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ARTICLE

Clinical Research

Whole-body electrical stimulation as a strategy to improve functional capacity and preserver lean mass after bariatric surgery: a randomized triple-blind controlled trial

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Abstract

Background/Objectives Bariatric surgery (BS) is a successful, long-lasting treatment option for obese. The early post-operative (PO) period is followed by dietary restriction and physical inactivity, leading to declines in muscle mass and functional capacity. Whole-body electromyostimulation (WB-EMS) may be a feasible and potential early rehabilitation strategy post BS. The aim was to evaluate the effects of WB-EMS with exercise training (Fe) on functional capacity, body composition, blood biomarkers, muscle strength, and endurance post BS.

Subjects/Methods This is a randomized, triple-blind, sham-controlled trial. Thirty-five volunteers underwent a Roux-en-Y gastric bypass and were randomized into a WB-EMS (WB-EMSG) or control group (ShamG). Preoperative evaluations consisted of maximal and submaximal exercise testing, body composition, blood biomarkers, quadriceps strength, and endurance. After discharge, functional capacity and body composition were obtained. Exercise training protocols in both groups consisted of 14 dynamic exercises, 5 days per week, completing 30 sessions. The WB-EMSG also underwent an electrical stimulation protocol (Endurance: 85 Hz, 350 ms, 6 s of strain, 4 f of rest; Strength: 30 Hz, 350 ms, 4 s of strain, 10 seconds of rest, with bipolar electrical pulse). After intervention, subjects were reevaluated.

Results The protocol started on average 6.7 ± 3.7 days after discharge. Both groups presented with a decline in functional capacity after *BS* ($p < 0.05$) and a reduction in all body composition measurements ($p < 0.05$). The exercise training program led to significant improvements in functional capacity (ShamG – PO: 453.8 ± 66.1 m, Post: 519.2 ± 62.8 m; WB-EMSG- PO: 435.9 ± 74.5, Post: 562.5 ± 66.4 m, $p < 0.05$), however, only the WB-EMSG demonstrated significant changes of distance walked (interaction time vs group effect, $p < 0.05$). In addition, adiponectin significantly increased only in the WB-EMSG ($p < 0.05$). The WB-EMSG was also able to preserve muscle strength, endurance, and fatigue index, while the ShamG demonstrated significant decline ($p < 0.05$).

Conclusion WB-EMS + Fe can be an attractive and feasible method following BS to enhance functional capacity and prevent deterioration of muscle function in the early PO.

Clinical trial registration ReBEC, RBR-99qw5h, on 20 February 2015.

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Introduction

Excessive weight is commonly associated with comorbidities due to altered metabolic function, physical inactivity, musculoskeletal dysfunction [1], and dyslipidemia; impairments in functional capacity and quality of life are a consequence of these pathophysiologic alterations [2]. In addition, obesity is considered a complex multifactorial disease with chronic, systemic low-grade inflammation [3] and significant alterations in cytokines production [4], leading to an increased risk for cardiovascular disease [5], type 2 diabetes, and certain cancers [4, 6]. Weight loss surgery is now considered a successful treatment for obese patients, a condition that has become a major public health concern reaching epidemic proportions, resulting in significant medical expenses and poor health outcomes [6]. In Brazil, the prevalence of obesity in the adult population is 16.8% and 24.4% in men and women, respectively [7].

The demand for bariatric surgery (BS) is significant in Brazil, currently ranking second in the world for annual procedures, only the United States performs more annual procedures [8]. The Roux-en-Y gastric bypass procedure has proven to lead to beneficial long-term effects, including sustained weight loss, remission of comorbidities, and substantial metabolic improvements [9]. Post BS, patients achieve metabolic changes through a reduction in skeletal muscle insulin resistance, improving glucose metabolism, lower levels of pro-inflammatory biomarkers, amelioration of anti-inflammatory markers and lipid profile [10]. Although advantages of BS are demonstrated in the literature, the early postoperative period (PO) is followed by important nutritional deficiencies in short and long-term restrictive and malabsorptive surgical procedure [11]. Moreover, following BS, persistent physical inactivity and rapid weight loss may alter body composition distribution with loss of lean mass, negatively affecting muscle bioenergetics [12].

Unfortunately, the adherence to exercise programs as a conservative treatment in obese patients is low, fail in almost 90% of cases [14], with considerable sample loss [13]. Despite the well-established positive effects of exercise training, there is, to our knowledge, a lack of studies assessing exercise training acutely following BS. In this context, whole-body electrical stimulation (WB-EMS) may be an effective intervention during the early phases of rehabilitation when other techniques are contraindicated [14, 15]. WB-EMS is a relatively new technology that can stimulate all major muscle groups simultaneously and may enhance the systemic effects of muscle contraction. The repetitive stimulation of several large muscles with WB-EMS has been shown to enhance weight loss, improve exercise capacity and peripheral muscle strength, increase insulin action and glucose metabolism, decrease systemic inflammatory biomarkers and decrease abdominal fat mass [16].

In this context, the aim of this study is to evaluate the effects of WB-EMS on functional capacity as well as muscle strength and endurance acutely following BS. In addition, the secondary objective is to analyze the effects of WB-EMS on body composition distribution and key blood markers including insulin, glucose, pro- and anti-inflammatory circulating biomarkers. The main hypothesis tested in the present study is that WB-EMS will be well-tolerated and prove to be an effective intervention, improving primary and secondary endpoints of interest.

Material and methods

Study design and population

This is a randomized, triple-blind, placebo-controlled, parallel group, clinical trial, approved by the Institutional Committee (number: 966.613) and registered at the Brazilian Registry of Clinical Trials (ReBEC - number: RBR-99qw5h) on February 20th, 2015 as well as the Consolidated Standards of Reporting Trials (CONSORT) [17]. Subjects were informed about all assessments and intervention associates with this study and signed an informed consent before participation. Recruitment and randomization of the present study were performed as previously described [15].

Procedures

Subjects were familiarized with all data collection procedures as well as the WB-EMS technique and counseled to stop smoking and drinking alcoholic beverages one year before BS. Assessments were applied: (1) at the same time of day to avoid variation in responses related to circadian rhythm, (2) at appropriate room, and (3) with specific instructions made according to a previous study [15] to ensure adequate assessments.

Following screening, recruited subjects returned on fo different days with at least 48 h between evaluations, to perform preoperative assessments that were repeated following conclusion of the intervention protocol. The PO evaluation occurred within 1 week of discharge, ≈2 days after BS (Fig. 1). All evaluations were also previously described [1].

Following the PO evaluation, randomization with a 1:1 allocation ratio by a computer-based permuted block randomization (www.randomization.com) was done as previously described [15]. Since the present study is a triple-blind clinical trial, subjects, the physical therapist who performed data collection and the researcher responsible for statistical analysis were blinded to the subjects' allocation. During the exercise program, other physical therapists overseeing training saved the parameters in codified smart

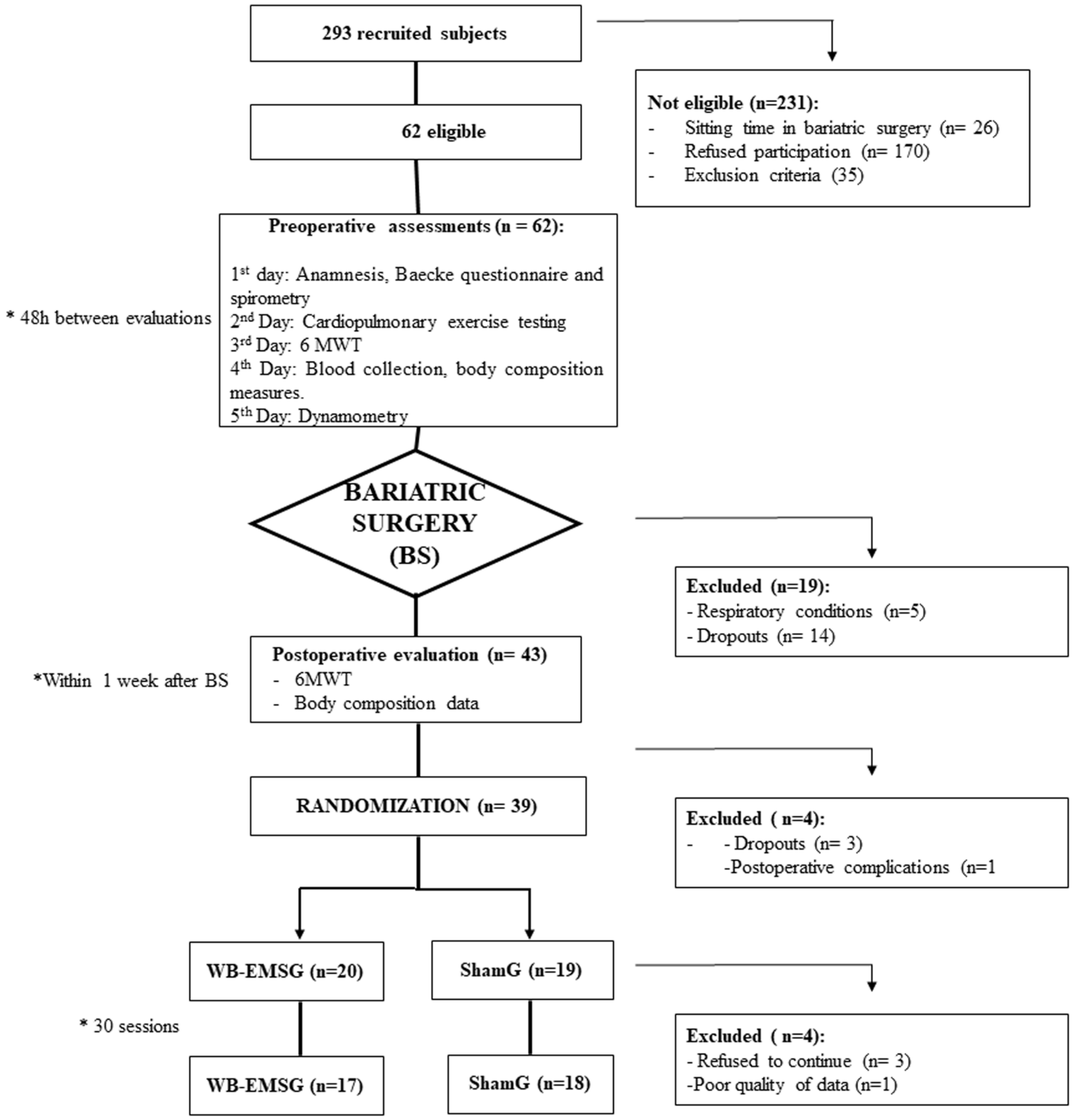

Fig. 1 Flowchart of a study showing flow of assessments, sample recruitment, and losses. 6MWT 6-minute walking test, WB-EMSG Whole-body electrical stimulation group, ShamG Sham group.

cards to ensure reliability and validity during each session; these physical therapists did not participate in the evaluations before and after the protocol. Following the completion of 30 sessions, all preoperative evaluations were performed again.

Assessments

1st Visit: Screening and spirometry measurements

Initially, an anamnesis and the Baecke questionnaire were applied to maintain a homogenous sample [18]. Subjects were also submitted to spirometry using an Oxycon Mobile® (Mijnhardt/Jäger, Würzburg, German) system. Spirometry was performed in accordance with specific guidelines and measures were compared to Brazilian predicted values [19, 20].

2nd Visit: Cardiopulmonary Exercise Testing (CPX)

Cardiopulmonary exercise testing was carried out on a treadmill (Super ATL, Porto Alegre, Rio Grande do Sul, Brazil) using the incremental Bruce protocol [21] with physician supervision, and being continuous 12-lead ECG (WinCardio System, Microme, Brasilia, Brazil) monitoring. Metabolic and ventilatory parameters obtained included: (1) oxygen uptake (absolute $\dot{V}O_2$ – ml.min^{-1} and relative $\dot{V}O_2$ – ml.kg^{-1}.min^{-1}); (2) carbon dioxide production ($\dot{V}CO_2$ – ml.min^{-1}); (3) the respiratory exchange ratio (RER); and (4) minute ventilation ($\dot{V}_E$), which were collected breath-by-breath using the portable Oxycon Mobile® ergospirometer (Mijnhardt/Jäger, Würzburg, Germany). Subjects were encouraged by the blinded researcher to achieve maximal effort until exhaustion and variables such as heart rate (HR), blood pressure (BP), and subjective responses of dyspnea and fatigue by the CR10 scale were collected following each completed stage. The procedures and termination criteria for aerobic assessment followed American Thoracic Society recommendations [22].

3rd Visit: 6-minute walking test (6MWT)

The 6MWT followed established guidelines [23] and cardiorespiratory and metabolic measurements were collected breath-by-breath using a portable Oxycon Mobile® ergospirometer (Mijnhardt/Jäger, Würzburg, Germany), obtained the same measures described for CPX. Before, during, and after the 6MWT, HR, BP, perceived exertion of leg fatigue, dyspnea and walking distance were collected.

4th Visit: Blood collection and body composition data

Blood samples were collected the morning after a 12-h fast from the upper limb antecubital vein by a qualified professional. Glucose levels, insulin, insulin resistance index by the Homeostasis Model Assessment method (HOMA), and the lipid profile (total cholesterol, HDL, LDL, VLDL, and triglycerides) were determined [24]. Concentrations of TNFα, adiponectin, leptin, and myostatin were also analyzed by the ELISA method in duplicates (Enzyme-Linked Immuno Sorbent Assay), using high sensitivity kits (Quantikine®HS, R & D Systems, Minneapolis, USA), according to recommendations [25].

Body composition was obtained by bioelectrical impedance analysis, performed by an In Body 720 device (Biospace, Seoul, Korea) [26]. Subjects were instructed to have a 4-h fast, to wear light clothes, not to have any metal objects in contact with their body, to urinate prior to the examination, not to drink alcohol, and not to perform strenuous exercises the day before the exam [26].

5th Day: Isokinetic, isometric, and endurance peripheral muscle assessment

Evaluations of concentric and isometric extension of the dominant knee were carried out using an isokinetic dynamometer (Biodex Multi-Joint System 3; Biodex Medical System, Inc., Shirley, NY, EUA) [27], using standardized encouragement by a single researcher to promote maximal effort using a previously described protocol [27]. The highest absolute concentric extensor and flexor torque as well as a BMI normalized value ($N.m.kg^{-1}.m^2$), peak torque normalized by dominant lower limb ($N.m.kg^{-1}$), the flexor/extensor ratio, total work (J), power (Watts), and quadriceps femoris muscle fatigue (%) at an angular speed of $60°.s^{-1}$ were measured.

Intervention protocol (WB-EMS or Sham protocol)

The intervention protocols were supervised by a trained physical therapist with WB-EMS equipment (Miha Bodytec®, Augsburg, Germany). The protocol involved a 6-week intervention, 5 days per week, for a total of 30 sessions, applying two types of program. After the 6-week program, the subjects were reevaluated. Subjects who missed up to five sessions during the intervention, concluded those sessions during the 7th week.

The experimental group (WB-EMSG, $n = 17$) performed the *WB-EMSG* protocol while the control group (ShamG, $n = 18$) performed the same protocol and exercises with EMS switched to “off” to avoid any stimulus influence. The sessions lasted ≈20–30 min using rectangular a wave by a symmetrical bipolar electric pulse [28]. The protocol was performed on three non-consecutive days of endurance training and 2 days of strength training per week as previously described [15].

Initially, the subjects were instructed to wear a set that consisted of a black T-shirt and shorts. Next, electrode strips were positioned on both arms, thighs, and on the gluteal region. After that, the subjects wore the vest, which was adjusted to the body by means of straps. The electrodes were previously wet with water to allow conduction of the electric current. The electrodes can simultaneously activate 14–18 regions or 10 muscle groups, allowing a total electrode area of up to 2800 cm² [28]. During the intervention protocol, current intensity was individually adjusted for each muscle group and progressively increased during each training session and saved on a smart card to ensure reliable and valid application [16, 29]. This approach allows achievement of submaximal muscle contraction levels, adjusted to each region according to current sensitivity, respecting visual and effective contraction, without pain or discomfort [16, 29]. In addition, subjects were asked to report muscle fatigue, using the *BORG* scale to maintain an adequate intensity.

The WB-EMS protocol was carried out with no loads performing dynamic exercises, specifically, a group of 10–14 dynamics movements (squat, trunk flexion, exercises of upper limbs, and isometric abdomen contraction) as previously described [15]. All movements were done at low intensity in the standing position to allow an effective voluntary contraction simultaneously with the electrical stimulation. In ShamG, time of each session and series of exercises were the same as applied in WB-EMSG, without any electrical current. Patients also wore the WB-EMS garb, with the EMS switched to “off” intensity current.

Statistical analysis and sample size

The sample size calculation was performed using GPower, Version 3.1.3 (Franz Faul Universität Kiel, Germany) based on a previous study performed on BS patients [13], showing a significant difference in the 6MWT distance after an aerobic exercise training program (49.7 ± 15 meters). Hypothesizing a better performance in 6MWT distance following the WB-EMS protocol as a primary outcome [13], a sample size with 80% power at a significance level of $\alpha = 0.05$, detecting a variation of 30% as a favorable outcome was determined. These parameters indicate a sample of five subjects were required to investigate functional gains after the intervention.

Secondary outcomes for this study included prevention of muscle mass loss and whether there is an association between 6MWT distance and lean mass [30] and, as such, the sample size was recalculated. Based on the bivariate normal correlation model, considering a significance level of 5%, a sample power of 95%, and a strong correlation (>0.70) between lean mass percentage and 6MWT distance performance as the main outcome, the calculated sample size was 16 subjects per group. Anticipating a dropout rate of ≈15%, a total of 36 patients were included in the present study.

The statistical analysis was performed by a blinded researcher working with codified subjects. Data were expressed as mean and standard deviation (SD) or median (minimum; maximum) and 95% confidence intervals with normality tested using the Shapiro–Wilk test. A two-way ANOVA with Bonferroni post hoc was applied to compare body composition data and 6MWT distance, emphasizing performance, considering three periods (preoperative, post-operative, and post intervention). If data was not normally distributed, non-parametric analysis was applied. An ANOVA one-way or Kruskal–Wallis test was performed for comparisons between both groups using deltas: post intervention versus PO period as well as PO versus preoperative period with all variables.

Correlations were made to assess the degree of association between body composition and improvements in functional tests, cytokines, and dynamometry parameters. After performing appropriate tests according to normality data distribution, correlations were defined as weak (0.20–0.50), strong (0.50–0.70), or very strong (>0.70) [31]. The statistical analysis was performed using SPSS Statistics for Windows, Version 17.0. (SPSS Inc., Chicago, Illinois, United States of America) and MedCalc, version 11.4.4.0 (MedCalc Software, Mariakerke, Belgium), adopting a significance level of 5%.

Results

Recruitment involved 293 male and female subjects; 39 subjects were considered eligible to perform the electrical stimulation protocol after *BS*, and 36 successfully completed the study. One subject was excluded from the final analysis secondary to poor-quality of data (Fig. 1). All volunteers were considered to have a sedentary lifestyle with a total Baecke score of 6.9 ± 1.3, with no differences in age between groups (ShamG: 37.4 ± 2.6; WB-EMSG: 39.4 ± 2.3 years old, $p = 0.62$). Regarding lung function, the spirometry test demonstrated no pulmonary impairments with FEV_1%pred (92.6 ± 2.8 vs 90.3 ± 5.1, $p = 0.88$) and FEV_1/FVC (86.7 ± 1.6 vs 88.0 ± 6.0, $p = 0.77$) in ShamG and WB-EMSG demonstrating similar values. Cardiopulmonary exercise testing demonstrated a diminished relative peak $\dot{V}O_2$ in both groups (WB-EMSG:15.9 ± 2.4 and ShamG: 16.5 ± 3.3 $mL.kg^{-1}.min^{-1}$) with no differences between them. In addition, the mean peak RER achieved was higher than 1.1 in both groups without any differences (WB-EMSG: 1.26 ± 0.13 and ShamG: 1.27 ± 0.13, $p >$ 0.05), demonstrating excellent effort in both groups.

Subjects started the intervention protocol 6.7 ± 3.7 days after hospital discharge; adherence was 87% and 91% in the ShamG and WB-EMSG, respectively. Moreover, subjects in the WB-EMSG did not report negative side-effects with training. Only two subjects reported dizziness/nausea/malaise, possibly due to the restrictive hypocaloric diet. All session absences were related to either work conflicts or medical appointments, with no pain or discomfort mentioned during the protocol.

Regarding functional capacity (Table 1), within-group analysis demonstrated a significant decrease in 6MWT distance in both groups in the acute PO phase as well as the mean gait speed. A significant increase in 6MWT distance occurred after the intervention compared with PO, but only the WB-EMSG demonstrated a clinically important improvement, with positive time-effect and interaction between groups ($p < 0.05$).

Regarding metabolic and pulmonary variables during the 6MWT, a positive time effect was shown, with a significant decrease in metabolic and pulmonary measurements in both groups at PO when compared with Pre ($p < 0.05$, Table 1). Following the intervention, both groups presented with a significant reduction in $\dot{V}CO_2$ and $\dot{V}_E$ compared to baseline, but only the ShamG demonstrated a significant reduction in VT and absolute $\dot{V}O_2$ ($p < 0.05$). Also, an increase in relative $\dot{V}O_2$ was present in both groups following the intervention compared to baseline. Regarding other measures, BP and leg fatigue perceived exertion decreased significantly only in the WB-EMSG following the intervention compared with baseline ($p < 0.05$), with significant time-effect and no group-effect nor interaction between time and group. Dyspnea reduced significantly in both groups post intervention related to baseline ($p < 0.05$).

Body composition analyses between both groups were performed (Table 2). Following BS, there was a significant

Table 1 Functional capacity evaluation, metabolic, cardiovascular, and pulmonary parameters at peak of 6MWT in both groups.

Variables	ShamG ($n = 18$)			WB-EMSG ($n = 17$)			p value		
	Pre	PO	Post	Pre	PO	Post	Time	Group	Interaction
6MWT distance. m	503.9 ± 76.4	453.8 ± 66.1[a]	519.2 ± 62.8[c]	503.7 ± 55.6	435.9 ± 74.5[a]	562.5 ± 66.4[bc]	0.00	0.20	0.03
Predicted distance. %	88.2 ± 8.8	77.3 ± 7.3[a]	87.0 ± 10.4[bc]	88.9 ± 10.3	75.5 ± 14.3[a]	93.7 ± 11.3[bc]	0.00	0.69	0.69
Mean Gait speed. km.h^{-1}	5.0 ± 0.7	4.5 ± 0.6[a]	5.2 ± 0.6[c]	5.0 ± 0.6	4.4 ± 0.8[a]	5.7 ± 0.7[bc]	0.00	0.51	0.05
Metabolic measures									
$\dot{V}O_2$. %pred	55.3 ± 10.0	46.7 ± 9.2[a]	52.5 ± 11.6[c]	54.9 ± 11.3	45.5 ± 13.2[a]	51.5 ± 12.1	0.00	0.74	0.89
$\dot{V}O_2$. mL.min^{-1}	1224.3 ± 372.0	1052.5 ± 287.9[a]	1045.7 ± 317.9[b]	1199.7 ± 166.1	1014.0 ± 181.0[a]	1064.1 ± 177.2	0.00	0.66	0.89
$\dot{V}O_2$. mL.kg^{-1}.min^{-1}	11.0 ± 2.7	9.3 ± 2.6[a]	11.3 ± 2.67[c]	10.7 ± 1.7	9.3 ± 2.4[a]	11.0 ± 2.4[c]	0.00	0.83	0.87
$\dot{V}CO_2$. mL.min^{-1}	1206.9 ± 393.3	889.8 ± 263.1[a]	951.1 ± 338.7[b]	1108.2 ± 205.9	836.3 ± 224.0[a]	959.7 ± 175.4[b]	0.00	0.46	0.29
RER	0.97 ± 0.08	0.84 ± 0.07[a]	0.90 ± 0.09[b]	0.93 ± 0.09	0.85 ± 0.08[a]	0.90 ± 0.07	0.00	0.99	0.07
Pulmonary measures									
$\dot{V}_E$. L.min^{-1}	41.2 ± 13.9	34.3 ± 12.2[a]	34.9 ± 12.5[b]	40.3 ± 8.7	32.6 ± 9.6[a]	35.9 ± 8.7[b]	0.00	0.77	0.66
RR. br.min^{-1}	32.5 ± 8.4	30.9 ± 7.8	30.9 ± 5.5	31.8 ± 6.6	29.7 ± 8.7	31.1 ± 6.4	0.20	0.86	0.75
Vt insp. mL	1411.7 ± 568.7	1249.4 ± 544.3[a]	1193.4 ± 378.7[b]	1350.7 ± 292.8	1184.8 ± 192.3[a]	1221.8 ± 203.5	0.00	0.66	0.60
Cardiovascular measures									
HR. bpm	123.2 ± 12.7	126.4 ± 17.9	119.6 ± 18	125.8 ± 9.4	121.5 ± 15.6	116.8 ± 14.4	0.08	0.64	0.31
HR. %pred	67.7 ± 8.0	69.3 ± 11.2	65.7 ± 11.1	69.5 ± 5.4	66.9 ± 9.0	64.6 ± 8.2	0.09	0.82	0.32
SBP. mmHg	161.3 ± 22.1	149.6 ± 16.9	152.1 ± 22.3	167.9 ± 25.9	158.2 ± 28.1	143.8 ± 17.0[b]	0.00	0.69	0.09
DBP. mmHg	98.4 ± 11.7	92.0 ± 8.3	93.6 ± 7.6	99.3 ± 7.5	95.5 ± 12.2	90.6 ± 9.2[b]	0.00	0.84	0.25
Symptoms									
Dyspnea	1.51 (0.0;7.0)	1.74 (0.0;7.0)	1.11 (0.0;5.0)[b]	1.47 (0.0;5.0)	1.14 (0.0;5.0)	0.85 (0.0;3.0)[b]	0.01	0.50	0.39
Leg fatigue	0.71 (0.0;2.5)	1.01 (0.0;5.0)	0.66 (0.0;2.0)	0.59 (0.0;3.0)	0.47 (0.0;3.0)	0.12 (0.0;0.5)[d]	0.12	0.11	0.38

Data presented as mean ± SD and median (min;max).

ShamG Sham group, *WB-EMSG* whole-body electrical stimulation group, $\dot{V}O_2$ oxygen uptake, $\dot{V}CO_2$ carbon dioxide production, *RER* respiratory exchange ratio, $\dot{V}_E$ minute ventilation, *RR* respiratory rate, *VT* insp inspiratory tidal volume, *HR* heart rate, *SBP* systolic blood pressure, *DBP* diastolic blood pressure.

Differences between groups and periods were assessed with the use of two-way ANOVA with post hoc Bonferroni correction: [a]Pre vs PO; [b]Pre vs Post; [c]PO vs Post; between groups: [d]Post vs Post. $p < 0.05$.

reduction in BMI, fat mass, and also lean mass of all muscle groups when compared to preoperative measurements ($p < 0.05$). A significant time-effect was observed in all measures, with no group-effect nor interaction between time and group. Following the intervention, both groups presented with a significant reduction in total muscle mass and losses in all respective body segments (lean mass, fat mass, and percentage of fat mass) compared with PO and was significantly higher during the preoperative period.

We observed a significant reduction in absolute extensor and flexor peak torque in both groups, ($p < 0.05$) post intervention, but only the ShamG presented with a significant reduction in relative values for peak torque ($p < 0.05$), with higher deltas in the average flexor torque and relative flexor peak torque ($p < 0.05$), showing positive time-effect and interaction between groups ($p < 0.05$) (Table 3). In addition, both groups demonstrated a reduction in extensor isometric torque, but only the ShamG had a significant reduction in flexor isometric torque ($p < 0.05$). Regarding the endurance evaluation, extensor power was reduced in the ShamG with important increase in fatigue indices (flexor and extensor, $p < 0.05$). Other variables such as absolute and relative torques were similar in both groups ($p < 0.05$).

The total cholesterol and fractions (HDL, LDL, VLDL), fasting insulin, basal glucose, quick and HOMA presented with a significant reduction post intervention in both groups ($p < 0.05$) without any difference between groups; similar trends were observed with important rations (i.e., Castelli I–Total Cholesterol/HDL and Castelli II– LDL/HDL) (Table 4). No group-effect nor group interaction between factor groups and time were found ($p > 0.05$).

In addition, TNF-α did not significantly change in either group following the intervention and between them. Both groups had a similar significant reduction in leptin and myostatin levels ($p < 0.05$). On the other hand, only the WB-EMSG presented with a significant increase in adiponectin, an anti-inflammatory cytokine ($p < 0.05$).

Interestingly, extensor peak torque was closely and strongly associated with body lean mass ($r = 0.67$), lean mass of lower limbs ($r = 0.65$), and $\dot{V}O_2$ ($r = 0.54$) following the intervention only in the WB-EMSG ($p < 0.05$, Fig. 2). However, no correlation was found in the Sham group.

Table 2 Comparisons of body composition data of both groups before bariatric surgery at postoperative period and after intervention protocol.

Variables	ShamG ($n = 18$)			WB-EMSG ($n = 17$)			p value		
	Pre	PO	Post	Pre	PO	Post	Time	Group	Interaction
BMI (kg/m^2)	40.9 ± 1.2	38.2 ± 1.2^a	34.2 ± 1.4^{bc}	40.1 ± 1.0	38.0 ± 0.9^a	33.5 ± 0.8^{bc}	0.00	0.71	0.26
Total lean mass (kg)	55.6 ± 10.7	51.6 ± 10.2^a	49.9 ± 9.7^{bc}	54.7 ± 9.5	51.9 ± 10.1^a	49.2 ± 9.5^{bc}	0.00	0.95	0.26
Total fat mass (kg)	58.4 ± 10.4	54.6 ± 10.8^a	53.0 ± 10.2^{bc}	60.2 ± 10.1	55.0 ± 10.6^a	52.2 ± 10.0^{bc}	0.00	0.85	0.36
Body fat (%)	46.9 ± 6.3	47.4 ± 6.3	42.5 ± 6.7^{bc}	48.2 ± 3.6	48.7 ± 3.5	44.1 ± 3.8^{bc}	0.00	0.35	0.63
Right arm									
Lean Mass (kg)	3.4 ± 0.9	3.3 ± 0.8^a	3.3 ± 0.8^{bc}	3.6 ± 0.8	3.4 ± 0.8^a	3.1 ± 0.8^{bc}	0.00	0.80	0.30
Fat mass (kg)	5.9 ± 2.2	5.3 ± 1.9^a	3.8 ± 1.5^{bc}	6.3 ± 1.7	5.7 ± 1.4^a	3.9 ± 1.0^{bc}	0.00	0.50	0.52
Percentage body fat (%)	6.6 ± 2.3	5.9 ± 1.9^a	4.2 ± 1.4^{bc}	7.7 ± 3.7	6.8 ± 3.2^a	4.7 ± 2.1^{bc}	0.00	0.27	0.33
Left arm									
Lean Mass (kg)	3.7 ± 0.8	3.4 ± 0.8^a	3.2 ± 0.7^{bc}	3.6 ± 0.8	3.4 ± 0.8^a	3.1 ± 0.7^{bc}	0.00	0.90	0.22
Fat mass (kg)	5.9 ± 2.2	5.3 ± 2.0^a	3.8 ± 1.5^{bc}	6.4 ± 1.7	5.7 ± 1.4^a	3.9 ± 1.0^{bc}	0.00	0.51	0.57
Percentage body fat (%)	6.6 ± 2.3	5.9 ± 1.9^a	4.1 ± 1.7^{bc}	7.8 ± 3.8	6.9 ± 3.2^a	4.8 ± 2.1^{bc}	0.00	0.26	0.61
Trunk									
Lean Mass (kg)	29.0 ± 5.0	27.1 ± 4.9^a	25.5 ± 4.6^{bc}	28.6 ± 4.5	27.3 ± 4.8^a	25.1 ± 4.6^{bc}	0.00	0.96	0.28
Fat mass (kg)	26.3 ± 4.2	25.4 ± 4.4^a	21.3 ± 5.4^{bc}	27.2 ± 2.9	26.2 ± 2.9^a	21.2 ± 3.2^{bc}	0.00	0.61	0.45
Percentage body fat (%)	5.1 ± 0.8	4.9 ± 0.8^a	4.0 ± 0.8^{bc}	5.4 ± 1.2	5.2 ± 1.1^a	4.2 ± 1.0^{bc}	0.00	0.45	0.93
Right leg									
Lean Mass (kg)	8.3 ± 1.7	7.8 ± 1.6^a	7.6 ± 1.7^b	8.6 ± 1.4	8.2 ± 1.5^a	7.9 ± 1.6^{bc}	0.00	0.50	0.29
Fat mass (kg)	6.0 ± 1.2	5.8 ± 1.0	4.8 ± 1.1^{bc}	6.6 ± 0.8	6.3 ± 0.7^a	5.3 ± 0.8^{bc}	0.00	0.11	0.88
Percentage body fat (%)	2.6 ± 0.5	2.5 ± 0.4	2.1 ± 0.4^{bc}	2.9 ± 0.7	2.8 ± 0.7	2.4 ± 0.7^{bc}	0.00	0.13	0.89
Left leg									
Lean Mass (kg)	8.3 ± 1.7	7.8 ± 1.6^a	7.6 ± 1.7^b	8.6 ± 1.4	8.2 ± 1.5^a	7.9 ± 1.5^{bc}	0.00	0.51	0.48
Fat mass (kg)	6.0 ± 1.1	5.8 ± 1.0	4.8 ± 1.1^{bc}	6.5 ± 0.8	6.3 ± 0.6	5.2 ± 0.6^{bc}	0.00	0.11	0.92
Percentage body fat (%)	2.6 ± 0.5	2.5 ± 0.4	2.1 ± 0.4^{bc}	2.9 ± 0.7	2.8 ± 0.7	2.3 ± 0.6^{bc}	0.00	0.14	0.94

Data presented as mean ± SD.

ShamG Sham group, *WB-EMSG* whole-body electrical stimulation group.

Differences between groups and periods were assessed with the use of two-way ANOVA with post hoc Bonferroni correction: ^{a}Pre vs. PO; ^{b}Pre vs. Post; ^{c}PO vs. Post. $p < 0.05$.

Discussion

Main findings of the present study

The main findings of the present study are: (1) both intervention protocols demonstrated favorable outcomes on functional capacity performance but only WB-EMS reached important amelioration of the same measures when compared to preoperative baseline, followed by decreased blood pressure, leg fatigue, and dyspnea during recovery; (2) both groups demonstrated similar improvements in body composition parameters; (3) WB-EMS prevented greater loss of muscle strength and endurance following the intervention; a significant decline in muscle performance (torques) and an increase in muscle fatigue was only apparent in the ShamG; and (4) WB-EMSG was not superior to exercise training alone in improving biochemical parameters but did lead to a significant increase in adiponectin.

In the current study, subjects already presented lower functional capacity during the preoperative and a significant reduction occurred early after BS, but other findings during this acute recovery period are scant. Excessive body weight is a significant contributor to profound limitations in cardiorespiratory [5] and biomechanical performance, leading to a low exercise/functional capacity [32]. Even though BS lead to significant reductions in fat mass, subjects in the current study also acutely lost lean mass and were still classified as obese or severely obese. In addition, dietary restriction imposed post BS may have impaired exercise performance.

In patients who have undergone BS, studies have demonstrated improvements in the functional capacity 3–6 months after BS, with even greater gains after 12 months [2, 32]. Improved exercise performance in these patients is attributable to weight loss, higher muscle oxidative capacity, and improvements in cardiovascular

Table 3 Muscle mass dynamometry measures: isokinetic, isometric and endurance test of dominant lower limb.

Variables	ShamG ($n = 18$) Pre	Post	Post-pre	WB-EMSG ($n = 17$) Pre	Post	Post-pre	p value Time	Group	Interaction
Isokinetic test									
Extensor PT (N.m)	129.1 ± 48.7	104.1 ± 38.0[a]	−25.0 ± 20.5	126.5 ± 31.1	110.5 ± 26.8[a]	−16.0 ± 12.9	0.00	0.87	0.13
Extensor PT/DLL (N.m.kg^{-1})	15.3 ± 3.4	13.4 ± 2.4[a]	−1.9 ± 2.1	14.8 ± 3.2	14.1 ± 2.7	−0.7 ± 1.9	0.00	0.96	0.08
AVG Extensor PT (N.m)	75.5 ± 32.2	64.9 ± 24.4[a]	−10.7 ± 14.9	77.1 ± 21.0	71.6 ± 16.7	−5.6 ± 9.2	0.00	0.60	0.23
Flexor PT (N.m)	62.4 ± 25.5	48.3 ± 21.2[a]	−14.09 ± 10.4	60.6 ± 13.4	52.9 ± 9.7[a]	−6.1 ± 8.8	0.00	0.81	0.07
Flexor PT/DLL (N.m.kg^{-1})	7.4 ± 1.8	6.3 ± 1.9[a]	−1.1 ± 1.0	7.1 ± 1.3	6.8 ± 1.6	−0.3 ± 1.0[b]	0.00	0.82	0.02
AVG Flexor PT (N.m)	57.5 ± 24.7	44.07 ± 19.5[a]	−13.4 ± 9.9	54.6 ± 13.2	48.5 ± 9.4[a]	−6.1 ± 8.8[b]	0.00	0.89	0.02
Flexor PT/Extensor PT	48.6 ± 9.6	46.4 ± 10.9	−2.2 ± 6.9	48.9 ± 9.7	49.2 ± 8.4	0.3 ± 8.7	0.46	0.60	0.34
Isometric									
Extensor PT (N.m)	132.9 ± 53.0	114.0 ± 37.0[a]	−17.2 ± 27.8	134.4 ± 28.1	119.0 ± 29.1[a]	−15.2 ± 17.8	0.00	0.75	0.81
Extensor PT/DLL (N.m.kg^{-1})	15.8 ± 3.6	15.11 ± 2.2	−0.8 ± 2.8	15.9 ± 2.4	15.3 ± 2.4	−0.7 ± 1.9	0.10	0.90	0.63
Flexor PT (N.m)	69.3 ± 21.4	54.5 ± 17.8[a]	−12.3 ± 16.7	68.5 ± 13.8	57.8 ± 10.5	−10.5 ± 6.9	0.00	0.84	0.78
Flexor PT/DLL (N.m.kg^{-1})	8.2 ± 1.6	7.4 ± 2.9[a]	-0.6 ± 2.5	8.0 ± 1.2	7.5 ± 1.4	-0.6 ± 0.8	0.00	0.82	0.02
Endurance									
Extensor PT (N.m)	117.5 ± 46.0	101.8 ± 33.3[a]	−15.8 ± 29.4	118.7 ± 36.2	101.8 ± 26.8[a]	−13.3 ± 18.3	0.00	0.84	0.78
Extensor PT/DLL (N.m.kg^{-1})	14.0 ± 3.3	13.2 ± 2.4	−0.7 ± 3.0	13.6 ± 3.1	13.0 ± 2.5	−0.7 ± 2.2	0.17	0.77	0.84
Extensor TW (J)	1759.3 ± 723.1	1551.4 ± 596.1[a]	−208.0 ± 431.6	1948.1 ± 6663.2	1554.5 ± 574.2[a]	−356.5 ± 314.2	0.00	0.61	0.28
Extensor Power (W)	61.7 ± 23.0	52.9 ± 19.5[a]	−8.9 ± 13.5	65.8 ± 20.7	54.6 ± 14.5	−9.9 ± 9.1	0.00	0.84	0.78
Extensor FI (%)	21.8 ± 16.4	32.0 ± 11.7[a]	10.2 ± 17.3	26.2 ± 8.4	32.8 ± 9.5	6.2 ± 9.3	0.00	0.50	0.45
Flexor PT (N.m)	59.6 ± 25.6	47.0 ± 18.9[a]	−12.7 ± 14.5	59.1 ± 17.7	48.5 ± 11.1[a]	−10.9 ± 11.8	0.00	0.85	0.75
Flexor PT/DLL (N.m.kg^{-1})	7.1 ± 2.2	6.1 ± 1.8	−1.0 ± 1.4	6.8 ± 1.4	6.2 ± 1.4	−0.8 ± 1.4	0.25	0.26	0.26
Flexor TW (J)	891.3 ± 460.2	691.1 ± 322.6[a]	−200.2 ± 272.7	936.2 ± 344.6	753.6 ± 205.4[a]	−180.1 ± 207.6	0.00	0.65	0.82
Flexor Power (W)	29.9 ± 14.5	22.9 ± 10.7[a]	−7.1 ± 7.9	30.9 ± 11.5	24.8 ± 6.9[a]	−6.0 ± 6.6	0.00	0.69	0.69
Flexor FI (%)	29.9 ± 25.9	44.7 ± 11.6[a]	14.8 ± 28.6	40.8 ± 16.2	41.7 ± 13.1	−0.4 ± 15.9	0.11	0.50	0.09

Data presented as mean ± SD.

PT Peak torque, *DLL* Dominant Lower Limb, *AVG* average, *TW* Total work, *FI* Fatigue index, *N.m* Newton meter, *J* Joules, *W* Watts, Delta Post-pre changes.

Two-way Anova: [a]Pre vs. Post; [b]One-way Anova – between groups for delta, $p < 0.05$.

performance [33, 34]. However, the literature also demonstrates the first 6 months after BS often leads to lower levels of physical activity [33] and the decline in fat-free mass negatively affects basal metabolic rate, with patients becoming more susceptible to weight regain or not achieving the surgical weight loss goal [35]. These findings highlight the importance of rehabilitation strategies following BS, beginning shortly after surgery and continuing for the long-term.

Researches have consistently reported improvements in cardiorespiratory fitness and functional capacity after BS with the employment of an exercise training program [32, 35]. These programs are often based on aerobic exercise, with protocols differing in initiation of the intervention (1–3 months post BS) as well as duration and frequency [13, 36]. Regarding WB-EMS, studies demonstrate this technique holds promise as an additional therapeutic mode when other approaches of exercise are not indicated [28], leading to improvements in exercise performance and aerobic capacity ($\dot{V}O_2$max) in runners and healthy volunteers [37, 38] as well as patients with chronic diseases, such as type II diabetes mellitus, sarcopenic obesity [29, 39–41] and chronic heart failure [42]. Previous research has demonstrated positive results with WB-EMS following a 6-week intervention [37, 38] corroborating the findings of present study and emphasizing the importance of including early rehabilitation programs following BS, which can be enhanced by WB-EMS technology.

In the present study, we observed a lower drop in muscle strength parameters, as measured by peak flexor torque parameters, with the use of WB-EMS (Interaction time vs group effect, $P < 0.05$). The use of WB-EMS can activate both endurance and strength muscle fiber types, applying specific parameters and allows a combined exercise stimulus [43] as proposed by this present study. This approach has been shown to be more effective for strength gains, to preserve lean mass than conventional training [44] and to reduce intermuscular adipose tissue [45] as demonstrated by enhanced leg extensor strength and functional performance.

A significant reduction occurred in all biochemical parameters with no difference between groups as well as important ratio indices (Castelli I – Total Cholesterol/HDL and Castelli II – LDL/HDL). Immediately after surgery, hepatic insulin sensitivity and consequently glucose uptake

Table 4 Parameters of total cholesterol and fractions, glucose and insulin, and cytokines in both groups before surgery and after WBS protocol.

	ShamG ($n = 18$)		WB-EMSG ($n = 17$)		p value		
Variables	Pre	Post	Pre	Post	Time	Group	Interaction
Total Cholesterol (mg/dl)	205.8 ± 49.3	160.9 ± 27.2[a]	198.8 ± 34.7	158.4 ± 27.6[a]	0.00	0.64	0.73
HDL (mg/dl)	45.4 ± 9.1	35.7 ± 6.4[a]	44.0 ± 7.4	38.1 ± 4.7[a]	0.00	0.81	0.06
LDL (mg/dl)	131.3 ± 43.2	97.4 ± 29.1[a]	122.4 ± 27.1	98.2 ± 24.3[a]	0.00	0.61	0.50
VLDL (mg/dl)	29.1 ± 15.5	19.6 ± 5.9[a]	32.5 ± 13.5	22.1 ± 6.5[a]	0.00	0.35	0.84
Triglycerides (mg/dl)	145.7 ± 77.3	97.4 ± 29.7[a]	162.8 ± 67.6	110.3 ± 31.9	0.00	0.34	0.84
Total Cholesterol/HDL	4.67 ± 1.37	4.64 ± 1.16	4.59 ± 0.92	4.20 ± 0.89	0.19	0.46	0.25
LDL/HDL	2.97 ± 1.12	3.07 ± 0.99	2.81 ± 0.95	2.61 ± 0.74	0.69	0.27	0.26
Fasting insulin (uU/ml)	15.2 ± 7.7	8.0 ± 4.3[a]	15.1 ± 9.0	8.4 ± 3.6[a]	0.00	0.93	0.84
Glycemia (mg/dl)	95.2 ± 9.0	86.1 ± 7.3[a]	97.5 ± 8.2	89.0 ± 7.6[a]	0.00	0.28	0.82
QUICK	0.32 ± 0.02	0.36 ± 0.04[a]	0.32 ± 0.02	0.35 ± 0.02[a]	0.00	0.66	0.35
HOMA	3.59 ± 1.91	1.72 ± 0.94[a]	3.70 ± 2.46	1.87 ± 0.84[a]	0.00	0.78	0.95
Leptin	560.5 ± 133.0	466.7 ± 113.3[a]	528.4 ± 144.1	456.3 ± 116.6[a]	0.00	0.59	0.50
Adiponectin	150.5 ± 26.0	160.1 ± 17.0	143.0 ± 13.7	155.9 ± 21.7[a]	0.02	0.24	0.72
Leptin/adiponectin ratio	3.85 ± 1.13	2.94 ± 0.75[a]	3.71 ± 1.04	3.00 ± 0.91[a]	0.00	0.59	0.85
TNF- α	71.4 ± 16.6	74.6 ± 28.3	76.2 ± 41.2	74.6 ± 33.6	0.10	0.62	0.25
Myostatin	370.9 ± 265.6	157.2 ± 149.0[a]	370.7 ± 220.2	197.9 ± 172.5[a]	0.00	0.74	0.56

Data presented as mean ± SD.

ShamG Sham group, *WB-EMSG* whole-body electrical stimulation group, *HDL* High density lipoprotein, *LDL* Low density lipoprotein, *VLDL* very low density lipoprotein, *QUICK* Quantitative Insulin Sensitivity Check Index, *HOMA* Homeostasis Model Assessment.

Differences between groups and periods were assessed with the use of two-way ANOVA with post hoc Bonferroni correction: [a]Pre vs. Post, $p < 0.05$.

improve due to the restrictive/hypocaloric diet [36, 46] and recently, not only adipose but muscle was defined as an endocrine tissue that secretes myokines, responsible for metabolic control [47]. Exercise training has also been shown to be important in improving biochemical measures, with higher energetic metabolism and mitochondrial function [48], reducing fat deposits that are associated with insulin resistance [48].

Other authors reported the advantages of WB-EMS on biochemical parameters. In untrained middle-aged subjects, improvements in blood parameters were noted, while glucose was significantly decreased with WB-EMS [28]. In patients with type 2 Diabetes Mellitus, WB-EMS led to significantly lower levels of fasting glucose [36]. To our knowledge, the current study is the first to assess the effects of WB-EMS following BS.

Our study is the first to show WB-EMS improved adiponectin following BS, an ant-inflammatory marker that promotes a reduction in myostatin and leptin. The significant improvement of adiponectin is related to insulin signaling, lipid metabolism regulation, and oxidative stress. Moreover, a reduction in myostatin may affect muscle strength, aerobic capacity and fatigability [49]. In our study, RYGB tended to increase adiponectin in ShamG, but not significantly, while WB-EMSG promoted a significant increase. Moreover, leptin/adiponectin, that is a marker of adipose tissue dysfunction, drives beneficial metabolic changes and correlates with insulin resistance and reduces atherosclerosis risk [50]. Regarding myostatin, both groups in the present study had a significant decrease in its levels. In a previous study, a 6-month exercise program following RYGB decreased plasma levels of myostatin and is concomitantly associated with increased aerobic capacity, skeletal muscle size, and decreased intermuscular adipose tissue [51].

This study has some limitations which are inherent to its blinding nature. Firstly, although we blinded the therapists to carry out the application of WB-EMS through the system's memory cards, it was not possible to visualize the muscle contractions due to the vest that covered the muscles. It is possible that patients could refer to sensations or absence of current sensations and report them during exercise sessions. Another important consideration in the present study is that the blinding validation questions were not explored. Moreover, we could not explore other measures that could assist us in assessing muscle catabolism such as CK levels or myoglobin concentration. Finally, our sample was composed mostly of women and, as such, the results of the present study may not be generalizable to males.

In conclusion, a 6-week WB-EMS program associated with dynamic exercises in early post BS patients improved

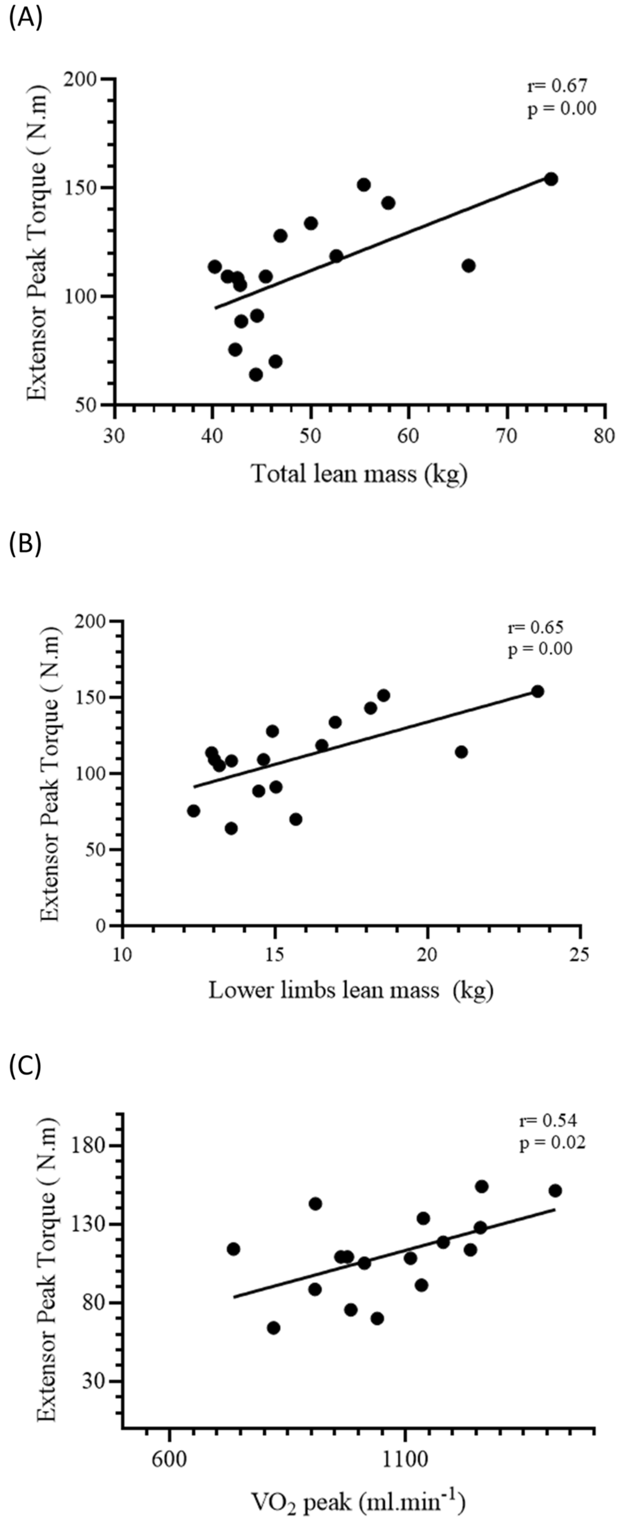

Fig. 2 Correlations between 6MWT, body composition, and dynamometry measures in WB-EMSG. Results are presented as mean values. a Extensor peak torque and total lean mass, (**b**) extensor peak torque and lower limbs lean mass, (**c**) extensor peak torque and VO_2 uptake at peak of 6MWT. VO_2 oxygen uptake, 6MWT 6-minute walking test.

functional capacity, preserved muscle strength, and endurance. However, WB-EMS was not able to enhance the effects of body weight reductions acutely following BS. Our results are important to show the feasibility of applying early rehabilitation protocols in morbidly obese patients after BS, and that WB-EMS may potentiate the positive effects of an exercise training program, being well tolerated and promoting adherence among early post BS patients.

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Compliance with ethical standards

Conflict of interest The authors declare no competing interests.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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