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Original Article

Effects of ankle biofeedback training on strength, balance, and gait in patients with stroke

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Abstract. [Purpose] This study aimed to investigate the effects of ankle biofeedback training on muscle strength of the ankle joint, balance, and gait in stroke patients. [Subjects and Methods] Twenty-seven subjects who had had a stroke were randomly allocated to either the ankle biofeedback training group (n=14) or control group (n=13). Conventional therapy, which adhered to the neurodevelopmental treatment approach, was administered to both groups for 30 minutes. Furthermore, ankle strengthening exercises were performed by the control group and ankle biofeedback training by the experimental group, each for 30 minutes, 5 days a week for 8 weeks. To test muscle strength, balance, and gait, the Biodex isokinetic dynamometer, functional reach test, and 10 m walk test, respectively, were used. [Results] After the intervention, both groups showed a significant increase in muscle strength on the affected side and improved balance and gait. Significantly greater improvements were observed in the balance and gait of the ankle biofeedback training group compared with the control group, but not in the strength of the dorsiflexor and plantar flexor muscles of the affected side. [Conclusion] This study showed that ankle biofeedback training significantly improves muscle strength of the ankle joint, balance, and gait in patients with stroke.
Key words: Stroke, Biofeedback training, Balance

INTRODUCTION

Although human life expectancy has increased with economic growth and developments in medicine, there are greater numbers of stroke patients because of irregular eating habits, environmental pollution, and excessive stress due to rapid social change[1]. Among 40% of stroke patients, 15 to 30% have severe functional damage[2]. The main symptoms of stroke patients are an imbalance in muscle strength, difficulty in shifting weight toward the affected side, impeded postural control, and gait disturbance[3].

Stroke patients have problems in the transmission process of nervous information involved in the stimulation of the foot, which is delivered to and from the central nervous system through the spinal cord and to the muscles[4]. These factors frequently result in paralysis of the plantar flexor and dorsiflexor muscles and a decrease in motor function and balance due to decreased muscle strength[5]. As a result, ankle strengthening can lead to improvements in the regulation of posture and strength of the dorsiflexor and plantar flexor muscles[6]. This, in turn, increases the impact on the biomechanical torque values[7].

Muscle strength is significantly improved by conventional physical therapy and progressive resistance training applied to the ankle muscles, as well as causing improvements in walking and balance[8]. However, sufficient improvement in the gait of

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Table 1. Comparison of the general characteristics of the subjects in the ABT and control groups

	ABT group (n=14)	Control group (n=13)
Gender (male/female)	8/6	7/6
Age (years)	51.2 ± 5.41	52.8 ± 7.89
Height (cm)	166.0 ± 6.47	164.3 ± 5.44
Weight (kg)	62.8 ± 7.58	62.0 ± 11.25
Lesion side (right/left)	7/9	10/6
MMSE (score)	24.8 ± 3.33	23.0 ± 4.76

Data are expressed as mean ± SD.
MMSE: Mini-Mental State Examination

the resistance exercise group compared with the non-resistance exercise group was not reported in this study. Furthermore, although walking ability, including walking speed, cadence and stride length, were improved with muscle strength training with body weight support in patients with stroke, the number of subjects was too small and the results did not show an apparent effect on the ankle[9]. Given that the effects of ankle strength training on balance are unclear, effective training methods are also unclear in patients with stroke.

Recently, balance training equipment has been used clinically to promote and improve muscle strength and balance in stroke patients[10]. This equipment helps balance by obtaining sufficient support from increased muscle activity of the weakened low extremities, stimulating muscle stability, and maintaining a standing position[11]. The effects of balance training on the strength of the muscles around the ankle and their effects on balance ability remain unclear.

Therefore, the effects of ankle balance training with biofeedback on muscle strength and the impact of improving the strength of the muscles around the ankle through ankle biofeedback training (ABT) on balance in patients with stroke were examined in this study.

SUBJECTS AND METHODS

The subjects of this research were 27 stroke patients hospitalized in the J rehabilitation hospital in Incheon, Korea. All experimental procedures and contents were explained to each participant, who subsequently provided written informed consent. The research protocols were approved by the institutional review board of Sahmyook University.

The inclusion criteria were as follows: presence of hemiparesis secondary to stroke that had occurred less than 2 years but more than 6 months ago; ability to walk 10 m independently with or without an assistive device or person; ability to communicate and understand, as indicated by a Mini-Mental Status Examination score of more than 21 points; and no visual disorders or visual field deficits. Exclusion criteria were use of medication or other therapies for cardiovascular disease or metabolic disorder and known musculoskeletal conditions that would affect the ability to walk safely.

The subjects were assigned to either of the two groups according to gender in a matched pair randomization design for equivalent distribution. Fifteen male and twelve female subjects were divided into the ABT (male: female, 8:6) and control groups (male: female, 7:6). There were no significant differences between the two groups in terms of their general characteristics (Table 1). Training for 30 minutes a day after the neurodevelopmental treatment, 5 times a week for 8 weeks was provided to all subjects. All participants were evaluated before training and at the end of the 8-week training period.

The Biodex Balance System[TM] SD (Biodex, USA, 2009) balance training equipment was used to train the ABT group. The training machine consists of a multiaxial standing platform that can be adjusted to provide varying degrees of platform tilt or instability[12]. Subjects were trained wearing footwear and were positioned on the platform in a comfortable position while gripping a handlebar. Subjects were instructed and challenged from a monitor to try to balance or hold the platform in various positions. Participants were offered real-time audio and visual biofeedback during training. A maximum of 20 degrees of surface platform tilt was selected. With this degree of surface tilt, a dynamic situation is created, similar to actual functional activities that result in instability[13].

In the control group, ankle-strengthening exercises for the plantar flexor and dorsiflexor muscles of the affected side were performed by a physical therapist at 70% of maximum muscle strength. The strengthening exercises consisted of isometric, isotonic, and open and closed kinetic chain exercises. Training was stopped immediately if subjects complained of discomfort, pain, or excessive fatigue.

Ankle plantar flexor and dorsiflexor strength was assessed using a Biodex Isokinetic Dynamometer[14]. Participants sat in the Biodex chair and a foot was placed on the footplate. Their position was adjusted so that the knee was comfortable (up to 60° flexion), and patients were secured with a Velcro belt across the chest, pelvis, and thighs. Maximum isometric plantar flexor and dorsiflexor strengths were assessed using the standard operating procedures for the dynamometer with the ankle at 60°. For plantar flexion, the foot of the participant was pushed downward, as hard as possible, against the footplate. It was

Table 2. Comparison of the muscle strength changes in the plantar- and dorsiflexors of the affected side in the ABT and control groups

Peak torque volume at 60 degrees per second (Nm)		ABT group (n=14)	Control group (n=13)
Plantar flexor	Pre	5.7 ± 2.81	6.1 ± 1.51
	Post	12.0 ± 2.82*	11.7 ± 2.20*
	Post–Pre (Difference)	6.3 ± 1.67	5.6 ± 2.47
Dorsiflexor	Pre	10.5 ± 3.79	10.8 ± 3.48
	Post	23.1 ± 6.07*	20.8 ± 4.55*
	Post–Pre (Difference)	12.6 ± 5.05	10.0 ± 4.17

Significant difference, paired t-test: *$p<0.05$; independent t-test: †$p<0.05$.

Table 3. Comparison of the changes in balance and gait between the ABT and control groups

		ABT group (n=14)	Control group (n=13)
FRT (cm)	Pre	18.9 ± 7.14	20.1 ± 6.00
	Post	25.0 ± 7.69*	22.4 ± 6.67*
	Post–Pre (Difference)	6.1 ± 3.24†	2.3 ± 1.96
10MWT (sec)	Pre	36.0 ± 14.84	40.1 ± 11.92
	Post	27.7 ± 11.92*	36.3 ± 11.40*
	Post–Pre (Difference)	8.3 ± 3.63†	3.8 ± 2.28

FRT: Functional Reach Test; 10MWT: 10 m Walk Test.
Significant difference, paired t-test: *$p<0.05$; independent t-test: †$p<0.05$.

then pulled upward, as strongly as possible, to assess dorsiflexion.

The functional reach test (FRT) was conducted by replicating Duncan et al.'s method[15]. The subject stood adjacent to a 100 cm tape measure that was placed at shoulder height. The start position and end position measurements were recorded by the therapists, and three trials were performed by each patient. Subjects were asked to reach as far forward as possible without losing their balance. FRT was determined as the mean difference between the start position and end position over the three trials. Patients were supervised by a physical therapist throughout the trials.

Patients' gait was evaluated using the 10 m walking test (10MWT). For the 10MWT, the subjects were instructed to walk a total of 14 m at their fastest speed. The speed for the middle 10 m, i.e., excluding the first 2 m and the last 2 m, was measured. The 10MWT time was measured with a stopwatch from the moment the subject's feet passed the starting line to the moment they crossed the finish line. To ensure that the subjects had adapted to the test, all measurements were performed three times and the average value was calculated. For the 10MWT, the test-retest and interrater reliability have been reported to be 0.95 and 0.90, respectively; both of these values are very high[16].

All statistical analyses were performed using SPSS Statistics ver. 18.0 (IBM Co., Armonk, NY, USA). The paired t-test was performed for comparison of ankle strength, balance, and gait within the group before and after exercises. The independent t-test was used for comparisons between the groups. The p-value for significance was set at 0.05 for all analyses.

RESULTS

According to the results of this study, there were significant changes in muscle strength, balance, and gait within each group. Additionally, significant differences in balance and gait ($p<0.05$), but not muscle strength, were found between the groups (Tables 2 and 3).

DISCUSSION

The first aim of our study was to determine whether ankle biofeedback balance training improves muscular strength as compared to conventional strengthening exercises in stroke patients. Although not all of the muscles of the lower extremity were measured, significant improvements were seen in the measurements of the ankle muscles after training. The strength of the ankle dorsiflexors and plantar flexors in the ABT group was found to have increased significantly. Greater stability during the trials, along with significant improvement in the strength of the lower extremity was indicated by the results. In the control group, significant increases in the strength of ankle dorsiflexor and plantar flexor muscles were also found. However, there were no significant differences in the strength between the two groups.

The gain in strength in the ABT group was similar to that in the control group and may possibly be due to improvements in sympathetic transmission of the motor neurons[17]. In earlier studies, electrophysiological traces of reinforcement were shown when certain movements were performed. These changes might be learning effects.

In the present study, balance significantly improved in the ABT group after 8 weeks of training. The findings of the present study agree with previous studies. Barcala et al. reported that a physical therapy program combined with balance training involving visual biofeedback led to improvements in body symmetry, balance, and function among stroke victims[18]. After balance training, an increase in balance performance could be expected and was shown in the measurement results. This increase was not apparent after strength training. After strength training, dynamic balance performance was also improved, presumably based on the effects of training on the reflex control of muscle activity induced by exercising in a closed kinematic chain with known proprioceptive effects[19, 20]. The significant improvement in balance in our study may be explained by the improved intramuscular and intermuscular coordination, as well as by more economic activation of agonists, which resulted in the stabilization of the extremities[21].

One previous study demonstrated that balance training using force plate biofeedback, in addition to a conventional rehabilitation program for stroke patients, is useful for enhancing postural control and weight bearing on the paretic side while walking[22]. Another study also reported that balance training with visual feedback improved the symmetry of the walking pattern[23]. However, both of the aforementioned studies did not describe how biofeedback balance training influenced the affected side of patients. In the present study, significant differences in balance and gait parameters, but not in strength, were demonstrated between the ABT and the control groups. This indicates that the muscle strength of the affected side significantly improved in both groups, verifying the therapeutic effects of ABT. It is possible that ABT of the affected limbs, which stimulates proprioceptive posture control, is crucial for the rehabilitation of balance in stroke patients.

There is evidence that balance and locomotor capacities are correlated in adults with stroke and patients with cerebral palsy[24, 25]. For example, adults with hemiplegia had decreased dynamic balance abilities compared with non-hemiplegic adults, and this ability was correlated with walking ability. The present study supports the suggestion by Park et al. that the use of ankle proprioceptive control programs improves balance and walking performance of patients with stroke[26]. Since the ability to control posture in static and dynamic situations is an essential prerequisite for walking, it is therefore not surprising that balance training has an impact on gait[22]. Despite the fact that an association between quiet standing and walking appears to be less straightforward, it has been demonstrated that postural control during quiet standing was related to weight-shifting capacity, suggesting that both tasks depend, at least in part, on the same physiological mechanisms[27].

There are some limitations in the present study. The first limitation is the small number of participants included. Further studies using the same study protocol could be performed in a larger population. The second limitation is that ankle strengthening in the control group does not involve the entire lower limb or whole body, which is necessary to maintain body balance. The final limitation is the ABT protocol because there were various conditions dependent on the status of the patients. Although we used the same ABT program throughout, it could be applied at different intensities. A gold standard protocol for ABT has not yet been formulated.

In conclusion, the results of the present study demonstrated that ABT is an effective method for improving muscle strength, balance, and gait in patients with stroke. The training increased the muscle strength around the ankle and improved dynamic balance and gait velocity. Therefore, ankle biofeedback training can be used to improve muscle strength around the ankle, balance, and gait in chronic stroke patients in clinical trials.

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