



Review Article

Whole-body vibration as a potential countermeasure for dynapenia and arterial stiffness

Arturo Figueroa*, Salvador J. Jaime, Stacey Alvarez-Alvarado

Department of Nutrition, Food and Exercise Sciences, Florida State University, Tallahassee, FL, USA

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ABSTRACT

Age-related decreases in muscle mass and strength are associated with decreased mobility, quality of life, and increased cardiovascular risk. Coupled with the prevalence of obesity, the risk of death becomes substantially greater. Resistance training (RT) has a well-documented beneficial impact on muscle mass and strength in young and older adults, although the high-intensity needed to elicit these adaptations may have a detrimental or negligible impact on vascular function, specifically on arterial stiffness. Increased arterial stiffness is associated with systolic hypertension, left ventricular hypertrophy, and myocardial ischemia. Therefore, improvements of muscle strength and arterial function are important in older adults. Recently, whole-body vibration (WBV) exercise, a novel modality of strength training, has shown to exhibit similar results on muscle strength as RT in a wide-variety of populations, with the greatest impact in elderly individuals with limited muscle function. Additionally, WBV training has been shown to have beneficial effects on vascular function by reducing arterial stiffness. This article reviews relevant publications reporting the effects of WBV on muscle strength and/or arterial stiffness. Findings from current studies suggest the use of WBV training as an alternative modality to traditional RT to countermeasure the age-related detriments in muscle strength and arterial stiffness in older adults.

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1. Introduction

Sarcopenia was originally defined as the age-related loss of appendicular lean (muscle) mass relative to height squared.¹ Recently, sarcopenia was redefined and either the loss of muscle strength and/or impaired physical performance was added

to the loss of muscle mass.^{2–4} Although reductions in muscle mass and strength are positively associated,⁵ the reduction in muscle strength exceeds that of mass.⁶ Therefore, Clark and Manini⁷ proposed to define the loss of muscle strength as dynapenia. Previous studies have shown that dynapenia combined with obesity is associated with increased cardiovascular risk.^{8–10} Furthermore, obesity increases the risk of

* Corresponding author. Department of Nutrition, Food and Exercise Sciences, Florida State University, 120 Convocation Way, Tallahassee, FL 32306-1493, USA.

E-mail address: afigueroa@fsu.edu (A. Figueroa).

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death in older adults with dynapenia.¹¹ By contrast, high muscle strength reduces the mortality risk in individuals aged 50–69 years.¹¹ These findings suggest that maintaining muscle strength may attenuate, to some extent, the adverse cardiovascular risk associated with aging and obesity.

Another important age-related process is increased arterial stiffness [pulse wave velocity (PWV)], which occurs primarily in the aorta.¹² The age-related increase in PWV leads to isolated systolic hypertension due to impaired buffering function of the aorta.¹³ Growing evidence suggests a strong negative relationship between increased PWV and reduced muscle mass, especially in the legs. Abbatecola et al¹⁴ demonstrated that increased carotid-femoral PWV (cfPWV), the gold-standard measure of aortic stiffness, was associated with limb muscle mass reduction. This negative relationship has been thoroughly investigated in Asian populations using brachial-ankle PWV (baPWV) rather than cfPWV. BaPWV is a composite of peripheral leg (femoral-ankle PWV, faPWV) and cfPWV, and thereby is a marker of systemic arterial stiffness. Each increase of 1 m/s in baPWV is associated with an increase in cardiovascular event and mortality by 12% and 13%, respectively.¹⁵ A higher baPWV was found in women with greater sarcopenic class based on appendicular skeletal mass/height.^{2,16} More specifically, reduced thigh muscle mass was negatively associated with baPWV in nonobese middle-aged and older men.¹⁷ Importantly, low muscle mass in obese adults, a condition termed sarcopenic obesity, has an additive adverse effect on baPWV.^{18,19} Although little evidence exists on the inverse relationship between upper-body muscle strength and cfPWV in young healthy men,²⁰ the association between handgrip or leg muscle strength and PWV is unknown in older adults. Currently, the optimal exercise training for improving muscle mass/strength concurrently with arterial stiffness has not been determined.

2. The effect of resistance training on arterial stiffness

High-intensity RT has shown to be effective in increasing muscle mass and muscle strength in older adults.^{21,22} The American College of Sports Medicine recommends RT at 60–80% of 1 repetition maximum (1RM) for improving both muscle strength and mass (quality) in older adults.^{23,24} Although high-intensity RT has shown to be effective for improving muscle quality, there are some concerns regarding a possible adverse effect on PWV.^{25,26} Some studies have found that RT increases arterial stiffness in young adults.^{27,28} In a meta-analysis, the increase in PWV by 0.7 m/s after RT may not have important clinical adverse implications in young healthy adults.²⁸ By contrast, other studies have demonstrated that PWV is not changed after RT in young and older men and women.^{21,29–32} Apparently, upper-body exercises and high-intensity training would be factors involved in the potential increase of baPWV induced by RT.^{25,33} Nevertheless, we reported that low-intensity RT, including only leg exercises, did not change PWV (systemic, aortic, and leg) in postmenopausal women.³² Collectively, these data suggest that RT may not reduce PWV in older adults.

3. Whole-body vibration

Exercise modalities targeting functional/structural improvements of the vascular and muscular systems are fundamental for the prevention and treatment of cardiovascular events. When integrating lifestyle modifications in order to attenuate the likelihood of these risk factors, individuals should not only consider their overall health benefit expectations, but also the practicality to adhere to the program (e.g., motivation, time-commitment, effort perception). During the past 15–20 years, whole-body vibration (WBV) exercise has become an attractive strength training modality for many healthcare providers since its incorporation into clinical therapies and performance-based settings. Additionally, the incorporation of a vibration-stimulus through passive or WBV in populations that are unable to perform intense exercise modalities may be a time-efficient alternative for reducing their risk of vascular dysfunction. While passive vibration (PV) propagates the vibration-induced oscillations to the exposed area without involving voluntary muscle contractions, WBV requires the individual to maintain/target respective joint angles while performing static or dynamic exercises over a vibrating platform. It has previously been shown that WBV promotes additional muscle contractions through the excitability of the spinal reflex via muscle spindles and α -motor neurons.³⁴ This may be a mechanism by which WBV exercise elicits an important effect on muscle strength.

3.1. Whole-body vibration and muscle strength

WBV training (WBVT) has shown to be an effective modality for the improvement of muscle strength in young and older adults (Table 1).^{35–38} Some studies have reported that the increases in muscle strength after WBVT are comparable to those observed after conventional RT in healthy young males and females, as well as older men and postmenopausal women.^{35,37,39–41,44–46} One of the first studies demonstrated that 12 weeks of WBVT and RT induced comparable increases in isometric (16.6%) and dynamic (9%) knee extensor strength in young untrained lean females.³⁹ These strength improvements were significant when compared to participants that performed the similar exercise protocol with no vibration or were in the nonexercising control group. Roelants et al³⁵ increased the duration of the study (24 weeks) and found a greater increase in isometric knee extensor strength (24.4%) in a similar population. In overweight and obese young women, we found that 6 weeks of WBVT induced a 6.5% increase in knee extensor strength.⁴² These findings were furthered by Milanese et al⁴³ when they increased the training duration to 10 weeks, the longer WBVT effectively increased knee extensor (14.2%), flexor (12.7%) and press (15.8%) strength.⁴³

While the previous studies have noted similar results between WBVT and RT, they were conducted in young untrained lean adults. It is known that high-intensity exercise training decreases adherence, while lower intensity with low perceived effort is a successful exercise program in obese participants.^{46,53} Obese postmenopausal women can perform 20 repetitions per set of a squat exercise, therefore the low-intensity explains the high adherence (98%) to WBVT in this

Table 1 – Characteristics of participants and WBVT protocols assessing muscle strength

Study	Age (y)	n	Characteristics*	Control	f (Hz)	A (mm)	Duration (weeks)	WBVT Protocol (sets × reps)	Muscle strength gain (%)
Younger adults									
Delecluse et al (2003)	21	67	Female Lean Untrained	RT, Sham, & NE	35–40	2.5–5	12	Not reported 3/wk	Isometric (16.6) and dynamic (9) knee extension
Osawa et al (2011)	28	19	8 Male, 11 Female Lean Untrained	Sham	0–40	0–2	12	8 Exercises 3 × 30 s 60s rest 2/wk	Knee flexion (22)
Osawa et al (2013)	37	32	6 Male, 27 Female Lean Untrained	RT	35	2	13	8 Exercises 1–2 × 8 reps 60 s rest 2/wk	Isometric knee extension (63.5)
Roelants et al (2004)	21	48	Female Lean Untrained	GF and NE	35–40	2.5–5	24	Not reported 3/wk	Isometric knee extension (24.4)
Figuroa et al (2012)	21	10	Female Overweight/obese	NE	25–30	1–2	6	3 × 30–60s 60–30 s rest 3/wk	Knee extension (6.5)
Milanese et al (2013)	47	50	Female Obese	NE	40–60	2–5	10	20 × 30–60 s 30 s rest 2/wk	Knee extension (14.2%) & flexion (12.7) Leg press (15.8)
Older adults									
Roelants et al (2004)	64	69	Female Lean/overweight Postmenopausal	RT & NE	35–40	2.5–5	24	2–9 Exercises 1–3 × 30–60 s 60–5 s rest 3/wk	Isometric (15) & dynamic (16.1) knee extension
Verschueren et al (2004)	64	70	Female Lean/overweight Postmenopausal	RT & NE	35–40	1.7–2.5	24	5 Exercises Not reported 3/wk	Isometric (15.1) & isotonic (16.5) knee extension
Machado et al (2010)	78	26	Female Lean/overweight/ obese	NE	20–40	2–4	10	4 Exercises 1–2 × 30–60s 180–120 s rest 3–5/wk	Isometric leg press (38.8)
Bogaerts et al (2007)	67	97	Male Overweight	GF & NE	30–40	2.5–5	48	8 Exercises 3 × 30–60 s 60–15 s rest 3/wk	Isometric knee extension (9.8)
Tapp et al (2014)	54	19	Female Overweight/obese Postmenopausal	RT & AT	30–40	1	8	1 Exercise 4–12 × 30–60 s 30–60 s rest 3/wk	Leg press (19.5)

Table 1 – (Continued)

Study	Age (y)	n	Characteristics*	Control	f (Hz)	A (mm)	Duration (weeks)	WBVT Protocol (sets × reps)	Muscle strength gain (%)
Figueroa et al (2014)	56	28	Female PreHTN/HTN Overweight/obese Postmenopausal	NE	25–35	1	6	6 Exercises 1–2 × 30–45 s 60 s rest 3/wk	Leg press (8.3)
Figueroa et al (2014)	56	25	Female PreHTN/HTN Overweight/obese Postmenopausal	NE	25–40	1–2	12	6 Exercises 1–6 × 30–60 s 60–30 s rest 3/wk	Leg press (19.3)
Figueroa et al (2015)	58	41	Female PreHTN/HTN Obese Postmenopausal	NE	25–40	1–2	8	8 Exercises 1–5 × 30–60 s 60–30 s rest 3/wk	Leg press (41)
Liao et al (2016)	61	84	62 Male, 22 Female Chronic stroke	Sham	20–30	1	10	4 Exercises 2–3 × 90 s 90 s rest 3/wk	Paretic knee isometric extension (14.5) & flexion (21.6), & concentric flexion (14.3)
Tankisheva et al (2014)	61	15	10 Male, 5 Female Chronic stroke	NE	35–40	1.7–2.5	6	5 Exercises 1 × 30–60 s Rest not reported 3/wk	Isometric knee extension strength 60° (18.7)
Lee et al (2013)	75	55	24 Male, 31 Female Diabetic neuropathy	BE & NE	15–30	1–3	6	3 × 180 s 60 s rest 3/wk	Lower limb (22)

* Lean/overweight/obese categorized by body mass index. Lean ≤ 24.9 kg/m²; overweight ≥ 25 kg/m² and ≤ 29.9 kg/m²; obese ≥ 30 kg/m².

AT, aerobic training control; BE, balance exercise control; GF, general fitness control (cardiovascular and strength); HTN, hypertension; NE, nonexercising control; RT, resistance training control; WBVT, whole-body vibration training.

Table 2 – Brief overview of WBV studies assessing arterial stiffness

Study	Age (y)	n	Characteristics*	Control	f (Hz)	A (mm)	Duration (wk)	Protocol (sets × reps)	Reduction in PWV (%)
Acute responses to WBV or PV									
Otsuki et al (2008)	27	10	Male Lean	Sham	26	2–4	N/A	10 × 60 s static squats 60 s rest	baPWV (2.6) 20 & 40 min post-WBV
Figuroa et al (2011)	21	15	Male Overweight	Sham	40	1	N/A	10 × 60 s static squats 60 s rest	faPWV (6.6) 15 & 30 min post-WBV
Wong et al (2012)	23	23	10 Male, 13 Female Lean	Sham	25	2	N/A	10 min of PV on legs	baPWV (10) & faPWV (11.8) 3 min post-WBV
Koutnik et al (2014)	62	11	7 Male, 4 Female Stroke survivors PreHTN/HTN	NE	25	2	N/A	10 min of PV on legs	Paretic & nonparetic baPWV (4.9 & 7.9) & faPWV (8.2 & 7.9) 5 min post-PV Paretic & nonparetic faPWV (5.2 & 7) 15 min post-PV
WBVT									
Lai et al (2014)	62	38	17 Male, 21 Female Lean	NE	30	Not reported	12	No exercise, standing 3/wk	baPWV (3.5)
Figuroa et al (2012)	22	10	Female Overweight/obese	NE	25–30	1–2	6	4 Exercises 2–3 sets × 30–60 s 60–30 s rest 3/wk	baPWV (8.1)
Figuroa et al (2014)	56	25	Female Obese PreHTN/HTN Postmenopausal	NE	25–40	1–2	12	4 Exercises 1–6 sets × 30–60 s 60–30 s rest 3/wk	baPWV (9.2) faPWV (7.9)
Figuroa et al (2014)	57	36	Female Obese PreHTN/HTN Postmenopausal	NE	25–40	1–2	12	4 Exercises 1–6 sets × 30–60 s 60–30 s rest 3/wk	baPWV (9.6) faPWV (8.8)
Figuroa et al (2015)	58	41	Female Obese PreHTN/HTN Postmenopausal	NES and ES	25–40	1–2	8	4 Exercises 1–5 sets × 30–60 s 60–30 s rest 3/wk	baPWV (6.9) faPWV (6.9)

* Lean/overweight/obese categorized by body mass index. Lean ≤ 24.9 kg/m²; overweight ≥ 25 kg/m² and ≤ 29.9 kg/m²; obese ≥ 30 kg/m².

baPWV, brachial-ankle pulse wave velocity; ES, exercises with supplementation; faPWV, femoral-ankle pulse wave velocity; HTN, hypertensive; NE, nonexercising control; NES, nonexercise with supplementation; PV, passive vibration; WBV, whole-body vibration; WBVT, WBV training.

population.⁴⁷ Figueroa et al⁴² and Milanese et al⁴³ examined the effects of WBVT in young (~21 years) and middle-aged (~47 years) overweight and obese adult females. A significant increase in leg extension (6.5%) was observed in the young overweight/obese population after 6 weeks of WBVT compared to the nonexercising controls.⁴² After 10 weeks of WBVT, Milanese et al⁴³ observed an increase in leg extension (14.2%), leg curl (12.7%) and leg press (15.8%) in middle-aged women. We and other groups have found that short-term (8–12 weeks) WBVT increased leg muscle strength in overweight/obese postmenopausal women.^{36,46,49,54,55}

Due to the improvements on muscle strength after WBVT, several recent studies have been conducted in older adults to counteract the deleterious impact of aging, physical inactivity, and disease on muscle strength. In community-dwelling healthy older adults (62–78 years), the increases in muscle strength after 8–48 weeks of WBVT were similar to those observed after RT (4.9–38.8%), but significantly greater when compared to sham and nonexercise controls.^{35–37,45,46,55} Similarly, WBVT has increased muscle strength in patients with chronic stroke and diabetic neuropathy (22%).^{50–52} Taken together, these findings suggest that the beneficial effect of WBVT on muscle strength gains are greater in populations with muscle weakness as a result of aging and/or diseases.

3.2. Effects of acute PV and WBV on arterial stiffness

While several studies have assessed the effects of PV and WBV exercise on muscle strength, bone mineral density, and cardiorespiratory function, only a limited number of studies have assessed the acute and chronic effects of this exercise modality on arterial stiffness. Acute reductions on systemic arterial stiffness (baPWV) in young healthy males have been previously observed by Otsuki et al⁵⁶ and Figueroa et al⁵⁷ following 10 1-minute sets of static squats (Table 2). Otsuki et al⁵⁶ initially evaluated the acute effects on baPWV and found significant decreases 20 minutes and 40 minutes following a single session of WBV, with values recovering to baseline 60 minutes after the last set. Subsequently, Figueroa et al⁵⁷ examined the acute effects of the WBV protocol used by Otsuki et al⁵⁶ on aortic (cfPWV), leg (faPWV) and baPWV. We observed significant reductions in faPWV within 30 minutes after the WBV protocol. Yet, this was not detected for cfPWV and baPWV.

Furthermore, Wong et al⁵⁸ and Koutnik et al⁵⁹ examined the effects of acute PV applied to the posterior side of the legs (ankles to glutes) in healthy young men and post-stroke patients, respectively; laying supine on the vibration platform. Wong et al⁵⁸ examined a session of 10 continuous minutes of PV and found decreases in baPWV and faPWV. Koutnik et al⁵⁹ utilized the same PV exposure to the legs and assessed faPWV and baPWV at 5 minutes, 15 minutes, and 30 minutes after the stimulus. PWVs were significantly decreased (paretic and nonparetic sides) 5 minutes after PV. After 15 minutes, the paretic and nonparetic faPWV remained significantly lower than baseline, yet only the nonparetic faPWV was different from control. Practically, these previous findings suggest that acute exposure to either PV or exercise with WBV acutely decrease baPWV through local arterial effects independent of aortic stiffness.

3.3. WBVT and arterial stiffness

The effects of WBVT on PWV have been assessed following 6 weeks, 8 weeks, and 12 weeks in populations that exhibit heightened risks for developing cardiovascular diseases and physical disability (e.g., obesity, aging, hypertension; Table 2). Figueroa et al⁴² assigned young sedentary overweight/obese women to 6 weeks of WBVT three times a week. Following WBVT, baPWV significantly decreased (-0.9 ± 0.3 m/s) when compared to a nonexercising control period in a cross-over study. Interestingly, this study combined static and dynamic semi-squats, wide-stand semi-squat, and calf-raise exercises over the vibrating platform. The dynamic exercises were performed with slow movements at a rate of 2 second concentric and 3 second eccentric phases, while the static movements were performed by maintaining the desired joint angle. Moreover, Figueroa et al^{48,54} examined the effects of 12 weeks of WBVT in postmenopausal women with pre- and stage 1-hypertension. Participants underwent the same exercises, with the exception of the wide-stance (they performed lunges instead). Importantly, significant decreases in baPWV (~ -1.23 m/s) and faPWV (~ -0.81 m/s) were observed. Moreover, Lai et al⁶⁰ investigated the effect of a 12-week WBVT program on baPWV in middle-aged and older adults. Notably, participants in this study performed natural full-standing postures at a set frequency (30Hz), which were not utilized in any of the previously addressed studies. They found that WBVT decreased baPWV by 0.65 m/s. A recent study by Figueroa et al⁴⁹ evaluated the effects of combining WBVT with L-citrulline supplementation in postmenopausal women. In addition to the well-known reductions in baPWV and faPWV induced by WBVT alone, combining WBVT with a vasodilatory amino acid supplementation resulted in significant decreases in cfPWV (~ -0.91 m/s), a reduction which had not been previously observed with low-intensity or high-intensity RT.^{32,33}

4. Conclusion

RT and WBVT improve muscle strength in older adults. However, a potential adverse effect of RT on PWV exists. By contrast, WBVT is associated with a decrease in systemic and leg arterial stiffness in young and older adults. This improvement in arterial stiffness occurs concurrently with increases in muscle strength. Further studies are needed to examine the long-term (≥ 6 months) effects of WBVT on muscle mass and aortic PWV in individuals with high cardiovascular risk.

Conflicts of interest

The authors declare no conflict of interest.

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