

Whole Body Vibration as a New Method for Exercise-Training Prescription

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Abstracts

Originally, whole body vibration (WBV) was developed for patients with osteoporosis and came into wide use as instrument for increasing bone density centering around Europe since 2000. Recently, many researchers have reported that WBV has various positive effects on improving physical performance, energy metabolism, blood flow, and so on during exercise. In addition, it has been suggested that WBV is more safe and useful exercise method in exercise field compared to the traditional type of exercise such as running and weight training. However, there is few information and study for scientific evidence on WBV in our country. In the present study, we investigated the effect of WBV on aerobic and anaerobic exercise and also reviewed previous studies on WBA in order to introduce WBV as a new method for exercise-training prescription to all kinds of exercise instructor, athletics, and coaching staff. Together with previous studies and the present results, it can be suggested that WBV enhances muscle functions, bone density, VO_2 max, and blood flow, while WBV decreases body fat mass. Although it is still short of study on the effect of type of vibration and changes of vibration number during WBV, it is considered that WBV would be pretty worthwhile prescription and training method for athletics, instructor, and exercise specialist.

Key Words: Whole body vibration; Exercise prescription; Training; Muscle function;
Fat metabolism

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Introduction

The ultimate purpose of all sports games is to win the victory. For this reason, most athletics, instructors, and sports scientists have searched for new regimes so as to get better physical condition and performance than their opponents. The most important thing to decide victory or defeat in most sports games is how to develop innate potential ability through improvement of physical fitness and training. Until now, it has been suggested by sports scientists that there are two ways to realize their objectives to improve physical condition and performance. First way is to develop the more effective training methods and new skills, and second one is to develop exercise supplemental agents which is called as "ergogenic aids" (Kim, Park, Lee, 1999).

Whole body vibration (WBV) exercise is one of the training method for stimulating muscle fiber to contract and relax with greater strength and speed; such powerful muscle contractions via modulating gravitational load artificially (Bosco, 1992). Originally, vibration exercise has been developed for the prevention and treatment of osteoporosis because vibration exercise elicits neuromuscular training, without much effort and in short periods. Previous studies have reported that WBV treatment has positive effects on musculoskeletal, circulatory, and endocrine systems. Lebedev and Peliakov (1991) have suggested the possibility that vibrations may elicit excitatory inflow through muscle spindle motoneurons connections in the overall motoneuron inflow and Kasai et al. (1992) have shown that the vibration-induced activation of muscle spindle receptors not only affects the muscle to which vibration is applied, but also affects the neighbouring muscles. It has also been reported that the facilitation of the excitability of the spinal reflex has been elicited through vibration of the quadriceps muscle (Burke et al., 1996) and the improvement of the muscle performance after a short period of vibration training was to be similar to what occurs after several weeks of heavy resistance training (Bosco et al., 1998). In addition, it has been shown that WBV treatment leads to acute responses of hormonal profile and neuromuscular performance. It is therefore likely that the effect of WBV treatment elicited a biological adaptation that is connected to a neural potentiation effect, similar to those reported to occur following resistance and explosive power training (Bosco et al., 2000).

Recently, low frequency vibration increased the mean blood flow velocity in the popliteal artery and significantly reduced resistive index of blood flow velocity while

high frequency vibration is supposed to have negative effects on blood flow and muscle strength (Kersch-Schindl, et al., 2001). In other words, this study indicates that circulatory response such like blood flow velocity depends upon the magnitude and frequency of vibration.

Based on these studies, it has been suggested that WBV is more safe and useful exercise method in exercise field compared to the traditional type of exercise such as running and weight training. Currently, it is widely in use as a new training regimes for muscle function only in various pro-sports teams but also in health and fitness centers, hospitals, and rehabilitative therapy facilities of America and Japan centering around Europe since late of 1990s because of its convenience and safety as a new exercise-training prescription.

However, there are still short of scientific evidences and information to apply for its use in the athletic setting of Korean sports science field. In particular, the research on WBV which can produce more low frequency vibration is not attracting public and sports scientist attention although new type of vibration system is developed in our country. Therefore, the aim of this study was to introduce general effect of WBV exercise and to investigate the effect of whole body vibration with vibration of lower frequencies than other vibration device, which has different vibration system, on alteration of blood lipid and muscle activation via measurement of blood free fatty acid (FFA) and electromyogram (EMG).

Theoretical Background on Whole Body Vibration

Numerous studies have been investigated the adaptive responses of the human body to training stimuli for enhancing muscular performance. We already know that the adaptation to the training is associated with biological system modified by the repetition of daily exercise, which are specific to the movements performed and these training adaptations are closely related to the skeletal muscles of human body. For this reason, strength training may be considered as a typical means for studying effective human performance and training method. The simulation of hypergravity such like wearing vests with extra loads has been utilized for improving explosive muscle power (Bosco et al., 1984; Bosco, 1985). However, the overload or simulation of hypergravity are not the only means for changing the gravitational conditions. In fact, mechanical vibrations applied to the body can produce changes in the gravitational conditions and determine specific responses.

The impact of WBV on neuroal adaptation

Whole body vibration (WBV) exercise is one of the training method for stimulating muscle fiber to contract and relax with greater strength and speed; such powerful muscle contractions via modulating gravitational load artificially (Bosco, 1992). In WBV training, the subject stands on a platform that generated vertical vibration at various frequencies. These mechanical stimuli are transmitted to the body where they stimulate in turn sensory receptors, most likely muscle spindles.

Previous studies have reported that WBV treatment elicited positive effects on neuromuscular system. Lebedev and Peliakov (1991) have suggested the possibility that vibrations may elicit excitatory inflow through muscle spindle motoneurons connections in the overall motoneuron inflow and Kasai et al. (1992) have shown that the vibration-induced activation of muscle spindle receptors not only affects the muscle to which vibration is applied, but also affects the neighbouring muscles. It has also been reported that the facilitation of the excitability of the spinal reflex has been elicited through vibration of the quadriceps muscle (Burke et al., 1996). These studies indicated that vibration exercise elicits powerful muscle contraction by inducing additional neuromuscular adaptation. In particular, adaptation by vibration was induced in most likely muscle spindles and alpha-motoneurons.

The impact of WBV on muscular system

Related to the muscular function, a lot of studies have suggested that vibration treatment may induce enhancement of muscular function and then improve muscular performance. Strength training with vibratory stimulation for 3 weeks led to an almost 50% increase in the one-repetition-maximum (1RM) compared with an average gain 16% with conventional training and no gain for the control group (Issurin et al., 1994). Bosco et al. (1998) also reported that muscle stimulation by vibration might improve the mechanical power of the lower limbs in elite athletes by means of neural adaptation and the improvement of the muscle performance after a short period of vibration training was to be similar to what occurs after several weeks of heavy resistance training. In another studies, acute treatment with WBV increase leg muscle force (F) and power (W), movement velocity and the velocity/F and W/F curves were shifted to the right after 10 min of vibration treatment and WBV increased the average velocity, average force and average power in well-trained subjects (Bosco et al., 1999a; Bosco et al., 1999b). Recently, Runge et al. (2000) showed gains of 18% in chair-rising time in elderly persons after 12 weeks WBV training with 27 Hz frequency and Torvinen et al. (2003) reported a significant increase of 8.5% in jump performance and a nonsignificant increase of 2.5% in isometric limb extension strength after 4-month WBV treatment with 25-30 Hz frequency in young nonathletic adults. In contrast, some studies reported that high frequency vibration led to different degrees of degeneration of muscle fibers in some muscle (Necking et al., 1996). It is postulated that the duration and frequency of the vibration seems to be both relevant and important and changes in the size of muscle fibers were the first indication of vibration-induced muscle injury.

Related to EMG, the root mean square (RMS) of the associated EMG did not change following the vibration treatment, but the ratio of EMG/W decreased showing an enhancement of neural efficiency (Bosco et al., 1999b). In another experiments, the EMG recorded in the biceps brachii of the experimental group in the study conducted on boxers showed a significant enhancement of the neural activity during the treatment period, as compared to normal conditions (Bosco et al., 1999a). EMG studies also revealed that WBV with 5 Hz frequency induced vibration-synchronous EMG activity in the erector spinae muscle, which exceeded the activity without WBV. These studies show that vibration induces muscle activation and therefore muscle training (Kersch-Schindl, et al., 2001).

The impact of WBV on circulatory and skeletal system

Related to the circulatory system, many studies have suggested that vibration treatment lead to alteration of circulatory system. Bosco et al. (2000) showed a significant increase in the plasma concentration of testosterone and growth hormone, whereas cortisol levels decreased. This results indicated that WBV treatment elicited a biological adaptation that is connected to a neural potentiation effect, similar to those reported to occur following resistance and explosive power training (Bosco et al., 2000). Rittweger et al. (2001) also reported that WBV exercise significantly increases oxygen uptake in vertical and squatting position and this increased metabolic power is associated with enhancement of muscular activity. In addition, low frequency vibration increased the mean blood flow velocity in the popliteal artery and significantly reduced resistive index of blood flow velocity while high frequency vibration is supposed to have negative effects on blood flow and muscle strength (Kerschman-Schindl, et al., 2001). Recently, it has been suggested that 6-month WBV training enhances hip density, and muscle strength, and postural control in postmenopausal women (Sabine et al., 2004).

In domestic researches, there are a few studies on WBV related to the energy metabolism and/or obesity. Kim (2000) reported that WBV exercise decreases weight, %body fat, total cholesterol, and triglyceride, whereas muscle power, agility, and reaction time significantly increased. Jeon (2001) showed a significant reduction of subcutaneous fat of triceps, chest, abdomen, suprailium, and subscapula in skinfold measurement. Also, a significant decreased VLDL and %body fat by WBV and diet regime was observed (Moon and Sun, 2003). Recently, Lee et al. (2003) suggested that WBV treatment elicits 31% of maximal oxygen intake, 58% of mean heart rate, 83% of systolic pressure, and 27% of blood lactate during cycle ergometer test in regardless of frequency (Hz). These results indicates that WBV exercise is relatively more safe than traditional training methods.

Materials and Methods

We performed two different experiments to investigate the effect of WBV exercise with vibration of various frequencies on blood lipid and muscle via measurement of blood free fatty acid (FFA) and electromyogram. WBV equipment used in this study is the vibration platform (Turbo Trainer, TSKOREA, Seoul, Korea) which applied a precision vertical vibration using high-performance acoustic amplifier systems and a novel magnetic circuit, the first of its kind. Therefore, the present results can be different if conventional equipment which utilized rotary motors system is used for same type of experiments.

Subjects and Treatments

In the first part of the experiment, the effect of WBV exercise on the circulating FFA from resting to recovery state was observed. Five males and three females of university students with major in physical education volunteered for this study. Physical characteristics of the subjects are presented in Table 1. Before starting treadmill exercise, the measurement of VO_2 max was performed to estimate the effect of WBV exercise as an aerobic exercise. Gas analysis of each subjects was taken during exercise involving vibration with various frequencies in the vertical direction and the changes of VO_2 max was recorded. With frequencies of 8 Hz, 10 Hz, and 12 Hz, the variation of VO_2 max was highly increased. circulating FFA, therefore, was assessed during WBV exercise with these frequencies.

In the second part of the experiment, the change of electromyogram according to the WBV exercise with various frequencies in the vertical direction was observed. Ten university males with major in physical education volunteered for this study. Physical characteristics of the subjects are presented in Table 2.

The study was approved by the review board of Research Institute of Sports Science, and all subjects took part after giving their informed consent. Each participant was in good health, with no medical history.

Table 1. Physical characteristics of the subjects Mean \pm SD

Item Group	Age (year)	Height (cm)	Weight (kg)	Body Fat (%)	Abdominal Fat (%)
Subjects (N=8)	22.53 \pm 3.11	175.25 \pm 7.30	64.46 \pm 12.04	13.29 \pm 3.80	0.77 \pm 0.03

Table 2. Physical characteristics of the subjects Mean ± SD

Group \ Item	Age (year)	Height (cm)	Weight (kg)	Muscle Mass (kg)
Subjects (N=10)	22.75 ± 2.92	179.13 ± 4.52	73.35 ± 7.53	60.65 ± 5.88

Treadmill exercise

In the first part of the experiment, each subjects attended the exercise test on two separate occasions. For 1st trial, a graded running test on the treadmill was performed without WBV exercise. For 2nd trial, the same running test was performed with 10 min WBV exercise 1 wk later. WBV exercise was carried out as a type of warm-up before treadmill exercise (Fig. 1-2). All subjects were made to run on a treadmill for 30 min a day. The exercise load consisted of running at a speed of 2.5 mph for 10 min, at 3.8 mph for 10 min, and at 5.0 mph for the last 10 min, with 0% grade. The exercise load and duration of the treadmill exercise used in this study correspond to light-intensity exercise, roughly equivalent from walking to jogging speed in men.

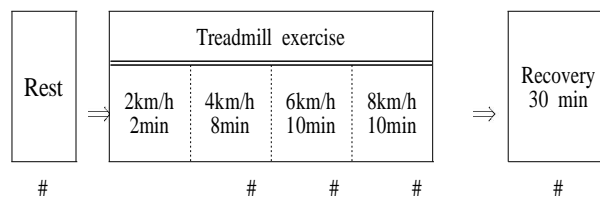


Fig. 1. Experimental procedure for 1st trial of treadmill exercise and blood sample collection. # represents collection point of blood sample.

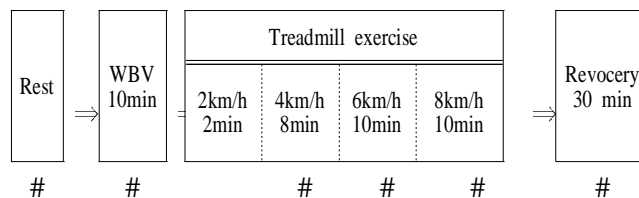


Fig. 2. Experimental procedure for 2st trial of WBV, treadmill exercise, and blood sample collection. # represents collection point of blood sample.

WBV

During a vibration session, each subject was instructed to stand in the center of the platform that generated a precision vertical vibration using high-performance acoustic amplifier systems and a novel magnetic circuit using the device called Turbo Trainer (TSKOREA, Seoul, Korea). For a while, the subjects keeps the vertical straight position on a platform without any motion and then WBV starts 10 sec later.

In the first part of the experiment, the duration of the WBV was for 10 min as a type of warm-up before treadmill exercise. The frequency of the vibrations was set at 8 Hz for 4 min, 10 Hz for 3 min, and 12 Hz for 3 min. The volume of vibration was 70 %.

In the second part of the experiment, the subjects were exposed nine times for a duration of 10 sec with 10 sec of rest between the treatment each. The frequency of the vibrations was progressively increased from at 4 Hz, 6 Hz, 8 Hz, 12 Hz, 16 Hz, 20 Hz, 24 Hz, 30 Hz, and to at 40 Hz.

Blood sample collection and FFA

In the second part of the experiment, an intravenous catheter was inserted into an antecubital vein of all subjects for collecting blood sample before starting experiment. Basal blood samples were taken at time 0 (just before exercise test). Further specimens were withdrawn at time 10 min, 20 min, 30 min during exercise period and at 30 min during recovery period. Collected blood samples were immediately centrifuged and plasma or serum frozen at - 20 until free fatty acid (FFA) analysis by specialized company on blood analysis.

Muscle activation measurement

Muscle activation was measured using electromyography (EMG; WEMG8, LAXATHA, Seoul, Korea). EMG recordings were made using a pair of surface electrodes placed over eight site of the human body including pectoralis major, rectus abdominis, biceps brachii, trapezius, erector spinae, gluteus maximus, quadriceps femoris, and soleus. EMG signals were amplified (5,000 times) no further than 10 cm from the recording site, and they were band-pass filtered (10 - 1,000 Hz). EMG signals were collected at a sampling frequency of 3,000 Hz. Root mean square (RMS) which means the total value of produced strength by muscle for established time is obtained by EMG analysis software.

Results

In the first experiment, the changes of circulation FFA on WBV exercise with various frequencies was obtained from eight university students.

Changes of circulating FFA concentration before and after WBV exercise

Fig. 3 shows the changes of circulating FFA concentration before and after 10 min WBV exercise. The concentration of circulating FFA was significantly increased from 358.00 ± 140.64 EqL/ before WBV exercise to 528.63 ± 228.83 EqL/ after WBV exercise ($p = .21$). This result indicates that WBV exercise may improve the rate of mobilization on lipid as a energy resource for daily life and physical performance.

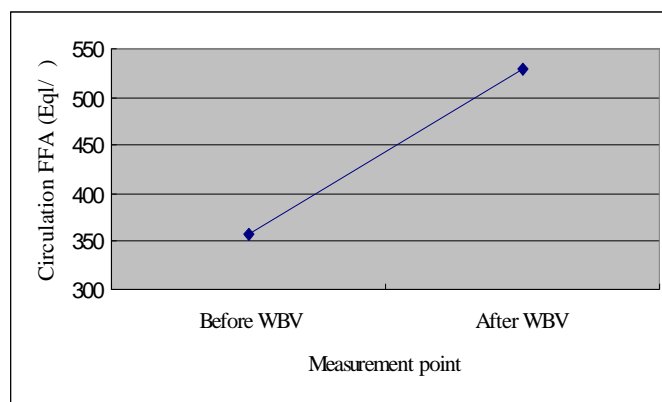


Fig. 3. Changes of circulating FFA concentration before and after WBV exercise

Changes of circulating FFA concentration with/without WBV exercise during treadmill exercise and recovery period

Fig. 4 shows the changes of circulating FFA with/without 10 min WBV exercise at rest, during exercise, and recovery period. Without WBV treatment before treadmill exercise, the concentration of circulating FFA was 432.50 ± 156.99 EqL/ at 10 min during treadmill exercise, 502.75 ± 179.51 EqL/ at 20 min during treadmill exercise, 430.50 ± 150.01 EqL/ at 30 min during treadmill exercise, and 499.50 ± 148.77 EqL/ at 30 min during recovery period. With WBV treatment before treadmill exercise, the concentration of circulating FFA was

480.00 ± 154.89 Eq/l/ at 10 min during treadmill exercise, 568.13 ± 181.75 Eq/l/ at 20 min during treadmill exercise, 463.63 ± 178.11 Eq/l/ at 30 min during treadmill exercise, and 552.13 ± 171.69 Eq/l/ at 30 min during recovery period.

Statistically, there was no significant difference at 10 min ($p = .055$), 20 min ($p = .172$), and 30 min ($p = .340$) during treadmill exercise on the concentration of circulating FFA compared treatment with WBV to non-treatment with WBV before treadmill exercise. However, treatment with WBV exercise mostly increase the concentration of circulating FFA during treadmill exercise and recovery period and significant difference was observed during recovery period ($p = .040$). These results suggested that WBV exercise may activate the lipid metabolism increasing the rate of mobilization on circulating FFA and then improve efficiency of aerobic exercise.

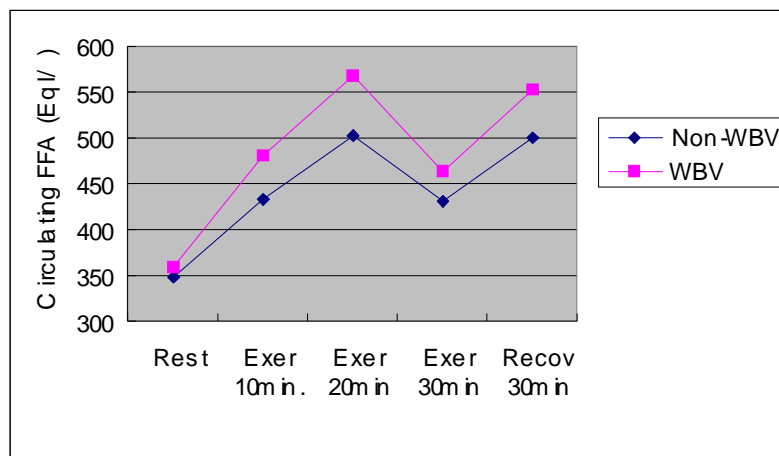


Fig. 4. changes of circulating FFA with/without WBV according to measurement point

In the second experiment, the effect of WBV exercise with various frequencies on muscle activation of eight sites of human body was investigated from ten university students.

The effect of WBV exercise with various frequency on EMG of eight site of human body

Muscle activation of pectoralis major, rectus abdominis, biceps brachii, trapezius, erector spinae, gluteus maximus, quadriceps femoris, and soleus measured by EMG was shown in Fig. 5 - 14. RMS which is the results of the total value of produced strength by muscle is established from 10 seconds WBV exercise with various frequencies.

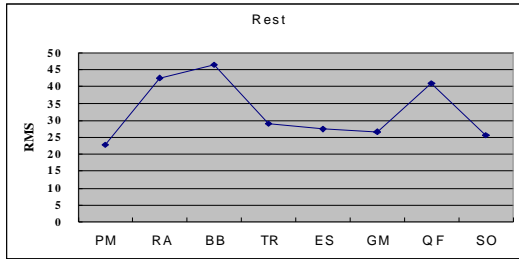


Fig. 5. EMG of eight muscles sites at rest

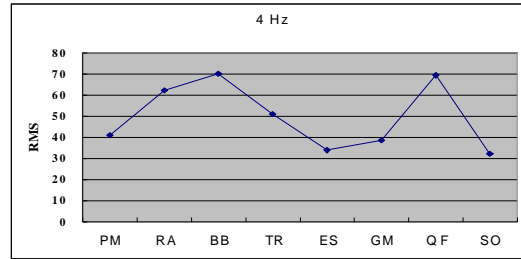


Fig. 6. EMG of eight muscles sites with 4 Hz

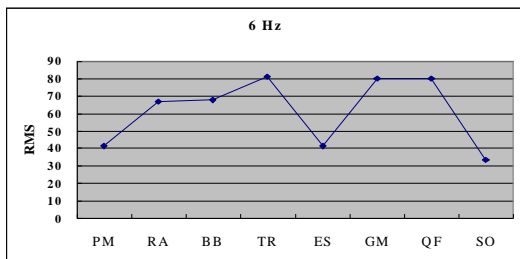


Fig. 7. EMG of eight muscles sites with 6 Hz

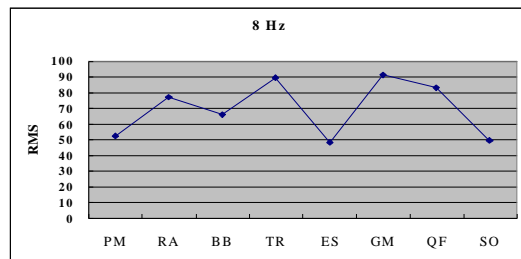


Fig. 8. EMG of eight muscles sites with 8 Hz

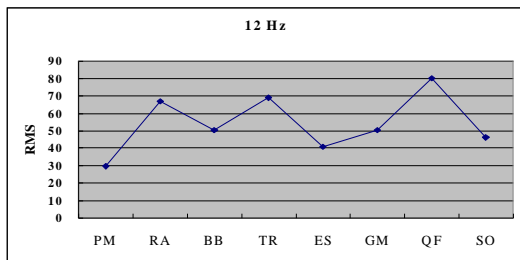


Fig. 9. EMG of eight muscles sites with 12 Hz

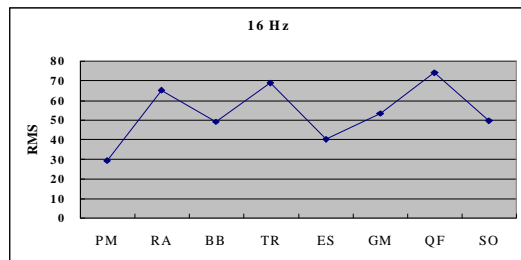


Fig. 10. EMG of eight muscles sites with 16 Hz

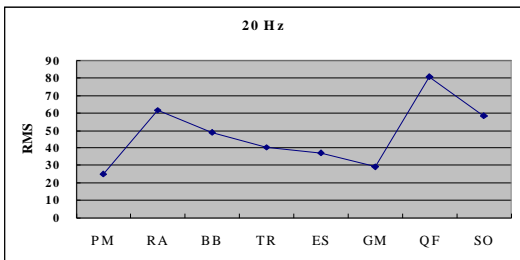


Fig. 11. EMG of eight muscles sites with 20 Hz

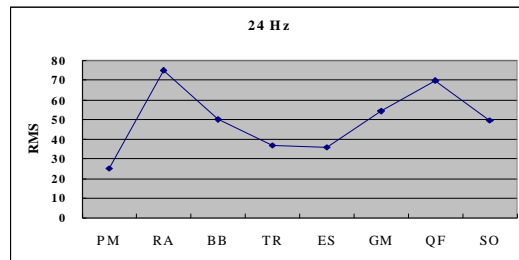


Fig. 12. EMG of eight muscles sites with 24 Hz

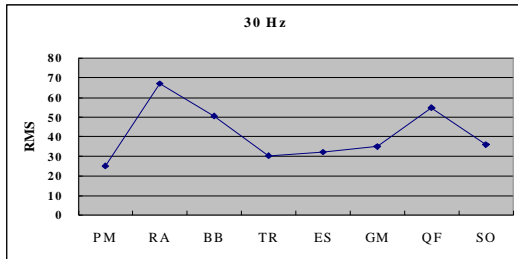


Fig. 11. EMG of eight muscles sites with 30 Hz

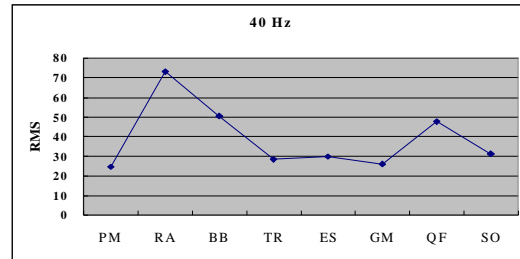


Fig. 12. EMG of eight muscles sites with 40 Hz

PM, pectoralis major; RA, rectus abdominis; BB, biceps brachii; TR, trapezius; ES, erector spinae; GM, gluteus maximus; QF, quadriceps femoris; SO, soleus; RMS, Root mean square

Vibration frequencies activating each muscles were summarized in Table 3 as follows:

Table 3. Vibration frequencies activating each muscles

Muscles	Vibration frequencies activating muscles
Pectoralis major	4Hz, 6Hz, 8Hz
Rectus abdominis	6Hz, 8Hz, 12Hz, 24Hz, 30Hz, 40Hz
Biceps brachii	4Hz, 6Hz, 8Hz
Trapezius	6Hz, 8Hz, 12Hz, 16Hz
Erector spinae	6Hz, 8Hz, 12Hz, 16Hz
Gluteus maximus	6Hz, 8Hz, 16Hz, 24Hz
Quadriceps femoris	4Hz, 6Hz, 8Hz, 12Hz, 16Hz, 20Hz, 24Hz
Soleus	8Hz, 16Hz, 20Hz, 24Hz

The present results suggested that WBV exercise has an positive effect on muscle activation and activating muscle is different according to the vibration frequency. Moreover, lower frequencies is relatively more effective than higher frequencies.

Discussion

In the present results, the level of circulating FFA was statistically difference between before and after WBV treatment for 10 min (Fig. 3). During treadmill exercise and recovery period, the level of circulating FFA also was increased by WBV treatment compared with the non-WBV treatment. Especially, the level of circulating FFA was significantly increased during recovery period (Fig. 4). This supports strongly the possibility that WBV treatment may improve the rate of mobilization on lipid as an energy resources and then enhance efficiency of aerobic exercise. A lot of studies have been shown that vibration treatment lead to alteration of circulatory system. WBV exercise significantly increased the concentration of testosterone and growth hormone, whereas cortisol level which is one of the stress factors was decreased by WBV exercise (Bosco et al., 2000). Additionally, low frequency vibration increased the mean blood flow velocity in the popliteal artery and significantly reduced resistive index of blood flow velocity (Kersch-Schindl, et al., 2001). Together with these studies, the present results indicated that WBV treatment has a positive effect on circulatory system during exercise and even recovery period.

Interesting finding in this study is the fact that the level of circulating FFA gradually is increased until 30 min after finishing exercise. With the present knowledge, a reasonable explanation for this increase of circulating FFA during recovery period cannot exactly be found. This result is just supported by previous studies. It has been reported that WBV exercise decreases weight, %body fat, total cholesterol, and triglyceride, whereas muscle power, agility, and reaction time significantly increased in obese middle-aged woman (Kim, 2000) and a significant reduction of subcutaneous fat in several part of body was observed in obese middle-aged woman (Jeon, 2001). Moreover, a significant decreased VLDL and %body fat by WBV and diet regime was observed (Moon and Sun, 2003). Together with above studies, this result therefore suggested the possibility that WBV exercise might be useful tool for exercise prescription in obesity.

Many studies have shown that vibration treatment may induce enhancement of muscular function and then improve muscular performance. Strength training with vibratory stimulation for 3 weeks led to an almost 50% increase in the one-repetition-maximum (1RM) compared with an average gain 16% with conventional training and no gain for the control group (Issurin et al., 1994). Bosco et al. (1998) also reported that muscle stimulation by vibration might improve the mechanical power

of the lower limbs in elite athletes by means of neural adaptation and the improvement of the muscle performance after a short period of vibration training was to be similar to what occurs after several weeks of heavy resistance training. In another studies, acute treatment with WBV increase leg muscle force (F) and power (W) after 10 min of vibration treatment and WBV increased the average velocity, average force and average power in well-trained subjects (Bosco et al., 1999a; Bosco et al., 1999b).

Related to EMG, the root mean square (RMS) of the associated EMG did not change following the vibration treatment, but the ratio of EMG/W decreased showing an enhancement of neural efficiency (Bosco et al., 1999b). In another experiments, the EMG recorded in the biceps brachii of the experimental group in the study conducted on boxers showed a significant enhancement of the neural activity during the treatment period, as compared to normal conditions (Bosco et al., 1999a). Similar to previous results, the present results showed that WBV treatment with different frequency elicits muscle activation of various part of body. Therefore, it can be suggested that WBV treatment induces muscle activation and therefore muscle training.

However, the results obtained in this study is distinguished from the results of previous studies. Most previous studies used relatively high-frequency vibration. Runge et al. (2000) showed 27 Hz vibration elicits gains of 18% in chair-rising time in elderly persons after 12 weeks WBV training and Torvinen et al. (2003) reported that 25-30 Hz frequencies with WBV significantly induces increase of 8.5% in jump performance after 4 month in young nonathletic adults. Additionally, Kerschman-Schindl et al. (2001) suggested that a short-term exposure to WBV with 26 Hz frequency does not have the negative effects know from long-term exposure to high frequency. In contrast, some studies reported that high frequency vibration more than 80 Hz led to different degrees of degeneration of muscle fibers in some muscle (Necking et al., 1996).

In the present study, lower frequencies than 10 Hz is relatively more effective than higher frequencies for activating muscle training. Vibration with 8Hz mostly increases activity of all muscles used in this study. Consistent with the present result, WBV with 5 Hz frequency induced vibration-synchronous EMG activity in the erector spinae muscle compared to the non-WBV treatment (Kerschman-Schindl, et al., 2001). It is, therefore, postulated that the duration and frequency of the vibration seems to be both relevant and important.

In conclusion, the present results showed that WBV exercise may activate the lipid metabolism increasing the rate of mobilization on circulating FFA and then improve efficiency

of aerobic exercise. This result, therefore, suggested the possibility that WBV exercise might be useful tool for exercise prescription in obesity. On the other hand, the present results also suggested that WBV exercise has an positive effect on muscle activation and activating muscle is different according to the vibration frequency. In particular, lower frequencies is relatively more effective than higher frequencies for activating muscle. Most of all, the frequency of vibration is the crucial points considering a positive or negative results in further WBV study on circulatory system and muscle activation.

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