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Review Article

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

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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.

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 Manini[7] 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

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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 al[14] 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 al[35] 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 al[43] 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)
Figueroa 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/m^2; overweight ≥ 25 kg/m^2 and ≤ 29.9 kg/m^2; obese ≥ 30 kg/m^2.
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
Figueroa 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)
Figueroa 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)
Figueroa 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)
Figueroa 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)
Figueroa 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/m^2; overweight ≥ 25 kg/m^2 and ≤ 29.9 kg/m^2; obese ≥ 30 kg/m^2.
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 al[42] and Milanese et al[43] 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 al[43] 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 al[56] and Figueroa et al[57] following 10 1-minute sets of static squats (Table 2). Otsuki et al[56] 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 al[57] examined the acute effects of the WBV protocol used by Otsuki et al[56] 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 al[58] and Koutnik et al[59] 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 al[58] examined a session of 10 continuous minutes of PV and found decreases in baPWV and faPWV. Koutnik et al[59] 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 al[42] 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 al[60] 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 (30 Hz), 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 al[49] 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 ($\geq$ 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.

REFERENCES

1. Rosenberg I. Epidemiologic and methodologic problems in determining nutritional status of older persons. Proceedings of a conference. Albuquerque, New Mexico, October 19-21, 1988. *Am J Clin Nutr* 1989;50(Suppl 5):1121–235.

2. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, et al. Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People. *Age Ageing* 2010;39:412–23.
3. Newman AB, Kupelian V, Visser M, Simonsick E, Goodpaster B, Nevitt M, et al. Sarcopenia: alternative definitions and associations with lower extremity function. *J Am Geriatr Soc* 2003;51:1602–9.
4. Roubenoff R, Hughes VA. Sarcopenia Current Concepts. *Journals Gerontol Ser A Biol Sci Med Sci* 2000;55:M716–24.
5. Frontera WR, Hughes VA, Lutz KJ, Evans WJ. A cross-sectional study of muscle strength and mass in 45- to 78-yr-old men and women. *J Appl Physiol* 1991;71: 644–50.
6. Goodpaster BH, Park SW, Harris TB, Kritchevsky SB, Nevitt M, Schwartz AV, et al. The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. *J Gerontol A Biol Sci Med Sci* 2006;61:1059–64.
7. Clark BC, Manini TM. Sarcopenia =/= dynapenia. *J Gerontol A Biol Sci Med Sci* 2008;63:829–34.
8. Stephen WC, Janssen I. Sarcopenic-obesity and cardiovascular disease risk in the elderly. *J Nutr Health Aging* 2009;13:460–6.
9. Stenholm S, Mehta NK, Elo IT, Heliövaara M, Koskinen S, Aromaa A. Obesity and muscle strength as long-term determinants of all-cause mortality–a 33-year follow-up of the Mini-Finland Health Examination Survey. *Int J Obes (Lond)* 2014;38:1126–32.
10. Lawman HG, Troiano RP, Perna FM, Wang CY, Fryar CD, Ogden CL. Associations of Relative Handgrip Strength and Cardiovascular Disease Biomarkers in U.S. Adults, 2011-2012. *Am J Prev Med* 2016;50:677–83.
11. Stenholm S, Mehta NK, Elo IT, Heliövaara M, Koskinen S, Aromaa A. Obesity and muscle strength as long-term determinants of all-cause mortality–a 33-year follow-up of the Mini-Finland Health Examination Survey. *Int J Obes (Lond)* 2014;38:1126–32.
12. Mitchell GF, Parise H, Benjamin EJ, Larson MG, Keyes MJ, Vita JA, et al. Changes in arterial stiffness and wave reflection with advancing age in healthy men and women: the Framingham Heart Study. *Hypertension* 2004;43:1239–45.
13. Berry KL, Cameron JD, Dart AM, Dewar EM, Gatzka CD, Jennings GL, et al. Large-artery stiffness contributes to the greater prevalence of systolic hypertension in elderly women. *J Am Geriatr Soc* 2004;52:368–73.
14. Abbatecola AM, Chiodini P, Gallo C, Lakatta E, Sutton-Tyrrell K, Tylavsky FA, et al. Pulse wave velocity is associated with muscle mass decline: Health ABC study. *Age (Dordr)* 2012;34:469–78.
15. Vlachopoulos C, Aznaouridis K, Terentes-Printzios D, Ioakeimidis N, Stefanadis C. Prediction of cardiovascular events and all-cause mortality with brachial-ankle elasticity index: a systematic review and meta-analysis. *Hypertension* 2012;60:556–62.
16. Sanada K, Miyachi M, Tanimoto M, Yamamoto K, Murakami H, Okumura S, et al. A cross-sectional study of sarcopenia in Japanese men and women: reference values and association with cardiovascular risk factors. *Eur J Appl Physiol* 2010;110:57–65.
17. Ochi M, Kohara K, Tabara Y, Kido T, Uetani E, Ochi N, et al. Arterial stiffness is associated with low thigh muscle mass in middle-aged to elderly men. *Atherosclerosis* 2010;212:327–32.
18. Kim TN, Yang SJ, Yoo HJ, Lim KI, Kang HJ, Song W, et al. Prevalence of sarcopenia and sarcopenic obesity in Korean adults: the Korean sarcopenic obesity study. *Int J Obes (Lond)* 2009;33:885–92.
19. Ohara M, Kohara K, Tabara Y, Ochi M, Nagai T, Igase M, et al. Sarcopenic obesity and arterial stiffness, pressure wave reflection and central pulse pressure: the J-SHIPP study. *Int J Cardiol* 2014;174:214–7.
20. Fahs CA, Heffernan KS, Ranadive S, Jae SY, Fernhall B. Muscular strength is inversely associated with aortic stiffness in young men. *Med Sci Sports Exerc* 2010;42:1619–24.
21. Casey DP, Beck DT, Braith RW. Progressive resistance training without volume increases does not alter arterial stiffness and aortic wave reflection. *Exp Biol Med (Maywood)* 2007;232:1228–35.
22. Figueroa A, Going SB, Milliken LA, Blew RM, Sharp S, Teixeira PJ, et al. Effects of exercise training and hormone replacement therapy on lean and fat mass in postmenopausal women. *J Gerontol A Biol Sci Med Sci* 2003;58:266–70.
23. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee I, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc* 2011;43:1334–59.
24. Wernbom M, Augustsson J, Thomeé R. The influence of frequency, intensity, volume and mode of strength training on whole muscle cross-sectional area in humans. *Sports Med* 2007;37:225–64.
25. Okamoto T, Masuhara M, Ikuta K. Upper but not lower limb resistance training increases arterial stiffness in humans. *Eur J Appl Physiol* 2009;107:127–34.
26. Collier SR, Kanaley JA, Carhart R, Frechette V, Tobin MM, Hall AK, et al. Effect of 4 weeks of aerobic or resistance exercise training on arterial stiffness, blood flow and blood pressure in pre- and stage-1 hypertensives. *J Hum Hypertens* 2008;22:678–86.
27. Cortez-Cooper MY, DeVan AE, Anton MM, Farrar RP, Beckwith KA, Todd JS, et al. Effects of high intensity resistance training on arterial stiffness and wave reflection in women. *Am J Hypertens* 2005;18:930–4.
28. Miyachi M. Effects of resistance training on arterial stiffness: a meta-analysis. *Br J Sports Med* 2013;47:393–6.
29. Heffernan KS, Fahs CA, Iwamoto GA, Jae SY, Wilund KR, Woods JA, et al. Resistance exercise training reduces central blood pressure and improves microvascular function in African American and white men. *Atherosclerosis* 2009;207:220–6.
30. Croymans DM, Krell SL, Oh CS, Katiraie M, Lam CY, Harris RA, et al. Effects of resistance training on central blood pressure in obese young men. *J Hum Hypertens* 2014;28:157–64.
31. Rakobowchuk M, McGowan CL, de Groot PC, Hartman JW, Phillips SM, MacDonald MJ. Endothelial function of young healthy males following whole body resistance training. *J Appl Physiol* 2005;98:2185–90.
32. Figueroa A, Vicil F, Sanchez-Gonzalez MA, Wong A, Ormsbee MJ, Hooshmand S, et al. Effects of diet and/or low-intensity resistance exercise training on arterial stiffness, adiposity, and lean mass in obese postmenopausal women. *Am J Hypertens* 2013;26:416–23.
33. Okamoto T, Masuhara M, Ikuta K. Effect of low-intensity resistance training on arterial function. *Eur J Appl Physiol* 2011;111:743–8.
34. Cardinale M, Lim J. Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. *J Strength Cond Res* 2003;17:621–4.
35. Roelants M, Delecluse C, Goris M, Verschueren S. Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. *Int J Sports Med* 2004;25:1–5.

36. Machado A, García-López D, González-Gallego J, Garatachea N. Whole-body vibration training increases muscle strength and mass in older women: a randomized-controlled trial. *Scand J Med Sci Sports* 2010;20:200–7.
37. Verschueren SMP, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. *J Bone Miner Res* 2004;19:352–9.
38. Nordlund MM, Thorstensson A. Strength training effects of whole-body vibration? *Scand J Med Sci Sports* 2007;17:12–7.
39. Delecluse C, Roelants M, Verschueren S. Strength increase after whole-body vibration compared with resistance training. *Med Sci Sports Exerc* 2003;35:1033–41.
40. Osawa Y, Oguma Y, Onishi S. Effects of whole-body vibration training on bone-free lean body mass and muscle strength in young adults. *J Sports Sci Med* 2011;10:97–104.
41. Osawa Y, Oguma Y. Effects of resistance training with whole-body vibration on muscle fitness in untrained adults. *Scand J Med Sci Sports* 2013;23:84–95.
42. Figueroa A, Gil R, Wong A, Hooshmand S, Park SY, Vicil F, et al. Whole-body vibration training reduces arterial stiffness, blood pressure and sympathovagal balance in young overweight/obese women. *Hypertens Res* 2012;35:667–72.
43. Milanese C, Piscitelli F, Zenti MG, Moghetti P, Sandri M, Zancanaro C. Ten-week whole-body vibration training improves body composition and muscle strength in obese women. *Int J Med Sci* 2013;10:307–11.
44. Roelants M, Delecluse C, Verschueren SM. Whole-body-vibration training increases knee-extension strength and speed of movement in older women. *J Am Geriatr Soc* 2004;52:901–8.
45. Bogaerts A, Delecluse C, Claessens AL, Coudyzer W, Boonen S, Verschueren SMP. Impact of whole-body vibration training versus fitness training on muscle strength and muscle mass in older men: a 1-year randomized controlled trial. *J Gerontol A Biol Sci Med Sci* 2007;62:630–5.
46. Tapp LR, Signorile JF. Efficacy of WBV as a modality for inducing changes in body composition, aerobic fitness, and muscular strength: a pilot study. *Clin Interv Aging* 2014;9:63–72.
47. Figueroa A, Kalfon R, Madzima TA, Wong A. Effects of whole-body vibration exercise training on aortic wave reflection and muscle strength in postmenopausal women with prehypertension and hypertension. *J Hum Hypertens* 2014;28:118–22.
48. Figueroa A, Kalfon R, Wong A. Whole-body vibration training decreases ankle systolic blood pressure and leg arterial stiffness in obese postmenopausal women with high blood pressure. *Menopause* 2014;22:1–5.
49. Figueroa A, Alvarez-Alvarado S, Ormsbee MJ, Madzima TA, Campbell JC, Wong A. Impact of L-citrulline supplementation and whole-body vibration training on arterial stiffness and leg muscle function in obese postmenopausal women with high blood pressure. *Exp Gerontol* 2015;63:35–40.
50. Liao LR, Ng GYF, Jones AYM, Huang MZ, Pang MYC. Whole-Body Vibration Intensities in Chronic Stroke: A Randomized Controlled Trial. *Med Sci Sports Exerc* 2016;48:1227–38.
51. Tankisheva E, Bogaerts A, Boonen S, Feys H, Verschueren S. Effects of intensive whole-body vibration training on muscle strength and balance in adults with chronic stroke: a randomized controlled pilot study. *Arch Phys Med Rehabil* 2014;95:439–46.
52. Lee K, Lee S, Song C. Whole-body vibration training improves balance, muscle strength and glycosylated hemoglobin in elderly patients with diabetic neuropathy. *Tohoku J Exp Med* 2013;231:305–14.
53. De Feo P. Is high-intensity exercise better than moderate-intensity exercise for weight loss? *Nutr Metab Cardiovasc Dis* 2013;23:1037–42.
54. Figueroa A, Kalfon R, Madzima TA, Wong A. Whole-body vibration exercise training reduces arterial stiffness in postmenopausal women with prehypertension and hypertension. *Menopause* 2014;21:131–6.
55. Marín-Cascales E, Rubio-Arias JA, Romero-Arenas S, Alcaraz PE. Effect of 12 weeks of whole-body vibration versus multi-component training in post-menopausal women. *Rejuvenation Res* 2015;18:508–16.
56. Otsuki T, Takanami Y, Aoi W, Kawai Y, Ichikawa H, Yoshikawa T. Arterial stiffness acutely decreases after whole-body vibration in humans. *Acta Physiol (Oxf)* 2008;194:189–94.
57. Figueroa A, Vicil F, Sanchez-Gonzalez MA. Acute exercise with whole-body vibration decreases wave reflection and leg arterial stiffness. *Am J Cardiovasc Dis* 2011;1:60–7.
58. Wong A, Sanchez-Gonzalez MA, Gil R, Vicil F, Park SY, Figueroa A. Passive vibration on the legs reduces peripheral and systemic arterial stiffness. *Hypertens Res* 2012;35:126–7.
59. Koutnik AP, Figueroa A, Wong A, Ramirez KJ, Ormsbee MJ, Sanchez-Gonzalez MA. Impact of acute whole-body cold exposure with concurrent isometric handgrip exercise on aortic pressure waveform characteristics. *Eur J Appl Physiol* 2014;114:1779–87.
60. Lai CL, Chen HY, Tseng SY, Liao WC, Liu BT, Lee MC, et al. Effect of whole-body vibration for 3 months on arterial stiffness in the middle-aged and elderly. *Clin Interv Aging* 2014;9:821–8.