ORIGINAL ARTICLE

Arch AHS

Archives of Allied Health Sciences 2024; 36(1): 1-11.

The immediate effects of whole-body vibration on flexibility and ankle systolic blood pressure in middle-aged individuals with type 2 diabetes mellitus

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KEYWORDS
Vibration exercise;
Ankle brachial index;
Ankle blood pressure;
Diabetes mellitus;
Squat exercise.

ABSTRACT

Poor body flexibility in middle-aged individuals with type 2 diabetes mellitus (T2DM) could increase the risk of falls and injuries. Insulin resistance induces vascular alterations in the lower extremities, leading to increased ankle systolic blood pressure (SBP), which correlates with an increased risk of cardiovascular disease. The aim of this study was to investigate the acute effects of whole-body vibration (WBV) on flexibility and ankle SBP in middle-aged T2DM patients. This randomized single-blinded crossover design was used to study 14 participants (average age: 49.71 ± 5.28 years, average body mass index: 26.98 ± 3.24 kg/m^2, average duration of diabetes: 2.32 ± 1.74 years) who were randomly assigned to two intervention sequences, starting with non-whole-body vibration (NWBV) or WBV, with seven participants in each sequence. On days 1 and 8, the intervention varied between NWBV and WBV. The outcomes, including flexibility, ankle blood pressure, brachial blood pressure, and the ankle brachial index, were measured at baseline and 15 min, and 45 min after completing the interventions. A repeated measures two-way ANOVA was used for the data analysis. After a 7-day washout period, neither group exhibited a carryover effect. At the post-intervention period, the WBV intervention resulted in a significant increase in flexibility (+3.52 cm after 15 min and +4.20 cm after 45 min; *p*-value < 0.05) and a significant decrease in ankle SBP (-7.91 mmHg after 15 min; *p*-value < 0.05) and the ABI (–0.09 after 15 min and –0.07 after 45 min; *p*-value < 0.05). In contrast, the NWBV intervention led to a significant increase in ankle SBP (+10.50 mmHg after 45 min; *p*-value < 0.05). These findings show that middle-aged patients with T2DM might benefit from a single session of 12-min WBV training in terms of improving flexibility, ankle SBP, and the ABI. Therefore, it may be an exercise option for middle-aged T2DM patients.

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Received: 6 November 2023/ Revised: 28 December 2023/ Accepted: 29 December 2023

Introduction

In 2019, Thailand had an estimated 4.8 million adults with type 2 diabetes mellitus (T2DM), and this number is projected to increase to 5.3 million by 2039[1]. T2DM typically emerges in middle-aged individuals over the age of 45[2]. It reduces flexibility, especially in overweight or obese individuals, due to decreased mobility and glycation of joint structures, particularly in the lower extremities, significantly impacting overall quality of life[3]. Additionally, insulin resistance-induced vascular changes in the lower extremities, evidenced by increased ankle systolic blood pressure (SBP), are linked to cardiovascular disease risk[4]. Implementing interventions for middle-aged individuals with T2DM at an early stage of the disease is essential to control blood sugar and prevent irreversible vascular and joint limitations[5].

Aerobic, resistance, and flexibility exercises are effective physical therapy approaches for people with T2DM. However, individuals with T2DM who cannot follow prescribed exercise routines since they are strenuous, time-consuming, and difficult to follow may encounter difficulties in maintaining optimal blood sugar levels[6]. Whole-body vibration (WBV) is an innovative fitness practice that involves standing on a platform with electric motors that provide regulated vibrations. This activity has acquired popularity as an alternative or complementary treatment for several health issues, including diabetes[7].

Research has found that a single WBV session led to immediate flexibility improvements in middle-aged individuals with metabolic syndrome and Parkinson's disease, which was attributedto circulatory, thermoregulatory, and neural factors[8,9]. However, these studies did not explore the effect of WBV on flexibility beyond the immediate post-WBV period. Another research found that a single WBV session significantly lowered ankle SBP at 30 minutes, but not at 15 minutes, in healthy participants as a result of activating endothelial function, leading to increased nitric oxide production[10]. In addition, Figueroa and colleagues found that after 12 weeks of WBV, ankle SBP decreased in post-menopausal women with hypertension[11]. However, these studies did not investigate the impact of WBV on ankle SBP at 15 and 45 minutes following the WBV session. Hence, there is a notable gap in evidence regarding the immediate impact of WBV on flexibility and ankle SBP at 15 and 45 minutes after completing the intervention in middle-aged individuals with T2DM. Consequently, the objective of this study was to investigate the immediate effects of WBV on flexibility and ankle SBP in middle-aged patients with T2DM.

Materials and methods

Study design and participants

This study used a randomized, single-blinded crossover design. The participants were recruited through posters displayed at the village hall in Mueang Khon Kaen District in Khon Kaen, Thailand, between March and July 2023. Figure 1 presents a flowchart of the study enrollment. The sample size calculation was conducted employing the crossover study design formula[12] and considered a 2.1 cm change in flexibility following WBV, as observed in a prior study[8]. A significant level of alpha of 0.05 and a statistical power of 0.8 were chosen for the two-tailed test, and the total sample size resulted in 11 participants. Given a 10% rate of loss to follow-up, the adjusted total sample size would require 14 participants[13]. Therefore, there were 14 middle-aged individuals with T2DM, of which 7 participants were allocated to non-whole-body vibration (NWBV) and 7 participants to WBV in a randomized crossover design using stratified block randomization (block sizes of 4 and 6), with sex as the stratification variable.

The inclusion criteria were as follows: (1) diagnosis with T2DM between 1 and 10 years earlier; (2) age between 40 and 59 years; (3) body mass index (BMI) of 18.5–29.9 kg/m^2; (4) ability to walk without any assistive devices; and (5) ability to understand and follow the instructions in the research protocol. The exclusion criteria were as follows: (1) brachial blood pressure (BP) ≥ 140/90 mmHg; (2) lower extremity pain (visual analog scale > 3) at rest or in a high squat position; (3) regular physical exercise (moderate intensity of ≥ 30 min/session ≥ 3 sessions/week); (4) musculoskeletal, cardiovascular, or neurological problems; (5) retinopathy and nephropathy; (6) diabetic foot ulcer; (7) tumors or metastases; (8) gall bladder and kidney stones; and (9) pregnant women.

This study was carried out at the School of Physical Therapy, Faculty of Associated Medical Sciences, Khon Kaen University, Thailand. The protocol of this study was registered in the Thai Clinical Trial Registry (ID 20230125003) and approved by the Ethics Committee of the Center for Ethics in Human Research, Khon Kaen University (HE652122) and written informed consent was obtained from all participants for this study.

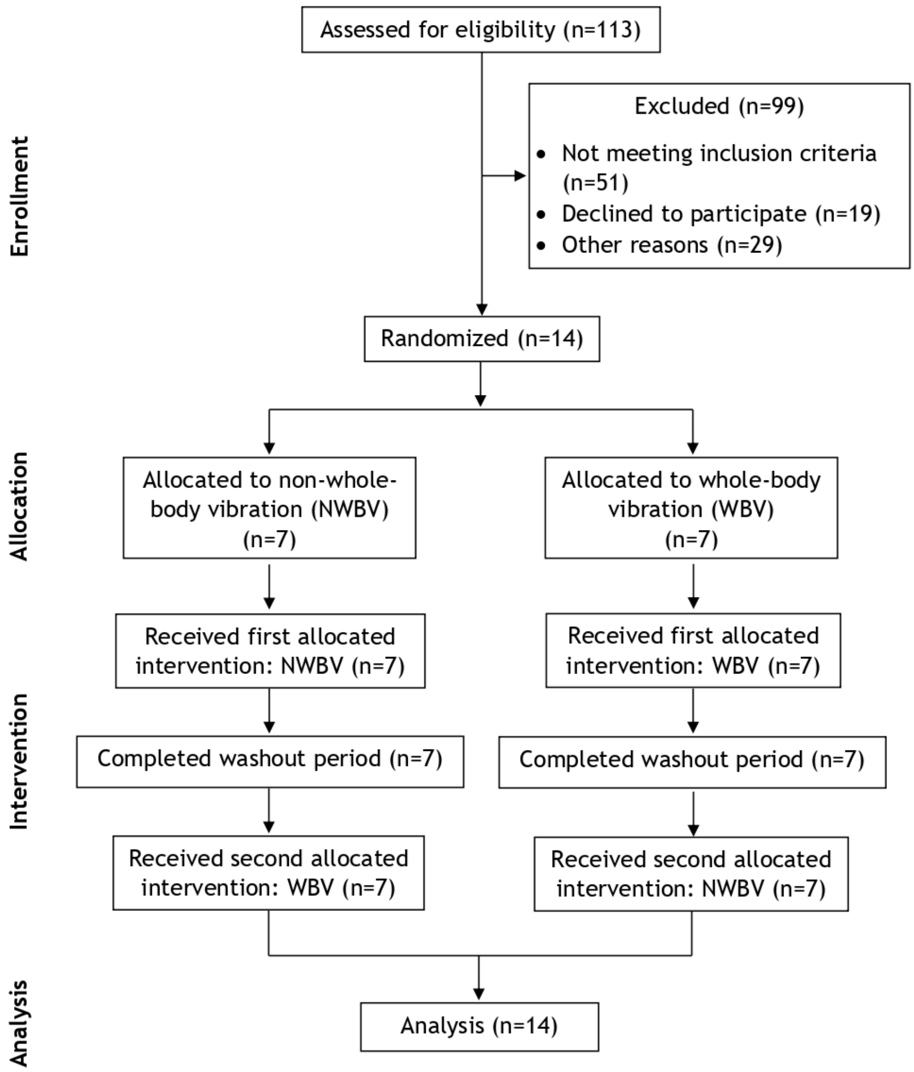

Figure 1 Flowchart of study participants.

Interventions

At the beginning of the study, all participants received a 3-minute educational session, and information was provided in a take-home brochure that included a QR code for a video-based education program on T2DM. This session occurred during a 15-minute resting period in the supine position before the initial measurements. The participants were randomized to first receive either NWBV or WBV intervention and after a seven-day washout period[14], they were crossed over to receive the other intervention. The WBV protocol, including frequency, amplitude, and duration was adjusted for participant safety based on previous studies[10,11,15] and our own trials. The participants were asked to maintain a static squat position (knees bent at 120°) on a vibrating plate for 1 minute at 25 Hz frequency and 2 mm amplitude. Six sets were performed, with a one-minute rest between sets in a comfortable standing position. Both the WBV and NWBV interventions thus lasted for 12 minutes. This high squat position was employed to reduce vibration transmission to the participant's head, minimizing risks such as vertigo and visual impairment[16]. The participants also wore socks to prevent skin irritation. The WBV was administered using a Galileo® S 35 device (Novotec Medical GmbH, Pforzheim, Germany). The NWBV intervention followed the same protocol without the WBV machine being turned on. Before the study began, all participants had the opportunity to become familiar with the equipment and research procedures.

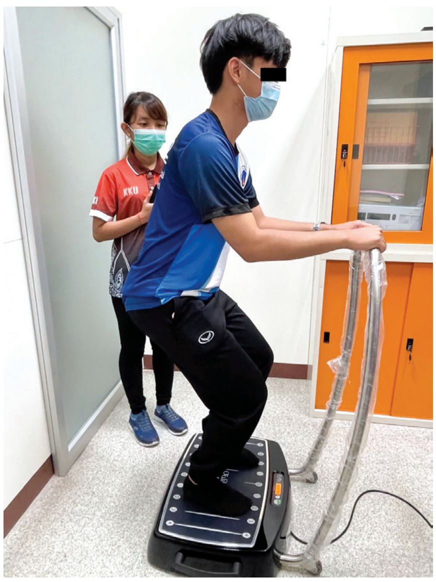

Figure 2 Standing with high squat position on the whole-body vibration machine

Outcome measures

The participants were instructed to avoid alcohol and caffeine, not to engage in strenuous physical activity for 24 hours, and refrain from heavy meals for a minimum of 4 hours before the experimental sessions to reduce the possibility of external factors affecting the measurements. A physical therapist with at least five years of clinical experience, who was blinded to the study procedure, sequentially measured brachial and ankle BP and flexibility to minimize confounding factors. The measurements were taken individually before the intervention and at 15 minutes and 45 minutes after the intervention on both days. Each measurement session lasted for 15 minutes, and the participants were required to rest for 15 minutes before each measurement, according to the American Heart Association guideline[17]. The room temperature was kept at 25°C, and external stimuli were minimized.

Ankle and brachial BP were measured using a digital sphygmomanometer in the supine position (ICC > 0.9)[18,19]. The automatic device's cuff was placed above the ankles[20] and on the upper arms[17] in a random sequence. The BP readings were taken three times on each side, with a 2-minute gap between each measurement. The average of the higher side measurements was used for the statistical analysis.

The sit and reach test was used to assess hamstring and lower back flexibility (ICC = 0.92)[21]. The participants were seated on the floor without shoes and with their legs extended straight in front of them. They were instructed to slowly lean forward, aiming to reach as far as possible toward a measuring ruler positioned on a box, which ranged from -30 to +30, without bending their knees. Flexibility was measured twice for each participant, and the average of these two measurements was used for the statistical analysis[21].

The ankle brachial inde x was determined through utilization of a formula derived from a prior study[22].

Statistical analysis

The data were analyzed using SPSS version 28.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics were employed to analyze the participants' demographic data. The normality of the data was analyzed using the Shapiro–Wilk test. The parametric test was selected for the data analysis because all the variables were normally distributed. All data are expressed as means and standard deviations. The baseline and post-intervention data within the groups and interventions were compared using a repeated measures two-way ANOVA (*p*-value corrected using the Bonferroni procedure). A *p*-value < 0.05 was considered significant.

Results

Table 1 shows the participants' demographic characteristics. Throughout the study duration, neither group exhibited any adverse events, such as nausea, dizziness, hypoglycemia, itching, or skin lesions. Furthermore, no carryover effect was observed, since the baseline values in both groups did not show statistical significance.

Table 1 Demographic characteristics of the participants (n = 14)

Characteristic	Values [Min–Max]
Age (years)	49.71 ± 5.28 [41–59]
Male/female, n (%)	2 (14.29) / 12 (85.71)
BMI (kg/m^2)	26.98 ± 3.24 [19.98–29.94]
Duration of diabetes (years)	2.32 ± 1.74 [1–6]

Note: All values are presented as mean and SD.

Abbreviation: BMI, body mass index; kg/m^2, kilogram per square meter.

In terms of flexibility, significant time*group interaction and time effects were observed (*p*-value < 0.05). Furthermore, significant increases were observed between baseline and both 15 and 45 minutes and between 15 minutes and 45 minutes after the WBV intervention (*p*-value < 0.05), while the NWBV intervention showed no difference (Table 2).

Ankle SBP showed a significant time*group interaction and time effects (*p*-value < 0.05). The NWBV intervention showed a significant increase in ankle SBP at 45 minutes after the intervention compared to the baseline. In contrast, the WBV intervention showed a significant decrease from baseline to 15 minutes and a significant increase between 15 minutes and 45 minutes after the intervention (*p*-value < 0.05). Furthermore, at 15 and 45 minutes after the intervention, the WBV intervention showed a statistically significant lower ankle SBP than the NWBV intervention (*p*-value < 0.05), as shown in table 2.

Regarding the ABI, time*group interaction, time, and group effects were significant (*p*-value < 0.05). Compared to the baseline, only the WBV intervention demonstrated significant decreases at 15 and 45 minutes after the intervention (*p*-value < 0.05). Interestingly, at 15 and 45 minutes after the intervention, the WBV intervention had a statistically significant lower ABI than the NWBV intervention (*p*-value < 0.05), as shown in table 2. In contrast, no significant changes from the baseline were observed in ankle diastolic blood pressure (DBP), brachial SBP, and brachial DBP at any time points following between the interventions, as shown in table 2

Table 2 Analysis of the variables between the WBV and NWBV interventions (n = 14)

Variables	Group	Baseline (95% CI)	15 minutes after interventions (95% CI)	45 minutes after interventions (95% CI)	Time*group interaction effect	Time effect	Group effect
Flexibility (cm)	NWBV	1.52 ± 5.95 (-1.92 to 4.96)	1.87 ± 6.04 (-1.61 to 5.36)	2.05 ± 5.91 (-1.37 to 5.46)	$F(1.45, 37.79) = 46.85$ $p < 0.001$ $\eta^2 = 0.64$	$F(1.45, 37.79) = 75.12$ $p < 0.001$ $\eta^2 = 0.74$	$F(1, 26) = 1.26$ $p = 0.272$ $\eta^2 = 0.05$
	WBV	1.72 ± 5.91 (-1.69 to 5.14)	5.24 ± 5.71* (1.94 to 8.54)	5.92 ± 5.80*,† (2.57 to 9.27)			
Ankle SBP (mmHg)	NWBV	146.38 ± 9.70 (140.78 to 151.98)	151.52 ± 13.52 (143.72 to 159.33)	156.88 ± 18.37* (146.28 to 167.49)	$F(2, 52) = 10.42$ $p < 0.001$ $\eta^2 = 0.29$	$F(2, 52) = 6.03$ $p = 0.004$ $\eta^2 = 0.19$	$F(1, 26) = 4.03$ $p = 0.055$ $\eta^2 = 0.13$
	WBV	145.60 ± 10.51 (139.53 to 151.66)	137.69 ± 12.17$^{*,\#}$ (130.66 to 144.72)	143.26 ± 14.13$^{\dagger,\#}$ (135.11 to 151.42)			
Ankle DBP (mmHg)	NWBV	75.71 ± 6.82 (71.78 to 79.65)	78.60 ± 7.48 (74.28 to 82.92)	78.93 ± 6.69 (75.07 to 82.79)	$F(1.56, 40.35) = 0.78$ $p = 0.435$ $\eta^2 = 0.03$	$F(1.56, 40.35) = 3.29$ $p = 0.059$ $\eta^2 = 0.11$	$F(1, 26) = 1.18$ $p = 0.288$ $\eta^2 = 0.04$
	WBV	74.36 ± 7.39 (70.09 to 78.63)	75.17 ± 7.45 (70.87 to 79.47)	75.62 ± 7.13 (71.50 to 79.73)			
Brachial SBP (mmHg)	NWBV	124.60 ± 7.35 (120.35 to 128.84)	126.81 ± 10.78 (120.58 to 133.04)	128.95 ± 12.08 (121.98 to 135.93)	$F(1.58, 41.19) = 0.02$ $p = 0.957$ $\eta^2 = 0.00$	$F(1.58, 41.19) = 5.89$ $p = 0.009$ $\eta^2 = 0.19$	$F(1, 26) = 0.25$ $p = 0.624$ $\eta^2 = 0.01$
	WBV	122.62 ± 6.57 (118.83 to 126.41)	125.12 ± 9.40 (119.69 to 130.55)	127.55 ± 11.96 (121.98 to 135.93)			
Brachial DBP (mmHg)	NWBV	79.88 ± 5.87 (76.49 to 83.27)	83.12 ± 7.23 (78.94 to 87.30)	81.91 ± 6.72 (78.03 to 85.78)	$F(2, 52) = 0.69$ $p = 0.507$ $\eta^2 = 0.03$	$F(2, 52) = 2.54$ $p = 0.088$ $\eta^2 = 0.09$	$F(1, 26) = 2.09$ $p = 0.160$ $\eta^2 = 0.08$
	WBV	77.40 ± 7.20 (73.25 to 81.56)	78.43 ± 6.72 (74.55 to 82.31)	79.21 ± 6.96 (75.20 to 83.23)			
ABI	NWBV	1.18 ± 0.06 (1.14 to 1.21)	1.20 ± 0.07 (1.16 to 1.24)	1.22 ± 0.09 (1.17 to 1.27)	$F(2, 52) = 10.92$ $p < 0.001$ $\eta^2 = 0.30$	$F(2, 52) = 3.66$ $p = 0.03$ $\eta^2 = 0.12$	$F(1, 26) = 9.65$ $p = 0.005$ $\eta^2 = 0.27$
	WBV	1.19 ± 0.06 (1.15 to 1.22)	1.10 ± 0.05$^{*,\#}$ (1.07 to 1.13)	1.12 ± 0.05$^{*,\#}$ (1.09 to 1.15)			

Note: All values are presented as means and SDs. *indicates a statistically significant difference within the group compared with the baseline (p-value < 0.05); †indicates a statistically significant difference within the group when comparing 15 minutes to 45 minutes (p-value < 0.05); $^{\#}$indicates a statistically significant difference between the groups (p-value < 0.05).

Abbreviation: 95% CI, 95% confidence interval; F, F-test; η^2, partial eta square; WBV, whole-body vibration; NWBV, non-whole-body vibration; Ankle SBP, ankle systolic blood pressure; Ankle DBP, ankle diastolic blood pressure; Brachial SBP, brachial systolic blood pressure; Brachial DBP, brachial diastolic blood pressure; ABI, ankle brachial index.

Discussion

This study aimed to examine the acute effects of WBV on flexibility and ankle SBP in middle-aged individuals with T2DM. The results showed that the WBV intervention significantly increased flexibility and decreased ankle SBP and the ABI. The higher number of female participants might be attributed to increased insulin resistance and decreased estrogen levels following menopause in the 49–51-year-old age group[23]. The participants, with a mean BMI of 26.98 kg/m^2, were overweight and at increased risk of diabetes[24]. Additionally, our study did not show significant carryover effects for any variables, indicating that the washout duration was adequate.

Flexibility improved from “fair” to “good”[25] at different time points: 15 minutes (+3.52 cm) and 45 minutes (+4.20 cm) post-WBV compared to the baseline, indicating a lasting positive effect for at least 45 minutes after a single WBV session. Similar findings have been observed in elderly people with Parkinson’s disease, in whom flexibility increased by 3.86 cm immediately after WBV[9]. Another study showed that middle-aged healthy females had a 3.6 cm flexibility improvement following two months of WBV[26]. A 2.5 cm improvement in the sit and reach test is considered clinically meaningful[27]. A single WBV session likely increases flexibility by enhancing stretch reflex sensitivity through Ia inhibitory neurons, altering muscle activity patterns, reducing braking forces, and decreasing muscle stiffness[9]. WBV also stimulates Golgi tendon organs via the Ib pathway, inducing muscle relaxation and inhibiting contractions[9]. Improved blood circulation, thermoregulation, and neural mechanisms during WBV contribute to enhanced flexibility by increasing vasodilation, elevating blood flow and muscle temperature, reducing tissue thickness, and promoting muscle elasticity while minimizing discomfort[28].

The current findings revealed a significant 7.91 mmHg reduction in ankle SBP at 15 minutes compared to the baseline, remaining within the normal range. This indicates that the acute effect of a single WBV session on ankle SBP persisted for a minimum of 15 minutes. Previous research has also demonstrated a decrease in ankle SBP by 9.8 mmHg in healthy adults after 30 minutes of a single WBV session[10]. Another study reported a 6.68 mmHg decrease in ankle SBP after 50 heel raises in a standing position among healthy elderly individuals[29]. Furthermore, a more substantial 24 mmHg reduction in ankle SBP was observed in postmenopausal women with high baseline ankle SBP (≥ 175 mmHg) after 12 weeks of WBV, likely due to the longer training duration and higher initial SBP levels of participants[11].

A previous study has suggested that a reduction in ankle SBP exceeding 30 mmHg post-treadmill exercise indicates peripheral arterial disease[30]. However, our participants, with an average diabetes duration of 2.32 years, might not have progressed to that PAD stage[31]. WBV exercise in a high squat position enhances lower limb muscle activation, relaxing vascular smooth muscles, reducing arterial stiffness, and promoting local vasodilation through nitric oxide production, thus lowering ankle SBP[10]. Conversely, a NWBV intervention increases ankle SBP due to muscle contractions during static high squat exercises performed without WBV, constraining blood capillaries and obstructing circulation[32].

In this study, significant ABI reductions were observed post-WBV intervention: a 7.56% decrease at 15 minutes and 5.88% at 45 minutes, which all remained within the normal range. This finding suggests that the effect of a single session of WBV on the ABI persists for at least 45 minutes. Figueroa and colleagues observed a 3.85% reduction in the ABI after 12 weeks of WBV in postmenopausal women with increased ankle SBP[11]. Another study reported a 9.62% ABI reduction after 50 heel raises in a standing position for healthy elderly people[29]. Our findings align with research indicating a 5% reduction in the ABI following a single exercise session in healthy individuals[33]. In this study, the observed ABI reduction may be attributed to the following mechanisms: 1) increased central aortic pressure and decreased peripheral BP at the ankles during exercise, delivering more oxygenated blood to meet leg muscle metabolic demands, leading to a small reduction in the ABI, and 2) high shear stress, such as during WBV exercise, triggering endothelial substance release and vasodilation(10). This study observed non-significant increases in ankle DBP, brachial SBP, and brachial DBP after both interventions, indicating that the increased parameters were within the normal range according to American Heart Association standards(34). Previous studies found that a single WBV session did not result in significant decreases in ankle DBP or brachial SBP or DBP in healthy young adults(10) and adults with obesity(35). Another study found that a high squat position reduced vibration transmission to the upper extremities, resulting in insignificant vasodilation(36). Holding the WBV machine handles to maintain this position during both interventions also caused a pressor rise in brachial BP, which is vital for muscle perfusion during prolonged contraction(37).

Regarding limitations, the findings of our study may not be generalizable to different populations, such as obese individuals with T2DM. Future research should include individuals with T2DM across various age groups, especially those with longer diabetes duration (> 10 years) and higher ankle SBP (>175 mmHg), with a focus on potential clinically significant improvements. Furthermore, our study did not extend its assessment of the acute effects of WBV beyond the 45-minute recovery period. Thus, future research should investigate the effects of WBV over longer durations. Additionally, relying solely on the sit and reach test may be insufficient for accurately evaluating changes in lower extremity flexibility. Despite these limitations, the strength of our study lies in its use of a crossover design, which allowed for a more comprehensive evaluation of treatment impact by comparing outcomes within each participant, thus mitigating individual differences, and potentially reducing the influence of covariates.

Conclusions

A single 25 Hz, 2 mm, 12-minute WBV session can significantly enhance flexibility and lower ankle SBP and the ABI in middle-aged T2DM patients without any adverse effects or complications.

Take home messages

WBV offers a safe and promising alternative exercise method with the potential to mitigate cardiovascular risk in middle-aged individuals with T2DM. Nevertheless, it is crucial to exercise caution, especially for those with hypertension, as the high squat exercise without WBV can raise both brachial and ankle BP levels.

Conflicts of interest

The authors declare no conflict of interest.

Acknowledgments

The authors would like to thank all participants who contributed to this study. This research was supported by the Khon Kean University Scholarship for ASEAN and GMS Countries.

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