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Research article

The effect of the stability of the free ankle joint on the gait balance of chronic stroke patients by the ankle foot orthosis

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ABSTRACT

Stroke patients have high foot instability and a high risk of falling down in walking and standing positions due to muscle and sensory disorders. There are many patients who complain of inconvenience in their daily lives, but independent walking is very difficult. In this work, we explore the effect on walking and dynamic balance by securing internal and external stability of the foot. Fifteen participants participated in the experiment, with 10m walk tests, timed and go tests, and functional reach tests. The walk 10m test was not statistically significant, with 0.59 ± 0.23 m/s before the device was worn and 0.66 ± 0.29 m/s after the device was worn. Timed up and Go tests were statistically significant 26.57 ± 6.12 seconds before wearing the device, 22.31 ± 4.32 seconds after wearing the device, 222.59 ± 10.31 cm before wearing the device, and 230.93 ± 11.33 cm after wearing the device. Securing internal and external stability of the foot can have a positive impact on securing a dynamic balance in which weight movement is performed.

Keywords: Chronic stroke, Ankle foot orthosis, stability, gait

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INTRODUCTION

A stroke occurs due to ischemic infarction in the brain and cerebral hemorrhage. Two major causes of stroke are cerebral infarction that blocks blood flow and cerebral hemorrhage that ruptures blood vessels. Cerebral infarction occurs when embolization in other body parts or blood clots in the cerebral blood vessels block the cerebral blood vessels. [1]. Cerebral infarction caused by blockage of cerebral blood vessels can be divided into thrombosis and embolism depending on the cause. Thrombosis refers to thrombocytosis in the arteries that interferes with blood flow in the blood vessels, whereas embolism refers to thrombocytosis that flows along the blood vessels and blocks the blood vessels in the brain.[2]. Stroke patients have difficulty living independently due to severe physical restrictions on movement caused by chronic disabilities in areas such as motor function, cognition, perception, and sensation. Impaired balance strategies and proprioceptive sensations are observed in more than 60% of stroke patients. Many patients also exhibit decreased or abnormally increased muscle tension, increased postural instability, and decreased movement efficiency. As a result, their static and dynamic balance is compromised, increasing the risk of falls and decreasing their walking speed. [1].

Normal and rhythmic walking is achieved through sensory feedback and cooperation of muscles. Stroke patients experience impairments in balance and walking due to muscle issues, such as stiffness or relaxation of the feet. Abnormalities in proprioceptive and tactile senses that receive signals from the ground when standing or walking impede normal walking not only on irregular grounds but also on flat surfaces. Stroke patients are at a higher risk of injuries due to accidents, such as falls, due not only to reduced walking speed but also to reduced accuracy caused by impaired sensory feedback. Sensory feedback transmits exclusive sensory signals to the sensory cortex of the brain and affects even the motor area to regulate the tension of the asymmetrical muscles of the sole, triggering appropriate new movements to improve the motor sense and postural control, thereby helping to maintain balance and stability. [2].

Balance is the ability to maintain one's center of gravity within the base of support and is broadly divided into static and dynamic balance. Static balance refers to balance in stationary postures, such as standing and sitting postures, while dynamic balance refers to balance during movement of the body, such as walking, and posture changes. Healthy adults employ several strategies to maintain balance. As an external force that disturbs the balance increases, the hip joint, ankle joint, and one-step strategies are employed—in that order—to maintain balance. As both the ankle joint and the one-step strategy are based on the modification of the ankle joint, it is necessary to secure its stability. [3].

Various assistive devices, such as ankle/foot braces, insoles, and wedges, are used to secure the stability of deformed feet of stroke patients. [4]. In most cases, stroke patients have cavus feet with lifted heels, which compromise their stability while they are walking. Such feet also receive reduced sensory feedback because their soles do not make sufficient contact with the ground. Given that stroke patients have difficulty in controlling their balance through sensory feedback when walking or standing, assistive devices help their feet firmly touch the ground and secure their ankles' stability, thereby improving their balance. [5]. Ankle stability in walking and balance provides primary stability and provides sensory feedback through repulsive forces on the ground. Therefore, if ankle stability is secured in patients with ankle instability, functional improvement on balance and walking can be sought. However, the use of assistive devices remains controversial. Some medical experts traditionally believe that these assistive devices interfere with or reduce the work of the muscles, thus preventing or delaying motor recovery. Most experts, however, agree that such devices are beneficial for muscle recovery. [6].

Previous studies have reported that foot braces reduce energy consumption during walking. Although the mechanism of this effect is unclear, Simmons et al. [7] reported that foot braces provided a reduction in energy consumption during 10-meter walk, berg balance, and timed up and go tests. However, Lewallen et al. found that assistive devices did not make a significant difference in gait in terms of kinematic morphology. On the other hand, it has been reported that foot braces help improve gait by improving the standing posture and control motion and by properly aligning the ankle of a deformed foot.[8]. In particular, it has been reported that securing the ankle's stability during the stance phase can increase walking speed.

Ankle foot support device can provide internal and external stability to the patient's ankles to assist in the function of the medial and lateral ligaments. However, because bulky braces can interfere with sensory feedback and movements, the production of assistants has been manufactured through companies with more than 20 years of experience in manufacturing assistants and individually tailored through plastering of each subject's body. The type of the joint of the ankle foot support is a free joint type, preventing the movement of the ankle's inversion and eversion and causing only the movement of the dorsi-flexion and platar-flexion to occur. Since there is no spring in the joint, there is no concern about the increased tension of the patient's calp muscle when walking. Stroke patients with spasticity experience a rapid increase in muscle tone when joint movements occur rapidly. Therefore, the springy type of klenzak joint should not be used in stroke patients with spasticity.

Although it appears that the use of assistive devices has both advantages and disadvantages, for patients suffering permanent damage, such as stroke patients, assistive devices are essential for daily life and training. Therefore, in this study, we applied mediolateral splints on the ankles of stroke patients to secure the mediolateral stability of their feet and investigated the effects on their dynamic balance and gait.

MATERIALS AND METHODS

The Experimental Subjects

For this experiment, outpatients of D hospital, D city, Korea, was recruited. The inclusion criteria were (1) foot drop (equinovarus) deformity with stroke onset more than six months previously, (2) lower limbs classified as Brunnstrom's motor recovery stages 3–5, (3) hemiplegic gait without assistive devices, (4) ability to understand and follow verbal instructions, (5) ability to walk at least 10 meters without assistive devices, (6) no orthopedic diseases in the lower limbs, and (7) a Mini-Mental State Examination, Korean version (MMSE-K) score of 24 or higher. The exclusion criteria were (1) visual, auditory, or vestibular disorders and (2) walking or balance problems due to other neurological problems unrelated to a stroke.

Based on the inclusion and exclusion criteria, a total of 10 patients, 10 males, were recruited. Their mean age was 62.32 ± 2.53 years, their mean height was 169.86 ± 5.21 cm, and their mean weight was 69.25 ± 5.53 kg. The average MMSE-K score was 28.12 ± 0.91 points. Cerebral infarction was the stoke type of all patients, and the average time elapsed from the onset of stroke was 12.29± 2.34 months.

The study was conducted in accordance with the ethical standards described in the Declaration of Helsinki. All participants provided written informed consent prior to the study.

For comparative analysis, the patients underwent the 10-meter walk, functional reach, and timed up and go tests before and while wearing ankle braces to secure the mediolateral stability of the foot without controlling or aiding dorsiflexion and plantar flexion.

The 10-Meters Walk Test

As a tool that can measure the short-distance walking speed and ability of elderly people, this test can also be applied in clinical practice to patients with central nervous system conditions, such as stroke and Parkinson's disease. Each patient was instructed to walk a total of 14 meters without using a cane or walker. To evaluate the gait cycle, a distance of 10 m was measured, excluding 2 m at the beginning and 2 m at the end. To prevent a possible fall, the test was conducted under close supervision by an examiner. Each patient was instructed to perform the test three times, and the average of the three measurements was calculated. At 10 m walk test, only indoor movement is possible if the speed is lower than 0.4 m/s; outdoor movement is limited when 0.4 to 0.8 m/s; outdoor movement is possible when 0.8 m/s or higher.

The 10 m walk test can evaluate the gait speed following disease;

- Acquired brain injury
- Cerebral palsy
- Geriatrics
- Hip fracture
- Lower limb amputation
- Multiple sclerosis
- Parkinson's disease
- Spinal cord injury
- Stroke
- Traumatic brain injury.

Orthosis

Figure 1. Ankle foot orthosis making

Table 1. Normal 10m walks speed each age

Age (men and women)	Average walk speed (m/s)
20 - 29	1.36 – 1.34
30 - 39	1.43 – 1.34
40 - 49	1.43 – 1.39
50 - 59	1.43 – 1.31
60 - 69	1.34 – 1.24
70 - 79	1.26 – 1.13
80 - 99	0.97 – 0.94

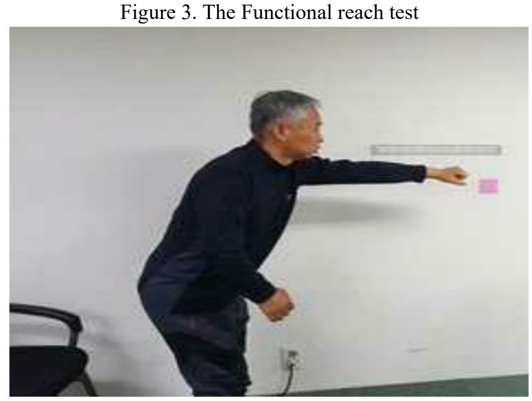
Figure 2. The 10m walk test

The Functional Reach Test

The functional reach test is an evaluation tool for identifying problems related to balance and estimating the risk of falling in elderly people and has high inter-rater reliability. In this test, each patient stood beside a wall with both feet shoulder-width apart, the 3th fist of the dominant arm lightly clenched, and the shoulder bent 90 degrees, ensuring that the shoulder did not touch the wall. The patient extended the arm to the front as far as possible without moving either foot, and the point where the end of the third metacarpal bone reached was measured. To prevent a possible fall, this test was also performed under close supervision. The test was performed three times, and the average of the measurements was calculated.

The sensitivity of this test is 76 %, accuracy is 46%, and specificity is 34%. The results of the functional reach test show that the risk of falling is very low above 250 mm, and the risk of falling between 150 mm and 250 mm is twice as high as the normal. And if it is less than 150mm, the risk of falling is four times higher than normal.

Figure 3. The Functional reach test



The Timed Up and Go Test (TUG)

As a tool for evaluating balance ability and the risk of falling, this test can measure both static and dynamic balance. Each patient was seated in a chair and, on the examiner's instructions, walked to a point 3 m away and back to the chair without using a cane or walker. The time from getting out of the chair to sitting back on it was measured. A healthy adult can complete the test within 10 s. A patient who can complete it within 20 s belongs to the threshold level of weak elderly people or disabled patients. More than 20 s indicates that the patient needs help from others while walking, and more than 30 s indicates that the patient has a very high risk of falling. In this study, each patient performed the test three times, and the average value was used for the analysis. To prevent a possible fall, this test was also performed under close supervision.

Figure 4. The timed up and go test

The timed up and go test can evaluate the gait performance following disease;

- Cerebral vessel disease
- Hip fracture
- Huntington disease
- Multiple sclerosis
- Parkinson's disease
- Alzheimer's disease

Table 2. Normal TUG average time

Age (men and women)	Time (sec)
20 - 29	5.31 ± 0.25
30 - 39	5.39 ± 0.23
40 - 49	6.24 ± 0.67
50 - 59	6.44 ± 0.17
60 - 69	7.24 ± 0.17
70 - 79	8.54 ± 0.17

Swing/stance phase ratio measurements

The human gait cycle is broadly divided into the swing and stance phases. Healthy adults show symmetry in normal gait, with a swing/stance phase ratio of 40/60. On the other hand, stroke patients' gait shows asymmetry, and the proportion of the stance phase on the affected side is very low, which makes their gait unstable. As a result, the risk of falling increases and the overall walking speed decreases significantly. In this study, three patients were randomly selected, and their swing/stance phase ratios before and after their foot stability had been secured were measured and compared to determine whether they were comparable to those of healthy adults when the patients were walking while wearing an ankle brace.

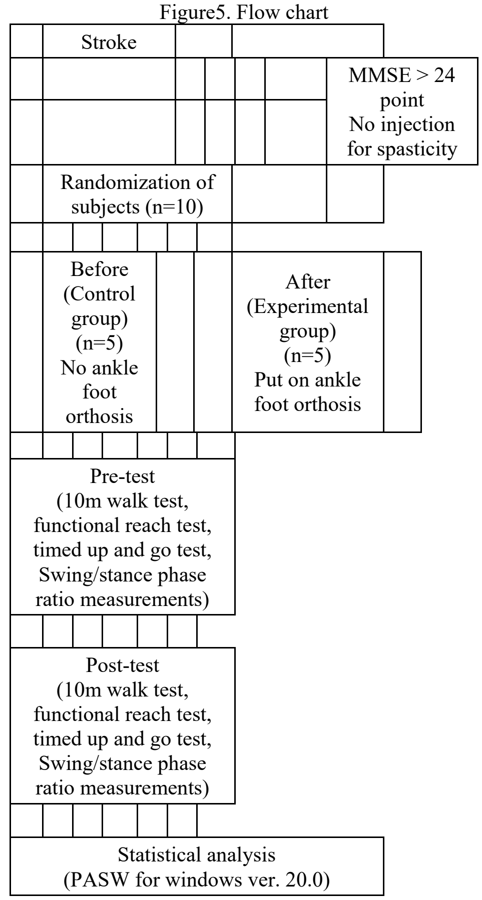
Data analysis

Data analysis was performed using the average values of the three measurements for each test. The data were expressed as means ± standard deviations. A paired t-test was used for comparisons of measurements taken before and while the patients were wearing the ankle brace. The statistical analysis was performed using IBM SPSS Statistics 20.0 for Windows. The swing/stance phase ratio was assessed through descriptive comparisons.

RESULTS

The FRT and TUG score showed statistically significant differences between experimental and control groups, respectively ($p < 0.05$) (Figure 7, 8). However, the 10 m walk test score did not showed statistically significant differences between experimental and control groups ($p > 0.05$).

Figure5. Flow chart



Meter Walk Test

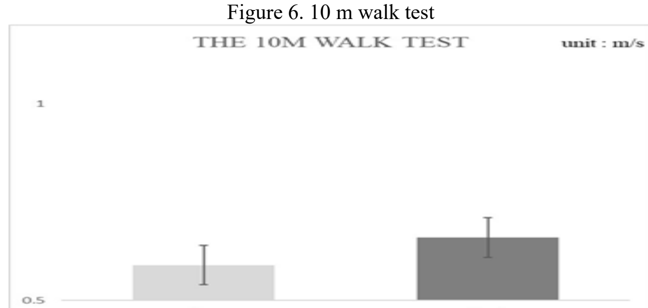
The mean time to complete the 10-meter walk test was 0.59 ± 0.23 m/s before and 0.66 ± 0.29 m/s while wearing the ankle brace. The difference was not statistically significant.

Table 3. 10m walk test

Group	Mean	SD	*p*
Pre	0.59	0.23	0.159
Post	0.66	0.29	

*SD: standard deviation
p <0.05, <0.01**, <0.001***
*unit: seconds

Figure 6. 10 m walk test



Functional reach test

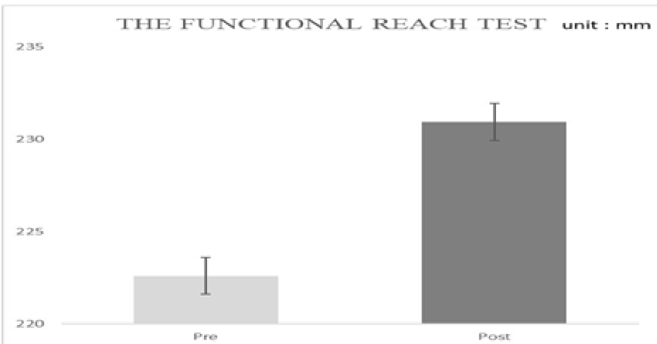
The mean reach in the functional reach test was 242.23 ± 10.31 mm before and 265.39 ± 11.33 cm while wearing the brace. The difference was statistically significant.

Table IV. Functional reach test

Group	Mean	SD	*p*
Pre	222.59	10.31	0.000***
Post	230.93	11.31	

*SD: standard deviation
p <0.05, <0.01**, <0.001***
*unit: mm (10-3m)

Figure 7. Functional reach test



Timed up and go test

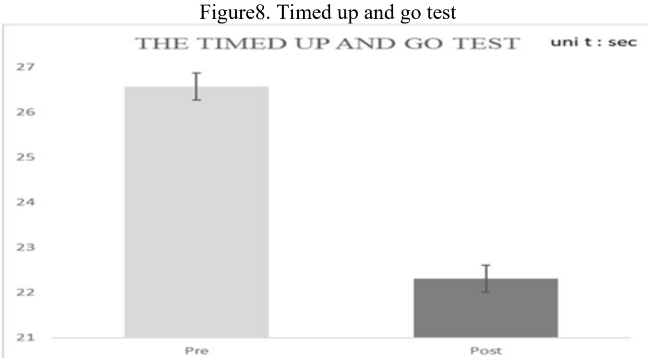
The mean time to complete the timed up and go test was 26.57 ± 6.12 s before and 22.31 ± 4.32 s while wearing the brace. The difference was statistically significant.

Table V. Timed up and go test

Group	Mean	SD	*p*
Pre	26.57	6.12	0.000***
Post	22.31	4.32	

*SD: standard deviation
p <0.05, <0.01**, <0.001***
*unit: seconds

Figure8. Timed up and go test



Swing/stance phase ratio measurements

In the case of Patient 1, the proportion of the stance phase increased from 51.58% without the ankle brace to 61.36% with the brace, which was considered a normal range. Consequently, the step length also increased from 34.07 to 35.15 cm. Furthermore, cadence increased from 75.79 to 81.82 steps per minute. In the case of Patient 2, the proportion of the stance phase increased slightly, from 57.89% to 58.67%, and the step length increased from 34.74 to 38.09 cm. Cadence increased from 94.74 to 96 steps per minute. In the case of Patient 3, the proportion of the stance phase increased from 56.76% to 63.01%, which was considered a normal range, and the step length increased from 55.99 to 62.77 cm. Cadence increased from 97.29 to 98.63 steps per minute.

DISCUSSION

Stroke patients suffer from balance, coordination, and dysfunction throughout their bodies due to muscle strength, cognitive dissonance, and impaired self-acceptance. The study compared dynamic balance and walking efficiency in patients with foot instability stroke due to muscle weakness and foot abnormalities while wearing aids that provide moderate stability to their ankles.

Balance is the ability to maintain one's center of gravity within the body's base of support, that is, to return the center of gravity to the body's base support without falling even if the body is moved out of the base support by external forces or stimuli. This balance is achieved through sensory and muscle coordination and feedback, mainly in subcortical regions. [9]. If this function is impaired, stroke patients lose control of their bodies due to abnormal body alignment, muscle tension, and slow response to external stimuli or forces. [10].

Foot stability should be the first thing to be secured when standing or walking. If stability is not obtained during the weight bearing process at the time of the heel's contact with the ground during the postural phase and the weight is transferred to the next leg, the patient may stagger and, in severe cases, fall.[11]. This anxiety is a major aspect of patient discomfort. In this work, we obtain mediolateral stability of the ankle to ensure foot stability. This resulted in significant differences in functional reach before and during ankle brace wear, not in the 10m walking test, where only slight differences were observed. This is because while no device was used to aid muscles needed for walking, only moderate side stability of the foot was guaranteed. However, securing ankle stability showed that performance improved when the patient sat up and moved the center of gravity to the outside of the base support. Although there were no statistically significant differences in the 10m walking test, the results of this study can still be seen as significant because of reduced walking time and significant changes in other walking and balance tests. Taken together, these results suggest that ankle stability in stroke patients is important to obtain with aids while they are walking. Shin (2017) showed a significant difference in the 10-meter walking test using the Klensak ankle brace, contrary to the findings. [12]. Klenzak brace seems to increase flexibility when walking through the auxiliary features of the dorsiflexion it provides. However, it is prohibited in stroke patients with spastic paralysis. [13].

Stroke patients develop very serious disabilities in their daily lives. Due to the limitations of basic physical ability, independent living becomes difficult. Quality of life is very low due to restrictions on movement and functional activities as well as eating and washing. Walking is especially important, especially for most of everyday life. The quality of life of patients in the mental and emotional sectors can be improved as well as the daily life of patients by improving the function of walking and improving the function of balance. [14. 15. 16].

In this work, technical comparisons of gait ratio, step length, and cadence are also performed. Although little is statistically significant, it can be thought that significant results can be obtained with a larger sample size. Furthermore, only lateral stability of the foot was provided in this study. However, the combination of foot-sensory stimulation training and gait training while walking will provide valuable training and daily life support tools for chronic stroke patients. Furthermore, better performance can be achieved when devices that can provide feature support as well as intermediate side stability are used in future studies.

Some limitations of this study should be noted. Because of the small sample size, the results were heavily influenced by certain factors. In addition, outpatient comparisons were made, and changes in the patient's living environment could not be considered. Future studies that control specific variables can yield more robust results.

CONCLUSION

Although it is difficult to generalize findings due to the small sample size and multiple unregulated variables, this study shows that securing mid-lateral stability of the foot can have a positive effect on the dynamic balance of stroke patients.

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