The Comparison of "Whole Body Vibration "and" Routine Exercise Therapy" for a Period of 6 Weeks on Navicular Drop in Children with Bilateral Flexible Flat Foot

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Abstract

Introduction: Flat foot is a condition with decreased neutral foot arch due to different factors such as muscle weakness. It can cause excessive pronation of subtalar joint in the stance phase of the gait cycle, increasing of external rotation of the femur, apparent changes in lower limbs kinematics and also gait dysfunctions. Various studies showed the effects of the whole-body vibration on the strengthening of knee musculature, especially in a patient with anterior cruciate ligament deficiency. None of the study reported the positive impact of whole-body vibration in foot dysfunctions. The current study aimed to evaluate the navicular drop changes in children aged 6-12 years with flexible flat feet. **Materials and Methods:** The current Quasi-Experimental study enrolled 44 children (girls and boys, aged 6-12 years) with a flexible flat footand divided into two groups of 22 participants. One group received whole-body vibration, and the other group received routine exercise therapy for six weeks. The navicular drop was measured before and immediately after six weeks. **Results:** The results showed a significant change in both the groups in the direction of treatment of flat foot ($P<0.001$). However, the changes were more prominent in whole-body vibration group (47%) than the exercise group (15%) ($P<0.001$). **Discussion:** These findings show that both the presiders of the whole-bodyvibration and routine exercise therapy could make significant changes in treatments groups. However, whole-body vibration could be more efficient than the exercise therapy. Further studies in this field are recommended using higher number of samples and different age groups.

Key words: Child, Exercise Therapy, Flexible Flat Foot, Medial Longitudinal Arch, Whole Body Vibration

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Introduction

Flatfoot is a posture in which the natural arches of the foot collapse due to several factors, primarily muscle weakness. In this stance, there is an abnormal contact between the medial inside of the foot and the ground while bearing the weight (1). The presence of Transverse Arch, Medial Longitudinal Arch, and Lateral Longitudinal Arch can cause shock absorption and lower limb movement in routine activities (2). Nevertheless, many researchers disagree about the age of the full arches of the foot, especially the medial longitudinal arch, similar to that of adults. Various studies were perfomed on this topic in the children of different age groups such as the age of two (3), six (4), between six and eight (5), or even at nine years (6). The prevalence of flatfoot in children ranges from 0.6 to 77.9% depending on the age and the assessment method, but the incidence in studies conducted in children aged 8 to 13 years was 0.4 to 19.1% (7). Additionally, in a study in Iran, the prevalence of this complication has been reported 11.8% (8).

Flatfoot due to the postural morphology of the foot can cause pain in the foot inside, knees, hips, and waist, walking difficulties, decreased endurance, excessive pronation of subtalar joint during the stance phase of Gait, increased external rotation of femur and clear kinematic changes of the lower limbs (9, 10). Excessive foot pronation also causes overuse syndromes such as Plantar Fascia Inflammation (11), Hallux Valgus (12, 13), Achill Tendonitis,

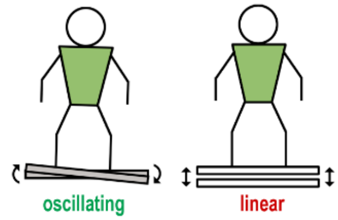

Figure 1. Whole Body Vibration (WBV) Tool

Tibia is Posterior Tendon Dysfunctions (15), and Patellofemoral Painful Syndrome (16) and increases the incidence of early arthritis (5).

The treatments used for flatfeet deformity mainly include surgical procedures, custom-made orthosis and exercise therapies. Surgical treatment is limited and primarily in rigid flat foot cases and patients who have not been cured by other treatments (17, 18). Custom-made orthosis is applied for pain (19), arthritis (20), in the unusual morphology of the foot, and in the cases that do not respond to other treatments (21). Various studies on exercise therapy indicate the role of foot intrinsic muscles (Tibialis Anterior Muscle, Tibialis Posterior Muscle, and Peroneus Longus Muscle) in stabilizing and supporting the Medial Longitudinal Arch during the stance phase of gait. Additionally, the role of Foot Extrinsic Muscles (Abductor HallusisLongus Muscle and Flexor DigitrumBrevis Muscle) in stabilizing the Medial Longitudinal Arch during the propulsion (22, 23).

Studies have also shown the effects of short-feet exercises on decreasing navicular drop and increasing the Arch Height Index and also the impact of Toe Curl exercise on increasing the electromyographic activity of the abductor hallucis muscle (24, 25).

WBV (Whole Body Vibration) device is an exercise platform with sinusoidal waves and repetitive amplitude of <1 to 10 mm, acceleration from 1 to 15 g (g is the gravity equal to 9.8 m/s^2) (26, 27) and the frequency between 1 and 50 Hz (28). This exercise device is presented in two forms: Vertical (linear) and Oscillatory (Side Alternative) (27). The Oscillatory is more comfortable than the Vertical due to less vibration transmission to the head and neck (29-31) (Figure 1, 2).

The aim of the present study was to determine the effect of WBV device in children and measured the increased speed and pace, increased thickness of Tibialis Anterior Muscle and Soleus Muscle (32), increased strength and mobility of the lower limbs(33), increased volume of Femoral and Par spinal muscles (34, 35), and increased strength and volume of quadriceps muscles (36). Various studies have shown the effectiveness of using WBV device on strengthening the knee muscles especially in patients (Figure 2).

Figure 2. The position of subjects on the WBV tool

with Anterior Cruciate Ligament Deficiency (37). In most studies, it is necessary for the therapists and researchers to find simple, understandable, and more controllable exercises. The purpose of the present study is to compare the effects of using WBV device and exercise therapy on Navicular Drop in children aged 6-12 years with bilateral flexible flat foot.

Materials and Methods

In this quasi-experimental study, 44 girls and boys aged 6 to 12 years with bilateral flexible flat foot were selected from the schools of Amol city, Mazandaran provience, Iran using simple random sampling method. The selection criteria were the presence of Navicular Drop more than 9 mm in sitting and standing positions (38), the positive jack test result (observation of inflammation in the hind foot), and the external rotation of foot and the improvement of the foot arch without external rotation of tibia during the passive extension of the thumb while standing on both feet (39, 40)). The inclusion criteria were children (girl and boy) aged 6-12 year with flexible flat foot; lack of lower limb fractures (in the last 6 months) and unhealed fractures in the whole body (in the last year); no history of lower limb surgery, neuromuscular diseases, balance and chromosomal disorders, and systemic diseases such as cancer; lack of hearing or vision problems; no gait abnormalities; no history of musculoskeletal deformities in the lower limbs such as Club Foot, lack of stiffness in the plantar flexor muscles and difficulty in the range of wrist and foot joints; lack of using WBV device or entry into the scheduled progressive exercises in the last three months, and no simultaneous orthosis or exercise therapy. The exclusion criteria were unilateral flatfoot and the unwillingness of the

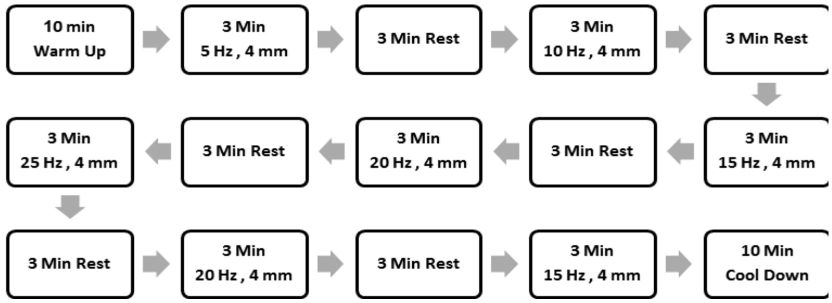

Figure 3. The protocol used in this study (according to Lee *et al.*, 2013)

child or parents to continue the treatment. After selecting the subjects and explaining the procedure and also filling the consent form (Appendix 1), the height, weight, and body mass index (BMI) of children were recorded. Then, the subjects were divided into two groups (n=22 each) in the form of permutation randomized blocks. The two WBV devices and exercise therapy groups were matched regarding age, sex, and BMI. The subjects were received three sessions per week intervention for six weeks. Selected treatment protocol in the WBV group was determined according to *Lee et al.* (32). The type of vibration in all cases was considered to be oscillatory or see-saw and side alternative.

The subjects were asked to warm up (for ten minutes using the fixed bike) and 20 sets of sitting down and standing up and enter the intervention stage after 3 minutes of active rest, including walking. At the end of the intervention, the 10 minutes cool down exercise including slow walking was performed. The treatment protocol in this group, according to the program recommended by Lee *et al.* (32), includes 3 minutes WBV with frequencies of 5, 10, 15, 20, 25, 20, and eventually 15 Hz, respectively, and the amplitude of 4 mm with 3-minute rest between each stage (Figure 4). The child's position on the device was 30 to 100 degrees scout workout to prevent vibration transmission to the head and neck. The patient was asked to bend forward and try to maintain balance without relying on the shield (Figures 2, 3)

The Fit Massage WBV (Luch Rich company, China), was used in this, whose vibration intensity was graded from one to 50 (Figure 4).

Intervention protocol in the exercise therapy group:

The subjects in this group were treated with Intrinsic (short feet) and Extrinsic Muscles (toe curl) (Figure 5). For short feet exercise, according to the 2006 Bahram Jam Protocol (41), the child was asked to stand against the wall, open the shoulders as wide as the shoulder width, bend the knees slightly, and put the tip of fingers on the front wall to prevent the imbalance. Afterthat, the child was asked to keep foot in Subtalar Joint neutral posture, for this purpose, the child was asked to keep the foot in a state of supination, as stood on its two feet and while slowly lifting its fingers. In this posture, keeping the medial longitudinal arch of the foot, the child tries to put fingers back on the floor. If the child didn't understand the exercise, he/she was asked to make the heel and paw closer without lifting the head of the metatarsus, while keeping the foot supinate. Once the child retained the medial longitudinal arch, he/she was asked to stand on one leg and bend the bearing knee by 10 to 20 degrees, so that the contraction of the quadriceps muscle facilitates the contraction of the intrinsic muscles of the foot. The child was asked to hold the posture for 10 seconds, and then slowly pronate the foot (Figure6). The above steps were repeated after one or two seconds. The child should have 5 sets of this exercise including Concentric Muscle Contraction, Isometric Muscle Contraction, and Eccentric Muscle Contraction (during release) of the intrinsic muscles for 10 to 15 times a day.

Toe Curl exercise were perfomed according to the protocol described by Shiroshima, (42). Ten isometric contractions of the flexor muscles of the fingers and thumbs were performed by the child. Then a towel was placed under the child's feet and was asked to perform the Towel Gathering exercise twice a day and each time three sets of five, resting for one minute between each set. The Navicular Drop rate of children's feet was recorded before and immediately six weeks after the intervention.

In the Navicular Drop Test, first the uppermost point of the navicular bone was touched, and then the foot was passively in the neutral position of the subtalarjoint so that the child was asked to extend the toes and put the fingers slowly and passively on the floor while keeping the medial longitudinal arch. The distance to the ground and the height of this bony prominence from the ground in standing position using the caliper, and the difference between the two numbers is the Navicular Drop was recorded (41, 43) (Figure 6). Given the quantitative nature of dependent variables and the existence of two independent groups in this study, we used the following formula to determine the number of the necessary samples in each group:

$n=(Z_{1-\alpha/2}+Z_{1-\beta})^2(\sigma_1^2+\sigma_2^2)/(\mu_1-\mu_2)^2$

Figure 4. The WBV device used in the study

Based on this formula and assuming the first-type error $\alpha=0.05$ ($Z_{1-\alpha/2}=1.96$) and the second-type error $\beta=0.2$ ($Z_{1-\beta}=0.84$), it means that the test power is 80% and extraction of $\sigma_1=1$ and $\sigma_2=1.2$, and $\mu_1=27$ and $\mu_2=28$ according to Ibrahim *et al.* (44), the number of samples was 22 in each group and 44 in total.

Data were designed in the form of quantitative and qualitative variables in Excel. After the end of the study, SPSS version 24 was used for statistical analysis.

Results

Before giving descriptive and analytical results, the rate of repeatability of variables was obtained using the device used in the study, and the following results were obtained.

Repeatability (ICC) of Measurement Tools

Before the main study, to examine the reproducibility of the tools, three tests (the first stage in the morning, the second stage in the evening of the same day, and the third stage three days later) were performed on six children with flexible flat foot and the Navicular Drop was measured in the samples. The repeatability values are given in the table 1.

Since the ICC value was higher than 0.8, the repeatability was evaluated to be "excellent," and the results can be generalized.

According to the data from table 2, the studies showed that there were no significant differences between the two groups regarding the underlying variables of age, height, gender, weight, and BMI. So the results can be cited for both groups.

The Kolmogorov-Smirnov test was used to evaluate the distribution of numerical variables regarding compliance with theoretical normal distribution.

According to table 3, the distribution of data for this variable follows the normal distribution. Therefore, paired t-test was used to examine the differences before and after the intervention.

Since there was a significant difference between the two groups in Navicular Drop of right and left foot in the baseline, Analysis of covariance was used to compare the two groups more accurately and to adapt the differences between the two groups in the baseline as follows:

Figure 5. From right: the correct and wrong way to practice Short Feet

In the currentstudy, Navicular Drop value in the WBV group for the right foot was reduced significantlly (47%) after the intervention ($P<0.001$). However, it decreased by only 15% in the exercise therapy group, which was also significant ($P<0.001$). In other words, the Navicular Drop reduced more prominently in the WBV group in comparison to exercise therapy group.

The analysis of navicular drop parameter for the left foot showed significant (47%, $P<0.001$) reduction after the intervention in the WBV group. However, in the exercise therapy group also reduction was significant (13%, $P<0.001$). The changes in the WBV group for navicular drop were more evident that the exercise therapy group ($P<0.001$).

Discussion

Both WBV and exercise groups were able to make significant improvements in the navicular drop of the samples' right and left foot after six weeks, while these changes were significant in the WBV group ($P<0.05$).

Various studies have documented different mechanisms for the physiology of the effects of WBV on the body. Vibration stimulates the muscle spindles and alpha motor neurons, as well as intramuscular contractions, followed by the activation of Tonic vibration reflex through single and multiple synaptic paths and eventually increased the activity of the motor units (45, 46). The stimulation of tonic vibration reflex activates the muscle duct and also triggers the stretch reflex and increases the level of electromyographic activity of the muscles. Also, the vibration applied at different frequencies enables the sensory cortex activation of the primary and secondary body, along with the supplementary, caudal cingulate and the 4a area in the brain (47).

Studies have also shown that the use of WBV has increased strength and power, which can be attributed to changes in neuropsychiatric factors, such as increased recruitment, muscle adaptation, and increased proprioceptive sense (45). Studies have

Figure 6. Navicular Drop in sitting (right) and standing (left) positions

also shown that increased electromyography activity of the muscles following the vibration is a result of rapid change in the movement of muscle spindles to modulate the incoming waves, increased the sensitivity of contraction units to calcium and thus increased neuromuscular activity (45, 48).

The body has various structures and mechanisms for reducing vibrational amplitudes such as bones, cartilage, synovial fluid, soft tissue as well as muscles, which can be used as a response known as "Tuning." The use of muscle activity to reduce vibration amplitude is called the "Muscle Tuning" strategy (27). During vibration, the vibrational waves from the distal muscle group reach more proximal muscle groups. According to this law, the vibration increases the electromyogram activity of the muscles at the level of the actin and myosin strands of each cross-bridge (27, 28).

The effect of the WBV device is related to individual posture and previous muscle activity. The muscles that stretched higher during the vibration will be more affected (30). In the present study, to concentrate the effects of vibration, individuals were asked to bend their knees between 30 to 100 degrees during the vibration and then try to keep their balance. In this case, the muscles of the lower limbs are in a stretched posture and show little fundamental activity.

According to studies, the best frequency required to influence the muscles under the knee was between 5 and 25 Hz with 4 to 6 mm amplitude (32-36, 49), so the present study was performed at a frequency of 5 to 25 Hz and an amplitude of 4 mm.

Various studies performed on adult population have shown the significant effect of WBV device on increased knee extensor muscle strength and jump height (50), dynamic and isometric strength of knee extensor muscles (51), lower limb muscle strength in patients with muscular imbalance (52), the strength of ankle muscles in non-athlete women (53), and the muscle contractility as well as the strength of ankle plantar flexor muscles at lower speeds in the young skiers (54), improved muscular performance of the lower limbs (55), and increased activity of Surface EMG of the anterior tibialis muscles in athletes and non-athletes (56).

Studies have also reported that the use of WBV device had reduced the rehabilitation and re-exercise time to half of the standard exercise therapy and the stability was increased significantly in patients undergoing anterior cruciate ligament (ACL) reconstruction. Although no significant increase has been observed in the isometric and isotonic strength of the knee muscles, the result can be attributed to the strengthening of other muscles of the lower extremity and thus the improved knee function (37). Studies on children have reported contradictory results (57, 32, 35, 36, 37, 49). There are some studies which are consistent (57, 36, 32) with the results of the present study and some are contradict (35, 49).

The results of this study are not consistent with the results of the study performed by Gilsanz *et al*., may be due the fact that their intervention lasted 52 weeks, while the present study was performed for six weeks. One of the drawbacks of the study by Gilsanz *et al.* was the use of above 30 Hz frequency and low amplitude that increased the para-spinal muscle cross-section without affecting the lower limb muscles.

The results of the present study are consistent with the study conducted by Semler *et al.* regarding the strengthening of the lower limb muscles after WBV (57). Among the positive aspects of the study conducted by Semler *et al.* was the use of 15 to 25 Hz vibration frequency, while the negative aspect was not determining the correct position according to the Muscle Tuning Law (the samples were treated while lying on their back with their feet on the platform).

The present study was consistent with the study of Stark *et al.* regarding the increased volume and maximal force of knee extensors (36). The positive aspect of this study was the use of a 5 to 25 Hz frequency and a 0 to 7.8 mm amplitude. One of the shortcoming with this study was to place the subject standing without any particular position on the WBV device.

The results of the present study are not in corroboration with the study of Wren *et al.* (49), since the intervention was seven times a week for 26 weeks, while the present study was carried out three times a week for six weeks. One of the drawbacks of this study is the use of frequency above 25 Hz (30 Hz) and less than one-millimeter amplitude, which can be the reason for insignificant effect on the strength of cuff muscles.

The results of this study are consistent with the results of the Lee and Chon (32). In the Lee and Chon study, children aged 8 to 12 years were placed in two groups, WBV and control. The subjects were exposed to WBV at a frequency of 5 to 25 Hz and an amplitudeof1to 9mm with a position of 30to100 degrees of knee flexion for eight weeks, three times a week, and for 18 minutes a day. Three minutes of vibration (5 to 25 hz) and three minutes of rest between each step as well as warm up and cool down for 10 minutes each was carried out. The results showed a significant

Table 1. Repeatability values of NDT, in right and left foot (n=6)

Variable	ICC
NDT Right Foot	0.913
NDT Left Foot	0.918

Table 2.The individual characteristics of the participants in the study for the two groups (n=44)

Parameter	Groups		*P*-value
	WBV(n=22)15 girls and 7 boys	Exercise (n=22)14 girls and 8 boys	
Age (year)	8.8 (1.3)	9.1 (1.4)	0.376
Height (cm)	133.4 (7.7)	132.5 (8.2)	0.707
Weight (kg)	30.5 (7.1)	33.3 (10.2)	0.285
BMI	17(2.8)	18.8 (4.6)	0.126

Table 3. The mean of the results of the variables before and after the intervention

Parameter	Right/Left	Groups	Pre-intervention	Post-intervention	*P*-value	↓↑	(ANCOVA)
Navicular Drop(mm)	Right	WBV	13.2 (0.6)	7 (0.7)	<0.001*	47%↓	<0.001*
		Exs	15.2 (0.6)	12.9 (0.5)	<0.001*	15%↓	
	Left	WBV	13.4 (0.7)	7.1 (0.5)	<0.001*	47%↓	<0.001*
		Exs	15.5 (0.7)	13.5 (0.5)	<0.001*	13%↓	

**: Significant, ND: Navicular Drop, WBV: Whole Body Vibration, Exs: Exercise*

increase in gait speed, pace, and thickness of the anterior and soleus tibialis muscles, while there was no change in the diameter of the gastrocnemius muscle. The results of the Lee and Chon study support the results of the current study with similar protocol and statistical population.

The results of the present study were inconsistent with the results of OKeefe *et al*., 2013 (58), which indicate that there was no effect on muscle strength after using WBV. The limitations of the OKeefe study were the use of a short-range frequency (22 Hz), the amplitude of 1mm and small sample size (n=7).

The problem of treating flat foot with exercise therapy is not to ensure that children have performed the exercises properly. Therefore, there is a need for a more accurate treatment with the ability to monitor the correct procedure. One of the strengths of the present study is the use of the WBV device to control the treatment process more precisely, using a frequency range of 5 to 25 Hz in stepwise manner (increase and decrease), with the gradual warmupcooldown of the body, the vibration amplitude of 4 mm, and the comparison of two WBV and exercise therapies. The limitations of the present study were the uncertainty about performing the therapeutic exercises in the exercise group. Further studies are needed to investigate the long-term effects of WBV on children with flatfoot at different ages, with more subjects, with follow-ups, as well as patients with disorders such as shine splint, foot pain in patients with rheumatoid arthritis, diabetic foot, etc.

Conclusion

The present study indicated that although WBV and exercise therapies were able to make a significant improvement in the navicular drop as a factor of the medial longitudinal arch of the foot, the changes in the WBV group were more significant than the exercise group (P<0.05). Based on studies explicitly conducted in patients with ACL deficiency, the WBV, despite the general effects on the entire muscles of the lower limbs, has strengthened the local muscles, which is also observed in the present study. It seems that the WBV in the present study also strengthened intrinsic and extrinsic local muscles of the foot, which improves the medial longitudinal arch following the strengthening of the involved muscles, and has caused this difference in the physical parameters affecting the WBV group compared to the exercise group. Considering the positive effects of using this method in reducing the rehabilitation period of patients with ACL deficiency and also the ability to control the stages of work more precisely than usual exercise therapy, this treatment is recommended as an efficient way to improve the flat foot.

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Authors' contributions:
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