Therapeutic effect of gait training with two types of ankle-foot orthoses on the gait of the stroke patients in the recovery phase

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ABSTRACT

Objectives: This study aimed to demonstrate the therapeutic effect of gait training using ankle-foot orthoses (AFOs) on the gait of stroke patients when not wearing AFOs with two different types of AFO, an AFO with an oil damper (AFO-OD) that resists plantarflexion and an AFO with a plantarflexion stop (AFO-PS), and to display the possible differences between the AFO types.

Patients and methods: Forty-two patients (38 males, 4 males, mean age: 59.7±10.9; range, 38 to 81 years) with subacute stroke were randomized to either an AFO-PS or an AFO-OD group. Participants were given gait training in a two-week period by physiotherapists wearing their allocated AFO. Nineteen patients were assigned to the AFO-PS group and 20 to the AFO-OD group. Patients' gait without an AFO before gait training and then after two weeks of training wearing allocated AFOs was recorded through a three-dimensional movement capture system.

Results: A therapeutic effect through two weeks of continuous use of AFOs and gait training was found in both AFO groups (main effect of time) in the spatiotemporal factors, ankle joint moments, ankle power generation, shank-to-vertical angle, and center of gravity velocity throughout the stance phase, pre-swing knee angular velocity, and hip flexion moment in pre-swing. The results did not show a large interaction between two AFOs group.

Conclusion: These findings reveal that both AFOs had significant therapeutic effects on stroke gait. There was no significant difference between the two AFO groups. Further studies with a control group representing the effects of gait training without wearing an AFO are needed.

Keywords: Ankle-foot orthosis, gait, orthotic, stroke, therapeutic effect, training.

Stroke, also known as cerebrovascular accident, is known as a leading cause of gait impairment which includes reduced walking speed, foot drop, gait asymmetry, increased energy expenditure, and inadequate muscle activity during gait.[1-3] Restoring the ability to walk, which is the main aim of any rehabilitation program, is of paramount importance to hemiplegic stroke survivors.[4,5] Numerous investigations have demonstrated that motor recovery from a stroke is greatest within the first three months after onset, with an initial steep recovery curve for around 6 to 12 months after the event.[6-8] Individuals with stroke usually undergo rehabilitation programs following the acute and subacute stages. Rehabilitation, including gait training, is crucial for the management of functional impairment in patients

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with subacute stroke.[9] Intensive, task-oriented, and repetitive training is therefore needed given the active functional and neurological recovery occurring during this time.[10,11]

Wearing an ankle-foot orthosis (AFO) during gait training within the subacute phase can improve ambulatory function following stroke.[12,13] These beneficial effects on walking with an AFO have been referred to as an "orthotic effect" and are suggested to be mainly due to improved biomechanics of walking.[14] Additionally, the effects of orthotic devices, including AFOs or functional electrical stimulation (FES), may also carry over to motor performance when the device is not applied. This carry-over effect is frequently described as a therapeutic effect.[15,16] Therapeutic effects may refer to a "training effect," which indicates the difference gained in measured walking behaviors without a device being worn compared with the baseline.[17,18] Despite these documented advantages, few studies of therapeutic effects of AFOs along with gait training have been conducted on individuals' walking with stroke. Everaert et al.[18] compared changes in walking speed after a six-week use of FES and AFO. They reported that both the FES and rigid AFO showed substantial therapeutic effect for walking speed; however, the therapeutic effect of FES was more apparent than the AFO, and the ankle motion restriction during gait with conventional AFOs was one of the causes for the AFO's lesser therapeutic effect. The most conventional AFOs, categorized as non-articulated and articulated, limit the ankle joint motion to stabilize the ankle joint during stance and facilitate clearance during swing to some extent, though these AFOs also constrain some movements with functional advantage.[19]

However, an AFO with an oil damper (AFO-OD) mechanism, which allows the leg to freely move into dorsiflexion while providing resistance during plantarflexion, has been developed.[20] Only Yamamoto et al.,[21] in a pilot study of eight patients with chronic stroke, found that after three weeks of gait training with the use of AFO-OD, patients' gait when not wearing the AFO (therapeutic effect) was improved, with a significantly increased ankle power generation during terminal stance and reduced pre-swing time. Hence, the therapeutic effect of the gait training with different AFOs in the recovery phase of stroke in a larger sample size would be expected to yield eye-catching results.

The study aimed to demonstrate the effect of gait training using AFOs on the gait of stroke patients when not wearing AFOs by comparing AFO-OD that resists plantarflexion and an AFO with a plantarflexion stop (AFO-PS) and to determine whether these AFO types had significant differences regarding the therapeutic effect. Previous investigations have indicated that AFO-PS may cause undesired knee flexion in the early stance phase.[22,23]

PATIENTS AND METHODS

The nonblinded, parallel, controlled trial included 42 poststroke hemiplegic patients (38 males, 4 males, mean age: 59.7±10.9; range, 38 to 81 years) in the subacute stage (less than 180 days after onset) who were undergoing general rehabilitation and had been prescribed an AFO and gait training sessions while wearing the device. Conventional gait training using an AFO for patients was prescribed by their physician. The individuals with a maximum spasticity score of less than 2 according to the Modified Ashworth scale, ankle range of motion greater than 0° in dorsiflexion, and no daily life use of an AFO were included. The individuals were excluded if they had confounding disorders, significant cardiopulmonary conditions, and cognitive problems that may limit their walking ability. Three patients were excluded since they could not be followed up in the second measurement. All participants had received gait rehabilitation by physiotherapists; however, none had used any AFOs before taking part in the present study. Two types of AFO that have a mechanical ankle joint with double metal uprights were used in this study (Figure 1). An AFO incorporating a Klenzak ankle joint and metal uprights was used as an AFO-PS, while an AFO-OD with metal uprights


Figure 1. Types of ankle-foot orthosis (AFO) used in this study. **(a)** AFO with plantarflexion stop (AFO-PS). **(b)** AFO with plantarflexion resistance (oil-damper, AFO-OD).

(Gait Solution; Kawamura Gishi Co., Osaka, Japan) was used as an AFO that resisted plantarflexion. The ankle joints allowed free dorsiflexion for both AFOs. The data on gait was recorded by six AMTI force plates (Advanced Mechanical Technology Inc., Watertown, MA, USA) connected continuously and a 10-camera Vicon motion analysis system (Vicon Motion Systems Ltd., Oxford, United Kingdom). The trajectory measurement for each marker and data from the force plates were obtained at a sampling rate of 100 Hz. Thirty-four markers were bilaterally located on the upper limbs, lower limbs, pelvis, and thorax. Using the same type of shoe (V-step; Pacific Supply, Osaka, Japan), participants walked at their normal self-selected velocity without an AFO, and their shod gait was measured. Use of a cane was kept constant in 29 patients (14 for AFO-OD group and 15 for AFO-PS). After the first measurement had been recorded, participants were randomly allocated to the AFO-OD group (n=20) and AFO-PS group (n=19) (Figure 2). Each participant engaged in daily 1-h gait training sessions with physiotherapists, which included the weight transfer from paretic limb to nonparetic and opposite direction, for two weeks while wearing the allocated AFO. After two weeks, gait was measured without the allocated AFO (only with shoes) under the same protocol. For randomization allocation, since the sampling method in the present study was consecutive, the randomization was also conducted consecutively. It should be noted that only one rehabilitation center was sampled in this study. A simple randomization method was used in this study, and the randomization unit was individual. Consequently, participants with an odd number assigned to them (by order of referral) were included in the AFO-OD group, and participants with the even number assigned to them were included in the AFO-PS group.

Trajectories of reflective markers and force plate data were filtered through a low-pass Butterworth digital filter with a cut-off frequency of 6 and 18 Hz, respectively. The link-segment model included 12 body segments: thorax, pelvis, upper arms, forearms, thighs, shanks, and feet. An inverse dynamic model was employed to calculate the joint kinematics and kinetics. The joints' moment, power, and ground reaction force were normalized by the weight of each patient. The normalization for step length was conducted by body height. Joint angles, joint moments, and ankle power were calculated for the affected limb. The peak values in each gait phase and the change in each phase were calculated. The 3D kinematics of the thorax and pelvis were also calculated. Data for pelvic rotation, thoracic obliquity, and thoracic rotation are not presented since no differences between conditions and groups were observed. Forty-nine gait parameters were analyzed. The Visual 3D version 5.0 software (C-Motion Inc., Germantown, MD, USA) was used to compute the gait indices.
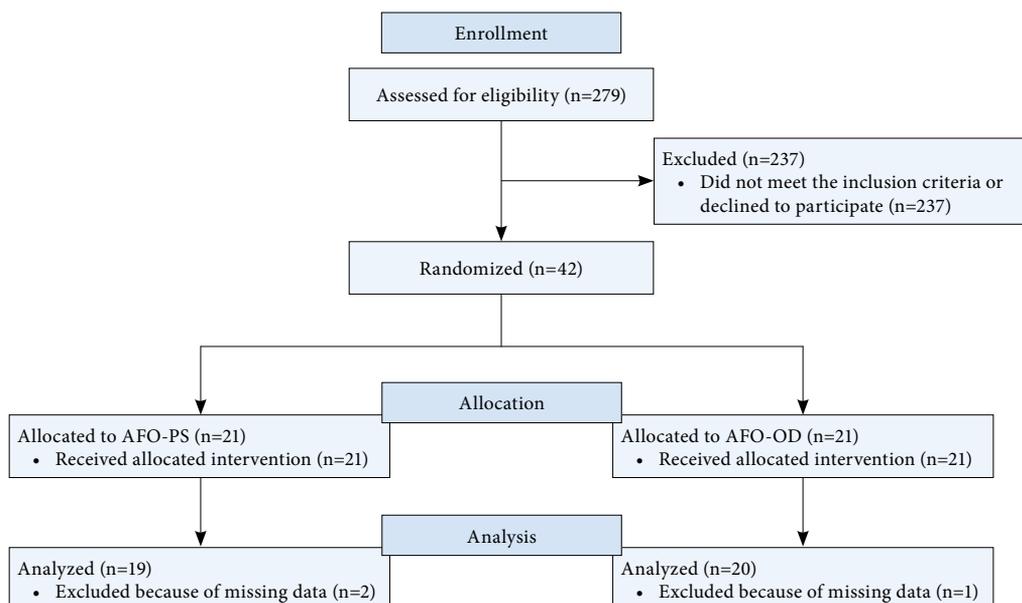
Figure 2. CONSORT diagram showing the flow of patients throughout the study.

AFO-PS: Ankle-foot orthoses plantarflexion stop; AFO-OD: Ankle-foot orthoses oil damper.

Statistical analysis

Statistical analyses were performed using IBM SPSS version 24.0 software (IBM Corp. Armonk, NY, USA). The gait indices mean of at least three repeated measures were recorded for each test condition (no AFO before gait training and no AFO after gait training). Gait data were evaluated for normality using the Shapiro-Wilk test. As for demographic characteristics and clinical features at baseline, the AFO groups were compared using the independent samples t-test, Mann-Whitney U test, or the chi-square test depending on the variable. A two-way mixed analysis of variance (ANOVA) with the Bonferroni correction (Bonferroni post hoc test) with within-group factors (therapeutic effect: without AFO before training gait and without AFO after training gait) and a between-group factor (AFO type) was used for normally distributed data to compare the conditions without AFOs before and after training. Additionally, Mauchly's test, Levene's test, and Box's M test were used for sphericity assumption, equality of variances, and homogeneity of covariances, respectively. In cases of no interaction, we considered the main effects, including the main effect of time (pre-training

vs. post-training) and the main effect of the group (AFO type: AFO-PS *vs.* AFO-OD). If a statistically significant interaction was identified, the paired t-test was performed to compare two conditions within each AFO group. Nonparametric statistics were conducted using the Wilcoxon signed-rank test for comparing the two test conditions and the Mann-Whitney U test for the AFO type. The descriptive statistics are presented as mean ± SD, median (interquartile ranges (IQR): the difference between 75th percentile and 25th percentile). A *p* value of <0.05 was considered statistically significant.

RESULTS

The patients' characteristics at inclusion are shown in Table 1. Data for pelvic rotation, thoracic obliquity, and thoracic rotation are not presented since no differences between conditions and groups were observed. There was no significant difference between groups for demographic characteristics and clinical features at baseline (p>0.05).

An interaction was found for only two parameters, ankle angle at initial contact (p=0.041) and maximum hip angular velocity in pre-swing

			TABLE 1								
			Patients' demographics and clinical characteristics at baseline								
	AFO-PS (n=19)					AFO-OD (n=20)					
Characteristics	n	%	Mean±SD	Median	IQR	n	%	Mean±SD	Median	IQR	*p*
Age (year)			59.2±9.8					60.2±12.3			0.226
Sex											>0.999
Male	17	89.5				18	90.0				
Female	2	10.5				2	10.0				
Body height (cm)			169.0±6.0					165.5±7.8			0.829
Body weight (kg)			65.1±10.9					63.9±9.8			0.313
Diagnosis											0.863
C. hemorrhage	11	57.9				10	50.0				
C. infarction	8	42.1				10	50.0				
Paretic side											>0.999
Right	11	57.9				12	60.0				
Left	8	42.1				8	40.0				
Time since onset (day)				84.00	59.00				63.00	39.00	0.550
Brunnstrom stage in lower extremities											0.691
II	2					1					
III	5					8					
IV	5					3					
V	6					7					
VI	1					1					
Velocity without an AFO (m/s)			0.3±0.2					0.3±0.1			0.281
AFO-PS: Ankle-foot orthoses plantarflexion stop; AFO-OD: Ankle-foot orthoses oil damper; SD: Standard deviation; IQR: Interquartile range.											

TABLE 2
Comparison of the spatiotemporal parameters, ground reaction forces, and shank-to-vertical angle measurements between the groups

Parameters	AFO-PS Pre-intervention① Mean±SD	Median	IQR	AFO-PS Post-intervention② Mean±SD	Median	IQR	AFO-OD Pre-intervention③ Mean±SD	Median	IQR	AFO-OD Post-intervention④ Mean±SD	Median	IQR	Therapeutic effect①②/③④ Interaction	Main effect Time	Main effect Group
Spatiotemporal parameters															
Velocity (m/s)	0.3±0.2			0.3±0.2			0.2±0.1			0.3±0.2			0.416	**<0.001**	0.810
Paretic to nonparetic (m/BH)	0.1±0.1			0.1±0.1			0.2±0.1			0.2±0.1			0.843	**0.021**	0.186
Nonparetic to paretic (m/BH)	0.2±0.1			0.2±0.1			0.2±0.1			0.2±0.1			0.134	0.171	0.757
Loading response time (s)		0.41	0.37		0.32	0.39		0.57	0.42		0.39	0.39	-	**0.002**	0.147
Single-stance time (s)	0.4±0.1			0.4±0.1			0.4±0.2			0.5±0.1			0.234	**0.046**	0.235
Pre-swing time (s)	0.7±0.4			0.5±0.4			0.7±0.3			0.5±0.3			0.803	**<0.001**	0.948
Swing time (s)	0.6±0.1			0.6±0.1			0.7±0.2			0.7±0.2			0.305	0.932	0.138
Cycle time (s)	2.2±0.6			1.9±0.7			2.5±0.6			2.2±0.7			0.822	**0.001**	0.152
Max COG velocity (m/s)															
In loading response		0.36	0.08		0.45	0.20		0.32	0.15		0.38	0.30	-	**<0.001**	0.254
In pre-swing		0.23	0.10		0.40	0.22		0.30	0.15		0.30	0.27	-	**<0.001**	0.497
Ground reaction forces															
Max posterior component (N/BW)		-0.08	0.05		-0.12	0.37		-0.07	0.08		-0.09	0.10	-	**0.002**	0.928
Max anterior component (N/BW)		0.03	0.04		0.04	0.20		0.04	0.03		0.05	0.04	-	**0.002**	0.834
COP progression in loading response (m)	0.1±0.0			0.1±0.0			0.1±0.0			0.1±0.0			0.298	0.358	0.780
COP progression in single stance (m)		0.03	0.04		0.04	0.20		0.04	0.03		0.05	0.04	-	**<0.001**	0.021
SVA															
At initial contact (°)	-7.0±5.5			-7.0±6.0			-7.4±5.1			-8.5±5.8			0.350	0.334	0.602
At non-paretic foot-off (°)	3.5±5.6			3.9±4.4			1.3±6.4			0.7±7.8			0.424	0.820	0.167
At non-paretic initial contact (°)	8.8±7.8			12.1±7.5			7.0±8.1			9.4±8.7			0.503	**<0.001**	0.378
At foot-off	28.1±13.2			32.0±12.1			28.7±13.5			30.4±12.6			0.203	**0.002**	0.914
Difference in single stance (°)	5.2±4.1			8.2±5.2			5.7±5.3			8.7±6.4			0.998	**<0.001**	0.775

AFO-PS: Ankle-foot orthoses plantarflexion stop; AFO-OD: Ankle-foot orthoses oil damper; Pre-intervention: Without AFO before 2 weeks' use; Post-intervention: Without the AFO after 2 weeks' use; SD: Standard deviation; IQR: Interquartile range; BH: Body height (m); COG: Center of gravity; BW: Body weight (kg); COP: Center of pressure; SVA: Shank-vertical-angle; Main effect of time: pre-training vs. post-training, Main effect of group: AFO type: AFO-PS vs. AFO-OD; AFO-PS: AFO with plantarflexion stop; AFO-OD: AFO with oil damper.

(p=0.048). After gait training, although the ankle joint angle at initial contact became more dorsiflexed in the AFO-PS group and slightly plantarflexed in the AFO-OD group, statistical analysis revealed no significant difference in each group (AFO-PS: p=0.306; AFO-OD: p=0.747). For hip angular velocity, however, this parameter was significantly increased in the shod gait after training in comparison to the shod gait before training in the AFO-PS group (p=0.008), and statistical analysis revealed no significant difference in the AFO-OD group (p>0.999).

TABLE 3
Comparison of the kinematics and kinetics at the ankle, knee, and hip and pelvic and thoracic angles measurements between the groups

Parameters	AFO-PS Pre-intervention① Mean±SD	AFO-PS Post-intervention② Mean±SD	AFO-OD Pre-intervention③ Mean±SD	AFO-OD Post-intervention④ Mean±SD	Therapeutic effect①②/③④ Interaction	Main effect Time	Main effect Group
Ankle joint angle							
Initial contact (°)	-10.9±9.0	-8.0±7.6	-6.2±6.5	-7.4±6.3	0.041	-	-
Loading response (°)	-12.6±9.0	-10.4±7.1	-8.7±6.8	-10.3±6.4	0.054	**0.754**	0.373
Max dorsiflexion in single stance (°)	1.6±9.3	4.4±6.4	4.9±6.6	4.7±6.4	0.094	0.122	0.400
Max plantarflexion in pre-swing phase (°)	-4.0±8.4	-3.1±6.9	-1.4±8.0	-2.1±8.0	0.449	**0.925**	0.438
Ankle joint moment							
Max dorsiflexion in loading response (Nm/BW)	-0.0±0.0	-0.0±0.1	-0.0±0.0	-0.0±0.1	0.056	**0.022**	0.209
Max plantarflexion in stance phase (Nm/BW)	0.6±0.3	0.7±0.3	0.7±0.3	0.7±0.3	0.557	0.008	0.655
Ankle joint power							
Max power in pre-swing (W)	0.3±0.3	0.4±0.4	0.2±0.2	0.3±0.2	0.593	0.047	0.235
Knee joint angle and knee angular velocity							
Initial contact (°)	9.4±5.2	9.0±6.3	6.5±7.4	5.2±6.7	0.447	**0.183**	0.096
Max flexion in loading response (°)	17.2±4.4	15.3±5.9	11.5±9.6	12.0±10.8	0.063	0.276	0.632
Max extension in single stance (°)	6.9±8.7	6.0±10.6	1.0±12.1	1.1±12.2			
Max flexion in swing (0)	41.8±11.9	43.2±11.0	37.3±14.9	38.1±14.3	0.507	**0.591**	0.126
Max angular velocity in pre-swing (deg s⁻¹)	144.8±76.0	181.6±108.3	146.2±69.8	171.3±78.8	0.697	0.198	0.254
Knee joint moment					0.324	**<0.001**	0.865
Max extension in loading response (Nm/BW)	0.2±0.2	0.2±0.2	0.2±0.2	0.2±0.2			
Hip joint angle and hip angular velocity					0.831	0.762	0.587
Initial contact (°)	18.1±5.5	21.1±6.4	18.3±7.2	17.6±7.9			
Max extension in single stance (°)	8.3±9.7	7.2±12.4	7.0±11.1	5.1±10.4	0.122	0.308	0.384
Max angular velocity in pre-swing (deg s⁻¹)	64.6±32.9	76.8±40.5	68.0±37.8	64.0±36.5	0.778	0.223	0.615
Hip joint moment					0.048	-	-
Max extension in loading response (Nm/BW)	0.3±0.2	0.3±0.2	0.5±0.7	0.5±0.6			
Max flexion in pre-swing (Nm/BW)	-0.3±0.2	-0.4±0.3	-0.3±0.2	-0.3±0.2	0.797	0.856	0.242
Pelvic tilt					0.583	0.024	0.265
Initial contact (0)	-2.8±5.0	-6.1±6.8	-5.6±6.4	-5.3±6.0			
Nonparetic foot-off (0)	-7.1±4.4	-9.9±7.1	-10.1±6.1	-10.0±6.4	0.061	0.126	0.560
Nonparetic initial contact (0)	-8.7±4.7	-11.2±5.0	-11.7±6.4	-12.4±6.0	0.140	0.158	0.364
Foot-off (0)	-7.0±5.4	-10.2±7.5	-11.0±6.3	-11.7±6.0	0.112	0.356	0.233
Pelvic obliquity					0.193	0.048	0.130
Initial contact (0)	2.3±3.0	1.6±2.1	2.6±3.2	2.7±2.8			
Nonparetic foot-off (0)	0.6±2.6	0.2±2.8	0.6±2.6	0.6±3.1	0.404	0.559	0.380
Nonparetic initial contact (0)	0.3±2.4	-0.6±2.7	1.4±2.7	0.6±3.2	0.598	0.668	0.771
Foot-off (0)	1.7±3.0	0.6±2.8	2.7±2.8	1.9±3.2	0.825	0.042	0.173
Thoracic tilt					0.722	0.041	0.188
Initial contact (0)	-2.7±5.5	-3.0±6.4	-3.9±5.8	-1.8±6.1			
Nonparetic foot off (0)	-5.2±6.2	-5.1±7.0	-6.8±6.5	-5.1±8.5	0.088	0.197	0.980
Nonparetic initial contact (0)	-7.7±6.7	-7.0±7.1	-9.2±7.4	-8.3±8.9	0.208	0.169	0.723
Foot-off (0)	-5.8±6.3	-6.3±7.6	-8.3±7.4	-7.7±9.6	0.871	**0.310**	0.537

AFO-PS: Ankle-foot orthoses plantarflexion stop; AFO-OD: Ankle-foot orthoses oil damper; Pre-intervention: Without AFO before two weeks' use; Post-intervention: Without the AFO after two weeks' use; SD: Standard deviation; IQR: Interquartile range; BW: Body weight (kg); BH: Body height (m); COG: Center of gravity; COP: Center of pressure; SVA: Shank-vertical-angle; Joint angle: positive numbers: Flexion/dorsiflexion; Negative numbers: Extension/plantarflexion; Internal joint moment: Positive numbers: Extension/plantarflexion; negative numbers: Flexion/dorsiflexion; Ankle power: Positive numbers: Generation; negative numbers: Absorption: Tilt angle: negative values indicate forward tilt; Obliquity angle: A positive value indicates that the pelvis is higher on the paretic side than on the nonparetic side; Pre-intervention: Without AFO use before two weeks' use; Post-intervention: Without the AFO after two weeks' use; AFO-PS: AFO with plantarflexion stop; AFO-OD: AFO with oil damper;

As shown in Tables 2 and 3, the main effect of the group (AFO type) was not significant in all variables. However, main effects of the time in both groups were significant for walking speed, step length, posterior and anterior components of the ground reaction force, center of pressure progression during single stance, the shank-to-vertical angle at foot-off and nonaffected foot-off, shank-to-vertical angle change in single-stance, and the maximum center of gravity velocity during loading response and pre-swing, with a significant increase after training compared to before the training. Temporal factors including loading response time, pre-swing time, and cycle time were also significantly reduced after training. There were no significant differences for the ankle, knee, and hip kinematics during gait regarding the main effect (p>0.05), except the maximum angular velocity of pre-swing knee flexion with a higher value following the two-week use of an AFO. In addition, some kinetic parameters such as maximum ankle dorsiflexion moment in loading response, maximum ankle plantarflexion moment in stance phase, maximum ankle power in pre-swing, and maximum hip flexion moment during pre-swing were significantly increased in both groups after gait training. In terms of pelvic kinematics, obliquity at nonaffected initial contact and foot-off were significantly reduced after two weeks of using the AFOs. There were no statistically significant differences in the thoracic variables concerning the main effect of time.

DISCUSSION

The main effect of time (pre-training *vs.* post-training) was observed for many gait indices, including spatiotemporal factors, ground reaction force, shank-to-vertical angle, joints kinetics, and pelvic obliquity. These findings confirm the beneficial effects of two weeks of both AFOs' use with gait training. The findings support the second hypothesis that the AFOs would have therapeutic effects. Given that this study involved patients in the subacute phase, the promotion of gait performance probably reflected the process of recovery following a stroke and the training effectiveness related to gait practice using an AFO. The result of the present study is in agreement with those of previous studies, which have shown the therapeutic advantages of FES as a gait-retraining therapy in the off condition (without a device) the in recovery phase.[17,18,24]

Despite the improvement of ankle kinetics (joint moment and power) following gait training for both groups for the main effect of time, we found no significant improvement in ankle kinematics in either group. It should be noted that ankle kinetics are related to the alignment of the whole body and the ground reaction forces but not simply related to the ankle kinematics.[25] The improvement of ankle alignment at initial contact affects the dorsiflexion moment, and the center of gravity progression in stance affects the plantarflexion moment.[14,26] The main problem of ankle kinematics in stroke comes from the insufficient activity of the dorsiflexors and the inappropriate activity of the plantar flexors.[27,28] The activity of plantar flexors can be controlled by adequate gait training;[29] however, the improvement of activity of the dorsiflexors is difficult to achieve. Therefore, ankle kinetics is improved to some extent, but its kinematics cannot be improved easily. Hence, the movement of the ankle joint is the most difficult parameter to improve for patients without wearing AFOs. The previous systematic reviews showed the improvement of ankle joint angles of gait with an AFO.[14,26] Therefore, the ability to dorsiflex the foot while walking likely requires wearing an AFO in the subacute phase.

Regarding the third rocker function during pre-swing for the main effect of time, significant improvements were seen in pre-swing time, anterior ground reaction force, positive ankle power generation, maximum ankle plantarflexion moment, maximum knee flexion angular velocity, and hip flexion moment in both groups. These results partially confirm those of a previous study where the increased ankle joint power generation at push-off and reduced pre-swing time using an AFO-OD were observed while individuals were tested without the AFO-OD.[21] Additionally, we found that training along with an AFO-PS could also improve these parameters. Thus, the kinds of AFO function did not affect the gait improvement by training with AFOs. In addition, although some indices related to the forefoot rocker function improved for both groups, this was not enough to demonstrate an improvement in push-off function using the AFOs since the ankle plantarflexion angle in this phase was not improved. Furthermore, we did not measure the activity of the soleus and gastrocnemius or the angular velocity of ankle plantarflexion in the third rocker phase. In a study, electromyographic analysis of AFO-OD use demonstrated that ankle plantarflexion torque did not result in a definite peak during the pre-swing in adults affected by stroke.[30] Therefore, the effect of

gait training using an AFO by physiotherapists on the push-off is not clear, and it should be investigated in additional studies that include electromyography at the ankle and hip joints.

The second objective of this study was to show whether kinds of AFO function affect the gait change by training with AFOs. We had hypothesized that the therapeutic effect of AFOs would be affected by AFO type. According to the results, the interaction effect of the type of AFO and time was found for only two gait indices, particularly the ankle angle in the initial contact and maximum hip angular velocity in pre-swing. For ankle angle at initial contact, although it became more dorsiflexed in the AFO-PS group and slightly plantarflexed in the AFO-OD group after training, these changes were not significant. Concerning the parameter related to hip, it should be noted that forward propulsion of lower extremities can be performed by either the plantar flexors in the push-off phase or the hip flexors in the pull-off phase,[31,32] and it has been hypothesized that pulling the paretic extremity off using the hip flexors may compensate for the reduced push-off ability.[27,31,33] In the present study, the hip flexion moment was increased for both AFO groups after gait training, and an increased statistical significance in the hip flexion angular velocity during pre-swing was observed for the AFO-PS group. A possible reason is that an AFO-PS probably prevents smooth plantarflexion during pre-swing; as a result, patients have to flex the hip rapidly, resulting from the increased hip angular velocity by pulling off the paretic limb to compensate for the lack of plantarflexion in pre-swing. Additionally, AFO-OD promotes plantarflexion gradually in the loading response phase with the assistance of the oil damper. Nevertheless, the results could not confirm our hypothesis since large interactions in most indices were not observed between groups. Thus, the AFO function did not affect the effect of gait training largely. The difference might be found in orthotic effect, as a previous study showed that the AFO-OD when wearing assists better alignment in the thorax during stroke gait and that the AFO-PS induces pelvic forward tilt.[34] We speculate that extended gait training with physiotherapists using AFOs may detect enough change between AFOs during stroke gait, and this possibility should be investigated in additional studies. One of the limitations of this study was that individual effects (the lack of the control group having gait training without any AFOs) could not be distinguished due to the study design.

Additionally, the electromyography measurement was not conducted for a better understanding of the effect of the gait training using AFOs on gait of survivors with stroke. In future studies, it is recommended that gait analysis in association with measurement of muscle activity be explored in patients with stroke receiving gait training in the subacute phase as well as in the chronic phase.

In conclusion, although the results did not show a significant difference between the two AFO groups, a therapeutic effect through two weeks of continuous use of AFOs and gait training by physiotherapists was found in both AFO groups in the spatiotemporal factors, ground reaction forces, shank-to-vertical angle, joints kinetics, and pelvic obliquity.

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