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# Effects of the Dual AFO on gait parameters in stroke patients

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**Abstract**. This study investigated how to improve the walking patterns in stroke patients by using the Dual AFO, which was devised as an alternative AFO consisting of two thin pierced plastic pieces for the lower leg and foot. Fifteen individuals with hemiplegia were recruited. Participants were seven males and eight females. Gait parameters were measured with the GAITRite system to analyze the spatial and temporal parameters of walking by stroke patients.The Dual AFO significantly improved the step time of the non-affected foot compared with barefoot walking. There was no significance difference in the affected swing time between the two conditions, and participants with the Dual AFO had a significantly shorter non-affected swing time. There was a significant difference in the affected single support time between walking with and without the Dual AFO. Additionally, the velocity was increased significantly in subjects with the Dual AFO compared with barefoot. Consequently, the Dual AFO might enhance stability during the stance phase on the affected side and mobility during the swing phase on the non-affected side to promote better walking in stroke patients.

Keywords: Ankle-foot orthosis, modified AFO, assistive device, walking, foot drop

## 1. Introduction

Stroke is the third leading cause of death worldwide after cardiovascular disease and cancer, causing death in 1 in 18 people. Every year, approximately 800,000 people in the USA suffer from a first or second stroke [1]. This means that such an event occurs every 40 seconds on average. Some authors suggest that 70∼80% of surviving stroke patients can ambulate without assistance, although Jorgensen et al. [2] reported that 18% of their subjects could not walk properly, 11% needed some assistance, and only 50% were able to walk independently. In the community, few people with stroke are able to ambulate outside the house when they wish, and about 20% cannot move outdoors at all without aid [2]. Clinically, most stroke patients experience hemi-paralysis, and they characteristically have reduced metabolic efficiency, a high risk of falling, and slow speed and low endurance when walking [3, 4]. Other problems in hemiparetic walking include decreased balance control, instability in the mid-stance phase, excessive muscle tone, involuntary uncontrolled posture of the ankle and foot, genu recurvatum, and instability of the knee. It would be helpful to use adjustable assistive devices to overcome these weaknesses [5].

An ankle-foot orthosis (AFO) is generally used to improve hemiparetic gait [6–8]. AFOs differ according to materials, uses, and functions. Regarding materials, AFOs are classified as plastic and metal types.These orthoses also have several practical applications. Posterior plastic AFOs support the back of the tibia for ankle stability and prevention of foot drop, whereas anterior plastic AFOs support the shin and dorsum of the foot; hinged AFOs assist ankle mobility, and tone-inhibiting dynamic AFOs have been developed to re-

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strain excessive muscle tonus. There are four main types of AFO classified according to their functions: flexible AFOs assist dorsiflexion of the ankle and stabilize weak subtalar joints; anti-talus AFOs limit ankle dorsiflexion and stabilize the subtalar joint; rigid AFOs limit ankle motion, stabilize the subtalar joint, and control adduction and abduction of the forefoot; and Tamarack AFOs assist ankle dorsiflexion and limit plantar flexion to simultaneously provide ankle stability and prevent foot drop [9]. A case study of stroke patients reported that subjects wearing dynamic AFOs and plastic AFOs had greater walking velocity than did barefoot subjects [10], a finding reproduced by other researchers [6,11,12].

Stride length was increased significantly in stroke patients with AFOs. Similarly, AFOs have been effective in improving the walking ability of stroke patients as reflected in step length, step width, walking speed, step frequency, and functional ambulatory ability [11–14]. Various AFOs have been used to correct joint alignment, improve walking velocity, increase energy efficiency during walking, enhance ankle stability during the stance phase, and prevent foot drop during the swing phase [15]. Although AFOs have various advantages, some clinicians and specialists believe that wearing AFOs inhibits patients' learning to walk because wearing an AFO alters the normal kinematics of walking and might contribute to increased clonus [16]. Additionally, patients walking continuously with AFOs would not use their ankle dorsiflexors properly, i.e., the role of ankle-muscle activity in improving foot clearance could be replaced by the AFO [17–19]. This clinical shortcoming would delay functional recovery. Each AFO takes a relatively long time to manufacture and costs \$500$\sim$700 [20].

Therefore, we believe that a new AFO design is needed not only to reduce costs and production time but also to utilize lighter materials and improve comfort. Furthermore, we believe that a reduction in the thickness of AFOs is important to minimize deviation during gait and increase sensory inputs from the ground to the foot. This study investigated how to improve the walking patterns in stroke patients with using the Dual AFO and compared the Dual AFO with standard plastic AFOs.

## 2. Methods

### 2.1. Subjects

Fifteen individuals with hemiplegia were recruited from S hospital in Busan, Korea. The participants gave their consent after we explained our experiments. Participants were seven males and eight females; nine had right hemiplegia, and six had left hemiplegia. All participants presented with foot drop. The mean value of ankle passive ROM showed the ankle plantar flexion (movement downward) 39.5 $\pm$ 5.1, ankle dorsiflexion (movement upward) 18.9 $\pm$ 4.3, foot inversion (turned inward) 10.2 $\pm$ 2.7, foot eversion (turned outward) 8.5 $\pm$ 1.6.

Inclusion criteria were (a) a diagnosis of hemiplegia due to hemorrhagic or ischemic stroke, (b) more than 6 months post stroke, (c) the ability to follow simple instructions, (d) the ability to walk independently or with assistive devices, (e) no orthopedic problems involving the lower extremities that would affect gait, and (f) no participation in other investigations for 6 months. The exclusion criteria were (a) a stroke involving more than one hemisphere, (b) more than two strokes, and (c) premorbid or other orthopedic problems that would impede gait patterns. Informed consent was acquired from these subjects prior to the execution of the study according to the requirements of the Inje University Faculty of Health science Human Ethics Committee. The demographic characteristics of the patients are summarized in Table 1.

### 2.2. Set-up and measurement

#### 2.2.1. GAITRite

Gait parameters were measured with the GAITRite system (CIR Systems, Easton, PA, USA) to analyze the spatial and temporal parameters of walking by stroke patients. The GAITRite has an 8.3-m-long, 0.89-m-wide electronic gait mat on which 13,824 1-cm-diameter sensors are spaced at 1.27-cm intervals to collect information on temporal and spatial variables. The sensor pads of the GAITRite were covered with a roll-up carpet that provides an active measurement area that is activated by mechanical pressure from the contact of feet on the mat. Data from the activated sensors are collected by a computer at a sampling rate of 80 Hz, and the footsteps are identified and parameters calculated automatically [21]. The validity and reliability of the device has been established [22,23].

#### 2.2.2. Dual AFO

The Dual AFO consists of two thin pierced plastic pieces for the lower leg and foot, four straps, and a pad (Fig. 1). The thin plastic piecesaremade up of light polyethylene, approximately 90 grams and customized to fit an individual's leg. The feature of the large one

Table 1
Demographic characteristics of the hemiparetic subjects

| Subject | Gender | Age (years) | Diagnosis | Affected limb | Height (cm) | Weight (kg) | Post stroke (months) |
|---|---|---|---|---|---|---|---|
| 1 | M | 57 | ICH | R | 170.0 | 65.0 | 45 |
| 2 | M | 54 | INF | R | 168.4 | 70.0 | 32 |
| 3 | M | 48 | INF | R | 160.0 | 58.3 | 26 |
| 4 | M | 71 | INF | L | 162.6 | 62.6 | 33 |
| 5 | M | 61 | INF | R | 170.2 | 75.0 | 8 |
| 6 | M | 76 | INF | R | 165.1 | 60.1 | 7 |
| 7 | M | 66 | INF | R | 164.0 | 50.2 | 13 |
| 8 | F | 64 | ICH | R | 145.5 | 55.1 | 25 |
| 9 | F | 61 | ICH | R | 155.0 | 55.0 | 19 |
| 10 | F | 73 | ICH | R | 153.0 | 54.6 | 10 |
| 11 | F | 79 | INF | L | 156.1 | 53.0 | 13 |
| 12 | F | 81 | INF | L | 141.0 | 55.0 | 11 |
| 13 | F | 53 | ICH | L | 158.2 | 58.3 | 32 |
| 14 | F | 68 | ICH | L | 163.1 | 70.1 | 6 |
| 15 | F | 62 | ICH | L | 150.0 | 56.2 | 10 |

F: female; ICH: intracerebralhemorrage; INF: infarction; L: left; M: male; R: right.

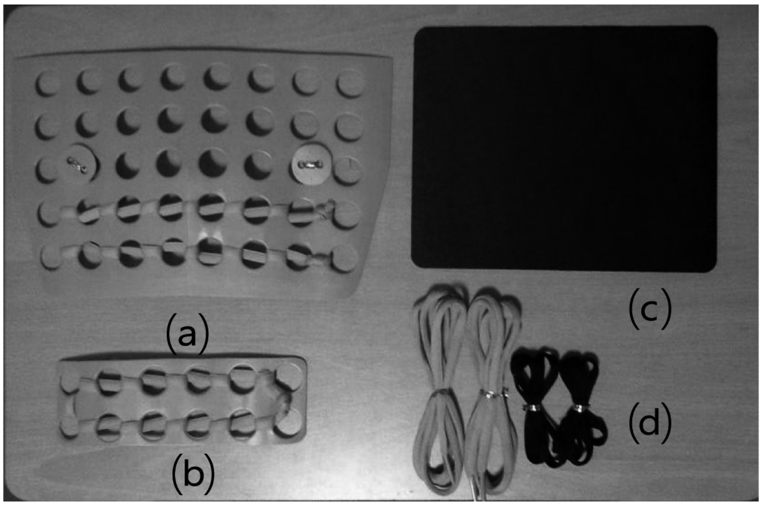


Fig. 1. Components of the Dual AFO. (a) and (b): double pieces of plastics, (c): a pad, (d) straps.

is formed as a trapezoid, and the lower base is nearly 23 cm, the upper base is about 29 cm and the height is closely 18 cm. The shape of small one is a rectangle. Two straps hold each piece to the lower leg and foot, and the other two connect the lower leg and foot sections at the ankle and control the tension of each part to assist active dorsiflexion. The strap tension confers stability to the ankle. The Dual AFO is lighter, more portable, and better customized than are typical AFOs. In contrast to a typical AFO, the Dual AFO is constructed of plastic material that bends more and is elastic. The Dual AFO consists of two parts; one part attaches to the calf and the other to the foot. There are figures illustrating the anterior and lateral view of Dual-AFO (Figs 2, 3). The advantages of the new AFO are that it enables flexible movement at the ankle, allowing contact of the heel with the ground while walking. The tension of the angles at the ankle can be controlled with straps to selectively control the amount of inversion and eversion at the ankle and to prevent the foot-drop often seen with typical AFOs.

### 2.3. Procedure

The investigator outlined the tests before the patients performed on the GAITRite. The subjects were asked to walk at a comfortable speed. If needed, human assistants were provided for their safety. The participants performed two trials of each test. To minimize the learning effect with the Dual AFO, the barefoot test was performed first, and a 5-minute rest was provided between tests. When patients first used the Dual AFO,

Fig. 2. The anterior view of Dual-AFO.

Fig. 3. The lateral view of Dual-AFO.

we let them get accustomed to walking with it for only 1∼2 meters. The participants began walking 1 meter before they reached the carpet of the GAITRite system and continued for 1 meter beyond the mat [24].

### 2.4. Statistical analysis

The differences in the mean values for walking with and without the Dual AFO in stroke patients were compared using the Wilcoxon singed rank test. The data were processed using SPSS ver. 18.0 (SPSS, Chicago, IL) for Windows. The level of statistical significance was $p < 0.05$.

## 3. Results

When patients walked with the Dual AFO, there was no significant difference in the step time with the affected foot compared with barefoot walking. Furthermore, the Dual AFO significantly improved the step time of the non-affected foot compared with barefoot walking, as shown in Table 2. There was no significance difference in the affected swing time between the two conditions, and participants with the Dual AFO had a significantly shorter non-affected swing time. There was a significant difference in the affected single support time between walking with and without the Dual AFO, but no significant difference in the non-affected single support time. Both the affected and non-affected stride length were increased significantly in participants with the Dual AFO. Additionally, the velocity was increased significantly in subjects with the Dual AFO compared with barefoot. There was no significant difference in cadence between walking with and without the Dual AFO.

## 4. Discussion

We studied the effects of the Dual AFO, which is a light, flexible, portable device, during walking in stroke patients. This study showed that the affected single support time increased significantly, which means a prolonged stance phase on the affected side, whereas the affected step time was not significantly different, but tended to increase, and the non-affected step time decreased significantly. These results support the hy-

Table 2
Comparison of gait parameters with and without Dual-AFO in stroke patients

| | Without AFO | With Dual-AFO | $p$ |
|---|---|---|---|
| Affected step time(sec) | $1.29 \pm 0.61$ | $1.23 \pm 0.49$ | 0.63 |
| Non-affected step time(sec) | $1.25 \pm 0.073$ | $0.93 \pm 0.31$ | 0.03* |
| Affected swing time(sec) | $0.68 \pm 0.33$ | $0.79 \pm 0.33$ | 0.35 |
| Non-affected swing time(sec) | $0.30 \pm 0.098$ | $0.36 \pm 0.13$ | 0.03* |
| Affected single support time(sec) | $0.30 \pm 0.09$ | $0.36 \pm 0.12$ | 0.01* |
| Non-affected single support time(sec) | $0.68 \pm 0.32$ | $0.80 \pm 0.32$ | 0.54 |
| Affected stride length(cm) | $43.24 \pm 14{,}53$ | $48.68 \pm 12.05$ | 0.01* |
| Non-affected stride length(cm) | $43.89 \pm 14.91$ | $48.48 \pm 12.27$ | 0.02* |
| Velocity(cm/sec) | $20.80 \pm 13.42$ | $24.72 \pm 12.12$ | 0.01* |
| Cadence(steps/min) | $56.05 \pm 19.99$ | $60.94 \pm 19.27$ | 0.21 |

Values are mean ± SD. *Significant at $P < 0.05$.

pothesis that the stability of the affected leg was increased with the Dual AFO, and the naturally mobility of the non-affected leg was increased during the reduced step time on the affected leg. There was also a significant increase in the non-affected swing time. The single-limb support phase is needed to generate kinetic energy for the next swing, and it is known clinically that the stronger and longer stance phase is, the better the swing pattern [25]. Dieli et al. [26] suggested that stroke patients with an AFO had increased stride length with a prefabricated posterior leaf-spring AFO versus barefoot and with a plantar-flexion-stop dynamic AFO versus barefoot. It was also reported that stride length was increased with a plastic AFO (the ankle angle was not specified) versus barefoot in stroke patients [11]. When patients walked with an AFO, there was a marked increase in the stride length of the affected and non-affected sides, whereas there was no difference in cadence. This means that walking speed increased; as a result, the immediate increase in the magnitude of walking with the Dual AFO was similar to the increased magnitude of walking with an AFO for a long period [27,28].

Several researchers reported that an AFO was useful for increasing the walking speed of patients, although according to Mulroy et al. [29], a rigid AFO limited ankle dorsiflexion during stance phase and knee flexion during swing phase, whereas Burdett et al. [30] and Lehmann et al. [31] reported no differences. In our study, the walking velocity increased in patients with the Dual AFO. We believe that this is because the Dual AFO is made from flexible plastic materials which facilitates walking and that the Dual AFO consists of two pieces to control plantar flexion and dorsiflexion while not limiting the movement of the ankle joint. The stiffness of an AFO resisting plantar flexion is important for generating smooth plantar flexion during the initial contact [32], and the stiffness of the AFO in resisting dorsiflexion makes push-off more effective [7]. Various AFOs have been developed to control the stiffness of articulated joints in the sagittal plane, including AFOs with a torsional spring damper [33], artificial pneumatic muscles [34], and oil dampers [35], which support the major functions of the Dual AFO. To improve the postural (body) schema, tactile stimuli from sensory input are needed [36]. Unlike typical AFOs, the Dual AFO allows the heel of the affected side to contact the ground directly, thereby increasing tactile stimuli, which might improve gait patterns. Ensuring proper heel contact with the ground is a major factor in maintaining ankle stability and selective dorsiflexion and plantar flexion of the ankle. For stable heel contact with the ground, it is necessary to generate selective knee and hip movement during mid-stance [37]. According to Simkin et al. [38], an AFO is important for limiting forward motion, but the section of the Dual AFO on the forefoot is made of thin materials that would be considerably more effective in walking because of the reduced limitation of "push" on the forefoot. As mentioned, a typical AFO takes a long time to manufacture and costs \$500∼700. Unlike typical AFOs, the Dual AFO could be commercialized in small, medium, and large sizes so that it would be easier to provide and less expensive for patients. The Dual AFO has important advantages: the foot does not drag, and it is easy to fit on any patient using the straps. A pad on the Dual AFO protects the skin on the calf and increase friction. Its plastic components make the Dual AFO lighter than typical AFOs. It is very portable and might be designed to wear inside shoes. Nevertheless, patients with marked spasticity cannot use the Dual AFO because it does not provide enough stability while walking. Therefore, we need to identify the proper patients in whom to use the Dual AFO.

This study was limited by the small number of subjects. Nevertheless, there appears of be clinical benefit in using the Dual AFO in stroke patients who are more than 6 months post stroke. We need to evaluate the effect of the pressure caused by the straps on the patient's circulation. Our results were based on the very short-term use of the Dual AFO, and its long-term effects need to be studied. The changes in the kinematics of the hip, knee, and ankle while using the Dual AFO also need to be determined to adjust the sagittal plane alignment.

## 5. Conclusion

This study compared that 15 stroke patients walked on barefoot and with Dual-AFO. The results were that non-affected step time (sec) significantly decreased and non-affected swing time (sec), affected single support time (sec), affected/non-affected stride length (cm), velocity (cm/s) increased significantly. These results demonstrated that Dual-AFO could be an alternative fitted assistive device for individual as a primary role instead of ordinary AFOs. The new AFO is to be lighter, low-priced and more portable than those. However, there are other methods needed to put on Dual AFO easily, and following studies will be needed to be effective on walking wearing Dual AFO for a long period instead of a short period.

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