Nr 2019;9 (3):433-441

Electromyostimulation and whole-body vibration effects in elder sarcopenic patients

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DOI:
10.32098/mltj.03.2019.18

LEVEL OF EVIDENCE: 1A

SUMMARY

Background. Sarcopenia is a progressive and generalized loss of the skeletal muscle mass and function associated to aging. Among the different possible practical approaches, the Electromyostimulation (EMS) and the whole-body vibration (WBV) were proposed. The aim of this review is to synthetize the most up-to-date evidence behind the use of this therapeutic approaches.

Methods. A systematic review and Meta-Analyses of the randomized clinical trials (RCTs) present in the literature was performed. The focus was on use of WBV and EMS in sarcopenic human subjects.

Results. Whole Body Vibration seems to be an effective alternative to other exercise and in particular resistance training in sarcopenic subjects. All the studies involved in our systematic review reported several muscle benefits, both locally and overall in the body of the patients involved. The use of WB-EMS and the consequent full body involvement is interesting and promising. In all the included RCTs several primary and secondary outcomes were evaluated: from local to overall muscle quality, size and performance, fat distribution and strength parameters

Conclusion. The EMS and WBV seems to be an effective and safe solution for sarcopenia. They should be considered in elder sarcopenic patients among the others possible approaches.

KEY WORDS

electromyostimulation; exercise; muscle loss; sarcopenia; whole-body vibration.

Abbrevation

EMS: Electromyostimulation
WBV: whole body vibration
RCTs: randomized clinical trials
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses
WB-EMS: whole body electromyostimulation
HWBV: high frequency whole body vibration
LWBV: low frequency whole body vibration

BACKGROUND

Sarcopenia, as described by the European Working Group on Sarcopenia in 2010, is a progressive and generalized loss of the skeletal muscle mass and function associated to aging (1). While in the case of muscular atrophy following disuse, the size of muscle fibers can be restored over time through physical activity, loss of muscle strength and mass following illness or sarcopenia is particularly problematic (2). The quality of muscle fibers is severely affected and usually not so easily recoverable, which is together with the performance the most significant factors in the prognosis and quality of life of these subjects (3,4). In addition, sarcopenia is one the main factors in the pathogenesis and presentation of frailty syndrome (5,6). Older “frail” people with sarcopenia exhibit a reduced body mass and undergo a decrease in muscle strength leading to functional dysfunction and physical disability 7. The underlying causes of sarcopenia and frailty are multifactorial. Although the progressive loss of muscle mass with aging has been recognised for a long time, it is only with more recent techniques and longitudinal prospective studies that the age-related changes in body composition have begun to be described (8–11). Sarcopenia and frailty is associate with higher risk of hospitalisation (12,13), a later discharge (13) and higher mortality risk (14). Although its complex pathogenesis, emerging evidence demonstrated that this process may be slowed down, interrupted, and even inverted thanks to exercise, nutritional support and active life (2,15–17). While exercise training, and in particular high intensity (≥ 70–85% of one repetition maximum) strength training, has been recommended for enhancing skeletal muscle mass quality, volume and strength in older individuals (18–20) there can be exercise prescription concerns for individuals with specific risk factors and those with comorbidities. Since these subjects may need a different training approach, several innovative possibilities were studied to better the patient's compliance. Among the different possible practical approaches, the Electromyostimulation (EMS) and the whole-body vibration (WBV) were proposed. The EMS is based on the induction of muscle contractions independently of voluntary muscle activation up to supra-maximum level. One of the evolution of EMS treatment was the possibility to apply the EMS to all body. The whole body electromyostimulation (WB-EMS) equipment enables the simultaneous activation of up to 10 regions or 14 muscle groups. The total stimulated area, up to 2600–2800 cm^{2}, can be simultaneously activated, with selectable intensity for each region (21). The WBV is based on the tonic reflex occurring in the muscle exposed to repetitive vibrations. Reflex contraction is the result of vibration-induced small changes in muscle length (22) that leads to an increase in the activity of primary afferent endings (Ia) within the muscle spindles. The evidence for stretch reflex involvement with WBV was provided by electromyography (EMG) studies of increased neuromuscular activity during vibration both in able-bodied individuals (22,23). The aim of this review is to synthetize the most up-to-date evidence behind the use of this therapeutic approaches.

MATERIALS AND METHODS

Literature Search Strategy

We conducted this systematic review according to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (24). A systematic review of different medical electronic databases (PubMed, Science Direct, SCOPUS, Crossref and Google Scholar) was performed from their date of inception to the 20th of June 2018. To achieve the maximum sensitivity of the search strategy, we combined the terms: "EMS OR WBV" with "Sarcopenia OR muscle loss" with "clinical trial" as either key words or MeSH terms. The reference lists of all retrieved articles were reviewed for further identification of potentially relevant studies and assessed using the inclusion and exclusion criteria. This study was performed according to international ethical standards (25–27).

Selection criteria

Eligible studies for the present systematic review included those dealing with the RCTs involving sarcopenic subjects and either WBV or EMS. The initial titles and abstracts screening was made using the following inclusion criteria: RCTs, written in English, published in peer review journals and dealing with the sarcopenia prevention or treatment. Exclusion criteria were articles written in other languages or studies with a focus on disuse atrophy, denervation atrophy or involving bed-constricted and neurologic patients. We also excluded all the remaining duplicates, articles dealing with other topics, involving patients with muscular degenerative diseases or without accessible abstract. Reference lists were also hand-searched for further relevant studies. All publications were limited to those involving human subjects. Abstracts, case reports, conference presentations, editorials, reviews and expert opinions were excluded.

Data Extraction and Criteria Appraisal

All data were extracted from article texts, tables and figures. All authors independently reviewed each article. Discrepancies between the authors were resolved by discussion and consensus. The final results were approved by all authors.

RESULTS

Included Studies

A total of n=239 articles were found. After the exclusion of duplicates n=112 articles were selected. At the end of the first screening, following the previously described selection criteria, we selected n=20 articles eligible for full text reading. Ultimately, after full text reading, and reference list check, we selected n=17 articles following previous written criteria. A PRISMA ([24]) flowchart of the method of selection and screening is provided (**Figure 1**). The included articles focus on WBV (25-40) and EMS (21,41–45). All the significant findings of the included articles were summarized in **Table I** and in **Table II**.

In our study we included six studies on the use of EMS (21,41–45) involving 319 sarcopenic subjects and thirteen studies on the use of WBV (28–30,33–40) involving 865 sarcopenic subjects. The protocol of treatment for EMS studies was similar in all the studies (bipolar, 85 Hz, impulse-width: 350 μs practising simple free weight or isometric exercises) with minor variation (time of session, nr of sessions per week). The WBV studies used heterogenous protocols of intervention with a focus on lower limb exercise in six studies and full body exercise in only one study.

DISCUSSION

Whole Body Vibration

Whole Body Vibration seems to be an effective alternative to other exercise and in particular resistance training in sarcopenic subjects. All the studies involved in our systematic review reported several muscle benefits, both locally and overall in the body of the patients involved. While all the other studies used the same protocol of intervention for all patients, two (29,35,38) investigated low-frequency and high frequency WBV (38) and in one case an additional medium frequency (29), in different groups. In the first study, no significant treatment effect of either form of WBV was observed for any variable. However, there is evidence to support the use the high-frequency protocol. Both group subjects (particularly HWBV) exhibited significant improvement in muscle performance and strength while controls did not. LWBV subjects lost 2.1% WB BMC and 1.4% PFA BMD during the course of the 8-mo trial (38). Importantly, the LWBV group did not lose significant bone at the hip and spine (indeed a slight increase occurred in FN area), suggesting that the vibration stimulus ameliorated the

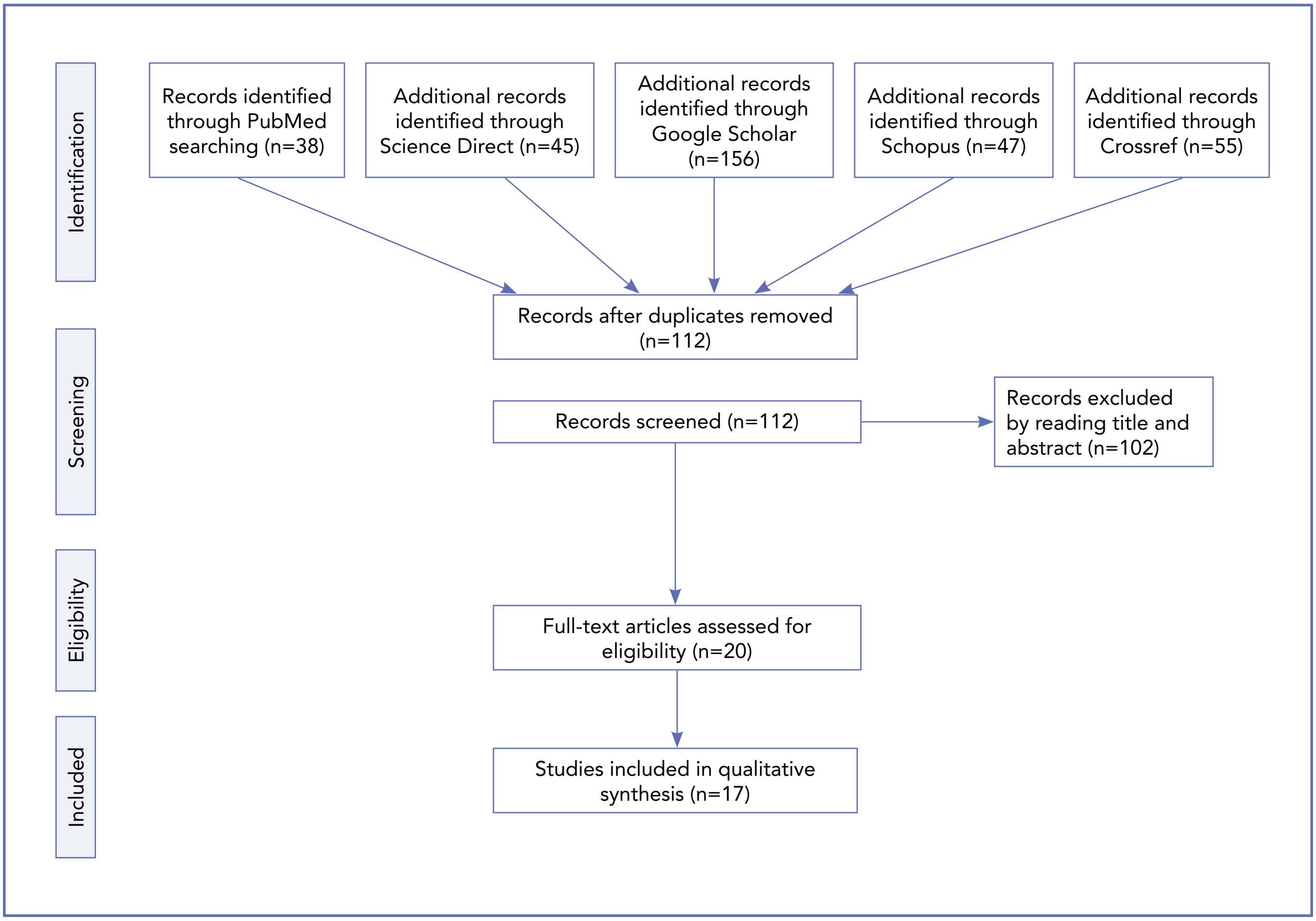

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) flowchart of the systematic literature review.

Table I. The main findings of trials involving WBV are reported.

Subjects involved	Mean age and SD	Protocol of treatment	Time of follow up	Outcome of WBV group	Reference
HF-WBV (n=17) LF-WBV (n=15) CON (n=14)	HF-WBV: 68.9 ± 7.0 LF-WBV: 68.5 ± 8.6 CON: 74.2 ± 8.1	8 months twice-weekly HWBV (2- 3 mins, 12.5 Hz, 1 g) 8 months twice-weekly LWBV (15 mins, 30 Hz, 0.3 g)	8 months	↑ FN area ($p<0.05$) ↔ LS area ($p<0.05$) ↑ BUA (dB/MHz) ($p<0.05$) ↑↑ Wall squat (D) (secs) ($p<0.05$) ↑↑↑ Wall squat (ND) (secs) ($p<0.05$)	Beck 2010 (38)
WBV(n=83) CON: (n=27) TG (n=56)	Original: CON: 68.20 ± 0.66 INT: 67.19 ± 0.36	3 times weekly for 1 year, performing a combined resistance training and aerobic training program or a whole-body vibration training program	1 year of treatment and 7 years of follow up	↑ STAT ($p<0.001$) ↑ DYN 60 ($p<0.001$) ↑ DYN 20 ($p<0.001$)	Kennis 2013 (33)
WBV (n=13) CON: (n=13)	WBV: 79.3 ± 7.3 CON: 76.2 ± 8.4	10 weeks on a vibration platform with lower-body-training program consisting of unloaded static and dynamic exercises.	10 weeks	↑ Muscle cross sectional area ($p<0.05$) ↑ MVIC ($p<0.001$) ↔ MVIC with an external resistance of 20%, 40%, and 60% decreased from pre-test to post-test only in the CON group ($p<0.05$) ↓ Mobility ($P<0.01$)	Machado 2010 (34)
WBV (n=31) CON: (n=36) TG (n=30)	WBW: 67.3 ± 0.7 CON: 68.6 ± 0.9 TG: 67.4 ± 0.8	Exercised for a maximum of 40 minutes on a vibration platform with lower-body-training program consisting of unloaded static and dynamic exercises.	12 months	↑ Isometric muscle strength ($p<0.05$) ↑ Explosive muscle strength ($p<0.001$) ↑ Muscle mass ($p<0.001$)	Bogaerts 2007 (28)
WBV n=56 CON: N=57; Woman stratified for BMD of the total body with high or low of Vit.D	WBW High dose: 80.3 ± 5.3 Conventional dose: 79.8 ± 5.3 CON: High dose: 78.7 ± 5.6 Conventional dose: 79.6 ± 5.2	WBV three times a week with lower-body-training program consisting of unloaded static and dynamic exercises and Vit. D supplementation	6 months	↑ dynamic muscle Strength ($p<0.001$) ↑ hip BMD ($p<0.001$) ↑ vitamin D serum levels ($p<0.001$)	Verschueren 2011 (36)
WBV n=50 CON: N=51; TG n=50 postmenopausal women	WBV: 68.8 ± 3.6 TG: 68.6 ± 3.0 CON: 68.1 ± 2.7	20 min of aerobic, 5 min of coordination and balance, 20 min of functional strength training for the trunk and upper extremities performed on the floor (using elastic bands and body weight for resistance), and finally 15 min of strength training for the legs on vibration platforms	18 months	No effect of vibration on lean body mass, total body fat, and abdominal fat of vibration Muscle strength and power: there was a tendency in favour of the TG ↑ leg and trunk extension Strength ($p<0.001$) ↑ trunk flexion ($p<0.05$)	Von Stengel 2012 (37)

Subjects involved	Mean age and SD	Protocol of treatment	Time of follow up	Outcome of WBV group	Reference
HF-WBV (n=20) MF-WBV (n=20) LF-WBV (n=20) CON (n=20)	HF-WBV: 74 ± 4 MF-WBV: 75 ± 6 LF-WBV: 78 ± 4 CON: 76 ± 6	3 days/week: low-frequency long duration (20Hz× 720 s), medium-frequency medium duration (40Hz×360 s), high-frequency short duration (60Hz×240 s) and control (no training) stood barefoot with their knee joint flexed at 60° on the platform	12 weeks of training and 12 weeks of follow up	↑ knee extension strength ($p<0.001$) (Best in 40Hz and 360 s group) ↑ Walking test ($p<0.001$) ↑ Sit to stand test ($p<0.001$)	Wei 2017 (29,35)
WBV (n=17) CON (n=16)	WBV: 60.7 ± 6.1 CON: 61.40 ± 7.30	Standing 2-minute sessions for a total of 6 minutes per training session twice weekly for 6 months	6 months	↑ Speed of movement ($p<0.005$) ↑ Power ($p<0.02$)	Russo et al. (2003) (39)
WBV (n=15) TG (n=13) CON (n=15)	WBV: 74.3 ± 5.0 TG: 73.1 ± 4.1 CON: 73.1 ± 4.6	WBV using a Galileo Sport platform. The frequency used for this study was set at 26 Hz,19,23 with peak-to peak amplitude ranging from 5 to 8 mm. 3 sessions per week for 8 weeks	2 months	↑ Knee extension ($p<0.05$) ↑ Ankle planter flexion ($p<0.05$)	Rees et al. (2007) (40)
WBV (n=15) TG (n=15)	WBV: 74.3 ± 5.0 TG: 73.1 ± 4.1	WBV using a Galileo Sport platform. The frequency used for this study was set at 26 Hz,19,23 with peak-to peak amplitude ranging from 5 to 8 mm. 3 sessions per week for 8 weeks	2 months	↑ Ankle planter flexion ($p<0.01$)	Rees et al. (2008) (30)
WBV + training (n= 21) TG (n=22) CON (n=12)	WBV + training: 62.8 ± 1.1 TG: 63.9 ± 0.9 CON: 63.1 ± 1.4	resistance exercise protocol + WBV (low intensity with 15 s at 30Hz on low amplitude (3 mm), then the frequency and duration were increased during the course of the study, and the final exposures consisted of 2–60 s sets at 40Hz on low amplitude)	8 months	↓ Body fat % ($p<0.05$) ↑ Bone free lean mass ($p<0.05$)	Fjeldstad et al. (2009) (31)
WBV (n=13) CON (n=11)	WBV: 90.7 ± 7.5 CON: 83.8 ± 9.3	five 1-min vibration periods with a 1-min break between each set. The IG vibrated with a basic frequency of 3 Hz and noise level 4. To reach progressive exertion, the basic frequency was increased to 6 Hz, depending on possibilities of the individual concerned. 3 days a week for 4 weeks.	1 month	↑ SPPB ($p=0.035$)	Kessler et al. (2014) (33)

WBV: whole body vibration group. CON: control group. TG: training group without vibration. PFA, proximal forearm; FN, femoral neck; HWBV, high-intensity whole body vibration; LWBV, low-intensity whole body vibration; LS, lumbar spine; BUA, broadband ultrasound attenuation; BMC, bone mineral content; BMD, bone mineral density; D, dominant leg; ND, nondominant leg; SLS, single leg stance; Static strength (STAT); Dynamic Strength at low speed (DYN 60); Dynamic strength at high speed (DYN 20); Maximal voluntary isometric contraction (MVIC); short physical performance battery (SPPB). Only statistically significant values were reported (p values were reported).

Table II. The main findings of trials involving EMS are reported.

Subjects involved	Mean age and SD	Protocol of treatment	Time of follow up	Outcome of WB-EMS group	Reference
WB-EMS (n=15) TG (n=15) postmenopausal women	WB-EMS: 65.6 ± 5.6 TG: 63.3 ± 5.4	2 times per week 20-minute WB-EMS training (bipolar, 85 Hz, impulse-width:350 µs)	14 weeks	↑ MIS-leg ($p<0.001$) ↓ WC ($p<0.001$)	Kemmler 2010 (41)
WB-EMS (n=38) TG (n=38) lean, non-sportive women	WB-EMS: 74.7 ± 3.7 TG: 74.7 ± 4.4	18 min of WB-EMS (bipolar, 85 Hz) 3 sessions in 14 days (1.5 sessions/week)	12-months	↑ ASMM ($p<0.05$) ↑ LBM ($p<0.05$) ↑ MIS-leg ($p<0.001$) ↑ MIS-trunk ($p<0.001$)	Kemmler 2014 (43)
WB-EMS (n=23) TG (n=23) lean, non-sportive women	WB-EMS: 74.7 ± 3.9 TG: 74.7 ± 3.9	18 minutes of intermittent, bipolar WB-EMS (85 Hz) 3 sessions in 14 days	12 months	↑ ASMM ($p<0.05$) ↑ MIS-leg ($p<0.05$)	Kemmler 2013 (42)
WB-EMS&P (n= 21) WB-EMS (n=24) NT (n=22) women ≥70 with sarcopenic obesity	WB-EMS&P: 76.4 ± 2.9 WB-EMS: 77.3 ± 4.9 NT: 77.4 ± 4.9	WB-EMS program in a supine sitting/lying position with slight movements (e.g., leg and arm flexion and extension during the impulse phase) of the lower and upper limbs once a week. (bipolar, 85 Hz, impulse-width:350 µs) intermittently with 4–6 s of EMS simulation using a direct impulse boost and 4 s of rest. The length of the session was progressively increased up to 20 min after 8 weeks.	6 months	↓ Sarc-Z-score ($p<0.001$) ↑ SMI ($p<0.001$)	Kemmler 2016 FORMOsA study (44)
WB-EMS&P (n=33) CON (n=34) Sarcopenic and obese Bavarian men ≥70 years	WB-EMS&P: 77.1 ± 4.3 CON: 76.9 ± 5.1	WB-EMS standard protocol (bipolar, 85 Hz, impulse-width:350 µs) in a standing position 1.5 × 20 min 3 per week	16 weeks	↑ ASMM ($p<0.001$) ↓ TBF ($p<0.001$) ↓ TF ($p<0.001$) ↑ MV ($p<0.001$) ↔ IMF ($p<0.001$) ↑↑MDS ($p<0.001$) ↔ HGV ($p<0.001$)	Kemmler FranSO study (21,45)

WB- EMS: whole body electromyostimulation group. CON: control group. TG: training group without vibration. Whey protein supplementation group (WPS). Whole body electromyostimulation and protein group (WB-EMS&P). No training group (NT).

Appendicular skeletal muscle mass (ASMM); Lean body mass (LBM); Maximum isometric leg (MIS-leg) and trunk strength (MIS-trunk). total body fat mass (TBF); trunk fat mass (TF); fat-free intra-fascial muscle volume (MV) and intra-fascial fat (IMF) of the mid-thigh; maximum dynamic strength (peak torque) of the leg and hip extensors (MDS); habitual gait velocity (HGV); waist circumference (WC); skeletal muscle mass index (SMI: ASMM/body height 2; measured in kg/m2); sarcopenia Z-score (sarc-Z-score). Only statistically significant values were reported (p values are reported).

effects of systemic bone loss at sites most directly exposed to the stimulus (38). The results were not definitive. In the second study, the combination of 40Hz and 360 s of WBV exercise had the best outcome among all other combinations tested. In order to clear out the role of the frequency of WBV we highly encourage further RCTs with different frequency protocols. In all the study, there is evidence of a gain in isometric and dynamic strength in all the subject treated which is a key factor in the quality of life of these patients (2,3).

However, out of seven study included in these articles only three studies involved a training group in addition to the control not active group. While, in one meta-analysis by Osawa and Oguma (46) it was reported a significant increase in muscle strength in the whole body vibration group compared to control, it has been show how resistance training facilitated greater improvements in muscle strength than other interventions and WBV itself (47). For this reason, the body composition modification, with a special focus on muscle performance should be studied together with a resistance training group. In addition, while whole-body vibration may give small improvements in physical performance in older people, there are some practical considerations. Standing on the vibration system is most effective and easier for older people who are unable to follow instructions and thus find it difficult to perhaps complete other forms of exercises. Nevertheless, the price of a vibration machine may be prohibitive for some people.

Whole Body Electromyostimulation

The use of WB-EMS and the consequent full body involvement is interesting and promising. In all the included RCTs several primary and secondary outcomes were evaluated: from local to overall muscle quality, size and performance, fat distribution and strength parameters. The WB-EMS seems to both affect muscle parameters, which was to be expected, and abdominal body fat, which is a one of main risk factors in metabolic syndrome (48). Although the exercise volume was low (twice a week 20 minutes to 3 times a week 20 min) and the patients were older than 60 years in all the studies, WB-EMS with its simultaneous stimulation of 2,650 cm of total area along with the subsequent adaptive response may trigger the corresponding effect. However, the author in one study (42) also used an indirect calorimetry to investigate the energy expenditure without reporting a result high enough (412 ± 61 kcal/hour) to explain the corresponding abdominal fat mass changes (49). However, this may be due to the not-detectable extra-mitochondrial fraction of energy with this method, so metabolic effect of WB-EMS is still not clearly known. The effects on appendicular muscle mass in the Test-III trial (42,43), and in FranSO study were comparable to the lean body mass changes with conventional resistance exercise (50,51), at least with respect to the elderly subgroup of this aging adult cohort. Thus, with an adequate protocol of exercise, followed for at least 6 months and a high patients compliance, WB-EMS seems a good alternative to resistance-training in old sarcopenic subjects. In addition, in the FORMOsA and FranSO studies conducted by Kemmler et al. (19,44,45) WB-EMS effects on obese patients were evaluated. While the muscle effects were similar to those involving normal weight subjects, the intervention showed also some changes in energetic metabolism affecting fat presence in the body. Even though both the WB-EMS and WB-EMS&P group showed favourably effects on body composition and lean MV, the study failed to show any relevant change of intra-fascial fat content of the mid-thigh in the group with a protein supplementation. Although a possible reason behind this result may be related to the short follow up in the case of FranSO study (16wks), similar results were reported in FORMOsA study (6 months). Basing on these data, we can conclude that the longer follow-up was not enough to get a better result although in the FORMOsA study, the intervention was significantly different and low-demanding compared to the other studies. What emerged is that the physical activity duration and the protocol of exercise used were more significant than macronutrients split changes.

There are some limitations in our analyses e.g the great heterogeneity of primary and secondary outcome of both WBV and EMS studies did not allow a comparative statistical analysis, several points come out after reviewing the previously enlisted RCTs. These conclusions may be limited by the absence of the criteria to do a metanalysis of the studies involved in the review. While our analysis is clinically relevant, to achieve a better analysis of the present and future results, we highly encourage a standardization of both EMS and WBV based on the recent literature available and on our study. In addition, the current literature on WB-EMS is based on the numerous work made by Kemmler et al. during the last 10 years. Moreover, vibration therapy has been proposed as an option to improve physical performance and reduce the negative effects of ageing on bone, cartilage, muscles and tendons (52). Several discrepancies exist on the type of applications, frequency and magnitude (53). These differences reflex on the contradictory clinical results in the literature for the clinical applications of vibration therapy and exercise in orthopaedic practice (54-56).

CONCLUSION

Both WBV and EMS seems to be effective as alternative to resistance training in elder sarcopenic people. In addition, these low demand activities, seems to augment the subject's compliance thanks to a high accessibility. What emerged by this review is that both WBV are safe and effective therapeutic approach for Sarcopenia in elder patients. Their use should be considered among the different clinical solutions. While both treatments seem to have also metabolic effect and could be used safely in elder obese subjects, further RCTs are needed to standardize the protocol and confirm the previously reported RCTs clinical outcomes.

Acknowledgements

This study was supported by the University Research Project Grant (Triennial Research Plan 2016–2018), Department of Biomedical and Biotechnological Sciences (BIOMETEC), University of Catania, Italy and by IFASS SWISS SA, Chiasso, Switzerland.

Conflict of interest

The Authors declare that they do not have any conflict of interest.

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