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The Effects of Squat Exercises with Vertical Whole-Body Vibration on the Center of Pressure and Trunk Muscle Activity in Patients with Low Back Pain

Background: Patients with low back pain (LBP) experience misalignments in the center of pressure (COP) and muscle imbalances due to frequent one-sided posture adjustments to avoid pain.
Objectives: To identify the effects of Squat Exercises with Vertical Whole-Body Vibration on the Center of Pressure and Trunk Muscle Activity.
Design: Randomized controlled trial.
Methods: Thirty LBP patients with an imbalance in the COP were sampled and randomly assigned to an experimental group of 15 patients who under went an intervention involving squat exercises with vertical WBV and a control group of 15 patients who were treated via a walking intervention. As pretests before the interventions, the subjects' COP was identified by measuring their stability index (ST), and erector spinae, rectus abdominis, transverse abdominis, gluteus medius muscle activity was analyzed by determining the % reference voluntary contraction (%RVC) value using surface electromyography while sit to stand. After four weeks, a post test was conducted to remeasure the same variables using the same methods.
Results: Statistically significant differences were found in the ST ($P<.01$) and trunk muscle ($P<.05$, $P<.001$) in the experimental group before and after the intervention. In terms of the differences between the left- and right-side (RL) muscle activity, only the transverse abdominis (TrA) and gluteus medius (GM) exhibited statistically significant increase ($P<.05$). A comparison of the groups showed statistically significant differences in the TrA with respect to muscle activity ($P<.05$) and in the RLTrA and RLGM in terms ofthe difference between left- and right-side muscle activity ($P<.01$).
Conclusion: Squat exercises with vertical WBV produced effective changes in the COP of patients with LBP by reducing muscle imbalances through the delivery of a uniform force. In particular, strengthening the TrA and reducing an imbalance in the GM were determined to be important factors in improving the COP.

Keywords: *Low back pain; Muscle activity; Vertical whole-body vibration*

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INTRODUCTION

Balance is the ability to maintain the body's center of gravity with minimal swaying within the base of support.[1] Balance ability is known as a highly complex function that maintains posture with various functional elements via interactions between the nervous system and the musculoskeletal system.[2] This balance control can be undermined not only when the components of balance are not integrated properly, but also when any of the related sensory or motor elements become defective.[3] Individuals with Low back pain therefore frequently experience declines in their balance ability. Low back pain (LBP) can occur in anyone regardless of gender and age, and about 60%–80% of individuals experience LBP in their life time.[4] Although most LBP cases are cured, 5%–15% of them continue without responding to treatment, which points to the importance of enhancing balance ability.[5] In addition, people with LBP are more likely to develop an imbalance in the muscles of the hip joint than those without LBP, and at least 15% of all LBP patients experience imbalanced muscle strength around the hip joint.[6] Notably, about 60% of LBP patients exhibit a weakening of the gluteus medius.[7] The resolution of imbalances in the hip joint therefore have positive implications for the treatment of LBP by increasing lumbar stability and thereby enhancing efficiency in the performance of complex exercises and promoting protection from damage in the region[8] and muscle imbalance causes a change in weight, and is closely related to core muscle and gluteus medius at body balance.[7,8]

Squats are the most suitable closed kinetic chain exercise for simultaneously developing the thigh and calf muscles, rectus abdominis, external oblique, internal oblique, and transverse abdominis.[9,10] Trunk stability, which is one of the roles that core muscles such as the transverse abdominis, internal oblique, and external oblique perform, is considered an important variable in the prevention of spinal cord injuries and the rehabilitation of LBP patients. The simultaneous contraction of the core muscle saids the lumbar vertebrae in the same way as a corset, maintains the spine's neutral position regardless of its location, and provides stability to the spinal segments during functional exercise.[11] In recent years, it has become possible to enhance these effects through the application of a type of exercise that allows individuals to apply vibrations to their whole body while standing on a vibration plate. These whole-body vibration (WBV) exercises induce responses and adjustments in the neuromuscular system through the application of various frequencies of mechanical stimulations to sensory receptors such as muscle spindles.[12] WBV is an exercise method that develops the whole body's muscular strength instead of that of only specific areas. It is also an effective exercise method for improving muscular strength as well as balance and gait abilities.[13,14] Despite many studies having been conducted on WBV exercises, additional research is needed to understand muscle imbalance improvement through WBV exercises. This study therefore aimed to investigate the effects of an intervention involving squats with vertical WBV on the center of pressure (COP) and muscle activity in LBP patients who were experiencing severe muscle imbalances due to one-sided movements and distorted postures in response to pain. In addition, the study aimed to provide basic clinical data on the effects of symmetry exercises on the recovery of LBP patients with COP misalignment by analyzing the relationship between the left- and right-side muscular differences and balance.

SUBJECTS AND METHODS

Subjects

This study was conducted after receiving approval from the Institutional Review Board of Sehan University (SH-IRB 2019-52). It involved 30 LBP patients who received treatment at J Hospital in Seoul city between December 2019 and February 2020. The patients were advised of and understood the study's purpose and agreed to participate. The patients who met the following criteria were included in the study:

1) Have an imbalance of the COP
2) A pain index score of at least 5 points
3) Have no spine-related diseases such as fractures or spondylolisthesis on X-ray
4) Have no orthopedic or neurological diseases
5) Have no history of surgery

The 30 clinically sampled LBP patients were randomly divided two groups, each comprising 15 patients. The experimental group received an intervention involving squat exercises with vertical WBV while the control group was required to do a walking exercise (Table 1).

Outcomes Measure

Stability Index

A postural balance analysis system (Tetrax) was used to evaluate the patients' static balance ability. This system identifies vibrations during specific postures from the COP's movement patterns, and these are measured with pressure sensors using force plates. Force plates are four independent ground reaction force measuring devices for the heel and toes of subjects' left and right feet. If the stability index is greater than 0, the COP can be considered unbalanced. In this study, the stability index (ST) in a standing position with the eyes open and the head straight was selected from among a total of eight postures available for measurement. This evaluation tool has shown high reliability with test-retest reliability of r=0.89.[15,16]

Muscle Activity

Muscle activity around the lumbar region was measure dusing the eight–channel MP 150 system (Biopac, USA) to collect the surface electro magnetic signals. Electromagnetic electrodes were attached to a point 3 cm lateral to the L2 spinous process in the erector spinae (ES), a point 2 cm lateral to the navel in the rectus abdominus (RA), a middle point (the inguinal ligament's upper region) between the anterior superior iliac spine and the pelvic midline in the transverse abdominis (TrA), and the proximal one third of the line from the crista iliaca to the greater trochanter in the gluteus medius (GM).[17] The %RVC method was used to normalize the measured values. The effective amplitude values during the performance of the reference motions were measured while the subjects were in the standing position for five seconds, and the mean value for three seconds, which excluded the first and last seconds, was adopted. The effective amplitude value during a specific motion was set as the mean value of three measurements during the sit–to–stand exercise in the reference positions.

$$\frac{\text{Peak envelop mean value of RMS during sit–to–stand}}{\text{Peak envelop mean value of RMS during standing position}} \times 100 = \%\text{RVC}$$

Interventions

In this study, a sonic wave vibration exercise device (Turbosonic) was employed for the WBV exercises. This device can be utilized according to the user's physical conditions given that it can be operated at a low–frequency (Hz) in the sonic wave vibration mode, and its power can be controlled precisely. Experimental group had their muscles relaxed at a frequency of 20 Hz or below for the first and last 5 minutes of their exercises at standing, and a frequency of 30 Hz was applied to the main exercise for 10 minutes. The half squat was applied for 10 minutes by repeating 20 seconds hold and 40 seconds rest within 1 minute and exercise was applied for 4 weeks. At the beginning and end of the exercises, each subject performed a vibration exercise in a comfortable standing position while holding on to an attached handle. During the main exercise, they repeatedly maintained a static half–squat position at a knee angle of 120° while keeping the spine straight until there was no pain or compensatory action.[18] The control group walked for 30 minutes at speed 5 on the treadmill for 4 weeks.

Data and Statistical Analysis

SPSS 20.0 for Windows was used for data processing to produce the means and standard deviations of the measurement items. Levene's test was performed to test the homogeneity of the subjects' general characteristics. In addition, paired t–tests were employed to compare the changes in each group before and after the intervention, and an analysis of covariance was used to compare the differences in the changes between the two groups. And muscle activity was analyzed using the mean and difference in EMG activity between left and right sides, the right EMG value and the left EMG value were subtracted and applied as a positive number. The significance level was set at α=.05.

RESULTS

Comparison of changes in the COP and muscle activity and differences between the left– and right–side muscle activity in the experimental group

Based on a comparison of the variables in the experimental group before and after the intervention, the ST showed a statistically significant decrease with regard to the COP ($P<.01$), and trunk muscle exhibiteda statistically significant increase in terms of muscle activity ($P<.05$, $P<.001$) (Table 2). With respect to the differences between the left– and right–side muscle activity, only the transverse abdominis and the gluteus medius showed statistically significant decrease after the intervention ($P<.05$) (Table 2).

Comparison of changes in the COP and muscle activity in the control group

Based on a comparison of the variables in the control group before and after the intervention, the ST showed a statistically significant decrease terms of the COP ($P<.05$), whereas only the erector spinae and the gluteus medius exhibited statistically significant increase in terms of muscle activity ($P<.01$) (Table 2).

With respect to the differences between the left- and right-side muscle activity, only the erector spinae showed a statistically significant difference after the intervention ($P<.05$) (Table 2).

Table 1. General characteristic of subjects

Items	Experimental group (n=15) M±SD	Control group (n=15) M±SD	P'
Gender (male/female)	15 / 0	15 / 0	
Age (years)	37.8 ± 5.85	36.7 ± 8.62	.186
Height (cm)	171.17 ± 5.27	173.67 ± 5.84	.635
Weight (kg)	72.98 ± 7.36	77.18 ± 8.12	.785
SMM (kg)	29.32 ± 6.43	31.98 ± 6.89	.892
BMI (kg/m^2)	22.712 ± 4.78	23.27 ± 3.72	.368

Experimental group: Squat exercise with vertical whole-body vibration
Control group: Walking exercise
SMM: Skeletal muscle mass, BMI: Body mass index

Table 2. Comparison of changes in center of pressure and muscle activity within experimental group

Items		Pre-test (M±SD)	Post-test (M±SD)	t	P
ST	Experimental group	22.51 ± 6.12	16.19 ± 5.78	6.763	.001**
	Control group	23.28 ± 5.75	20.15 ± 7.95	2.558	.011*
RA	Experimental group	318.96 ± 27.98	397.25 ± 42.78	-7.224	.000***
	Control group	322.12 ± 31.42	375.22 ± 28.45	-2.184	.073
ES	Experimental group	598.45 ± 69.25	700.14 ± 78.64	-7.536	.021*
	Control group	587.65 ± 75.34	687.41 ± 81.23	-4.935	.001**
TrA	Experimental group	247.86 ± 33.81	317.58 ± 39.58	-8.629	.035*
	Control group	230.49 ± 29.45	254.36 ± 31.71	-.935	.313
GM	Experimental group	338.18 ± 45.78	467.25 ± 61.48	-6.093	.000***
	Control group	341.45 ± 38.59	451.38 ± 51.94	-4.646	.002**
RLRA	Experimental group	41.55 ± 31.57	32.64 ± 18.75	.875	.396
	Control group	35.87 ± 25.98	48.74 ± 38.13	-1.652	.121
RLES	Experimental group	106.42 ± 98.65	97.42 ± 83.93	.823	.424
	Control group	108.08 ± 115.71	105.11 ± 19.09	.14	.048*
RLTrA	Experimental group	33.57 ± 26.47	15.66 ± 16.01	2.623	.02*
	Control group	31.54 ± 25.94	26.42 ± 25.32	-.669	.515
RLGM	Experimental group	30.11 ± 21.48	24.19 ± 14.29	2.331	.035*
	Control group	31.42 ± 18.21	34.78 ± 25.52	-1.021	.325

'Paired t-test
*$P<.05$, **$P<.01$, ***$P<.001$
Experimental group: Squat exercise with vertical whole-body vibration
Control group: Walking exercise
ST: Stability index, RA: Rectus abdominis, ES: Erector spinae
TrA: Transverse abdominis, GM: Gluteus medius
RLRA: | Right RA-left RA |, RLES: | Right ES-left ES |
RLTrA: | Right TrA-left TrA |, RLGM: | Right GM-left GM |

Comparison of changes in the COP and muscle activity between the groups

In the comparison of the COP between the groups before and after the intervention, the ST showed no statistically significant difference (Table 2). When comparing muscle activity, only the transverse abdominis exhibited a statistically significant difference ($P<.01$). In terms of the differences between the left- and right-side muscle activity, only the transverse abdominis and the gluteus medius produced statistically significant differences after the intervention ($P<.05$) (Table 3).

DISCUSSION

LBP patients experience gait problem when any sensory or motor elements are impaired. Their ability to control balance declines, and this is followed by muscle imbalances and muscular weakening not only in the trunk muscles, but also in the hip muscles, such as the gluteus medius.[3] It was therefore necessary to investigate the effects of an intervention comprising squat exercises with WBV on the COP with the aim of alleviating these problems.

A study by Torvinen et al.[19] found a statistically significant improvement in balance ability among

Table 3. Comparison of changes in center of pressure and muscle activity between groups

Items		Pre-test (M±SD)	Post-test (M±SD)	F	P'
ST	Experimental group	22.51 ± 6.12	16.19 ± 5.78	1.807	.19
	Control group	23.28 ± 5.75	20.15 ± 7.95		
RA	Experimental group	318.96 ± 27.98	397.25 ± 42.78	1.161	.291
	Control group	322.12 ± 31.42	375.22 ± 28.45		
ES	Experimental group	598.45 ± 69.25	700.14 ± 78.64	3.292	.081
	Control group	587.65 ± 75.34	687.41 ± 81.23		
TrA	Experimental group	247.86 ± 33.81	317.58 ± 39.58	8.32	.008**
	Control group	230.49 ± 29.45	254.36 ± 31.71		
GM	Experimental group	338.18 ± 45.78	467.25 ± 61.48	.625	.424
	Control group	341.45 ± 38.59	451.38 ± 51.94		
RLRA	Experimental group	41.55 ± 31.57	32.64 ± 18.75	.806	.377
	Control group	35.87 ± 25.98	48.74 ± 38.13		
RLES	Experimental group	106.42 ± 98.65	97.42 ± 83.93	.035	.853
	Control group	108.08 ± 115.71	105.11 ± 19.09		
RLTrA	Experimental group	33.57 ± 26.47	15.66 ± 16.01	4.478	.044*
	Control group	31.54 ± 25.94	26.42 ± 25.32		
RLGM	Experimental group	30.11 ± 21.48	24.19 ± 14.29	5.223	.03*
	Control group	31.42 ± 18.21	34.78 ± 25.52		

'Analysis of covariance
*$P<.05$, **$P<.01$
Experimental group: Squat exercise with vertical whole-body vibration
Control group: Walking exercise
ST: Stability index, RA: Rectus abdominis, ES: Erector spinae
TrA: Transverse abdominis, GM: Gluteus medius
RLRA: | Right RA-left RA |, RLES: | Right ES-left ES |
RLTrA: | Right TrA-left TrA |, RLGM: | Right GM-left GM |

participants when WBV exercises were performed. Chen et al.[20] also confirmed the effects of WBV exercises in reducing the COP in their study. The present study similarly showed that the intervention involving squat exercises with WBV reduced the ST by a statistically significant margin. This is because the intervention helped maintain joint stability and balance by having proprioception delivered to the central nervous system via the receptors dispersed over the muscle spindles and the golgitendon organ.[21] Additionally, WBV increases proprioception by stimulating the muscle spindles through repeated concentric and eccentric contractions.[1] This suggests that the effects of sensory training through WBV facilitate proprioception, and training to maintain the COP on uneven surfaces enhances balance ability.

According to a study by Yarar-Fisher et al.,[22] the application of WBV exercises had greater effects on muscular strength improvement in patients than in normal individuals. Furthermore, Karatrantous et al.[23] noted that WBV exercises improve muscular asymmetry. In the present study, the improvements in the transverse abdominis and the imbalance between the left and right muscles after the intervention were similarly statistically significantin the group that underwent vertical WBV. This is because, compared to normal individuals, people with LBP have a high proportion of weight that needs to be supported by their muscles due to muscular weakening.[24] In addition, vibration exercises causesubtle changes in muscle length, and this stimulation activates muscle spindles and α-motor neurons, thereby contracting muscles and eventually stimulating the neuromuscular system.[25] Moreover, muscles around the hip joint largely affect the lumbar region by forming a biomechanical chain with the pelvis and changing pelvic movements following muscular contraction.[26] As a result, the squat movements accompanied by WBV used in the intervention in this study may have strengthened the LBP patients' lumbar muscles and reduced their muscle imbalances by reducing the shearing force of the lower lumbar vertebrae through further activation of the muscles around the hip joint. Bruyere et al.[27] and Eklund et al.[28] reported in their studies that muscular balance is a prerequisite for improving coordination, and muscle imbalances become the cause of muscular weakening or tension. They also asserted that vibration exercises generate the tonic vibration reflex, which can normalize tension in the agonists suppressed by antagonists and play an important role in postural control by inducing the stimulation of sensory afferent neurons in the sole of the foot. This view is supported by the findings of the present study. Accordingly, muscle-strengthening exercises accompanied by WBV are considered effective for patients who experience balance and muscle-related problems such as LBP.

This study had some limitations. First, the study was conducted at a single medical institution and involved only male patients who met its selection criteria. As a result, it would be problematic to generalize the study results to every LBP patient. Second, the subjects' medications, number of doses, or daily lives were not controlled, which could have generated various variables and affected the study results.

CONCLUSION

Patients who develop muscular weakening such as LBP experience severe COP sway and muscle imbalances in response to pain. In addition to the importance of symmetrical exercises, exercises with WBV, which stimulate the α-motor unit while using the left and right muscles evenly, can produce effective changes. Notably, the experimental group in this study showed a statistically significant reduction in COP sway and a statistically significant increase in muscle activity in the transverse abdominis after the intervention. Moreover, there were statistically significant decreases in the difference between the left- and right-side muscle activity in the transverse abdominis and the gluteus medius after the intervention. Accordingly, exercises that strengthen the transverse abdominis and reduce the imbalance of the gluteus medius can be effective in treating LBP patients with muscle imbalances.

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