
Article

Low-intensity whole-body vibration: a useful adjuvant in managing obesity? A pilot study

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Abstract: The use of whole-body vibration (WBV) for therapeutic purposes is far from being standardized and only very recently an empirical foundation for reporting guidelines for human WBV studies has been published. Controversies about safety and therapeutic dosage still exist. The present study aimed to investigate the metabolic and mechanical effects of low-intensity WBV in accordance to the ISO 2631 norm on subjects with obesity. 41 obese subjects (BMI ≥ 35 kg/m²) were recruited to participate in a 3-week multidisciplinary inpatient rehabilitation program including fitness training and WBV training. During WBV the posture was monitored with an optoelectronic system with 6 infrared cameras (Vicon, Vicon Motion System, Oxford, UK). The primary endpoints were: variation in body composition, factors of the metabolic syndrome, functional activity (sit-to-stand and 6-min walking test), muscle strength, and quality of life. Secondary endpoints were: modification of irisin, testosterone, growth hormone, IGF1 levels. We observed significant changes in salivary irisin levels, Group 2 ($p < 0.01$) as compared to the control group, while muscle strength, function, and other metabolic and hormonal factors did not change after a 3-week low-intensity WBV training respect control group. Future studies are needed to deeper investigate the potential metabolic effect of low-intensity WBV in managing weight.

Keywords: obesity; irisin; whole-body vibration; exercise; weight loss; rehabilitation; weight management; muscle strength

1. Introduction

Obesity (BMI ≥ 30 kg/m²) is the most common form of malnutrition in industrialized countries. Excessive body weight increases mechanical stress to the joints and tissues and induces physical limitations and pain[1], leading to a reduction of physical activity that contributes to the loss of muscle mass and strength. Weight loss is conventionally

achieved through dietary modifications[2] behavioural correction, and/or exercise prescription [3]. In individuals with obesity, a modest weight loss (5 to –10% of body weight) helps to alleviate cardiovascular risk [2]. However, the success rate of therapy for obesity is very low: dieting may work in the short term, but severe dietary restriction alone reduces muscle mass and leads to a decline in physical fitness[4]; traditional exercise, such as aerobic and resistance training, improves heart rate variability, physical strength, and body composition. Pain is one of the major determinants of ceasing physical activity[1,5]. Aerobic or resistance exercise can be associated with increased risk of musculoskeletal injuries, thus reducing adherence to exercise prescription[5]. The majority of people with obesity are reluctant to enrol in conventional exercise programs due to physical limitations, musculoskeletal discomfort, and lack of self-motivation [5]. In the last two decades, whole-body vibration (WBV) emerged as an alternative exercise modality for strength training [6]. WBV involves exercising on a vibrating platform; vibrations mechanically generate rapid variations in the length of the muscle-tendon complex [7], stimulating repetitive eccentric concentric muscular work and reflexive muscle contractions [8]. WBV was first recognized as an alternative to resistance exercise for its ability in enhancing force and power in skeletal muscle [6,9]. Evidence that body vibrations slow down fat accumulation and reduce adipogenesis in rats [10] suggested a possible clinical use of WBV in the treatment of obesity. Some evidence exists that WBV improves body composition [11], muscle strength [6] and cardiovascular function in various populations, including individuals with obesity[12,13]. WBV is a neuromuscular training method that has the potential to induce both mechanical and metabolic adaptive responses. Changes in neuromuscular response, testosterone, and growth hormone (GH) concentrations have been observed after WBV [14]. An increase in circulating levels of irisin, favoring the browning of the adipose tissue, testosterone and IGF-1 has also been observed [15]. From the mechanical point of view, exposure to 20-30 Hz WBV has shown neuromuscular adaptations[7,8]. Scanty evidence on the effects of WBV in weight loss and reduction in visceral fat is present [16]. It may cause an increase in lipolysis and energy expenditure through enhancement of the afore-mentioned anabolic hormones [8,14,15]. WBV may also present the advantage of an easily accepted, rapid and “passive” application. A major problem in the field is that the different stimulus intensities and safety of WBV devices are often poorly described[17]. Only earlier this year, the empirical foundation for reporting guidelines for human WBV studies has been published and a final 40-item list of aspects of human WBV studies panel was established[18]. This list expands previous recommendations on the use of WBV[19]. However, concern about potential risks for musculoskeletal [20,21] circulatory and neurological disorders [22], Raynaud’s phenomenon [23] with exposure to WBV is still present in the literature. Vibration thresholds for human exposure are in use only in occupational medicine. Despite the growth of WBV as a surrogate or supplement to exercise, no similar limits have been set so far in rehabilitation [22]. WBV training modality is characterized by several variables: frequency (Hz), type of vibration (rotating or vertical), amplitude in terms of displacement (mm) or, acceleration (g), exposure time and knee flexion grade, series, number of repetitions, rest period, frequency and duration[24]. In some studies, WBV reported acceleration levels, exceeding the thresholds recommended by ISO [8,22]. The use of WBV for therapeutic purposes is therefore far from being standardized and caution should be used when using WBV devices providing high vibration levels on patients [22]. A recent systematic review [24] attempted to define the outcomes of WBV on individuals with obesity, the optimal combination of vibration and exercise setting, and to identify gaps of knowledge that may lead to improper use of WBV with consequent harmful effects. It was shown that when combined with dietary intervention, 10 or more weeks of WBV produced significant body weight reduction [16,25] and leg strength improvements[9,25]. The present study aimed to investigate the metabolic and mechanical effects of low-intensity WBV performed in a static position on subjects with obesity. The primary endpoints were: variation of body composition, metabolic syndrome, performance,

and strength. The secondary endpoints were: modification of irisin, testosterone, GH, IGF1 levels after WBV training.

2. Materials and Methods

This is a pilot, randomized, double-blind, and controlled clinical study that followed the guidelines set out in the Consolidated Standards of Reporting Trials (CONSORT) conducted with patients diagnosed with obesity ($BMI \geq 35 \text{ kg/m}^2$). An extensive medical screening was performed by a physician who checked the inclusion and exclusion criteria. Neither the patients nor the trainer who conducted the training program was blinded. Subjects were randomly assigned to one of the four groups after the initial evaluation. After randomization, 11 subjects were assigned to the WBV Group 1 (Group 1), 10 were assigned to the WBV Group 2 (Group 2), 10 were assigned to the first control group (Group 3), 10 were assigned to the second control group (Group 4). We used a customized platform to comply with the obese patients (Power club, Ferrara, Italy). One subject of Group 1 dropped out. The baseline data were collected during 3 time periods defined as Pre-T0, T0, and T1. During the Pre-T0, we collected biochemical samples, body composition data, and calorimetry analysis of the subjects. During T0, the day before the beginning of WBV training was collected from blood samples for hormonal analysis and the subjects performed biomechanical and functional tests. T1 was performed the day after T0 where the subjects performed the first training session of the protocol; during T1 we collected a biological sample of saliva immediately before and after the training session. The sample of saliva collected was assayed by ELISA kit only in those subjects who completed 9 series of WBV by the study end. All the tests reported above were repeated after 3 weeks of training, T9 (as T1), T10 (as T0), and Post-T10 (as Pre-T0) as reported in the timeline in figure number 1.

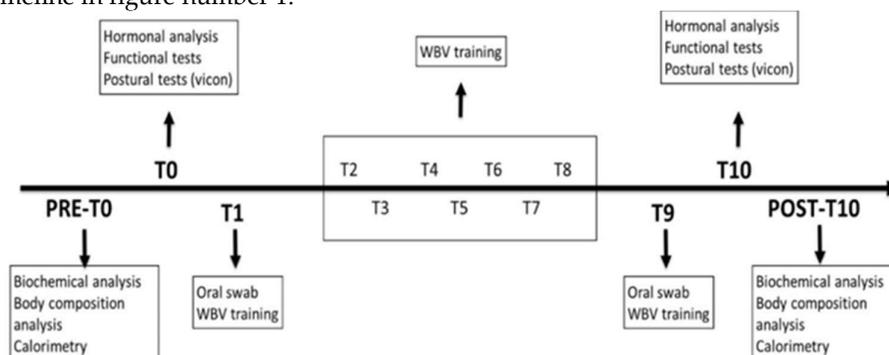


Figure 1. Timeline of the study protocol

2.1. Subjects

Forty-one obese ($BMI \geq 35 \text{ kg/m}^2$) subjects admitted to San Giuseppe Hospital, Pincavalle, Istituto Auxologico Italiano were recruited to participate in a 3-week multidisciplinary inpatient rehabilitation program.

The inclusion criteria for the study were as follows: (1) any gender, (2) age of 18-60, (3) well-controlled HbA1c. Exclusion criteria were (1) major orthopedic conditions or recent orthopedic surgery, (2) neurological conditions, (3) balance disorders, (4) neoplasms, (5) moderate or severe chronic kidney failure. Participants were informed about the design of the study and, they signed written informed consent before participation. The research was conducted according to the declaration of Helsinki and was approved by the Ethics Committee of the Istituto Auxologico Italiano.

2.2. Anthropometric Measurement

All measurements were performed in the morning, with patients in fasting conditions and undressed. Height was measured to the nearest 0.5 cm, and body weight was

measured with a digital scale to the nearest 0.1 kg. BMI was calculated as weight in kg over height in m². Waist circumference was measured at the mid-level between the lower rib margin and the iliac crest. Body composition was determined by BIA 101/s (Akern® - Firenze, Italy). This technique measures the total fat percentage of the body without making a distinction between peripheral subcutaneous, abdominal subcutaneous, or deep abdominal fat.

2.3. Metabolic Measurement

Basal metabolic rate was estimated using a ventilated hood system (Oxycon pro; CareFusion®).

2.4. Laboratory Analyses

A fasting blood sample was taken between 6:00 and 7:00 AM to determine fasting levels cholesterol, LDL HDL, triglycerides, calcium, phosphate, alkaline phosphatase, creatine phosphokinase, HbA1c, insulin, glucose, GH, IGF-1, testosterone, cortisol, sex hormone-binding globulin and irisin. The biological samples of saliva were collected in proper tubes (Salivette) immediately before and after the first and last training session from 9.00 AM to 11.00 AM. All the patients were asked to avoid any activity training from 5.00 PM of the day before. Lipids and glycemic metabolic profiles were measured with an enzymatic method (Roche Diagnostics GmbH). Plasma and salivary irisin was measured by an ELISA kit (EK-067–29, Phoenix Pharmaceuticals, and Phoenix, Arizona, USA).

2.5. Muscle strength and Function

Handgrip strength was measured to the nearest kilogram using a Jamar hand dynamometer (Sammons Preston, Inc., Bolingbrook, IL, USA). All participants were instructed to maintain an upright standing position, arms down by the side, and hold the dynamometer in the dominant hand without squeezing the arm against the body. The width of the dynamometer's handle was adjusted to the hand size of the participants such that the middle phalanx rested on the inner handle. Participants were allowed to perform one test trial, followed by three trials for the right (HG DX) and left (HG SX) hand, and the best measurement was taken for analysis. All participants performed an isokinetic strength test for the lower limbs in two different modalities (Humac Cybex Norm di CSMi). First, the isometric strength of the extensor muscles of the right lower limb was tested at 60° of knee flexion (ISO EX). Then, the dynamic strength of the same muscles was tested in the range of 90° to 0° of knee flexion (ISO DIN EX). Participants were asked to exert their maximal voluntary contraction.

All participants were evaluated with the 6-minutes walking test (6MWT). Subjects were instructed to walk as fast as they could along an even undisturbed 30-m hospital corridor marked every 5 m; the operator used a lap counter system and the complete distance walked during 6min was measured using a tape measure from the nearest marker with coloured tape on the floor. Encouragement was given every minute during the test until subject exhaustion using only standardized phrases as specified in the "ATS Statement: Guidelines for the Six-minute Walk Test". Chest pain, severe dyspnea, physical exhaustion, muscle cramps, sudden gait instability, or other signs of severe distress were additional criteria for stopping the test. The subject's pulse, respiratory rate, blood pressure, and perceived fatigue as assessed on the Borg's scale were measured before the test and at test completion. The distance covered in 6 min by each subject was used as a variable for the analysis [26].

The following instrumented tests were then performed: Sit To Stand (MAXFLEX_SIT2STAND), Stand To Sit (MAXFLEX_STAND2SIT), and 60-second stabilometric test with eyes open and closed were then performed. We used an optoelectronic device (MX Giganet units - Vicon Motion Systems, UK, registered no. 1801446) and a force platform (Kistler Type 5233A- Kistler Instrument Corp.- Novi, MI, US) to instru-

ment the tests. All the participants first performed a 5-minute warm-up consisting of 3 sets per 10 repetitions of sit to stand, 3 sets per 10 repetitions of leg extension (without weight) underlining the emphasis of quadriceps contraction and 2 trials for each session to familiarize with the test before the maximal effort of isokinetic strength test for the lower limbs in the two modalities reported before and a recovery of 3 minutes was conceded after each maximal effort repetition. All measures were taken at the Research Laboratory in Biomechanics and Rehabilitation of the San Giuseppe Hospital, Istituto Auxologico Italiano.

2.6. Laboratory Analyses

During the study period, all patients underwent a hypocaloric diet based on measured resting metabolic rate using a ventilated hood system (Oxycon pro; CareFusion ®; Yorba Linda, California, US). Caloric intake was 1650 kcal for the first week and the amount in kcal of the resting metabolic rate for the following weeks.

2.7. Fitness Training

The fitness training program consisted of aerobic low-intensity steady-state training 5 days a week: outdoor walking for 1 h in the morning and indoor cycling for 25 minutes in the afternoon at 65–70% of maximal measured heart rate (HR_{max}). Besides, general muscle strengthening exercises for the large muscle groups of the body were performed indoor for 30 minutes, including warm-up. During indoor activities, all participants were supervised by a skilled physiotherapist to monitor individual heart rate target zones during the training sessions (Pulse Oximeter; Model: MD300C63, Maxtec, Utah, US) in the hospital.

2.8. WBV

Patients were randomly allocated into four groups and performed WBV training 3 times a week for 3 consecutive weeks (table 1). All of the patients were asked to adopt a semi squat position (60° knee flexion) on the vibrating platform to minimize vibrations reaching the upper part of the body with feet apart at shoulders-width. Group 1 and Group 2 received vibration, while Group 3 and Group 4 did not. Patients were asked to hold the bar of the platform in front of them during the session. Visual feedback was provided for training and rest periods. In Group 1, the vibration frequency was 30 Hz for 1 minute followed by 1-minute rest for 6 series. In Group 2, frequency and duration were the same but repeated for 9 series. Group 3 and Group 4 adopted the same position without the use of vibration for 6 and 9 series, respectively. In such a way, the total volume of exercise and exposition to vibration differed between groups. The two control groups were blinded to the use of WBV.

The posture was monitored with an optoelectronic system with 6 infrared cameras (Vicon, Vicon Motion System, Oxford, UK) and reflecting markers positioned on the hip, knee, ankle, and the shoulders as shown in figure 2.

The vibration level of exposure used was weighed according to the ISO 2631 norm and normalized to an 8-hour exposure.

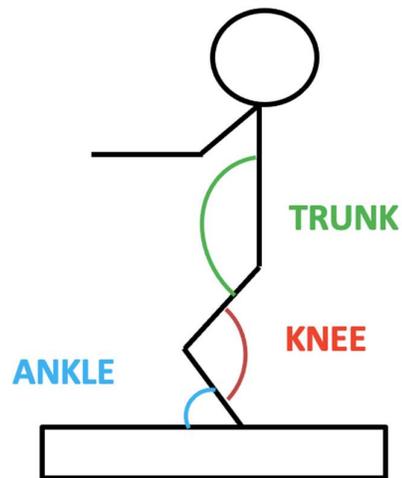


Figure 2. Angles used for controlling posture during the stimulation

2.9. Statistical analysis

The statistical analysis was performed using Minitab® (version 18.1, State College, Pennsylvania). A repeated measure ANOVA was performed on the data with the within-subject factor of *Time* (pre-and post-treatment) and the between-subject factor of *Group* (group 1 vs group 2 vs group 3 vs group 4). Post hoc tests were performed where appropriate by applying Fisher's correction for the significance threshold. Measures of effect size were provided as partial eta-square (η^2): a value of 0.01 was considered as a small effect, 0.06 medium effects and 0.14 large effects. A significance level of $\alpha=1\%$ was implemented throughout.

3. Results

Out of the total sample of 41 subjects, 21 were men and 20 were women. Age and anthropometric characteristics of the 4-four study group at baseline are shown in table 1.

Group	N (M/F)	Age[years]	Height [cm]	Body Mass [kg]	BMI [kg/m ²]
1	11 (6/5)	42.7 (13.0)	168.5 (10.5)	124.5 (19.3)	44.2 (7.1)
2	10 (5/5)	38.5 (12.3)	165.7 (9.1)	118.3 (16.1)	43.2 (6.4)
3	10 (5/5)	42.7 (9.6)	168.2 (7.7)	132.5 (18.3)	46.8 (5.2)
4	10 (5/5)	48.0 (9.4)	167.2 (10.6)	123.6 (27.0)	43.9 (7.2)

Table 1: the table shows the 4 study groups and the variables of number (male or female), age, height, body mass and BMI.

Baseline characteristics were not significantly different between groups. We registered any one dropped-out from group 1 as reported in figure 3.

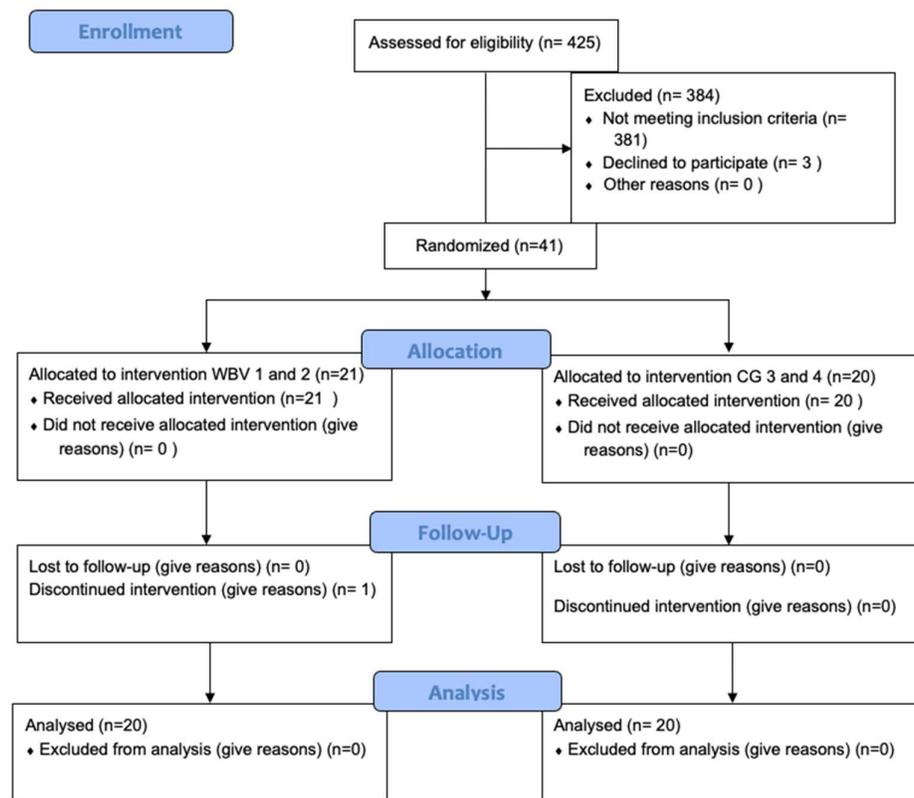


Figure 3. Flow chart which describes the recruitment, randomization, and allocation of patients

The vibration levels used in our protocol were lower than the recommended threshold according to the current EU legislation (Directive 2002/44/EC for – vibration). The records collected were reported in the following tables divided in metabolic (Table 2), hormonal (Table 3), and functional components (Table 4).

Variable	Factor	F	p	partial η^2
Weight [kg]	Time	2.26	0.14	0.03
	Group	1.74	0.17	0.07
	Group x Time	0.01	0.99	0.0003
BMI [kg/m ²]	Time	0.08	0.78	0.001
	Group	0.58	0.63	0.02
	Group x Time	0.86	0.47	0.034
Abdomen circumference [cm]	Time	1.43	0.24	0.02
	Group	6.59	0.001	0.22
	Group x Time	0.06	0.98	0.002

PAS [mm/hg]	Time	25.8	0.29*10⁻⁵	0.26
	Group	1.09	0.36	0.04
	Group x Time	0.35	0.79	0.01
PAD [mm/hg]	Time	11.24	0.001	0.14
	Group	3.95	0.01	0.04
	Group x Time	1.02	0.39	0.04
FC [bpm]	Time	15.3	0.21*10⁻³	0.17
	Group	0.32	0.81	0.01
	Group x Time	0.75	0.53	0.03
FFM [kg]	Time	0.27	0.61	0.004
	Group	0.57	0.64	0.02
	Group x Time	0.03	0.99	0.001
FFM [%]	Time	0.57	0.45	0.008
	Group	0.18	0.91	0.007
	Group x Time	0.09	0.97	0.003
CHO [mg/dl]	Time	21.6	0.17*10⁻⁴	0.24
	Group	0.15	0.93	0.007
	Group x Time	1.89	0.14	0.08
HDL [mg/dl]	Time	4.01	0.05	0.05
	Group	1.70	0.18	0.06
	Group x Time	0.19	0.91	0.007
LDL [mg/dl]	Time	14.1	0.34*10⁻³	0.16
	Group	0.74	0.53	0.03
	Group x Time	1.29	0.28	0.05
HB1Ac [%]	Time	3.22	0.08	0.04
	Group	2.29	0.09	0.09
	Group x Time	0.03	0.99	0.001
Insulin [mU/L]	Time	2.56	0.11	0.03
	Group	1.29	0.28	0.05
	Group x Time	1.13	0.34	0.04

Glucose [mg/dl]	Time	7.71	0.007	0.09
	Group	0.74	0.53	0.03
	Group x Time	2.14	0.10	0.08

Table2: Metabolic and Body composition characteristics. PAS: systolic blood pressure, PAD diastolic blood pressure, FC heart rate, FFM fat free mass in Kg, FFM% fat-free mass in %, CHO total cholesterol, HDL cholesterol, LDL cholesterol, HB1Ac glycated hemoglobin, Insulin, Glucose.

3.1. Metabolic syndrome and body composition

Body weight and BMI did not decrease significantly in any group concerning time, group and group x time after 3 weeks of intervention. Similar results were found in FFM (kg) and FFM (%) and for HDL, Hb1Ac and insulin. There was a significant decrease in cardiometabolic components including: systolic and diastolic arterial pressures, heart rate, cholesterol, LDL, and glucose in any groups concerning time.

3.2. Muscle strength and Functional components

In Table 3, Strength and Functional components are reported. The strength of the upper limbs tested with a handgrip for the right (HG DX) and left hand (HG SX) did not show any significant difference about time, group or group x time. Furthermore, the strength of the lower limb tested in static (ISO EX) and dynamic extension (ISO DIN EX) showed a nonsignificant difference in every group concerning time, group and group x time. No significant changes in 6MWT, MAXFLEX_SIT2STAND, and MAXFLEX_STAND2SIT were found.

Variable	Factor	F	p	partial η^2
HG DX [kg]	Time	0.26	0.61	0.004
	Group	0.40	0.75	0.02
	Group x Time	0.16	0.92	0.007
	Time			
HG SX [kg]	Time	0.18	0.67	0.002
	Group	0.35	0.79	0.01
	Group x Time	0.10	0.96	0.004
	Time			
ISO EX [newton-meters]	Time	2.11	0.15	0.02
	Group	1.85	0.15	0.07
	Group x Time	0.03	0.99	0.001
	Time			
ISO DIN EX [newton-meters]	Time	0.60	0.44	0.008
	Group	0.80	0.50	0.03
	Group x Time	0.18	0.91	0.007
	Time			

6MWT [m]	Time	0.51	0.48	0.007
	Group	0.80	0.50	0.03
	Group x Time	0.76	0.52	0.03
	Time			
MAXFLEX_SIT2STAND [s]	Time	4.89	0.03	0.06
	Group	3.29	0.03	0.12
	Group x Time	0.48	0.70	0.02
	Time			
MAXFLEX_STAND2SIT [s]	Time	2.91	0.09	0.04
	Group	3.05	0.03	0.11
	Group x Time	0.22	0.88	0.009
	Time			

Table 3: Strength and Functional Components. HG DX: Hand-Grip right hand, HG SX: Hand-Grip left hand, ISO EX: Isokinetic Isometric Extension right lower limb, ISO DIN EX: Isokinetic dynamic extension, 6MWT: six-minute walking test, MAX FLEX: SIT2STAND: maximal flexion sit to stand, MAXFLEX_STANDTOSIT: maximal flexion stand to sit.

3.3. Hormonal components

The circulating of testosterone and GH (Table 4) did not differ in time, group and group x time. Plasma irisin did not show any differences in time, group and group x time, whereas change in salivary irisin was observed in Group 2 ($p < 0.01$) as compared to the control group.

Variable	Factor	F	p	partial η^2
GH [$\mu\text{g/L}$]	Time	0.23	0.63	0.003
	Group	0.39	0.76	0.02
	Group x Time	0.87	0.46	0.46
Testosterone [nmol/L]	Time	0.10	0.75	0.001
	Group	0.57	0.64	0.02
	Group x Time	0.13	0.94	0.005

Table 4: Hormonal components. GH: growth hormone ($\mu\text{g/L}$), testosterone.

4. Discussion

The rationale was to study the effects of WBV exposure within the existing safety limits defined for the Italian occupational standards. To the best of our knowledge, previous studies have investigated high-intensity WBV associated with dynamic exercise and no randomized controlled trials at different WBV exposures are present in the literature. Our preliminary results showed that low-intensity WBV does not appear effective in improving strength or function in subjects with obesity. Upper and lower limbs strength and functional tests (sit-to-stand and stand-to-sit, 6MWT) did not show significant improvements in the two groups undergoing WBV and in the two groups exercising in semi squat without vibration. This result is in contrast with previous studies with WBV at high intensities (2.28 g to over 5 g), where an increase in strength in different

populations[6,9,13,27]and an improvement in walking capacity[28] were found. Two studies with WBV at lower intensities (0.3-0.4 g) showed improvements in the chair stand test [17]and maximal isometric knee extensors torque and performance as measured by a counter movement jump[9]. Several factors may account for such different results. Firstly, in our program, the patients did not perform any dynamic exercise. Secondly, the g-force output generated by the vibration platform was low intensity, which could have affected the musculoskeletal responses of neuromuscular spindles, tendon organs of Golgi and mechanoreceptors.

However, several metabolic variables usually included in the definition of metabolic syndrome improved. Systolic and diastolic arterial blood pressure, cholesterol, LDL, and glucose levels decreased significantly, independent of the study group allocation. This result underlines the beneficial effect of physical activity on metabolic variables [29,30]. The lack of a significant difference between the experimental and control group indicates an insufficient training stimulus from the vibration platform. Based on our results, a specific effect of the WBV platform on metabolic improvements cannot be identified. This is in contrast with what has been reported in a long-term WBV protocol on metabolic components[16]. The different results could depend on a different length of the study protocol, vibration platform intensity, and execution of the exercise. The latter was performed also in a dynamic modality.

In contrast with the pioneer observation published by Bosco [14], we did not find any difference in either testosterone or GH levels between groups after the training period, possibly due to the severe degree of obesity of our patients which blunted the training-induced response of these anabolic hormones [31]. Regarding irisine, a hormone that is associated to the browning of adipose tissue [32] holding a potential dual role as myokine and adipokine in obesity [33], we did not observe changes in its plasma levels after the 3-week program in both subjects exposed to WBV and controls. This lack of effect parallels observations obtained by others in healthy untrained females participating in a 6-week WBV program [15]. Interestingly, we detected an acute change in salivary irisine levels after the 9 series of WBV, while no changes occurred in controls. Our decision to test salivary irisine was primarily intended to avoid sampling caveats during acute exercise in this severely obese cohort. It has been documented that irisine is produced by salivary glands and its secretion has been shown to increase in response to acute exercise in moderately obese subjects [34,35]. Current findings reveal, therefore, the ability of salivary irisine to respond acutely to WBV bouts and parallel similar results obtained on serum irisine in healthy females subjected to acute vibrating exercise [15]. Whether salivary irisine acts as a function of muscle energy demand or oral nutrient sensing and energy metabolism remains to be investigated.

5. Conclusion

Isometric low-intensity WBV does not appear effective in improving strength or function in subjects with obesity due to an insufficient training stimulus from the vibration platform. On the other hand larger studies are needed to deeper investigate the relationship of irisine, exercise capacity and body mass and the potential role of low-intensity WBV in managing weight.

6. Study limitations

As this clinical trial was a pilot with a small number of participants, this study can serve as a basis for sample size estimation in future studies, taking into account the trends pointed out in the results presented. All of the patients were involved in multidisciplinary rehabilitation program with an hypocaloric diet but individual differences in energy restrictions were not taken into account. An increase in the sample size in a future study should be considered to infer more robust results.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of Istituto Auxologico Italiano (protocol WBV-Obesity, 2017_12_19_03, 19/12/2017).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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