sedentary individuals with type 2 diabetes. *J Cardiopulm Rehabil Prev* 2012; 32: 370-378.
56. National Institute for Health and Care Excellence (NICE). Weight Management: Lifestyle Services for Overweight or Obese Adults. Public Health Guideline PH53. London, NICE, 2014. URL: www.nice.org.uk/guidance/ph53 (accessed January 2020).
57. Williamson DA, Bray, GA, Ryan DH. Is 5% weight loss a satisfactory criterion to define clinically significant weight loss? *Obesity* 2015; 23: 2319-2320.
58. Korybalska K, Luczak J, Swora-Cwynar E, *et al*. Weight loss-dependent and -independent effects of moderate calorie restriction on endothelial cell markers in obesity. *J Physiol Pharmacol* 2017; 68: 597-608.
59. Sikorska D, Grzymislawska M, Roszak M, Gulbicka P, Korybalska K, Witowski J. Simple obesity and renal function. *J Physiol Pharmacol* 2017; 68: 175-180.
60. Fager G, Wiklund O. Cholesterol reduction and clinical benefit. *Arterioscler Thromb Vascul Biol* 1997; 17: 3527-3533. doi.org/10.1161/01.ATV.17.12.3527.
61. Zubrzycki A, Cierpka-Kmiec K, Kmiec Z, Wronska A. The role of low-calorie diets and intermittent fasting in the treatment of obesity and type-2 diabetes. *J Physiol Pharmacol* 2018; 69: 663-683.
62. Kemmler W, von Stengel S, Schwarz J, Mayhew JL. Effect of whole-body electromyostimulation on energy expenditure during exercise. *J Strength Cond Res* 2012; 26: 240-245.
63. Ross R, Janiszewski PM. Is weight loss the optimal target for obesity-related cardiovascular disease risk reduction? *Can J Cardiol* 2008; 24: 25-31..
64. Barry VW, Baruth M, Beets MW, Durstine JL, Liu J, Blair SN. Fitness vs. fatness on all-cause mortality: a meta-analysis. *Prog Cardiovasc Dis* 2014; 56: 382-390.
65. Lee DC, Sui X, Artero EG, *et al*. Long-term effects of changes in cardiorespiratory fitness and body mass index on all-cause and cardiovascular disease mortality in men: The

Aerobics Center Longitudinal Study. *Circulation* 2011; 124: 2483-2490.
66. Cho KH, Beom JW, Lee TS, Lim JH, Lee TH, Yuk JH. Trunk muscles strength as a risk factor for nonspecific low back pain: a pilot study. *Ann Rehabil Med* 2014; 38: 234-240.
67. De Sousa CS, De Jesus FL, Machado MB, *et al*. Lower limb muscle strength in patients with low back pain: a systematic review and meta-analysis. *J Musculoskelet Neuronal Interact* 2019; 19: 69-78.
68. Ma Y, Fu L, Jia L, *et al*. Muscle strength rather than muscle mass is associated with osteoporosis in older Chinese adults. *J Formos Med Assoc* 2018; 117: 101-108.
69. Jackson AW, Lee DC, Sui X, *et al*. Muscular strength is inversely related to prevalence and incidence of obesity in adult men. *Obesity* 2010; 18: 1988-1895.
70. Samuel D, Rowe P, Hood V, Nicol A. The relationship between muscle strength, biomechanical functional moments and health-related quality of life in non-elite older adults. *Age Ageing* 2012; 41: 224-230.
71. Newman AB, Kupelian V, Visser M, *et al*. Strength, but not muscle mass, is associated with mortality in the health, aging and body composition study cohort. *J Gerontol A Biol Sci Med Sci* 2006; 61: 72-77.
72. Ruiz JR, Sui X, Lobelo F, *et al*. Association between muscular strength and mortality in men: prospective cohort study. *BMJ* 2008; 337: a439. doi: 10.1136/bmj.a43
73. Jochem C, Leitzmann M, Volaklis K, Aune D, Strasser B. Association between muscular strength and mortality in clinical populations: a systematic review and meta-analysis. *J Am Med Dir Assoc* 2019; 20: 1213-1223.
74. Hill RJ, Davies PS. The validity of self-reported energy intake as determined using the doubly labelled water technique. *Br J Nutr* 2001; 85: 415-430.
75. Koehler K, Braun H, De Marees M, *et al*. Parallel assessment of nutrition and activity in athletes: Validation against doubly labelled water, 24-h urea excretion, and indirect calorimetry. *J Sports Sci* 2010; 28: 1435-1449.
76. Kemmler W, Teschler M , Weissenfels A, *et al*. Effects of whole-body electromyostimulation versus high-intensity resistance exercise on body composition and strength: a randomized controlled study. *Evid-Based Complement Alternat Med* 2016; 2016: 9236809. doi: 10.1155/2016/9236809.

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