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# Effects of 12-week whole-body vibration training versus resistance training in older people with sarcopenia

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**Sarcopenia is a syndrome commonly found in older people. The aim of this study was to evaluate the effects of whole-body vibration training (WBVT) and resistance training (RT) on body composition, muscle strength, physical performance and blood biomarkers in older people with sarcopenia. We conducted a 12-week, 3-times-weekly assessor-blinded, randomized controlled trial of 27 older people with sarcopenia aged ≥ 65 years. Subjects were randomized into WBVT group ($n = 14$) and RT group ($n = 13$). The primary outcome was knee extension strength (KES). Secondary outcomes were body composition [body weight, body mass index (BMI), percentage of body fat (PBF), and appendicular skeletal muscle mass index (ASMI)], muscle strength [handgrip strength (HS)], physical performance [gait speed (GS), 5-time chair stand test (5CST), and short physical performance battery (SPPB)], blood biomarkers (inflammatory factors, hormones, growth factors, and muscle injury biomarker), and quality of life questionnaire [medical outcomes study short-form 36 (SF-36)]. After 12-week intervention, in the WBVT group, we observed significant improvements in body composition (weight, BMI, PBF and ASMI), muscle strength (KES), physical performance (GS, SPPB and 5CST), blood biomarkers [insulin-like growth factor 1 (IGF-1), growth hormone, follistatin (FST) and creatine kinase (CK)] and quality of life. In the RT group, we observed significant improvements in body composition (weight, BMI and PBF), muscle strength (KES), physical performance (GS and SPPB), blood biomarkers (growth hormone, FST and CK) and quality of life. Between-group comparisons were only significant for KES ($P = 0.007$) and the role-physical (RP) dimension of the SF-36 ($P = 0.007$). WBVT and RT both improved the physical condition of older people with sarcopenia. RT excelled in muscle strength, but WBVT offered an alternative for those with restrictions. WBVT's low risk and flexibility suited diverse conditions, providing a new rehabilitation option for patients with sarcopenia.**

**Keywords** Sarcopenia, Whole-body vibration training, Resistance training

Sarcopenia is a syndrome commonly found in older people, characterized by progressive loss of muscle mass, strength, and/or physical performance[1]. With the accelerating trend of global aging, the prevalence of sarcopenia is gradually increasing and has become a public health challenge that cannot be ignored. The global prevalence of sarcopenia is 10% among people aged over 60 years[2] and up to 50% among people aged over 80 years[3]. It is expected that by 2050, 500 million people will suffer from sarcopenia[4]. Sarcopenia is not only associated with reduced quality of life[5], but also increases the risk of falls[6,7], fractures[6], and premature death[8], which worsen the healthcare burden. Therefore, it has become critical to explore effective interventions to delay the progression of sarcopenia.

Physical activity is widely recognized as an effective approach to managing sarcopenia. Traditional resistance training (RT) effectively improves muscle mass and muscle function through resistive loading[9]. Chen et al.[10] demonstrated that RT improved the percentage of body fat (PBF), muscle strength, and physical performance in older people with sarcopenia. Similarly, the meta-analysis by Lu et al.[11] RT significantly improved knee extension strength (KES) and gait speed (GS) in older people with sarcopenia. RT also leads to significant anti-

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inflammatory effects in the circulation to ameliorate the chronic inflammatory state of muscle in older people[12]. However, there may be some limitations with this type of training for some older people with sarcopenia. For example, their joints and bones may not be able to withstand the load of free weights or machines, and they may find it challenging to perform resistance movements correctly due to the lack of sufficient strength. Whole-body vibration training (WBVT) has recently attracted much attention as an emerging training method[13]. By transmitting mechanical vibration to the entire body, WBVT can promote muscle contraction and improve neuromuscular response. This, in turn, can activate more motor units and rapidly enhance muscle strength. Furthermore, WBVT stimulates type II muscle fibers, increasing the proportion of fast muscle fibers involved. Consequently, it enhances the explosive force and contraction efficiency of the muscles. Given these benefits, WBVT is expected to be an effective intervention for older people with sarcopenia[14–16]. The muscle strength enhancement effect is the most direct and definitive clinical improvement effect of WBVT[17,18]. Tihanyi et al.[19] identified that after WBVT intervention, the muscle strength of isometric and isotonic contractions of the quadriceps muscle of the subjects increased by 36.6 and 22.2%, respectively, suggesting that WBVT was able to activate the quadriceps muscle effectively. Vibration activates internal bone metabolism regulators and muscle function-related signaling molecules to improve bone density and muscle mass[20].

Although some progress has been made in research on the effects of WBVT and RT in older people with sarcopenia, there are still many unanswered questions. Firstly, these two interventions have been studied independently in past research, with few studies directly comparing their effectiveness in improving outcomes among older people with sarcopenia. Secondly, more interpretation of sarcopenia-related blood biomarkers (e.g., inflammatory factors, hormones, growth factors, and muscular injury biomarkers) is necessary. Although some studies have found changes in these markers after training, we need a deeper understanding of the physiologic significance of these changes and their relationship to sarcopenia, which is especially gaping in studies of WBVT.

Therefore, this study aimed to collectively assess KES as the primary outcome through the 3-month intervention with WBVT and RT at three times per week while also measuring body composition [body weight, body mass index (BMI), PBF and ASMI], muscle strength [handgrip strength (HS)], physical performance [gait speed (GS), 5-time chair stand test (5CST), and short physical performance battery (SPPB)], blood biomarkers (including inflammatory factors, hormones, growth factors, and muscle injury biomarker), and quality of life questionnaires [medical outcomes study short-form 36 (SF-36)] were used as secondary outcomes to measure the effects of the two training methods comprehensively. This study was expected to provide an essential clinical and scientific basis for developing more effective health anagement strategies for older people, thereby improving their quality of life and health status.

## Methods

### Study design and subjects

This study was a 12-week, assessor-blinded randomized controlled trial. It investigated the efficacy of WBVT and RT in terms of body composition, muscle strength, physical performance, blood biomarkers, and quality of life. The study protocol was approved by the Ethical Committee of Chongming Hospital Affiliated with Shanghai Medical College of Health Sciences in November 2020 (Approval Number: CMEC-2020-KT-42) and was registered in the Chinese Clinical Trial Registry on September 15, 2021 (ChiCTR 2100051178). The study was conducted per the principles of the Declaration of Helsinki. Written informed consent was obtained from all subjects.

Based on the inclusion and exclusion criteria, 27 study subjects were included for the intervention from February 2023 to May 2023 in Sanxing Town, Chongming District, Shanghai, China. The subjects were randomized into 2 groups: the WBVT group ($n = 14$) and the RT group ($n = 13$). The procedures of this study included subject recruitment, randomization, baseline measurements, 12-week intervention, post-intervention measurements, and data analysis.

### Screening

Recruited older people were initially screened using the SARC-F questionnaire. This screening questionnaire consists of five domains of assessment: muscle strength, assisted walking, sit-to-stand, stair climbing, and falls. The maximum score on the SARC-F screening scale is 10, with a score of ≥ 4 indicating a risk for sarcopenia[21].

Inclusion criteria were: (1) Age ≥ 65 years; (2) Meet the Asian Working Group for Sarcopenia-2019 (AWGS-2019) diagnostic criteria for sarcopenia. Sarcopenia is diagnosed when the subject with low ASMI (< 7.0 kg/m$^2$ for men and < 5.7 kg/m$^2$ for women) combined with either low HS (< 28 kg for men and < 18 kg for women) or poor physical performance (indicated by GS < 1.0 m/s, 5CST ≥ 12s, or SPPB score ≤ 9). When all three criteria (low ASMI, low HS, and poor physical performance) are met, the diagnosis is severe sarcopenia; (3) Physically healthy (without untreated diseases, such as gallstones or kidney stones, and infectious diseases); and (4) Physically inactive (exercise less than three days per week, 30 min of exercise per day within the last three months). The exclusion criteria were: (1) Having absolute contraindications to exercise, such as deep vein thrombosis and/or coagulation disorders; (2) Having a severe cognitive impairment affecting assessment or communication, like dementia and psychiatric disorders; (3) Having serious diseases that interfere with assessment and intervention, such as musculoskeletal disorders (e.g., fractures, dislocations, osteoporosis, and rheumatoid arthritis) and disabilities (e.g., loss of a hand, foot, or limb); (4) A history of severe spinal disease or surgery, such as vertebral fracture, ankylosing spondylitis, tumor, spondylolisthesis, or cauda equina syndrome; (5) Regularly use the following medications within the past 3 months: antiplatelet drugs, anticoagulants, or analgesics; (6) Uncontrolled hypertension (blood pressure > 160/100 mmHg) and dyslipidemia (total cholesterol > 220 mg/dl); (7) Other diseases for which the doctor did not recommend participation in this study; and (8) Failure to sign the informed consent form.

## Randomization

Study subjects who met the inclusion and exclusion criteria were stratified by gender and randomly assigned to either the WBVT group or the RT group in a ratio of 1:1. Randomization was generated by a researcher not involved in this study through a computer program (Research Randomizer Form www.randomizer.org). The randomized sequences and groupings were stored in an encrypted electronic file.

## Intervention

Before the formal intervention, the researchers trained the WBVT and RT groups for 1 week, 3 times in total, to familiarize them with the intervention process and considerations for their groups. All exercise training protocols were designed and guided by professional physiotherapists. All subjects were instructed not to change their daily habits or engage in additional physical activities during the intervention. If a subject could not participate in the exercise intervention on time, the researchers provided a supplemental intervention within that week to ensure the subject's attendance. The researchers recorded the participants' compliance and attendance throughout the intervention period. Both groups received the intervention 3 times a week for 12-weeks.

## WBVT group

Each intervention lasted 30 min, which included 5 min of warm-up, 20 min of vibration training, and 5 min of relaxation (as shown in Table 1). Subjects stood barefoot and with knees bent at 30° on a vertically vibrating platform (Maizu, Shenzhen, China) with hands that could grasp the vibrating rope for balance. The vibration frequency was 12 Hz with an inter-peak amplitude of 4 mm. Each vibration was held for 1 min, each group was repeated 10 sets, and the rest between groups was 1 min.

## RT group

Each intervention lasted 30 min, which included a 5-minute warm-up, 20 min of RT, and 5 min of relaxation (as shown in Table 1). Before the intervention, each subject was asked to complete a one-repetition maximum (1RM) test to determine resistance intensity. Subjects utilized TheraBand elastic bands to complete the required movements. Intensity was 60% 1RM for weeks 1–4, 65% 1RM for weeks 5–8, and 70% 1RM for weeks 9–12.

## Outcome measures

Measures of subjects' general information and outcomes were taken at baseline (week 0) and 24 h after the last intervention (week 12). Measurements were performed by 2 trained researchers who were independent of the intervention subgroups. Indicator measures included general information (demographic characteristics and anthropometric characteristics), primary outcome (KES) and secondary outcomes (body composition, muscle strength, physical performance, blood biomarkers, and quality of life).

## General information

Demographic characteristics were age, BMI, sex, smoking status, alcohol status, education, occupation, and exercise habits.

## Primary outcome: KES

Considering that the standard 1RM test might be difficult for older people with sarcopenia and even at risk of inducing injuries[22], measurements of KES in the present study were made by the estimated 1RM[23]. The estimated 1RM was calculated as follows: estimated 1RM (kg) = submaximal weight (kg)/(1.0278–0.0278 * the maximum number of repetitions). Subjects were asked to sit in an extensor chair with extended knees to resist the weight plate. The initial weight plate load was 45% of body weight for women and 64% for men[24]. If they could extend their knees for more than 10 repetitions, they were given a heavier weight to test. When the maximum number of repetitions was 10 or less, the value of the weight plate at that point was considered the submaximal weight. The maximum number of repetitions performed and the submaximal weight were used to calculate the estimated 1RM.

## Secondary outcomes

Body Composition. Body weight, BMI, PBF, and appendicular skeletal muscle mass (ASM) were measured directly by bioelectrical impedance analysis (BIA) (Inbody, S10, Korea). ASMI was calculated using the following

| Group | Frequency (Hz) | Range (mm) | Intensity (%1RM) | Duration of training (min/times) | Movements | Sets | Interval between sets (min) | Training frequency (times/week) | Training cycle (weeks) |
|---|---|---|---|---|---|---|---|---|---|
| WBVT | 12 | 4 | / | 30 (5 min warm-up,20 min vibration training and 5 min cool-down) | Stand on vibrating platform with bare feet and knee flexion of 30° | maintain 1 min/10 repetitions | 1 | 3 | 12 |
| RT | / | / | week 1–4: 60% 1 RM; week 5–8: 65% 1RM; week 9–12: 70% 1RM | 30 (5 min warm-up,20 min RT and 5 min cool-down) | Shoulder external rotation, elbow extension, elbow flexion, leg squat abduction, lunge and bend, shoulder abduction, half-squat stand-up | 3 sets/10 repetitions | 1 | 3 | 12 |

**Table 1**. Specific training programs for each group. Abbreviations: WBVT, whole body vibration training; RT: resistance training; 1RM: one repetition maximum.

formula: ASMI = ASM/height$^2$. Subjects stood barefoot on a mat with feet shoulder-width apart and shoulder abduction of 30 degrees and remained motionless throughout the test until the end.

Muscle Strength. HS was measured via a handheld grip dynamometer. Subjects held a handgrip dynamometer (Jamar Plus + Digital Hand Dynamometer; IL, USA) in a standing position with the upper arm close to the body and the elbow flexed at 90 degrees in the dominant hand. When instructed by the researcher, the subject squeezed the grip strength meter with maximum force for at least 5 s. Subjects kept their shoulders relaxed during the test, with their hands and the dynamometer always away from the body and not in contact with any other part of the body, to prevent the occurrence of compensatory body exertion. Three consecutive measurements were taken at 1-minute intervals, and the highest value was taken as the final test result.

Physical Performance. Tests included the 6-meter GS, 5CST, and SPPB measurements.

6-meter GS: Subjects walked 6-meters at their usual speed. The measurements were repeated 2 times with 3-minute intervals, and the average value was taken as the final GS.

5CST: Subjects sat with their backs straight and their hands clasped over their chests in a chair without a backrest 43 centimeters from the floor. When the researcher gave the command, the subject repeated the get-up-and-sit-down as fast as possible 5 times, and the completion time was recorded. A total of 3 measurements were taken with 1-min intervals between each measurement, and the average value was taken as the final test result.

SPPB: This is the method recognized by the National Institute on Aging for rating muscle function in older people[25]. There are three components: balance tests, the GS test, and the timed sit-to-stand test. The balance tests required subjects to stand in three positions: side-by-side, semi-tandem, and tandem stand. The subjects could use their arms or other ways to maintain balance but could not move the soles of their feet. The timer was stopped when the subjects moved the soles of their feet or grasped an external object to maintain balance or when the time exceeded 10 s. The GS test was performed by marking a 4-meter straight line distance on the ground with tape, leaving 0.6 m of unobstructed space in front of and behind the test area. Subjects were allowed to complete the 4-meter walk with the aid of crutches or other tools, and were asked to walk 2 times each at their usual GS, recording the results of the fastest one. The timed sit-to-stand test was the same as the 5CST. The total score of the SPPB is 12 points. 0–6 points suggest poor muscle function, 7–9 points suggest moderate muscle function and 10–12 points suggest good muscle function.

## Blood biomarkers

Nurses collected fasting venous blood samples from each subject at approximately 08:00 am after a 12-hour nighttime fast. Collections were made at baseline (week 0) and post-intervention (week 12). Blood samples were sent to the laboratory for enzyme-linked immunosorbent assay to determine the levels of blood biomarkers. Blood biomarkers included inflammatory factors [hypersensitive C-reactive protein (hs-CRP), tumor necrosis factor-alpha (TNF-α), and interleukin-6 (IL-6)], hormones [insulin-like growth factor 1 (IGF-1) and growth hormone], growth factors [myostatin (MSTN) and follistatin (FST)], and muscle injury biomarker [creatine kinase (CK)].

## Quality of life

The SF-36 is among the most internationally recognized and widely used quality-of-life questionnaires. We used the validated Chinese version of the SF-36 questionnaire for measurement[26]. The questionnaire consists of eight-dimensional scales [physical functioning (PF), role-physical (RP), bodily pain (BP), general health, vitality (VT), social functioning (SF), role-emotional (RE), and mental health (MH)]. In addition, the SF-36 includes an indicator, reported health transition (HT), used to evaluate the overall change in health status over the past year.

## Participation adherence

The researchers designed their exercise intervention diary to record the following: number of attendances, completion, adverse effects, heart rates and blood pressure before and after exercise. Participation adherence in this study = number of attendance/total number of interventions*100%.

## Sample size calculation

The sample size calculation was conducted using G*Power software version 3.1. Previous meta-analyses have indicated that the effect size of RT on KES in older people is 1.26[10]. The relevant parameters were set as follows: alpha at 0.05, power at 0.8, effect size at 1.26, and a total sample size of 22 subjects (11 per group). Considering a potential 15% dropout rate among subjects, the total sample size for our study should be 26. Ultimately, 14 subjects were allocated to the WBVT group and 13 subjects were allocated to the RT group.

## Statistical analysis

The SPSS version 26.0 statistical package (IBM, USA) was used for data analysis. GraphPad Prism version 9.0 software package (GraphPad Software, USA) was used to draw statistical graphs.

Normality was tested by the Shapiro-Wilk test. Measurement data were expressed as mean ± standard deviation (mean ± SD), and count data were expressed as frequency (%). In analyzing the baseline data, the independent samples t-test or Mann-Whitney U test was used to measure differences in measurement data between groups. Pearson's chi-squared test and fisher's exact test were used for differences in count data between groups. In analyzing the outcome indicators, a paired sample t-test was used to compare before and after differences within groups; analysis of covariance with each value of the indicators before the intervention as a covariate was used for comparison between groups (using the Bonferroni test). $P < 0.05$ indicated that the difference was statistically significant.

## Results

Figure 1 shows the flow chart of this study. Three hundred fifty-three older people were recruited and screened with the SARC-F questionnaire in Sanxing Town, Chongming District, Shanghai, China. Only if the SARC-F score was ≥ 4 could they be considered for the next round of eligibility. Of the 36 older people, 9 were excluded during eligibility for not meeting the inclusion criteria ($n = 6$), refused to participate in the intervention ($n = 2$), and other reasons ($n = 1$). The final 27 subjects were randomized into the WBVT group ($n = 14$) and RT group ($n = 13$). The baseline characteristics of the two groups are shown in Table 2, with the mean age (73.556 ± 3.916) years, of which 13 (48.15%) were men and 14 (51.85%) were women. There was no significant difference in age, BMI, gender, smoking status, alcohol consumption, educational level, occupational status, and exercise habit between the two groups of subjects ($P > 0.05$). No subjects dropped out of either group during the 12-week intervention. The WBVT group participated in an average of 34 sessions with an average attendance rate of 95.8%, and the RT group participated in an average of 33 sessions with an average attendance rate of 93.2%. No adverse events were reported.

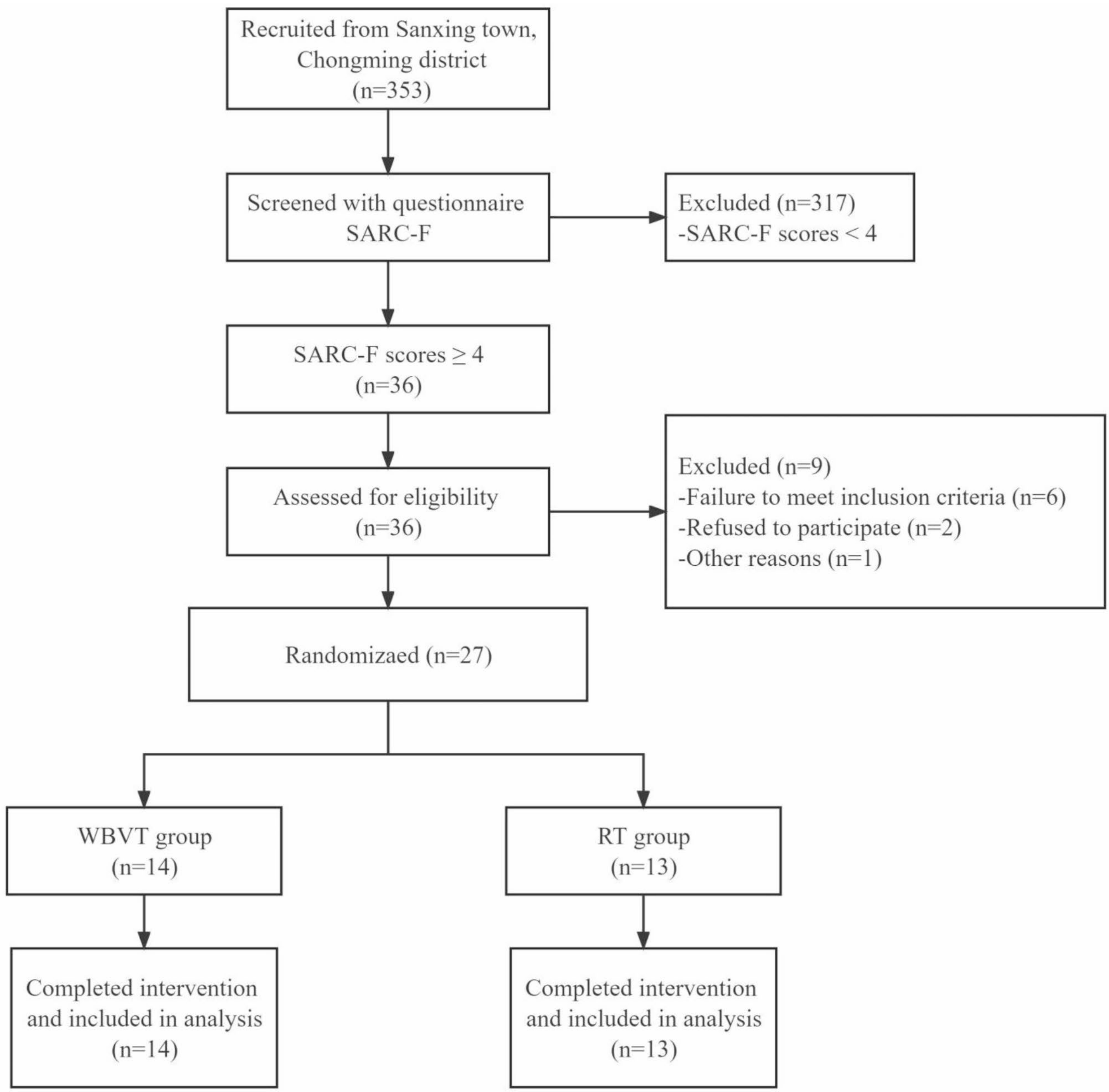


**Fig. 1**. Flow chart of this study. Abbreviations: WBVT, whole body vibration training; RT: resistance training.

| Variable | Total ($n=27$) | WBVT ($n=14$) | RT ($n=13$ ) | $P$ value |
|---|---|---|---|---|
| *Demographic characteristics* | | | | |
| Age (years), mean ± SD | 73.556 ± 3.916 | 73.929 ± 3.731 | 73.154 ± 4.22 | 0.617 |
| BMI (kg/m2), mean ± SD | 23.377 ± 4.151 | 23.359 ± 2.281 | 23.395 ± 5.629 | 0.983 |
| Gender (men/women), n (%)/n (%) | 13 (48.1)/14 (51.9) | 5 (35.7)/9 (64.3) | 8 (61.5)/5 (38.5) | 0.257 |
| Smoking status | | | | |
| Never smoked, n (%) | 16 (59.3) | 9 (64.3) | 7 (53.8) | 0.838 |
| Current smoking, n (%) | 10 (37.0) | 5 (35.7) | 5 (38.5) | |
| Ever smoked, n (%) | 1 (3.7) | 0 (0.0) | 1 (7.7) | |
| Drinking alcohol status | | | | |
| Never drank, n (%) | 20 (74.1) | 10 (71.4) | 10 (76.9) | 0.179 |
| Current drinking, n (%) | 5 (18.5) | 4 (28.6) | 1 (7.7) | |
| Ever drunk, n (%) | 2 (7.4) | 0 (0.0) | 2 (15.4) | |
| Educational level | | | | |
| Uneducated, n (%) | 6 (22.2) | 2 (14.3) | 4 (30.8) | 0.356 |
| Elementary school, n (%) | 12 (44.4) | 8 (57.1) | 4 (30.8) | |
| Middle school, n (%) | 8 (29.6) | 3 (21.4) | 5 (38.5) | |
| High school and above, n (%) | 1 (3.7) | 1 (7.1) | 0 (0.0) | |
| Farmer, n (%) | 23 (85.2) | 12 (85.7) | 11 (84.6) | 1.000 |
| Habitual exercise | | | | |
| Yes, n (%) | 5 (18.5) | 3 (21.4) | 2 (15.4) | 1.000 |
| No, n (%) | 22 (81.5) | 11 (78.6) | 11 (84.6) | |
| *Severe sarcopenia* | | | | |
| Yes, n (%) | 11 (40.7) | 6 (42.9) | 5 (38.5) | 0.816 |
| No, n (%) | 16 (59.3) | 8 (57.1) | 8 (61.5) | |

**Table 2**. Baseline characteristics of subjects ($n=27$). Abbreviations: WBVT, whole body vibration training; RT: resistance training; BMI: body mass index.

## Primary outcome

*KES*

After the 12-week intervention, the within-group comparison for subjects in both the WBVT and RT groups showed a significant increase in KES compared to baseline ($P=0.023$ and $P=0.002$, respectively). In the between-group comparison, KES was significantly higher in the RT group than in the WBVT group ($P=0.007$) [See Table 3; Fig. 3 (B)].

## Secondary outcomes

Changes are reported for within-group and between-group comparisons for the secondary outcome variables following the 12-week intervention (Table 3).

## Body composition

Within-group comparisons for subjects in the WBVT and RT groups showed significant improvements in body weight ($P=0.008$ and $P<0.001$, respectively), BMI ($P=0.005$ and $P<0.001$, respectively), and PBF ($P=0.021$ and $P<0.001$, respectively) compared to baseline. For ASMI, only the WBVT group showed a significant increase ($P=0.004$) compared to baseline. For between-group comparisons, no significant differences were observed between the two groups for any of the body composition variables ($P>0.05$) (Table 3; Fig. 2).

## Muscle strength

Neither within-group nor between-group comparisons showed significant improvement in HS from baseline for subjects in both the WBVT and RT groups ($P>0.05$) [Table 3; Fig. 3 (A)].

## Physical performance

Within-group comparisons for subjects in the WBVT and RT groups showed significant improvements in GS ($P=0.001$ and $P<0.001$, respectively) and SPPB ($P=0.001$ and $P<0.001$, respectively) compared with baseline. For 5CST, only the WBVT group showed a significant increase ($P=0.003$). For between-group comparisons, no significant differences between the groups were observed for physical performance variables (Table 3; Fig. 4).

## Blood biomarkers

Within-group comparisons for inflammatory factors (IL-6, hs-CRP, and TNF-α) showed no significant differences from baseline ($P>0.05$). For hormones, growth hormone was significantly higher among subjects in the WBVT and RT groups ($P<0.001$ and $P<0.001$, respectively). For IGF-1, only the WBVT group had a

| Variables | WBVT group ($n = 14$ ) | | RT group ($n = 13$ ) | |
|---|---|---|---|---|
| | Before (week 0) | After (week 12) | Before (week 0) | After (week 12) |
| *Body composition* | | | | |
| Weight (kg), mean ± SD | 58.679 ± 9.451 | 55.321 ± 9.98 | 59.685 ± 14.06 | 56.038 ± 12.61 |
| BMI (kg/m$^2$), mean ± SD | 23.359 ± 2.281 | 22.006 ± 2.722 | 23.395 ± 5.629 | 21.983 ± 5.153 |
| PBF (%), mean ± SD | 32.878 ± 6.649 | 29.194 ± 7.459 | 29.702 ± 8.908 | 25.885 ± 8.367 |
| ASMI (kg/m$^2$), mean ± SD | 5.839 ± 0.751 | 6.08 ± 0.823 | 6.344 ± 0.774 | 6.554 ± 0.905 |
| *Muscle Strength* | | | | |
| HS (kg), mean ± SD | 23.414 ± 7.03 | 24.2 ± 6.86 | 22.631 ± 5.445 | 24.954 ± 8.038 |
| KES (kg), mean ± SD | 40.357 ± 8.836 | 42.693 ± 8.107 | 43.692 ± 8.878 | 49.108 ± 5.885 |
| *Physical Performance* | | | | |
| GS (m/s), mean ± SD | 0.747 ± 0.142 | 1.005 ± 0.19 | 0.692 ± 0.118 | 0.914 ± 0.116 |
| 5CST (s), mean ± SD | 11.176 ± 2.322 | 8.694 ± 1.433 | 10.459 ± 3.582 | 9.085 ± 1.461 |
| SPPB (score), mean ± SD | 10.071 ± 1.385 | 11.571 ± 0.646 | 9.846 ± 1.345 | 11.692 ± 0.63 |
| *Blood Biomarkers* | | | | |
| Inflammatory factors | | | | |
| IL-6 (pg/ml), mean ± SD | 48.024 ± 8.106 | 46.706 ± 7.645 | 53.674 ± 9.678 | 52.257 ± 6.123 |
| hs-CRP (mg/l), mean ± SD | 3.869 ± 6.484 | 1.859 ± 2.149 | 7.632 ± 15.083 | 6.28 ± 12.833 |
| TNF-α (pg/ml), mean ± SD | 82.251 ± 12.075 | 88.088 ± 13.505 | 84.826 ± 12.199 | 86.638 ± 14.274 |
| Hormones | | | | |
| IGF-1 (ng/ml), mean ± SD | 166.83 ± 23.57 | 196.736 ± 45.64 | 178.881 ± 28.652 | 198.895 ± 44.163 |
| Growth hormone (pg/ml), mean ± SD | 16.238 ± 2.666 | 26.038 ± 4.542 | 17.92 ± 2.718 | 26.038 ± 3.033 |
| Growth Factors | | | | |
| MSTN (pg/ml), mean ± SD | 7.495 ± 0.958 | 7.7 ± 1.725 | 8.238 ± 1.609 | 8.158 ± 1.21 |
| FST (pg/ml), mean ± SD | 11.546 ± 1.761 | 9.488 ± 1.855 | 12.912 ± 1.622 | 9.915 ± 1.268 |
| Muscular Injury Biomarker | | | | |
| CK (u/l), mean ± SD | 69.038 ± 20.833 | 126.308 ± 55.983 | 74.00 ± 23.198 | 119.923 ± 61.192 |
| *Quality of Life* | | | | |
| PF (score) | 77.143 ± 17.619 | 85.714 ± 14.392 | 69.615 ± 23.758 | 80.385 ± 21.16 |
| RP (score) | 67.857 ± 24.862 | 98.214 ± 6.682 | 55.769 ± 39.731 | 71.154 ± 35.128 |
| BP (score) | 82.000 ± 14.884 | 88.143 ± 13.530 | 82.077 ± 19.393 | 86.308 ± 15.596 |
| general health (score) | 65.00 ± 22.101 | 79.286 ± 18.066 | 54.615 ± 28.022 | 69.615 ± 18.31 |
| VT (score) | 71.786 ± 19.075 | 83.929 ± 17.004 | 74.615 ± 19.839 | 81.923 ± 13.925 |
| SF (score) | 84.128 ± 22.525 | 90.477 ± 15.005 | 82.052 ± 25.067 | 93.163 ± 7.226 |
| RE (score) | 73.810 ± 23.31 | 88.095 ± 16.575 | 69.231 ± 34.592 | 79.487 ± 32.062 |
| MH (score) | 70.857 ± 21.249 | 86.857 ± 8.655 | 72.615 ± 12.738 | 81.462 ± 12.004 |
| HT (score) | 33.929 ± 15.833 | 43.714 ± 22.345 | 36.538 ± 12.972 | 53.846 ± 17.218 |

**Table 3**. Comparison of outcome variables before and after intervention. Abbreviations: WBVT, whole body vibration training; RT: resistance training; BMI: body mass index; PBF: percentage of body fat; ASMI: appendicular skeletal muscle mass index; HS: handgrip strength; KES: knee extension strength; IL-6: interleukin-6; hs-CRP: hypersensitive C-reactive protein; TNF-α: tumor necrosis factor alpha; IGF-1: insulin-like growth factor 1; MSTN: myostatin; FST: follistatin; CK: creatine kinase; PF: physical functioning; RP: role-physical; VT: vitality; SF: social functioning; RE: role-emotional; MH: mental health; HT: reported health transition.

significant elevation ($P = 0.024$). For growth factors, both groups showed a significant decrease in FST ($P = 0.001$). Both groups show a significant elevation for the muscle injury biomarker (CK) (WBVT, $P = 0.002$; RT, $P = 0.007$). No significant differences were observed between groups regarding sarcopenia-related blood biomarkers (See Table 3; Fig. 5).

## Quality of life

Within-group comparisons for subjects in the WBVT and RT groups showed significant improvements in PF ($P = 0.034$ and $P = 0.002$, respectively), RP ($P = 0.001$ and $P = 0.005$, respectively), general health ($P = 0.045$ and $P = 0.029$, respectively), and MH ($P = 0.013$ and $P = 0.022$, respectively) compared with those at baseline. For HT, only the RT group showed significant improvement ($P = 0.002$). For between-group comparisons, RP was significantly higher in the WBVT group than in the RT group $P = 0.007$). The two groups had no significant difference in any other dimension (See Table 3; Fig. 6).

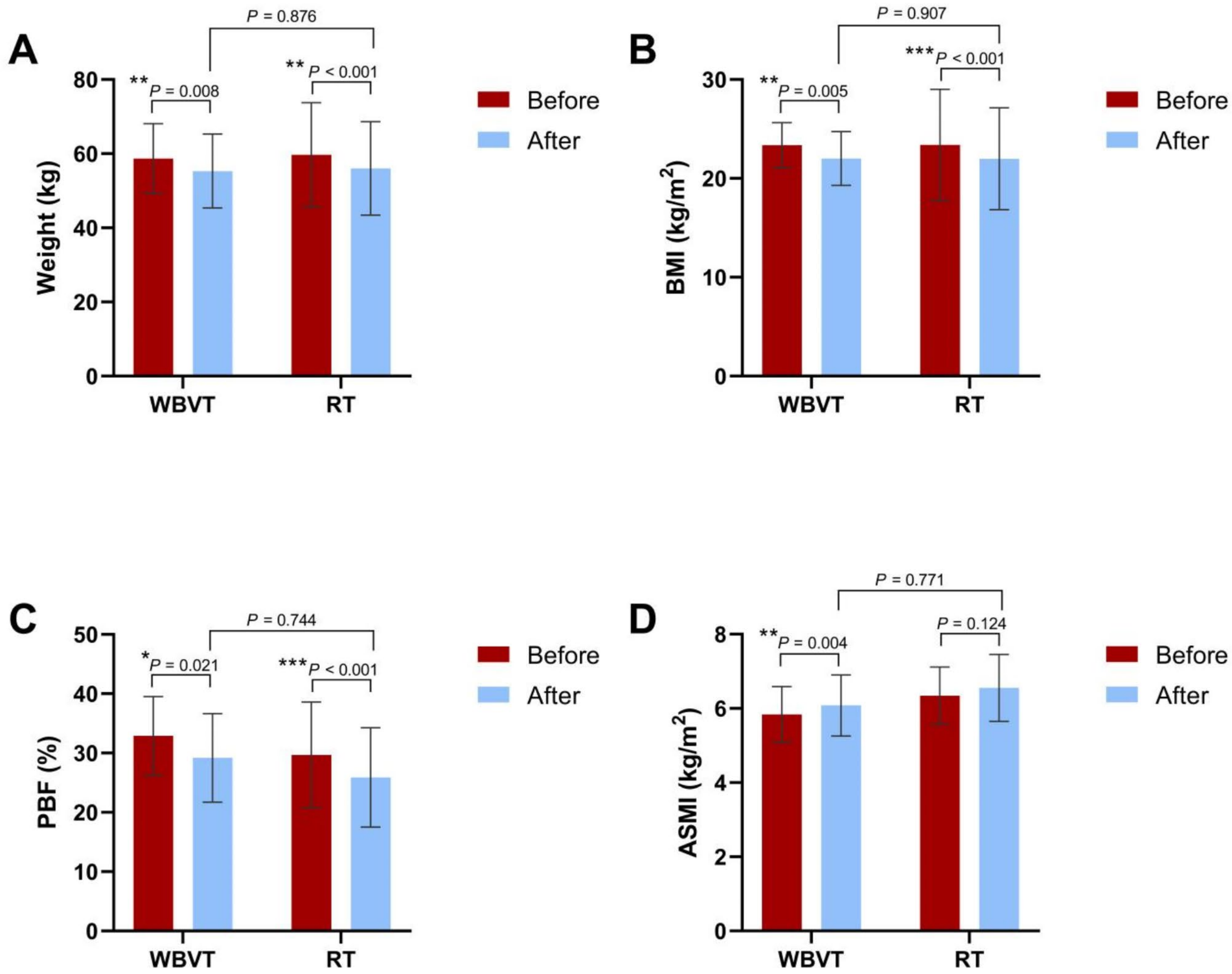


**Fig. 2**. Effects of different intervention methods on subjects' body composition. (**A**) weight, (**B**) BMI, (**C**) PBF, and (**D**) ASMI. Values are mean ± SD. *$P$-value < 0.05; **$P$-value < 0.01; ***$P$-value < 0.001. Abbreviations: WBVT, whole body vibration training; RT: resistance training; BMI: body mass index; PBF: percentage of body fat; ASMI: appendicular skeletal muscle mass index.

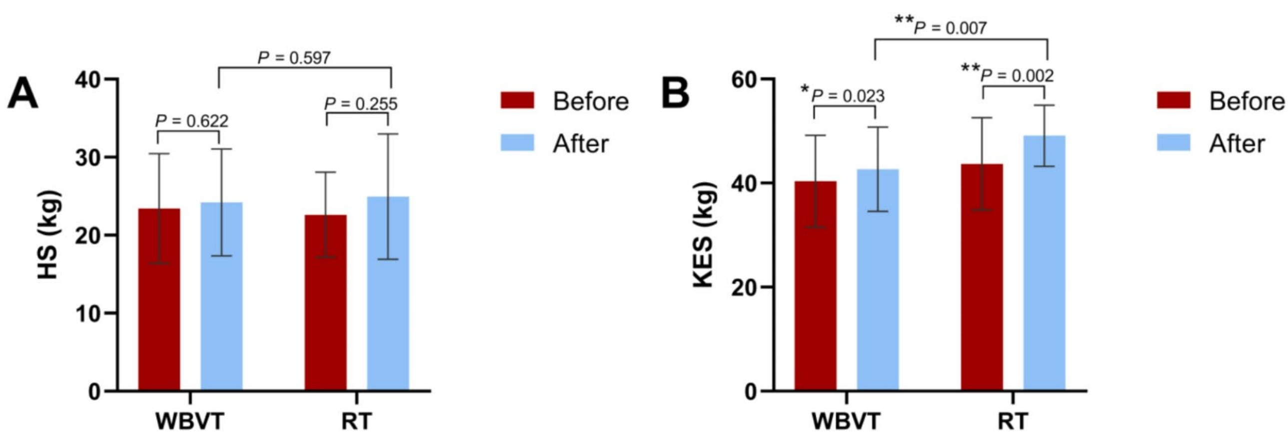


**Fig. 3**. Effects of different intervention methods on subjects' muscle strength. (**A**) HS and (**B**) KES. Values are mean ± SD. *$P$-value < 0.05; **$P$-value < 0.01; ***$P$-value < 0.001. Abbreviations: WBVT, whole body vibration training; RT: resistance training; HS: handgrip strength; KES: knee extension strength.

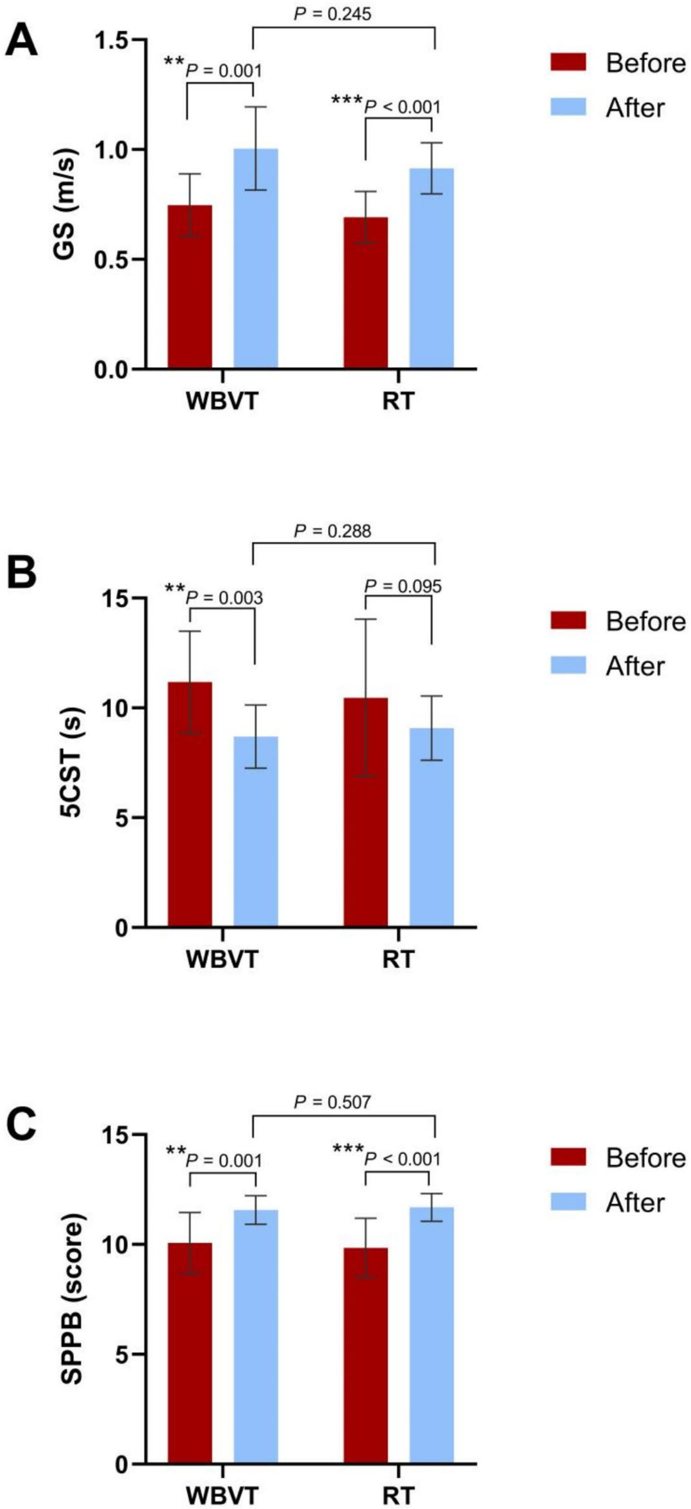


**Fig. 4**. Effects of different intervention methods on subjects' physical performance. (**A**) GS, (**B**) 5CST and (**C**) SPPB. Values are mean ± SD. **P*-value < 0.05; ***P*-value < 0.01; ****P*-value < 0.001. Abbreviations: WBVT, whole body vibration training; RT: resistance training; GS: gait speed; 5CST: 5-time chair stand test; SPPB: short physical performance battery.

## Discussion

To our knowledge, this study is the first randomized controlled trial to systematically intervene and compare the effects of WBVT versus RT on muscle strength, body composition, physical performance, blood biomarkers, and quality of life in older people with sarcopenia. KES, a muscle strength measure was the primary outcome

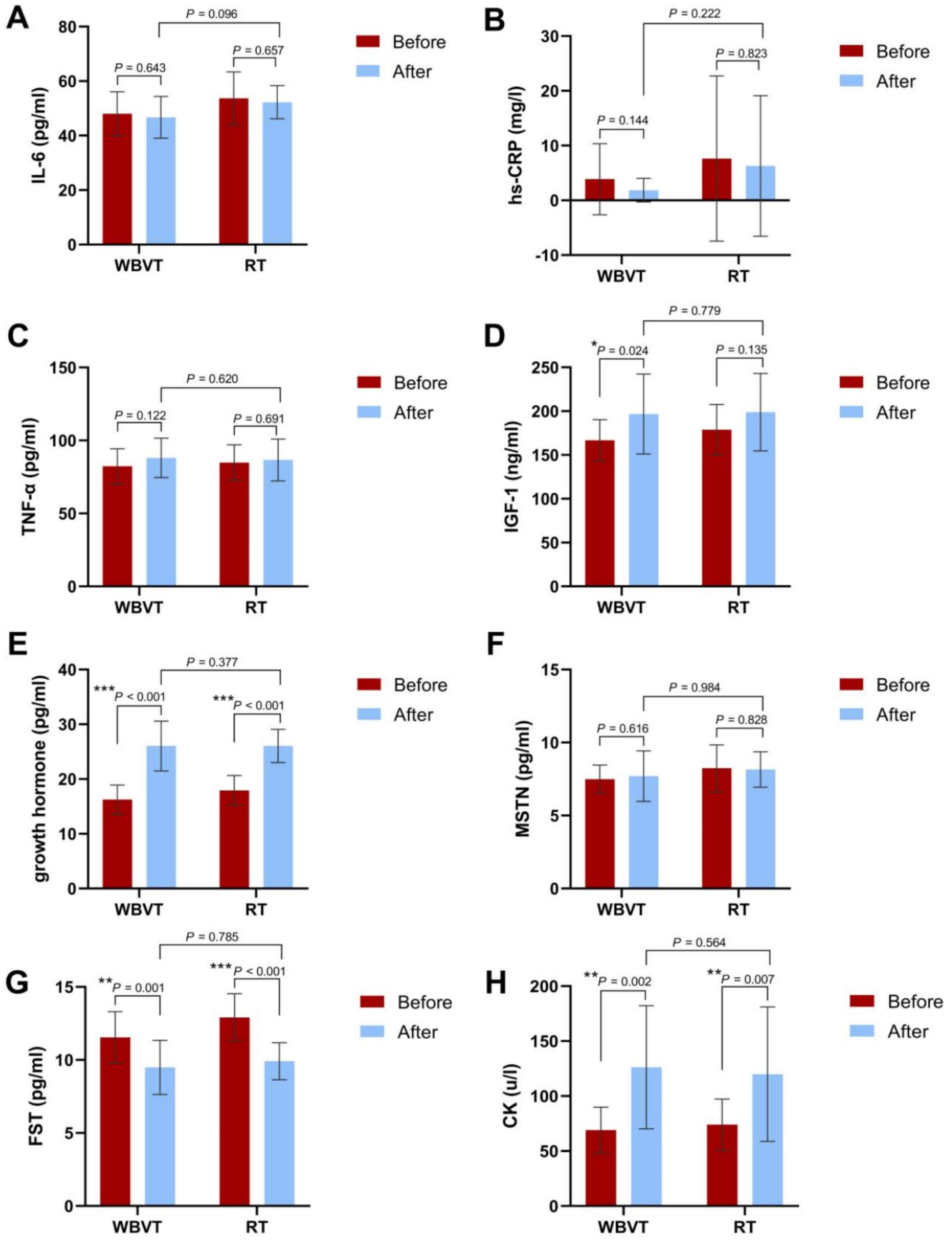


**Fig. 5**. Effects of different intervention methods on subjects' blood biomarkers. (**A**) IL-6, (**B**) hs-CRP, (**C**) TNF-α, (**D**) IGF-1, (**E**) growth hormone, (**F**) MSTN, (**G**) FST and (**H**) CK. Values are mean ± SD. *$P$-value < 0.05; **$P$-value < 0.01; ***$P$-value < 0.001. Abbreviations: WBVT, whole body vibration training; RT: resistance training; IL-6: interleukin-6; hs-CRP: hypersensitive C-reactive protein; TNF-α: tumor necrosis factor alpha; IGF-1: insulin-like growth factor 1; MSTN: myostatin; FST: follistatin; CK: creatine kinase.

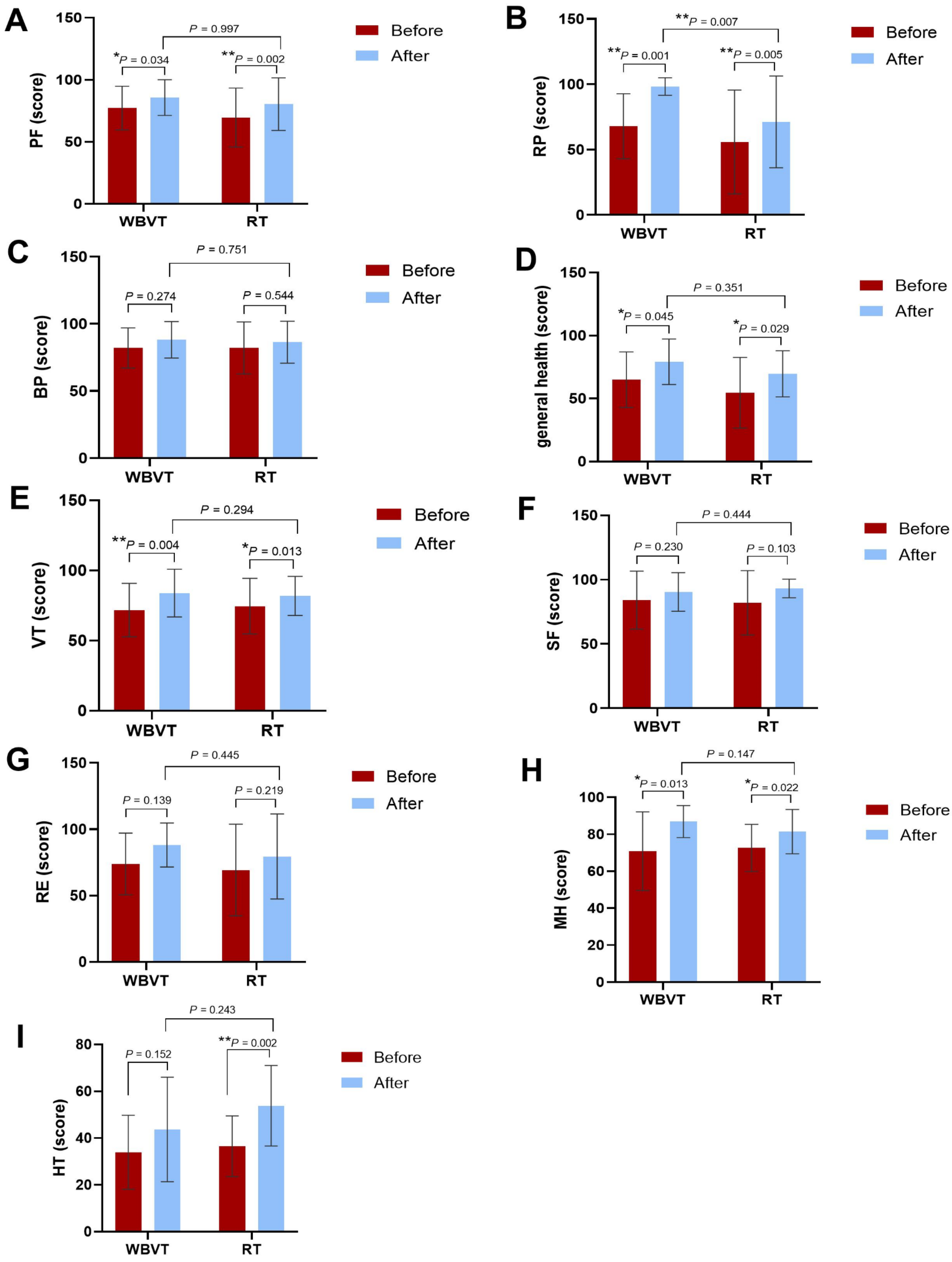


**Fig. 6**. Effects of different intervention methods on subjects' SF-36. (**A**) PF, (**B**) RP, (**C**) BP, (**D**) general health, (**E**) VT, (**F**) SF, (**G**) RE, (**H**) MH and (**H**) HT. Values are mean ± SD. *P-value < 0.05; **P-value < 0.01; ***P-value < 0.001. Abbreviations: WBVT, whole body vibration training; RT: resistance training; PF: physical functioning; RP: role-physical; BP: bodily pain; VT: vitality; SF: social functioning; RE: role-emotional; MH: mental health; HT: reported health transition.

and the remaining variables were secondary outcomes. Following the 12-week intervention, the WBVT and RT groups improved KES, body composition (weight, BMI, and PBF), physical performance (GS and SPPB), blood biomarkers (growth hormone, FST, and CK), and quality of life (PF, RP, general health, VT, and MH) ($P < 0.05$). The WBVT group also improved 5CST, ASMI, and IGF-1 and the RT group improved in HT also ($P < 0.05$).

Muscle strength is widely recognized as a motivational source for older people to maintain stability and perform daily life functions effectively, as well as one of the key indicators in the AWGS guidelines for diagnosing sarcopenia[1]. During daily activities such as walking, up and down stairs, and sit-to-stand, the KES is a key factor in maintaining stability and performing these tasks effectively[27]. Older people with sarcopenia are often accompanied by reduced muscle mass and decreased strength, especially in the lower extremity muscle groups, which can lead to difficulties in daily activities and an increased risk of falls[1,6]. HS, another secondary strength variable, is critical when performing various tasks in daily life (e.g., gripping objects, opening bottle caps, brushing hair, and so on). It also closely correlates with generalized muscle strength and overall quality of life[28]. Therefore, improving muscle strength through exercise is one of the most important strategies to improve the quality of life of older people with sarcopenia. This study found that after 12 weeks of exercise intervention, KES was significantly higher in both groups compared to before intervention. This was consistent with the findings of Raphael et al.[29] and Chen et al.[10]. This result emphasizes that even in old age, muscle strength remains plasticity and may be improved with an appropriate training program[30]. Although both groups achieved significant improvements in KES, the RT group showed more significant improvements in this aspect. This may be related to the nature of RT, which emphasizes targeted workouts for specific muscle groups. RT typically involves using external resistance (e.g., weights, elastic bands, barbells, and so on) to perform muscle exercises that allow for more precise targeting and loading of the targeted muscles. Skeletal muscle, in its continued opposition to the RT loading stimulus, may have contributed to the elevation of IGF-1, a cytokine secreted by the liver that regulates the growth and development of skeletal muscle[31]. It activates the IGF-1/phosphatidylinositol 3-kinase (PI3K)/Akt-1/mammalian target of rapamycin (mTOR)/S6K pathway or the IGF-1/PI3K/Akt-1/mTOR/eukaryotic initiation factor-4E-binding protein-1 (eIF4E-BP-1)/eukaryotic initiation factor-4E (eIF4E) pathway or IGF-1/PI3K/Akt-1/mTOR/GSK-3β/eukaryotic initiation factor-2B (eIF2B) pathway that induces positive protein metabolic homeostasis in skeletal muscle cells[31–3431–34]. This activation may lead to more rapid and noticeable strength improvements[35]. Although RT has demonstrated greater benefits in terms of KES, significant improvements in WBVT are still of practical importance. The muscle enhancement effect was the most direct and consistent clinical indicator of WBVT[17]. This mechanical stimulus has been found to activate α and γ motor neurons in the muscle or tendon, causing tonic contractions reflexively. At the same time, this extrinsic stimulation increased the proportion of type II muscle fibers involved[16,17]. WBVT is a low-impact exercise for individuals who may not be able to tolerate high-intensity RT, including the older people and those with joint problems[36,37]. Therefore, WBVT may be considered an alternative or complementary approach to RT that could potentially play a role in muscle strength improvement. Improvement in HS is usually influenced by a variety of factors, including muscle mass, neurologic function, coordination, and type of exercise[38]. In this study, we did not observe significant improvements in HS between the two types of training methods ($P > 0.05$), which may indicate that the training methods used did not sufficiently emphasize hand training.

Body composition includes the body's fat, muscle and water content, the percentage of which may reflect the overall health of the older people. Adverse changes in body composition, such as imbalances in muscle mass and PBF, is one of the mechanisms in the pathogenesis of sarcopenia[39]. The main focused body components in this study were weight, BMI, PBF and ASMI which were measured directly by BIA. In this study, it was observed that both groups showed significant improvement in weight, BMI and PBF as compared to the period prior to the intervention. The meta-analysis by Chen et al.[10] showed that RT was an effective way that could improve body composition in older people, which was consistent with the results of our study. In the study by Chang et al.[15], 12 weeks of WBVT similarly improved body composition in older people with sarcopenia. Weight loss reduces joint burden and improves mobility[40]. Similarly, a study spanning 6 weeks on WBVT revealed enhancements in blood redox status markers, elevations in irisin levels, and a decrease in visceral adipose tissue[41]. While improvements in BMI and PBF reflect the redistribution of body composition, with more lean muscle mass and diminished fat mass being critical to maintaining global health and reducing the risk of disease[42]. For ASMI, in this study there was a significant increase in the WBVT group before and after the intervention, but no significant difference within the RT group. However, after Minoru et al.[43] implemented RT for 24 weeks in older people with sarcopenia, ASMI was significantly improved. There may be two reasons why this was inconsistent with the results of the present study. One was that the intervention duration in the present study was insufficient and the effect of RT on muscle mass improvement was slowly. One study noted that at 8 to 12 weeks of RT, muscle strength increases rapidly early due to neural adaptation, rather than muscle structure, and that muscle mass only slowly increases after prolonged RT[44]. As Frimel et al.[45] found an increase in muscle mass in older people through RT intervention over 24 weeks. The second was the effect of different modes of exercise. WBVT involves high-frequency mechanical vibrations that are transmitted throughout the body via the sole of the foot. This stimulus induces the rapid shortening of the length of the muscle-tendon complex, mediated through mono- and poly-synapses, leading to the involvement of more muscle fibers in the exercise, thus increasing muscle activation[15,4615,46]. This mechanical vibration also promotes neuromuscular responses and improves motor coordination[47]. Therefore, it is possible that WBVT has positive effects on muscle mass, especially in ASMI, which may explain the significant improvement of WBVT in this indicator. This was consistent with the result of Chang et al.[15]. In contrast, RT improves muscle strength primarily by increasing external resistance. Although RT may lead to muscle thickening and an increase in muscle cross-sectional area, its primary focus is on strength gains and not necessarily on improvements in muscle mass[48,49]. Notably, there was no significant difference between the two groups, implying that for body composition improvement in older people with sarcopenia, the effects of WBVT and RT were similar.

Low physical performance is one of the indicators to diagnose sarcopenia[1]. The selection of indicators for physical performance in this study followed the AWGS-2019 guidelines that recommends measuring SPPB, GS, and 5CST.The results of this study showed that for within-group observations, all indicators of physical performance improved significantly after the intervention, except for the 5CST which showed significant difference between before and after only in the WBVT group. These results emphasize the positive impact of both methods of exercise on physical performance in older people. Of particular attention is the SPPB, which is a comprehensive assessment of physical performance through three areas: balance, GS and 5CST[50,51]. Strong evidence showed that SPPB scores were associated with all-cause mortality[52]. Thus, the overall improvement in SPPB reflected advances in multiple areas of muscle strength, balance, and coordination. In the present study, both training methods produced significant improvements in SPPB, further emphasizing their potential to improve physical performance in older people. Daniel et al.[53] observed significant improvement in physical performance of older people after 16 weeks of WBVT. Chang et al.[15] also found significant improvement in physical performance of older people with sarcopenia after 12 weeks of WBVT. Liang et al.[54] showed that 12 weeks of RT helped to improve GS, SPPB, and balance of older people with sarcopenia. These studies showed similar results to this study. Decreased sensitivity to proprioceptive feedback due to aging, followed by dysfunction of the central and peripheral nervous systems, negatively affected the older people's ability to process and synthesize information from their surroundings in time, which resulted in reduced physical mobility[55]. For improving central nervous system coordination and strengthening neuromuscular reflexes, previous study concluded that WBVT in the flexed knee position was more effective than WBVT in the extended knee position[56]. Because knee flexion lengthens the quadriceps against gravity thereby recruiting more motor units, reflexive contractions were enhanced[47]. Due to the upward shock of the vibrating platform, muscle spindle sensitivity of the popliteus muscle was elevated in order to maintain postural stability among the older people, which contributed to the enhancement of γ-neuron activity and improvement of proprioceptive function[57]. Our study used WBVT in the flexed knee position precisely considering that the initial length of the muscle would influence the effect of the intervention. In the RT group, the movements were designed in consideration of the function of the large muscle groups of the lower limbs. Prolonged RT resulted in more active muscle neurons, which helped to increase sensitivity of the proprioceptive organs, increased neurotransmitter release, and the brain's ability to analyze and process sensory stimuli. Combined with increased muscle strength, it may allow for timely adjustment of body posture when the nervous system detected the possibility of a fall or other danger[58]. Although both groups achieved significant improvements in the majority of physical performance indicators within their respective groups, between-group comparisons did not show significant differences. This suggested that they could both improve the overall physical performance of older people by similar degrees. Therefore, the choice of exercise mode could be based more on the preferences and physical condition of the older people, without worrying about differences in effectiveness in terms of physical performance.

In the present study, we observed that both WBVT and RT positively affected muscle strength, body composition, and physical performance, suggesting that there may be a close link between these effects. As defined by sarcopenia, sarcopenia is a whole-body syndrome[1]. First, improvements in body composition, including reductions in weight, BMI, and PBF, may be closely related to increases in muscle strength. Muscle is a metabolically active tissue, and its increase may lead to an increase in basal metabolic rate, helping to control weight and fat mass[59]. Thus, the decrease in PBF may be partially attributed to the increase in muscle mass and strength. This could also explain the positive results of both training methods in terms of KES and body composition. Secondly, the increased muscle strength played a key role in physical performance. The increase in muscle strength facilitated an improvement in muscle contractility, which in turn improved walking ability, balance and functional activity. This may confirm why both training methods show significant improvements in physical performance indicators such as SPPB and GS. Finally, the relationship between body composition, muscle strength and physical performance was also related to quality of life. Improvements in body composition and muscle strength not only improve the physical capacity and mental well-being dimensions of quality of life, but also increase the self-confidence and independence of older people, thereby improving quality of life. This was reflected in the improvements in the PF, RP, general health, VT and MH dimensions of the SF-36 questionnaire. Overall, there was a strong correlation between body composition, muscle strength and physical performance, suggesting that the synergistic effect of the two exercise methods contributes to the quality of life of older people with sarcopenia.

Sarcopenia not only involves loss of muscle mass, but is also closely linked to abnormal changes in a series of blood biomarkers. Common blood biomarkers include inflammatory factors (e.g., IL-6, hs-CRP, TNF-α), hormones (e.g., IGF-1 and growth hormone), growth factors (e.g., MSTN and FST), and muscle injury biomarker (CK). Although several studies have pointed to the beneficial effects of WBVT or RT on the management of sarcopenia, little was known about the physiologic mechanisms involved. Although we did not observe significant improvements in inflammatory factors, this does not mean that both exercises do not have the potential to improve the inflammatory state. Older people often come with chronic low-grade inflammation, which negatively affects muscle mass and function[60]. In addition, suppression of inflammation may have positive effects on the health of older people, including reduced risk of cardiovascular disease and improved cognitive function[60]. However, the biological processes of inflammation are complex and may take longer to significantly affect these biomarkers. This study found that WBVT and RT significantly improved body weight, BMI, and PBF, indicating a positive effect of exercise on fat metabolism. RT enhanced KES, while WBVT increased ASMI, potentially reflecting the role of exercise in promoting muscle enhancement and fat reduction by improving crosstalk between muscle and adipose tissue. Although inflammatory markers (IL-6, hs-CRP, TNF-α) did not reach statistical significance, both groups showed a trend of improvement, which may be related to exercise promoting the release of anti-inflammatory mediators and/or reducing the production of pro-inflammatory mediators. Previous studies have indicated that adiponectin and myokines are involved in maintaining muscle and fat homeostasis, and disruptions in their interactions as well as imbalances in immune-inflammatory responses may interfere with muscle regeneration, leading to sarcopenia or muscle wasting[61]. Exercise may serve as an effective intervention to improve this interaction, thereby helping to reduce inflammation levels. Although this study did not directly measure biomarkers such as adiponectin, future research can further explore the changes in these molecules under exercise interventions. Hormones play a key role in muscle growth, repair and metabolism[62]. Specifically, growth hormone is important in promoting protein synthesis and muscle cell proliferation, whereas IGF-1 plays an essential role in cell growth and repair[63,64]. Subjects in both the WBVT and RT groups showed significantly elevated levels of growth hormone, whereas for IGF-1, only the WBVT group showed significant elevation. This finding reflected the differences in hormone metabolism and utilization between the two exercises, with WBVT seemed to be more sensitive to the activation of growth factors, which may help to explain the significant increase in ASMI only in the WBVT group. It has been shown that elevated IGF-1 reduced muscle ring finger-1 (MuRF1) and muscle atrophy F-box (MAFbx) activity which accompanied muscle atrophy, thereby reducing protein degradation[65,66]. We also observed alterations in growth factors, in particular a significant decrease in FST. MSTN is usually considered a factor that negatively regulates muscle growth, whereas FST is its antagonist and helps to promote muscle growth[67,68]. Thus, the reduction in FST levels may help to explain the improvement in muscle strength between the WBVT and RT groups. However, for the changes in MSTN, we did not observe significant differences between the two groups. We speculate that the effects of WBVT and RT on growth factors may differ in pathways, which requires more in-depth studies to explain their physiological significance. Significantly elevated CK may reflect damage and repair processes in muscle tissue. Although elevated CK levels may cause concern, this was normal to some extent, especially during muscle training, and may be an expression of muscle adaptation[69]. However, it was noted that the differences between the WBVT and RT groups did not reach statistical differences in all blood biomarkers, implying that the two modes of exercise had similar effects in improving the physiological mechanisms of sarcopenia.

The strengths of this study are as follows. First, this study systematically compared the effectiveness of WBVT and RT for older people with sarcopenia. This comparison provided important information for understanding the advantages and disadvantages of different exercise methods, which could help guide future rehabilitation practices. Second, this study measured of multidimensional primary and secondary indicators, including muscle strength, body composition, physical performance, blood biomarkers, and quality of life. These comprehensive measurements provided a global understanding of the effects of different exercises. Also, blood biomarkers and quality of life were sarcopenia indicators that fewer studies have focused. Results showed that blood markers relating to the cascade of sarcopenia-promoting processes decreased and quality of life increased following the intervention. Third, there were no dropouts and adverse safety events during this study. Subjects showed high levels of interest in the study. Compliance with vibration interventions exceeded 75%, indicating that vibration was appropriate and enjoyable for the subjects[70].

However, this study has the following limitations. First, the sample size was small. Subjects were recruited from Sanxing Town, Chongming District, Shanghai, which is a small town with a low prevalence of sarcopenia that limited the sample size. Second, the intervention duration was only 12 weeks. Although some significant effects were observed following the intervention, a longer intervention duration still need to be investigated. Third, the vibration training postures used in this study may have had an impact on the results. Different frequencies, intensities, and differences in intervention duration may have different effects on the results of the study. Future studies could delve into the effects of different vibration postures. Fourth, the small sample size restricted stratifying the sample to determine the results by age and gender. confounding. The age ranged from 65 to 80 years for the subjects included in this study. One study noted that there were differences in the sensitivity of exercise to different ages[71]. Future studies could focus on performing stratified studies on age and gender.

## Conclusion

WBVT and RT showed similar effectiveness in improving the physical condition of older people with sarcopenia. Although RT had an advantage in enhancing muscle strength, WBVT provided a feasible alternative for subjects who were restricted or unsuitable for RT. In clinical practice, WBVT was suitable for various physical conditions due to its low risk and flexibility. It improved muscle strength, enhanced physical function, and potentially improved overall health by regulating hormone release. This study provided a new option for rehabilitation training in sarcopenia, emphasizing the importance of WBVT. Future research should further explore the optimal training parameters for WBVT.

## Data availability

The datasets generated and/or analyzed during this study are not publicly available due to the presence of personal health information, but they are available from the corresponding author on reasonable request.

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## Author contributions
MZ, YG and ZW contributed to the concept and design, data acquisition, data analysis and interpretation. YG and XH were responsible for drafting the manuscript and revising it critically. MZ, YG, ZW, XH and NC for final approval of the version to be published. NC had agreed to be accountable for all aspects of work.

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## Declarations

## Competing interests
The authors declare no competing interests.

## Additional information
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