sustainability

MDPI

Article

Whole-Body Vibration as Antihypertensive Non-Pharmacological Treatment in Hypertensive Individuals with Knee Osteoarthritis: Randomized Cross-Over Trial

Eloá Moreira-Marconi [1,2], Vanessa da Silva Caiado [2,*], Ygor Teixeira-Silva [2,3], Alexandre Gonçalves de Meirelles [2,4], Marcia Cristina Moura-Fernandes [1,2], Patrícia Lopes-Souza [2,3], Aline Reis-Silva [2,4], Danúbia C. Sá-Caputo [2,3,5], Laisa L. Paineiras-Domingos [2,3,5], Ana Cristina Rodrigues Lacerda [6], Vanessa Amaral Mendonça [6], Ricardo Gonçalves Cordeiro [7,8], Redha Taiar [9], Alessandro Sartorio [10], Alexei Wong [11], Borja Sañudo [12] and Mario Bernardo-Filho [2]

1 Graduate Program in Clinical and Experimental Pathophysiology, Rio de Janeiro State University, Rio de Janeiro, RJ 20.551-030, Brazil; marconi.eloa@posgraduacao.uerj.br (E.M.-M.); fernandes.marcia@posgraduacao.uerj.br (M.C.M.-F.)
2 Mechanical Vibration Laboratory and Integrative Practices—LAVIMPI, Biophysics and Biometrics Department, Institute of Biology Roberto Alcântara Gomes and Piquet Carneiro Polyclinic, Rio de Janeiro State University, Rio de Janeiro, RJ 20950-003, Brazil; ygor.silva@souunisuam.com.br (Y.T.-S.); alexandre.meirelles@estacio.br (A.G.d.M.); patricia.souza@inca.gov.br (P.L.-S.); silva.aline@posgraduacao.uerj.br (A.R.-S.); caputo.danubia@posgraduacao.uerj.br (D.C.S.-C.); domingos.laisa@posgraduacao.uerj.br (L.L.P.-D.); bernardo@uerj.br (M.B.-F.)
3 Graduate Program in Medical Sciences, Rio de Janeiro State University, Rio de Janeiro, RJ 20.551-030, Brazil
4 Professional Master in Health, Laboratory Medicine and Forensic Technology, Rio de Janeiro State University, Rio de Janeiro, RJ 20950-003, Brazil
5 Bezerra de Araújo Faculty, Rio de Janeiro, RJ 23052-180, Brazil
6 Faculty of Biological and Health Sciences, Federal University of the Vales do Jequitinhonha e Mucuri, Diamantina, MG 39100-000, Brazil; lacerda.acr@ufvjm.edu.br (A.C.R.L.); vanessa.mendonca@ufvjm.edu.br (V.A.M.)
7 Health Sciences Degree Program. Estacio de Sá University, Rio de Janeiro, RJ 20071-001, Brazil; ricardo.cordeiro@estacio.br
8 Graduate Program in Exercise Sciences and Sport, Rio de Janeiro State University, Rio de Janeiro, RJ 20550-000, Brazil
9 Groupe de Recherche en Sciences pour l'Ingénieur (GRESPI)/ University of Reims Champagne Ardenne, 51100 Reims, France; redha.taiar@univ-reims.fr
10 Istituto Auxologico Italiano, Division of Metabolic Diseases and Auxology & Experimental Laboratory for Auxo-endocrinological Research, 28824 Verbania, Italy; sartorio@auxologico.it
11 Department of Health and Human Performance, Marymount University, Arlington, VA 22207, USA; awong@marymount.edu
12 Departamento de Educación Física y Deporte, University of Sevilla, 41013 Sevilla, Spain; bsancor@us.es
* Correspondence: vanessa.caiado@uerj.br; Tel.: +55-21-23342367

Received: 29 August 2020; Accepted: 17 October 2020; Published: 28 October 2020

Abstract: (1) Background: Hypertension is a serious medical condition characterized by a persistent increase in blood pressure (BP), which is prevalent in individuals with knee osteoarthritis (KOA). Pharmacological interventions are normally used to treat both hypertension and KOA; however, a more sustainable form of treatment is desirable for these clinical conditions. Whole-body vibration (WBV) exercise has been proposed as a non-pharmacological therapy for reducing both BP and KOA symptomatology. This study aimed to evaluate the antihypertensive effect of WBV in hypertensive individuals with KOA. (2) Methods: Nineteen hypertensive individuals with KOA were randomly

allocated to either a control (CG) (n = 9) or a WBV group (WBVG) (n = 10). Subjects in the WBVG were positioned sitting in a chair in front of a vibrating platform (VP) with the feet on the base (peak-to-peak displacement 2.5, 5.0 and 7.5 mm; frequencies 5 to 14 Hz). In the CG, subjects assumed the same position with the VP turned off. The protocols in the CG and WBVG were performed 2 days/week for a total of 5 weeks. (3) Results: No baseline differences (age, anthropometrics, BP parameters and medications) between the groups were found ($p > 0.05$). WBV exercise reduced systolic BP (SBP: 126.1 ± 2.7 versus 119.1 ± 3.2 mmHg; $p = 0.001$; post hoc: $p = 0.02$; $F = 23.97$) and mean BP (MBP: 82.6 ± 1.8 versus 78.7 ± 1.8, $p = 0.001$, post hoc: $p = 0.02$; $F = 23.97$), while no significant changes were found in diastolic BP (DBP: 68.5 ± 2.2 versus 64.4 ± 2.3; $p = 0.11$; F = 2.68). (4) Conclusions: WBV might be considered a sustainable therapy for exerting an antihypertensive effect in medicated hypertensive individuals with KOA. This decline in BP might translate to a reduction in pharmacological need, although further studies are necessary to understand the mechanisms underlying the described effect.

Keywords: hypertension; whole-body vibration; knee osteoarthritis; physical and Rehabilitation medicine; non-pharmacological treatment; sustainability

1. Introduction

Currently, 1.13 billion people worldwide have hypertension [1]. This medical condition is characterized by a persistent increase in blood pressure (BP) [1] that can be associated with several chronic diseases (e.g., knee osteoarthritis - KOA [2], metabolic syndrome - MSyn [3,4], obesity [5] and diabetes [3]).

KOA, considered a systemic disease, is connected with biomechanical factors and an important inflammatory component affecting articular and periarticular structures [6,7]. In addition, KOA is also linked with some cardiovascular risk factors, as MSyn [8], obesity [9], elevated prevalence of diabetes and a rise in BP [10]. Liu et al. showed the association of mortality risk in individuals with symptomatic KOA, including hypertension, as one of these factors [11]. The new classification for phenotyping KOA involves components of MSyn, such as increased BP associated with cardiovascular risk factors (i.e., "pre-hypertension or hypertension") [12]. Although many studies reported the association between KOA and hypertension [13–15]; to our knowledge, only a longitudinal investigation reported the incidence of hypertension in individuals with KOA. The authors of this investigation concluded that individuals with KOA are 13% more likely to develop hypertension than those without KOA [2].

Different mechanisms seem to influence the elevated risk of cardiovascular disease (CVD) among KOA individuals, including: (i) the presence of low-chronic grade inflammation (inflamm-aging) [16,17]; (ii) relevant changes in extracellular matrix (ECM) [18,19] and (iii) pain and disability that may result in physical inactivity (sedentary lifestyle) [20].

Since individuals with KOA are more likely to develop hypertension, monitoring and treating BP in these individuals is desirable. Therefore, in order to obtain long-term health benefits and prevent CVD, the close surveillance and better management of BP in this population is recommended [2].

The use of medications is indicated for the treatment of hypertension and for the reduction of symptoms related to KOA [21,22]. The presence of these two diseases leads to an increase in the consumption of medicines, increasing the cost for the individual. In addition, the administration of a greater number of medications can have greater adverse/side effects for the individual and for the environment. Green Chemistry and Green Engineering have worked on the development of safer materials and chemicals, assessing the toxicological risk for both the environment and consumers (Green Toxicology) [23]. However, in order to achieve a sustainable and safe production of new chemical products, this process requires important measures. In the case of pharmaceutical compounds, there may be limitations on obtaining ecological medicines that are safe and effective

without increasing the final cost for the consumer [23]. In this context, a good strategy would be to investigate non-pharmacological and low-cost treatments in the health area. Ikeda et al. [24] reported that in some low- and middle-income countries, the use of medications for hypertension is reduced. This suggests that a comprehensive approach to the prevention and control of high BP has been investigated since medication is an expensive alternative and most people are hypertensive. Following these considerations, physical exercise has been prescribed to reduce both BP and symptoms related to KOA [22,25].

Among the various modalities of exercise proposed for KOA individuals, whole-body vibration (WBV) exercise has been suggested due to relevant responses related to the reduction of BP [26]. Moreover, WBV exercise promotes improvements in the quality of life, knee joint function (neuromuscular function, flexibility, muscle power and strength), bone mineral density, and decreases pain levels and number of falls [27–30]. WBV exercise has also been shown to have an important clinical application for subjects with cardiovascular risk [26,31–33], particularly for individuals unable to perform regular physical exercise, such as KOA individuals. Moreover, the WBV intervention is a non-pharmacological treatment option that is economic and safe for individuals who cannot use or refuse medication. Thus, the current study aimed to evaluate the antihypertensive effects of WBV exercise in hypertensive individuals with KOA. The hypothesis is that a WBV exercise program (5 weeks) would improve BP in hypertensive individuals with KOA.

2. Materials and Methods

2.1. Subjects

Nineteen outpatients from the Orthopedics Department of the *Hospital Universitário Pedro Ernesto, Universidade do Estado do Rio de Janeiro (HUPE-UERJ)* with KOA diagnostic according to the criteria of the Ahlbäck [34] participated in the current study. Subjects were recruited between March 2014 and July 2017. This investigation with hypertensive KOA individuals is included in a general project about the clinical intervention of WBV exercise in a KOA population, which was approved by the Ethics Committee in Research of the *HUPE-UERJ*. All the interventions are in accordance with the Declaration of Helsinki and have a clinical trial registration (CAAE- 19826413.8.0000.5259 and RBR-7dfwct, respectively).

2.1.1. Inclusion Criteria

Participants had a clinical diagnosis of KOA with Ahlbäck degree 2 and 3, were over 50 years of age, and had low functional capacity (International Knee Documentation Committee (IKDC) score between 20 and 50) [35]. All participants self-declared the continuous use of antihypertensive drugs prescribed by their doctors and were unaware of their hypertension level.

2.1.2. Exclusion Criteria

Participants with joint prosthesis or total knee replacement, other musculoskeletal disorders, neurological diseases or hypertension without treatment, and those that refused to sign the informed consent were excluded.

2.2. Study Design

The study was a two step crossover trial [36] with a washout period for the total elimination of the mechanical vibration effect, which is in accordance with a previous investigation [37] (Figure 1). Following an initial screening that included medical history, anthropometric (age, stature, body mass and body mass index (BMI)) and BP measurements, eligible participants were randomly assigned by arrival order to either a WBV group (WBVG) or a control group (CG). In WBVG, the individuals were exposed to mechanical vibration and in the CG, the individuals participated in the same protocol as

the WBVG, but with the vibrating platform (VP) turned off. Following the initial intervention and an 8-week washout period, the groups were switched to the second intervention step.

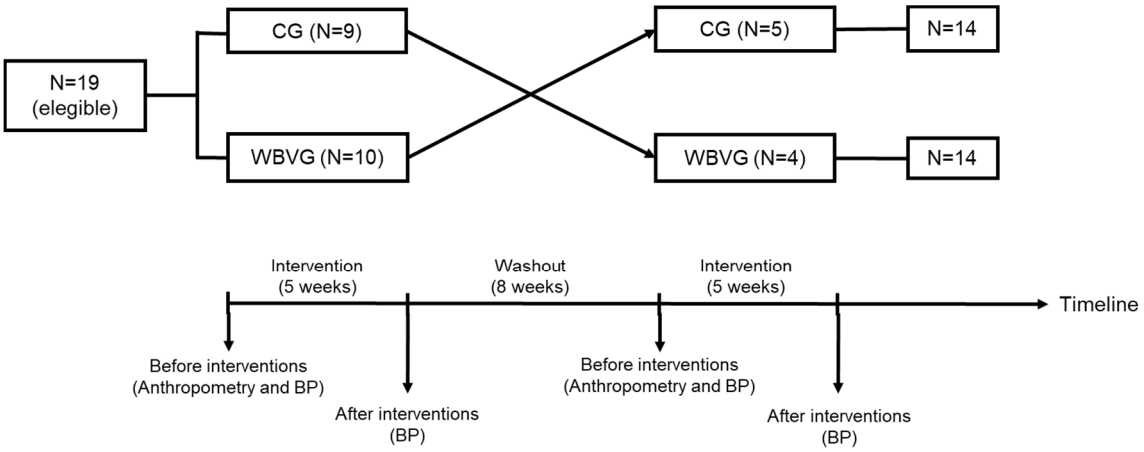


Figure 1. Randomized crossover clinical trial design.

Data were collected at baseline (before starting the protocol) and at the end of the protocol (after 5 weeks) always at the same time (±1 h), in the morning.

Participants were instructed to maintain the antihypertensive drugs prescribed by their doctors and not to modify their lifestyle habits (diet, exercise) during the study.

2.3. Anthropometry and BP

BP and anthropometric parameters were measured in a silent temperature-controlled room (22–25 °C). A digital scale (WelmyTM, São Paulo, SP, Brazil) was used to measure the body mass (kg) and a wall mounted stadiometer (American Medical do Brazil, São Paulo, SP, Brazil) was utilized to measure height (cm).

Before the start of the protocol (first session) the systolic BP (SBP) and the diastolic BP (DBP) were measured in a left arm, in the seated position, using an automatic device (Omron 705IT device; OmronTM Healthcare Co., Kyoto, Japan) after 10 min of rest. The SBP and DBP were also measured immediately after the last session. Three measurements at 1-min intervals were collected and the mean of the three values was used for comparison. The mean of BP (MBP) was calculated using the equation MBP = (DBP.2) SBP/3 [38]. A difference after and before the intervention (Δ = post - pre) was calculated in each BP parameter (SBP, DBP and MBP).

2.4. Whole-Body Vibration Intervention

The WBV protocol was performed for 5 weeks, two days per week (10 sessions) with an interval of at least 2 days between sessions. The position of the subjects during the WBV session was in accordance with previous studies [39–42]: (i) participant sitting in an ancillary chair in front of the VP, (ii) feet on VP base (barefoot), (iii) knee with a comfortable flexion between 100–120° (measured by manual goniometer), (iv) the hands on the knees to facilitate the transmission of the mechanical vibration for the whole body of the individual. The VP used was a side alternated movement of the base (Novaplate Fitness Evolution, *DAF Produtos Hospitalares LTDA*, São Paulo, Brazil). The participants were instructed to maintain this position with feet in each peak-to-peak displacement (2.5, 5.0 and 7.5 mm) indicated on the base of the VP for 3 min, resting 1 min after each bout. The frequency was increased in each session from 5 Hz (first session) up to 14 Hz (last session), corresponding to peak acceleration (a_{Peak}) from

0.12 to 2.95 g [39–42]. The CG followed the same protocol as the WBVG, but with the VP turned off (no vibration).

2.5. Statistical Analysis

The Kolmogorov-Smirnov test was used to test data normality. Mauchly's and Levene's tests were used to verify the sphericity and homogeneity of data and when necessary, the Greenhouse-Geisser correction was applied.

Student-t test was performed for calculation of possible baseline differences between the two groups. A 2-way ANOVA (group (G and WBVG) X time (pre and post treatments)) was performed to establish the intervention effects over time. In case of significant F ratio, the Bonferroni post-hoc test was applied. Data are expressed as mean ± standard error (SEM). The software SPSS 20.0 (SPSS IncTM, Chicago, IL, USA) was used for the statistical calculations and $p \leq 0.05$ was considered as probability level for statistical significance.

Based on previous study [31], the software G*Power 3.1.5 (Universitat Dusseldorf, Dusseldorf, Germany) performed a sample size taking into consideration a α error probability = 0.05; β error probability = 0.80; effect size f = 0.25; correlation among repeated measures = 0.5; nonsphericity correction $\varepsilon = 1$. A statistical power of 0.82 was estimated and after calculations, it was determined to be a total of n = 24 (12 participants per group).

3. Results

Nineteen individuals with KOA were randomly allocated in CG (n = 9) and WBVG (n = 10). Five individuals from the WBVG returned to perform the second step of the treatment (CG) and four individuals from the CG returned to the WBVG totaling fourteen people in each group (2 males and 12 females) (Figure 1). Therefore, 14 individuals in CG and 14 individuals in WBVG concluded all the protocols proposed which were similar to previous studies [31,43,44].

Table 1 shows that anthropometric and BP parameters collected before the interventions and the medications used by participants were not significantly different in the two groups ($p > 0.05$). Although all individuals were taking antihypertensive drugs, the SBP levels of both groups were compatible with prehypertension (n = 11) and hypertension (n = 3) [45].

Figures 2–4 show changes in BP data following the interventions of the two groups (WBVG and CG). A significant Group versus Time interaction showed differences between WBVG and CG decreasing the SBP ($F = 23.97$, $p = 0.001$) and MBP ($F = 23.97$, $p = 0.007$), as reported in the Figure 2A A, respectively. No significant changes were found in DBP ($F = 2.68$, $p = 0.11$) (Figure 4A). In addition, significant differences were found between post-conditions (WBVG versus CG) for SBP (119.1 ± 3.2 versus 126.1 ± 2.7 mmHg; Δ-9.6 mmHg; post hoc: $p = 0.02$), as shown in Figure 2B, and MBP (78.7 ± 1.8 versus 82.6 ± 1.8; Δ-5.0 mmHg; $p = 0.04$), as reported in Figure 3B, but not for DBP (64.4 ± 2.3 versus 68.5 ± 2.2; Δ-4.1 mmHg, $p = 0.2$) (Figure 4B).

Table 1. Anthropometric and blood pressure (BP) parameters and medications used by participants in both study groups: control group (CG) and whole-body vibration group (WBVG).

Variable	Control Group (CG) n = 14 (2 M and 12 F)	Vibration Group (WBVG) n = 14 (2 M and 12 F)	Independent T-Test
Age (year)	64.1 ± 3.3	67.1 ± 2.8	0.518
Body mass (kg)	82.8 ± 2.8	86.8 ± 3.8	0.642
Stature (cm)	160.8 ± 0.1	160.8 ± 0.2	0.431
BMI (kg/m^2)	33.2 ± 1.6	35.2 ± 2.0	0.428
IKDC score	26.14 ± 2.36	29.45 ± 2.51	0.349
SBP (mmHg)	127.2 ± 1.7	128.3 ± 2.7	0.871
DBP (mmHg)	69.0 ± 2.7	68.7 ± 2.3	0.881
MBP (mmHg)	88.4 ± 1.9	88.7 ± 1.5	0.943
Medications			**Chi-Square Test**
Diuretic + AT1 blocker or ACE inhibitor	3	5	0.50
AT1 blocker	6	6	0.64
ACE inhibitor	2	1	0.54
Beta-1 blocker	2	1	0.54
Calcium blocker	2	2	0.70
Metformin	2	1	0.54
Statins	3	4	0.66
SAIDs	2	3	0.62
Chondroitin sulphate	1	1	0.75

M—males; F—females; BMI—body mass index; IKDC—International Knee Documentation Committee; SBP—systolic blood pressure; DBP—diastolic blood pressure; MBP—mean blood pressure. Data expressed in mean ± standard error. ACE = angiotensin-converting enzyme; AT1 = angiotensin II receptor type 1; SAIDs: steroidal anti-inflammatory drugs.

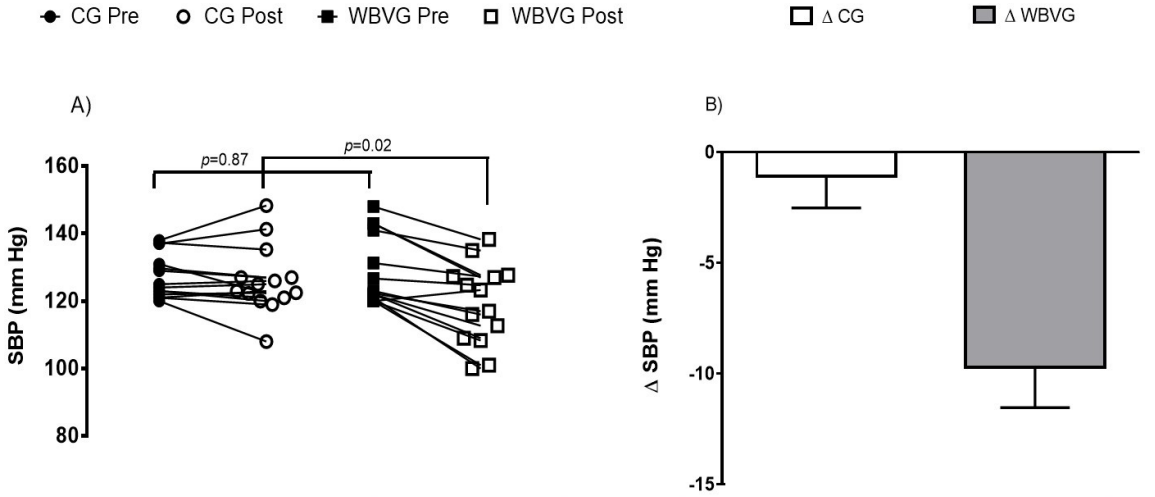
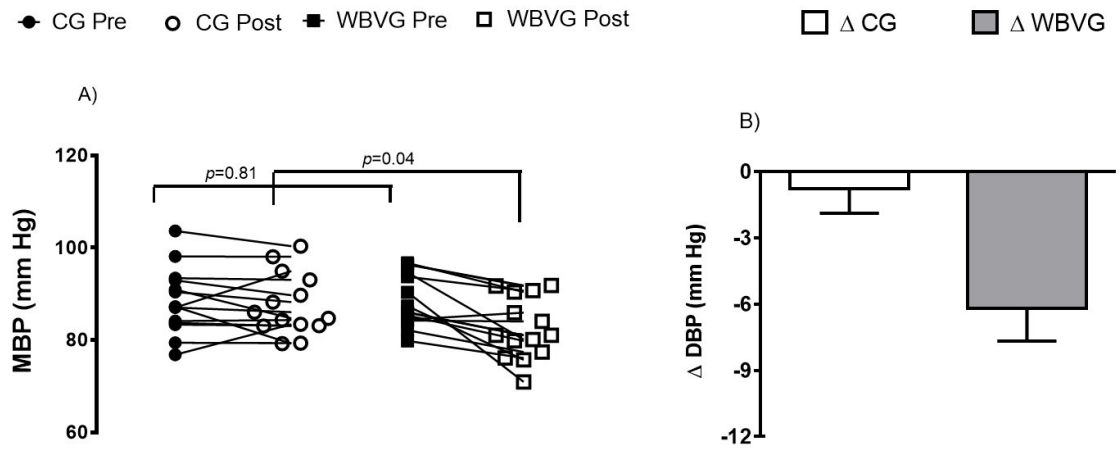
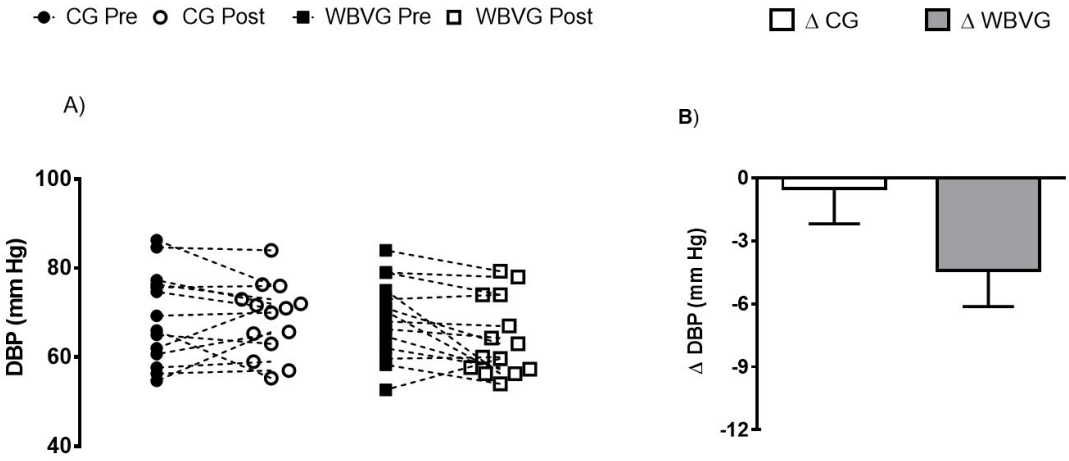


Figure 2. Systolic blood pressure in knee osteoarthritis individuals of control group compared with whole-body vibration group. (**A**) Group (CG and WBVG) X Time (pre and post treatments) and (**B**) Difference of means (Δ = post-pre).



MBP - mean blood pressure; WBVG – whole-body vibration group; CG - control group; Δ=post-pre (difference). Significant Group versus Time effect (F=8.56; p=0.007). Significant difference between WBVG versus CG (p=0.04).

Figure 3. Mean blood pressure in knee osteoarthritis individuals of control group compared with whole-body vibration group. (**A**) Group (CG and WBVG) X Time (pre and post treatments) and (**B**) Difference of means (Δ = post-pre).



DBP - diastolic blood pressure; WBVG – whole-body vibration group; CG - control group; Δ=post-pre (difference). No significant Group versus Time effect (F=2.68;p=0.114). No significant difference between WBVG versus CG (p=0.2).

Figure 4. Diastolic blood pressure in knee osteoarthritis individuals of control group compared with whole-body vibration group. (**A**) Group (CG and WBVG) X Time (pre and post treatments) and (**B**) Difference of means (Δ = post-pre).

4. Discussion

The association of KOA with cardiovascular risk factors has been discussed in several studies [10–12]. As far as we know, the current work is the first which aimed to evaluate the WBV exercise effects on the BP levels in individuals who suffer with KOA. It is important to report that the washout period of 8 weeks [37] was sufficient for a total elimination of the mechanical vibration effect, because the comparison of the baseline in both groups was similar (SBP – p = 0.87; DBP – p = 0.881 and MBP – p = 0.943). Although previous studies have used longer protocols (between 6 and 12 weeks) in non-KOA populations [31,43–47], we showed that an even shorter duration protocol (5 weeks) provides promising outcomes for hypertensive KOA individuals. This encourages further short studies in this population.

4.1. Blood Pressure and Whole-Body Vibration

The most relevant results of the present investigation are that SBP and MBP had a significant reduction after 5 weeks of WBV intervention in individuals with KOA compared with CG. These findings are in line with several authors that have previously demonstrated that resting BP decreases after WBV in different populations. Alvarez-Alvarado et al. [32] and Figueroa et al. [26] reported reductions at resting SBP (−5 mmHg) without changes in DBP in young women (overweight/obese) and normotensive (Baseline: SBP/DBP < 120/80 mmHg) after 6 weeks of a WBV program. Furthermore, authors observed SBP and MBP reduction after a WBV program versus a control group (6–12 weeks) in obese postmenopausal women with both elevated BP and hypertension [31,43–47]. Other investigations indicated a greater decrease in blood pressure between WBV intervention versus control group, when the baseline BP is high (>120/80 mmHg). Figueroa et al. [31] reported a decrease in SBP (~9 mmHg) in obese postmenopausal women with high BP. Figueroa et al. [44] showed a reduction of the SBP (~10 mmHg), DBP (~5 mmHg) and MBP (~6 mmHg) in postmenopausal women with hypertension. Wang et al. [47] found a decrease in SBP (~8 mmHg) and DBP (−3 mmHg) in obese hypertensive postmenopausal women. In the current study, we found significant reductions in SBP and MBP between intervention and control groups (~9.0 and 5.0 mmHg respectively). However, we note that three subjects that began the study with SBP levels above 140 mmHg (143, 144 and 148 mmHg) had a major reduction in SBP (~15 mmHg) after the WBV protocol. This find is similar to other studies [31,44,47], in which greater reductions in BP can be achieved in individuals who begin the WBV exercise with higher BP. Further studies are needed to confirm this suggestion.

Considering that the local vascular resistance was modulated by the high production of metabolites after several muscle contractions during physical exercise [48], chronic reductions in BP after WBV have been attributed to arterial vasodilation in the exercised limbs [31,44]. In the present study, reductions in SBP and MBP would be elicited by means of WBV without voluntary contraction of the musculature, due to the position of the individuals on the VP (sitting in an ancillary chair in front of the VP with the feet supported on its base). This decrease is compatible with another study that showed a decrease in SBP (−12 mmHg) and MBP (−9 mmHg) after WBV in obese postmenopausal women [44]. Despite this study not showing any significant changes in DBP, Manimmanakorn et al. reported that 12 weeks of WBV improved resting DBP pressure in type II diabetic patients [49]. Beijer et al. compared a resistance exercise with and without vibration performed by healthy males during 6 weeks of intervention. They found a positive effect of vibratory stimulus in decreasing DBP [50]. No modification in the antihypertensive treatment was detected in both groups during the study.

4.2. Association between Hypertension and Knee Osteoarthritis

Some symptoms of KOA may be related to hypertension; these include pain [51,52], physical inactivity [53] and inflammatory factor [54,55]. Furthermore, the use of some analgesics can affect BP and can interfere in the effects of antihypertensive therapy [56]. Authors have shown that WBV exercise might produce several benefits on the management of individuals with KOA such as a decrease in pain levels [29,57,58], improvement of functional capacity [29,57–59] and the concentration of inflammatory biomarkers [58]. Wang et al. found a decrease in the level of pain, joint stiffness (knee) and an improvement of functional capacity in individuals with KOA after 12 weeks of WBV [29]. Zafar et al. showed in a systematic review and meta-analysis that WBV reduces the level of pain and improves the functional capacity in individuals with KOA [57]. Similarly, Wang et al. showed that WBV programs of 8 and 12 weeks were beneficial for improving functional capacity in the same population; it is suggested that WBV could be included in rehabilitation programs [59]. Simão et al. suggested that 12 weeks of WBV would improve the self-perception of pain level, functional capacity (balance and gait quality) and inflammatory markers (reductions in the concentrations of soluble tumor necrosis factor receptor - sTNFR1 and sTNFR2) in elderly subjects with KOA [58]. These studies could justify our findings about the BP reduction in this population after a WBV program.

In addition, symptoms related to KOA can impair the maintenance of squat positioning which is usually performed in studies with hypertensive patients without KOA [26,31,32,43,44,46,47]. The current work uses a protocol in which the KOA individuals are exposed to WBV exercise in a comfortable and safe position [39–42]. The seated position in an ancillary chair allows patients to perform the WBV protocol without increasing the load on their knee joints. Naturally, it is relevant to highlight that this positioning could benefit other hypertensive individuals who have other clinical limitations, such as obesity, wheelchair use or diseases that prevent the squat posture. Further studies using the same protocol with hypertensive individuals without KOA but with other physical disabilities are suggested.

4.3. Possible Mechanisms of the Whole-Body Vibration to Reduce Blood Pressure

Considering the WBV intervention, BP reductions could be associated with vasodilation of the muscular arteries [60]. Some authors have shown WBV to acutely improve arterial function such as leg's skin blood flow in healthy persons [60–62]. Additionally, these studies indicated that vibratory stimulus could produce local vasodilation of peripheral arteries, decreasing the BP and reducing cardiovascular strain. Indeed, it has been shown that WBV intervention increases blood flow [63] and decreases arterial stiffness [60] as well as wave reflection [62] in the exposed limbs.

The same mechanisms that cause vascular improvements through vasodilation might justify declines in resting BP after our WBV intervention. Another possibility for the significant BP reduction after WBV intervention would be the increase in concentration of nitric oxide (NO) and endothelial NO synthase activity [46,63]. Furthermore to NO, the reduction of endothelin-1 (a vasoconstrictor) could be another endothelial factor involved with vasodilatory response to vibratory stimulus [64]. Another potential mechanism may be an improvement in autonomic nervous system activity. Joyner et al. [65] reported that the autonomic nervous system and its sympathetic pathway performs a great function in BP regulation. Furthermore, decreased parasympathetic and increased sympathetic activities modify sympathovagal balance and it would be the main mechanism to establish hypertension and pre-hypertension [66]. Previous research reported concomitant decreases in both resting BP and sympathovagal balance after WBV intervention in overweight/obese women [26,47].

4.4. Limitations of Study

Some limitations of this work include that there was no separate osteoarthritis classification by Ahlbäck criteria. Moreover, vasoactive substances and sympathetic activity were not measured, which would have helped in the explanation of the current findings. We also did not control for some covariates, like Na+ intake, K+ intake, serum Na+, K+ levels, diuresis, sleep, and daily physical activity and this may interfere in some responses to the investigation.

4.5. Strength of Study

The strength of this work is that it shows the effectiveness of a non-pharmacological and low-cost intervention for the treatment of hypertensive individuals with KOA. It offers a more sustainable treatment option, as this population could reduce the consumption of medications, reducing adverse/side effects, improving not only health but helping to preserve the environment (Green Toxicology) [23].

5. Conclusions

The current study showed that WBV exercise was able to produce antihypertensive effect on SBP and MBP in medicated hypertensive KOA individuals. Thus, WBV exercise might be considered a sustainable tool to decrease BP. Of importance, no participant increased the use of medications or left the research due to BP related issues during the interventions. This suggests that further research should be carried out to investigate the association between the use of WBV intervention and the reduction of the consumption of antihypertensive medications.

Author Contributions: Conceptualization, E.M.-M. and M.B.-F.; data curation, E.M.-M., A.R.-S., P.L.-S., R.G.C., and L.L.P.-D.; formal analysis, R.G.C., funding acquisition, E.M.-M., M.C.M.-F. and M.B.-F.; investigation, V.d.S.C., M.C.M.-F., A.G.d.M., R.G.C. and Y.T.-S.; methodology, E.M.-M., A.R.-S., P.L.-S., L.L.P.-D., Y.T.-S., and A.G.d.M.; supervision, D.C.S.-C. and M.B.-F.; writing—original draft, E.M.-M., M.B.-F.; writing—review & editing, E.M.-M., V.d.S.C., A.C.R.L., R.T., V.A.M., A.S., A.W., B.S. and M.B.-F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) (finance code 001), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), the Universidade do Estado do Rio de Janeiro (UERJ) and the Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. World Health Organisation (WHO) Hypertension. Available online: https://www.who.int/health-topics/hypertension/#tab=tab_1 (accessed on 17 April 2020).
2. Veronese, N.; Stubbs, B.; Solmi, M.; Smith, T.O.; Noale, M.; Schofield, P.; Maggi, S. Knee Osteoarthritis and Risk of Hypertension: A Longitudinal Cohort Study. *Rejuvenation Res.* **2018**, *21*, 15–21. [CrossRef]
3. Cheung, B.M.Y.; Li, C. Diabetes and Hypertension: Is There a Common Metabolic Pathway? *Curr. Atheroscler. Rep.* **2012**, *14*, 160–166. [CrossRef] [PubMed]
4. Mulè, G. Metabolic syndrome in hypertensive patients: An unholy alliance. *World J. Cardiol.* **2014**, *6*, 890. [CrossRef] [PubMed]
5. Jiang, S.-Z.; Lu, W.; Zong, X.-F.; Ruan, H.-Y.; Liu, Y. Obesity and hypertension. *Exp. Ther. Med.* **2016**, *12*, 2395–2399. [CrossRef] [PubMed]
6. Robinson, W.H.; Lepus, C.M.; Wang, Q.; Raghu, H.; Mao, R.; Lindstrom, T.M.; Sokolove, J. Low-grade inflammation as a key mediator of the pathogenesis of osteoarthritis. *Nat. Rev. Rheumatol.* **2016**, *12*, 580–592. [CrossRef]
7. Loeser, R.F.; Goldring, S.R.; Scanzello, C.R.; Goldring, M.B. Osteoarthritis: A disease of the joint as an organ. *Arthritis Rheum.* **2012**, *64*, 1697–1707. [CrossRef]
8. Lee, B.; Yang, S.; Kwon, S.; Choi, K.; Kim, W. Association between metabolic syndrome and knee osteoarthritis: A cross-sectional Nationwide survey study. *J. Rehabil. Med.* **2019**, *51*, 464–470. [CrossRef]
9. Khan, B.; Khan, O.Y.; Zehra, S.; Azhar, A.; Fatima, S. Association between obesity and risk of knee osteoarthritis. *Pak. J. Pharm. Sci.* **2020**, *33*, 295–298.
10. Kim, H.S.; Shin, J.-S.; Lee, J.; Lee, Y.J.; Kim, M.; Bae, Y.-H.; Park, K.B.; Lee, E.-J.; Kim, J.-H.; Ha, I.-H. Association between Knee Osteoarthritis, Cardiovascular Risk Factors, and the Framingham Risk Score in South Koreans: A Cross-Sectional Study. *PLoS ONE* **2016**, *11*, e0165325. [CrossRef]
11. Liu, Q.; Niu, J.; Huang, J.; Ke, Y.; Tang, X.; Wu, X.; Li, R.; Li, H.; Zhi, X.; Wang, K.; et al. Knee osteoarthritis and all-cause mortality: The Wuchuan Osteoarthritis Study. *Osteoarthr. Cartil.* **2015**, *23*, 1154–1157. [CrossRef]
12. DongXing, X.; Jie, W.; Chao, Z.; Tuo, Y.; Hui, L.; YiLun, W.; HuiZhong, L.; ZiYing, W.; YuXuan, Q.; KangHua, L.; et al. Association between metabolic syndrome and knee osteoarthritis: A cross-sectional study. *BMC Musculoskelet. Disord.* **2017**, *18*. [CrossRef]
13. Nielen, M.M.J.; Van Sijl, A.M.; Peters, M.J.L.; Verheij, R.A.; Schellevis, F.G.; Nurmohamed, M.T. Cardiovascular disease prevalence in patients with inflammatory arthritis, diabetes mellitus and osteoarthritis: A cross-sectional study in primary care. *BMC Musculoskelet. Disord.* **2012**, *13*, 150. [CrossRef] [PubMed]
14. Hawker, G.A.; Croxford, R.; Bierman, A.S.; Harvey, P.; Ravi, B.; Kendzerska, T.; Stanaitis, I.; King, L.K.; Lipscombe, L. Osteoarthritis-related difficulty walking and risk for diabetes complications. *Osteoarthr. Cartil.* **2017**, *25*, 67–75. [CrossRef] [PubMed]
15. Sohn, M.W.; Manheim, L.M.; Chang, R.W.; Greenland, P.; Hochberg, M.C.; Nevitt, M.C.; Semanik, P.A.; Dunlop, D.D. Sedentary behavior and blood pressure control among osteoarthritis initiative participants. *Osteoarthr. Cartil.* **2014**, *22*, 1234–1240. [CrossRef] [PubMed]
16. Ong, S.-M.; Hadadi, E.; Dang, T.-M.; Yeap, W.-H.; Tan, C.T.-Y.; Ng, T.-P.; Larbi, A.; Wong, S.-C. The pro-inflammatory phenotype of the human non-classical monocyte subset is attributed to senescence. *Cell Death Dis.* **2018**, *9*, 266. [CrossRef]
17. Nakayama, H.; Otsu, K. Mitochondrial DNA as an inflammatory mediator in cardiovascular diseases. *Biochem. J.* **2018**, *475*, 839–852. [CrossRef]

18. Radojčić, M.R.; Thudium, C.S.; Henriksen, K.; Tan, K.; Karlsten, R.; Dudley, A.; Chessell, I.; Karsdal, M.A.; Bay-Jensen, A.-C.; Crema, M.D.; et al. Biomarker of extracellular matrix remodelling C1M and proinflammatory cytokine interleukin 6 are related to synovitis and pain in end-stage knee osteoarthritis patients. *Pain* **2017**, *158*, 1254–1263. [CrossRef]
19. Lacolley, P.; Regnault, V.; Avolio, A.P. Smooth muscle cell and arterial aging: Basic and clinical aspects. *Cardiovasc. Res.* **2018**, *114*, 513–528. [CrossRef]
20. Stubbs, B.; Binnekade, T.T.; Soundy, A.; Schofield, P.; Huijnen, I.P.J.; Eggermont, L.H.P. Are Older Adults with Chronic Musculoskeletal Pain Less Active than Older Adults Without Pain? A Systematic Review and Meta-Analysis. *Pain Med.* **2013**, *14*, 1316–1331. [CrossRef]
21. Bergler-Klein, J. What's new in the ESC 2018 guidelines for arterial hypertension. *Wien. Klin. Wochenschr.* **2019**, *131*, 180–185. [CrossRef]
22. Kolasinski, S.L.; Neogi, T.; Hochberg, M.C.; Oatis, C.; Guyatt, G.; Block, J.; Callahan, L.; Copenhaver, C.; Dodge, C.; Felson, D.; et al. 2019 American College of Rheumatology/Arthritis Foundation Guideline for the Management of Osteoarthritis of the Hand, Hip, and Knee. *Arthritis Rheumatol.* **2020**, *72*, 220–233. [CrossRef]
23. Crawford, S.E.; Hartung, T.; Hollert, H.; Mathes, B.; van Ravenzwaay, B.; Steger-Hartmann, T.; Studer, C.; Krug, H.F. Green Toxicology: A strategy for sustainable chemical and material development. *Environ. Sci. Eur.* **2017**, *29*, 16. [CrossRef]
24. Ikeda, N.; Sapienza, D.; Guerrero, R.; Aekplakorn, W.; Naghavi, M.; Mokdad, A.H.; Lozano, R.; Murray, C.J.; Lim, S.S. Control of hypertension with medication: A comparative analysis of national surveys in 20 countries. *Bull. World Health Organ.* **2014**, *92*, 10–19C. [CrossRef] [PubMed]
25. Sakamoto, S. Prescription of exercise training for hypertensives. *Hypertens. Res.* **2020**, *43*, 155–161. [CrossRef] [PubMed]
26. Figueroa, A.; Gil, R.; Wong, A.; Hooshmand, S.; Park, S.Y.; Vicil, F.; Sanchez-Gonzalez, M.A. Whole-body vibration training reduces arterial stiffness, blood pressure and sympathovagal balance in young overweight/obese women. *Hypertens. Res.* **2012**. [CrossRef] [PubMed]
27. Lai, Z.; Wang, X.; Lee, S.; Hou, X.; Wang, L. Effects of whole body vibration exercise on neuromuscular function for individuals with knee osteoarthritis: Study protocol for a randomized controlled trial. *Trials* **2017**, *18*, 437. [CrossRef]
28. Newberry, S.J.; FitzGerald, J.; SooHoo, N.F. Treatment of Osteoarthritis of the Knee: An Update Review. *Comp. Eff. Rev.* **2017**, 190. [CrossRef]
29. Wang, P.; Yang, L.; Li, H.; Lei, Z.; Yang, X.; Liu, C.; Jiang, H.; Zhang, L.; Zhou, Z.; Reinhardt, J.D.; et al. Effects of whole-body vibration training with quadriceps strengthening exercise on functioning and gait parameters in patients with medial compartment knee osteoarthritis: A randomised controlled preliminary study. *Physiotherapy* **2016**, *102*, 86–92. [CrossRef]
30. Beck, B.R.; Norling, T.L. The Effect of 8 Mos of Twice-Weekly Low- or Higher Intensity Whole Body Vibration on Risk Factors for Postmenopausal Hip Fracture. *Am. J. Phys. Med. Rehabil.* **2010**. [CrossRef]
31. 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* **2015**. [CrossRef]
32. Alvarez-Alvarado, S.; Jaime, S.J.; Ormsbee, M.J.; Campbell, J.C.; Post, J.; Pacilio, J.; Figueroa, A. Benefits of whole-body vibration training on arterial function and muscle strength in young overweight/obese women. *Hypertens. Res.* **2017**, *40*, 487–492. [CrossRef] [PubMed]
33. Lage, V.K.S.; Lacerda, A.C.R.; Neves, C.D.C.; Chaves, M.G.A.; Soares, A.A.; Lima, L.P.; Matos, M.A.; Leite, H.R.; Fernandes, J.S.C.; Oliveira, V.C.; et al. Cardiorespiratory responses in different types of squats and frequencies of whole body vibration in patients with chronic obstructive pulmonary disease. *J. Appl. Physiol.* **2018**, *126*, 23–29. [CrossRef] [PubMed]
34. Ahlback, S. Osteoarthrosis of the knee. A radiographic investigation. *Acta Radiol Diagn* **1968**, *77*, 7–72. [CrossRef]
35. Silva Júnior, O.D.M.; Ohashi, B.D.N.; De Almeida, M.O.; Gonçalves, M.R. Resultado funcional relacionado ao posicionamento do enxerto na reconstrução do ligamento cruzado anterior. *Rev. Bras. Ortop.* **2015**, *50*, 57–67. [CrossRef]
36. Dwan, K.; Li, T.; Altman, D.G.; Elbourne, D. CONSORT 2010 statement: Extension to randomised crossover trials. *BMJ* **2019**, l4378. [CrossRef] [PubMed]

37. Hiroshige, K.; Mahbub, M.H.; Harada, N. Effects of whole-body vibration on postural balance and proprioception in healthy young and elderly subjects: A randomized cross-over study. *J. Sports Med. Phys. Fitness* **2014**, *54*, 216–224.
38. Brzezinski, W. Blood Pressure. In *Clinical Methods: The History, Physical, and Laboratory Examinations.*; Walkr, H., Hall, W., Hurst, J., Eds.; Butterworths: Boston, MA, USA, 1990.
39. Neto, S.B.; Marconi, E.M.; Kutter, C.R.; Frederico, E.H.; de Paiva, P.D.; Meyer, P.F.; Chang, S.; Sá-Caputo, D.; Bernardo-Filho, M. Beneficial effects of whole body mechanical vibration alone or combined with auriculotherapy in the pain and in flexion of knee of individuals with knee osteoarthritis. *Acupunct. Electrother. Res.* **2017**, *42*, 185–201. [CrossRef]
40. Ribeiro Kütter, C.; Moreira-Marconi, E.; Teixeira-Silva, Y.; Cristina Moura-Fernandes, M.; Gonçalves de Meirelles, A.; José dos Santos Pereira, M.; Chang, S.; Alexandre Bachur, J.; Liane Paineiras-Domingos, L.; Taiar, R.; et al. Effects of the whole-body vibration and auriculotherapy on the functionality of knee osteoarthritis individuals. *Appl. Sci.* **2019**, *9*, 5194. [CrossRef]
41. Moura-Fernandes, M.C.; Moreira-Marconi, E.; Gonçalves de Meirelles, A.; Paula Ferreira de Oliveira, A.; Silva, A.R.; Felipe Ferreira de Souza, L.; Lírio Pereira da Silva, A.; dos Santos-Fernandes, C.; Bessa Monteiro de Oliveira, B.; Antonio de Souza Gama, M.; et al. Effect of the Combined Intervention with Passive Whole-Body Vibration and Auriculotherapy on the Quality of Life of Individuals with Knee Osteoarthritis Assessed by the WHOQOL-Bref: A Multi-Arm Clinical Trial. *Appl. Sci.* **2020**, *10*, 1956. [CrossRef]
42. Moreira-marconi, E.; Dionello, C.F.; Morel, D.S.; Sá-caputo, D.C.; Sousa-gonçalves, C.R.; José, M.; Bernardo-filho, M. Whole body vibration and auriculotherapy improve handgrip strength in individuals with knee osteoarthritis. *J. Tradit. Chin. Med.* **2019**, *39*, 707–715.
43. Figueroa, A.; Kalfon, R.; Madzima, T.A.; 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.* **2013**, *28*, 118. [CrossRef] [PubMed]
44. Figueroa, A.; Kalfon, R.; Madzima, T.A.; Wong, A. Whole-body vibration exercise training reduces arterial stiffness in postmenopausal women with prehypertension and hypertension. *Menopause* **2014**, *21*, 131–136. [CrossRef] [PubMed]
45. Malachias, M.; Souza, W.; Plavnik, F.; Rodrigues, C.; Brandão, A.; Neves, M.; Bortolotto, L.; Franco, R.; Figueiredo, C.; Jardim, P.; et al. 7th Brazilian Guideline of arterial hypertension. *Arq. Bras. Cardiol.* **2016**, *107*, 1–6. [CrossRef] [PubMed]
46. Wong, A.; Alvarez-Alvarado, S.; Jaime, S.J.; Kinsey, A.W.; Spicer, M.T.; Madzima, T.A.; Figueroa, A. Combined whole-body vibration training and l-citrulline supplementation improves pressure wave reflection in obese postmenopausal women. *Appl. Physiol. Nutr. Metab.* **2015**, *41*, 292–297. [CrossRef]
47. Wong, A.; Alvarez-Alvarado, S.; Kinsey, A.W.; Figueroa, A. Whole-Body Vibration Exercise Therapy Improves Cardiac Autonomic Function and Blood Pressure in Obese Pre- and Stage 1 Hypertensive Postmenopausal Women. *J. Altern. Complement. Med.* **2016**, *22*, 970–976. [CrossRef] [PubMed]
48. Clifford, P.S.; Hellsten, Y. Vasodilatory mechanisms in contracting skeletal muscle. *J. Appl. Physiol.* **2004**, *97*, 393–403. [CrossRef]
49. Manimmanakorn, N.; Manimmanakorn, A.; Phuttharak, W.; Hamlin, M.J. Effects of Whole Body Vibration on Glycemic Indices and Peripheral Blood Flow in Type II Diabetic Patients. *Malaysian J. Med. Sci.* **2017**, *24*, 55–63. [CrossRef]
50. Beijer, Å.; Rosenberger, A.; Weber, T.; Zange, J.; May, F.; Schoenau, E.; Mester, J.; Bloch, W.; Rittweger, J. Randomized controlled study on resistive vibration exercise (EVE study): Protocol, implementation and feasibility. *J. Musculoskelet. Neuronal Interact.* **2013**, *13*, 147–156.
51. Saccò, M.; Meschi, M.; Regolisti, G.; Detrenis, S.; Bianchi, L.; Bertorelli, M.; Pioli, S.; Magnano, A.; Spagnoli, F.; Giuri, P.G.; et al. The relationship between blood pressure and pain. *J. Clin. Hypertens.* **2013**, *15*, 600–605. [CrossRef]
52. Bruehl, S.; Olsen, R.B.; Tronstad, C.; Sevre, K.; Burns, J.W.; Schirmer, H.; Nielsen, C.S.; Stubhaug, A.; Rosseland, L.A. Chronic pain-related changes in cardiovascular regulation and impact on comorbid hypertension in a general population: The Tromsø study. *Pain* **2018**, *159*, 119–127. [CrossRef]
53. Rissardi, G.D.; Cipullo, J.P.; Moreira, G.C.; Ciorlia, L.A.; Cesarino, C.B.; Giollo Junior, L.T.; Zanesco, A.; Vilela-Martin, J.F. Prevalence of Physical Inactivity and its Effects on Blood Pressure and Metabolic Parameters in a Brazilian Urban Population. *Int. J. Cardiovasc. Sci.* **2018**, *31*, 594–602. [CrossRef]

54. De Miguel, C.; Rudemiller, N.P.; Abais, J.M.; Mattson, D.L. Inflammation and Hypertension: New Understandings and Potential Therapeutic Targets. *Curr. Hypertens. Rep.* **2014**, *17*, 507. [CrossRef] [PubMed]
55. Bartoloni, E.; Alunno, A.; Valentini, V.; Luccioli, F.; Valentini, E.; La Paglia, G.; Bistoni, O.; Gerli, R. Role of Inflammatory Diseases in Hypertension. *High Blood Press. Cardiovasc. Prev.* **2017**, *24*, 353–361. [CrossRef]
56. Aljadhey, H.; Tu, W.; Hansen, R.A.; Blalock, S.J.; Brater, D.C.; Murray, M.D. Comparative effects of non-steroidal anti-inflammatory drugs (NSAIDs) on blood pressure in patients with hypertension. *BMC Cardiovasc. Disord.* **2012**, *12*. [CrossRef] [PubMed]
57. Zafar, H.; Alghadir, A.; Anwer, S.; Al-Eisa, E. Therapeutic Effects of Whole-Body Vibration Training in Knee Osteoarthritis: A Systematic Review and Meta-Analysis. *Arch. Phys. Med. Rehab* **2015**, *96*, 1525–1532. [CrossRef] [PubMed]
58. Simão, A.P.; Avelar, N.C.; Tossige-Gomes, R.; Neves, C.D.; Mendonça, V.A.; Miranda, A.S.; Teixeira, M.M.; Teixeira, A.L.; Andrade, A.P.; Coimbra, C.C.; et al. Functional performance and inflammatory cytokines after squat exercises and whole-body vibration in elderly individuals with knee osteoarthritis. *Arch. Phys. Med. Rehabil.* **2012**, *93*, 1692–1700. [CrossRef] [PubMed]
59. Wang, P.; Yang, X.; Yang, Y.; Yang, L.; Zhou, Y.; Liu, C.; Reinhardt, J.D.; He, C. Effects of whole body vibration on pain, stiffness and physical functions in patients with knee osteoarthritis: A systematic review and meta-analysis. *Clin. Rehabil.* **2015**, *29*, 939–951. [CrossRef]
60. Wong, A.; Sanchez-Gonzalez, M.A.; Gil, R.; Vicil, F.; Park, S.Y.; Figueroa, A. Passive vibration on the legs reduces peripheral and systemic arterial stiffness. *Hypertens. Res.* **2012**, *35*, 126–127. [CrossRef]
61. Lohman, E.B.; Petrofsky, J.S.; Maloney-Hinds, C.; Betts-Schwab, H.; Thorpe, D. The effect of whole body vibration on lower extremity skin blood flow in normal subjects. *Med. Sci. Monit.* **2007**, *13*, CR71–CR76. [CrossRef]
62. Sanchez-Gonzalez, M.A.; Wong, A.; Vicil, F.; Gil, R.; Park, S.Y.; Figueroa, A. Impact of passive vibration on pressure pulse wave characteristics. *J. Hum. Hypertens.* **2012**, *26*, 610–615. [CrossRef]
63. Maloney-Hinds, C.; Petrofsky, J.S.; Zimmerman, G.; Hessinger, D.A. The Role of Nitric Oxide in Skin Blood Flow Increases Due to Vibration in Healthy Adults and Adults with Type 2 Diabetes. *Diabetes Technol. Ther.* **2009**, *11*, 39–43. [CrossRef] [PubMed]
64. Nakamura, H.; Okazawa, T.; Nagase, H.; Yoshida, M.; Arüzumi, M.; Okada, A. Change in digital blood flow with simultaneous reduction in plasma endothelin induced by hand-arm vibration. *Int. Arch. Occup. Environ. Health* **1996**, *68*, 115–119. [CrossRef] [PubMed]
65. Joyner, M.J.; Charkoudian, N.; Wallin, B.G. Sympathetic Nervous System and Blood Pressure in Humans. *Hypertension* **2010**, *56*, 10–16. [CrossRef] [PubMed]
66. Pal, G.K.; Pal, P.; Nanda, N.; Lalitha, V.; Dutta, T.K.; Adithan, C. Sympathovagal Imbalance in Prehypertensive Offspring of Two Parents versus One Parent Hypertensive. *Int. J. Hypertens.* **2011**, *2011*, 1–8. [CrossRef] [PubMed]