



Original Article

The influence of an ankle-foot orthosis on the spatiotemporal gait parameters and functional balance in chronic stroke patients

VENDULA BOUCHALOVÁ^{1)*}, ELS HOUBEN²⁾, DORINE TANCŠIK³⁾, LOTTE SCHAEKERS³⁾, LENI MEUWS³⁾, PETER FEYS³⁾

¹⁾ Department of Public Health and Preventive Medicine, Faculty of Medicine in Pilsen, Charles University in Prague: Lidická 4, Pilsen, 301 66, Czech Republic

²⁾ Rehabilitation Department of Ziekenhuis Oost-Limburg, Belgium

³⁾ University of Hasselt, BIOMED/REVAL, Faculty of Medicine and Life Sciences, Belgium

Abstract. [Purpose] Observational study investigating the influence of various ankle-foot orthoses on the spatiotemporal gait parameters and functional balance in chronic stroke patients. [Subjects and Methods] Fifteen chronic stroke patients participated in this study after providing informed consent. Two groups of patients were differentiated based on the Timed Up and Go Test. Patients were tested in three different conditions: with standard prefabricated ankle-foot orthosis (Maramed), with individualized ankle-foot orthosis (Y-tech), and without any ankle-foot orthosis. Spatiotemporal gait parameters were obtained by walking on an instrumented walkway (GAITRite®) at usual and fastest speed. Balance was assessed with Timed Up and Go Test, Step Test, and Four Square Step Test. [Results] Maramed and Y-tech significantly improved the spatiotemporal parameters while walking at usual and maximal speed (single support time affected side; double support time affected side and step length unaffected side). The Y-tech in addition improved velocity and cadence. Among the balance tests, only the Timed Up and Go test showed improvements in favor of Maramed and Y-tech. [Conclusion] Patients benefited from wearing orthosis at both usual and maximal speed, irrespective of whether they wore Maramed or Y-tech. Only severe stroke patients benefited from wearing an orthoses compared to mild impaired group.

Key words: Stroke, Ankle foot orthosis, Spatiotemporal parameters

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INTRODUCTION

Gait is one of the most important physical features for the perception of good quality of life and independence^{1, 2)}. For healthy individuals, ambulation seems like an effortless task¹⁾, but for stroke patients, a safe and adequate gait pattern is a challenge. Stroke is the third leading cause of death and affects many aspects of life. Patients often have difficulties in mobility, activities of daily living, cognition, communication, concentration, etc. An altered gait pattern can be related to a number of factors such as muscle weakness, alterations in tone, abnormal reflexes, altered coordination and motor programming, and disturbances in balance²⁻⁴⁾. These impairments lead to unsafe walking and increased risk of falling.

Dependent on the individual, unique, and persistent problems of each patient, an ankle-foot orthosis (AFO) can be prescribed to promote better and safer walking. Many types of AFOs exist, all with their own specific functionalities. All AFOs can be classified into two groups: prefabricated and custom fabricated. The prefabricated AFOs are developed in standard sizes and forms. They are produced in series and no adaptations are made for the individual. The individualized AFOs can be adapted by optimal shaping to the foot characteristics by changing the angle and rigidity according to the individual's needs,

*Corresponding author. Vendula Bouchalová (E-mail: Vendula.Bouchalova@gmail.com)

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before and during the rehabilitation process.

Various clinical tests are used in rehabilitation practice to determine the gait and balance problems and degree of recovery in stroke patients. Motion Analysis Systems (VICON, RIVCAM), electronic walkways (GAITRite®), force plates, etc. provide a broad range and precise description of gait parameters⁵. It has already been well established that there are beneficial effects of wearing an AFO on the gait pattern. Wearing an AFO significantly increases walking speed^{2, 3, 5-17}, cadence^{2, 3, 5-7}, step length^{2, 3, 5, 9, 13, 14}, step length symmetry^{2, 17}, stride length^{3, 6-9, 18}, single support time^{2, 5, 19}, and reduces double support time^{2, 20}.

When testing functional balance with clinical tests, an overall positive effect was found in favor of the AFO. Tests with positive effects of wearing an AFO included the Timed Up and Go test (TUG), Berg Balance Scale (BBS), Functional Ambulation Categories (FAC), and modified Emory Functional Ambulation Profile (mEFAP)^{3, 6, 7, 10, 11, 21-26}. Other clinical tests, such as Functional Reach test (FR) and Timed Up Stairs (TUS), did not always report significant results regarding wearing an AFO^{10, 11, 22, 23, 27}.

Different study designs were used to test the effects of an AFO. Comparisons of different types of AFOs with the footwear or barefoot walking were used^{3, 5, 6, 8, 16, 17, 20}. Two studies have compared different subgroups of patients. In the study by Mulroy et al.⁸, both acute and chronic stroke patients benefited from wearing an AFO. Rao et al.⁵ reported a positive impact in a group of patients with plantar flexion contracture using a rigid AFO, and recommended the use of a plantar-free dorsiflexion AFO in patients without plantar flexion contracture. Twelve articles were focused on investigation of functional balance when wearing an AFO^{3, 6, 7, 10, 11, 21-27}. Only three articles studied functional balance in combination with spatiotemporal parameters^{3, 6, 7}. All the studies measured spatiotemporal parameters of gait at comfortable walking speeds. The effect of the orthosis at fastest ambulation remains unknown.

All of the above mentioned research leads to the research questions of interest: (1) Does an individualized AFO (Y-tech) change the gait pattern, gait speed, and functional balance of persons with stroke, compared with not wearing an AFO? (2) Is this effect different from a standard prefabricated AFO (Maramed)? (3) Are there any differences in the gait pattern and functional balance between two groups differentiated by the need of an assistive device during daily life walking?

SUBJECTS AND METHODS

Fifteen chronic stroke patients were recruited from the outpatient services of the Rehabilitation Department of Ziekenhuis Oost-Limburg (ZOL) in Lanaken, Belgium. Inclusion criteria were as follows: (a) diagnosis of hemi-paresis caused by a Cerebrovascular Accident, (b) chronic phase (three or more months post-stroke onset), (c) ability to walk safely with and without an AFO, (d) ability to understand simple instructions, and (e) familiarity with wearing an individualized AFO (Y-tech) for at least one month. Exclusion criteria were as follows: (a) bilateral assistive devices needed for walking, and (b) history of orthopedic problems (related to the lower extremities) that would interfere with gait performance.

The Committee Medical Ethics of the hospital Ziekenhuis Oost-Limburg and the University of Hasselt approved this study. Participants had read and approved the informed consent.

Two different types of AFOs were tested in this study: a prefabricated polypropylene plastic Maramed orthosis and an individualized Y-tech orthosis. The Maramed orthosis is shaped to a neutral dorsi-flexed position and has a thin and limited width of material behind the ankle. The Maramed orthosis was available for testing in three different sizes: small (United States [US] size 3-6), medium (US size 6-9), and large (US size 9-11). The hybrid individualized Y-tech AFO (V!GO, Wetteren, Belgium) is made from a polypropylene sheet (4-5 mm) with integrated thermoplastic carbon reinforcement. It can be adapted according to the individual needs of the patient. An incorporated strap around the ankle serves for better fixation of the foot in the AFO. Each patient included in this study had already used his or her own Y-tech orthosis. To avoid bias, standardized sport shoes in different sizes were available during the testing for each participant.

This observational study consisted of two testing days, within 3 weeks (Fig. 1). In a preparatory session (day one), participants were familiarized with the Maramed AFO and standardized sport shoes. Patient characteristics and descriptive

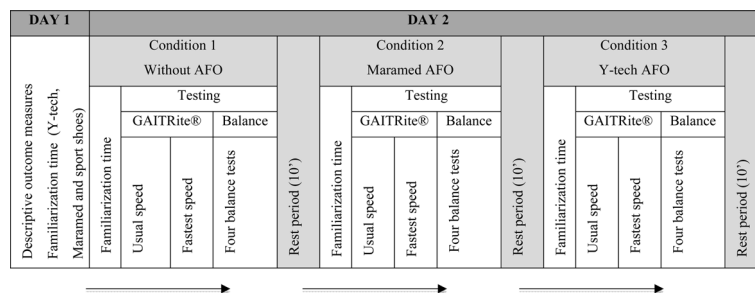


Fig. 1. Study design

outcome measures were collected, and each experimental clinical test was demonstrated and practiced once. According to Podsiadlo and Richardson²⁸)_ENREF_25, elderly people who need 20 and more seconds to complete the TUG test are more prone to falling. Based on the results of this publication and in order to decrease the risk of falling, all patients in the “with assisted device” group (AD-group) were instructed to use a walking cane during the examinations on testing day 2.

The second test session consisted of functional balance and walking tests examined under three different conditions. Condition 1 was when patient was tested without any AFO; condition 2 was while wearing a standardized AFO (Maramed); and condition 3 was with an individualized AFO (Y-tech). The order of the conditions was randomized for each participant. First, spatiotemporal parameters were recorded at usual, followed by fastest speed, while walking on a 5.37-m long gait analysis carpet (GAITRite[®]). Each patient performed two trials at each walking speed. Due to the limited length of the carpet, start and finish lines were positioned 2 m ahead and behind the borders of the carpet to ensure recording the constant walking pattern while walking over the GAITRite[®]. Walking tests were immediately followed by performing functional balance tests (TUG, Step Test – ST and Four Square Step Test – FSST), during which all patients received standardized instructions and were examined in a standardized set up. A 10-min resting period was established between the testing conditions, during which patients could rest in the sitting position while the examiners changed the AFO condition according to randomization.

Demographic data such as Gender, weight (kg), height (cm), body mass index (BMI – kilogram/meters squared), age (years), stroke onset (months), lateralization of stroke (right/left hemisphere), stroke location (hemisphere, cerebellum, other), stroke type (ischemic/hemorrhagic), and time using the Y-tech AFO (months) were collected from each patient.

The severity of motor and sensory dysfunction was examined by several tests. The active and passive range of motion (ROM) in the affected ankle was measured with a goniometer in both lying and sitting positions. The degree of spasticity was measured with the Tardieu Scale (TS). Reflex activity, synergies, and coordination of the lower extremities were evaluated by the Brunnstrom Fugl-Meyer test (BFM). The Sensory Extinction test (SE) was used to identify sensory neglect for light touch on the patient’s lower extremities. This test was performed only in patients with intact sensation. Motricity Index (MI) was used to evaluate maximal isometric strength of lower extremities.

Activity level was described by the BBS, FAC, Brunel Balance Assessment (BBA) and the TUG test. All descriptive tests were performed in standardized shoes and without any AFO.

The second testing day contained the experimental part of this study, where in three different conditions (no AFO, Maramed, and Y-tech), walking at usual and fastest speed and four functional balance tests were performed. For the spatiotemporal gait pattern analysis, the following parameters were used: velocity (cm/second), cadence (steps/minute), step length (cm), single support time (sec), and double support time (sec). Static and dynamic balance were examined by the following tests: TUG, ST, and FSST. TUG test is reliable measure that assesses mobility, balance, and walking ability²⁹). ST assesses an individual’s ability to place one foot onto a 7.5 cm high step and then back down to the floor repeatedly as fast as possible for 15 sec. The score is the number of steps completed in the 15 sec period for each lower extremity³⁰). FSST is a reliable and valid test of dynamic balance that clinically assesses the ability to step over objects forward, sideways, and backwards in post- stroke patients^{31, 32}).

Statistical analysis was carried out using a Statistica 7 StatSoft program. Patients were divided into two groups according to achieved average time of three trials of the TUG test. Those who completed the test in less than 20 sec were allocated into the “without assistive device group” (without AD-group). Those who completed the test in more than 20 sec were allocated into the “with assistive device group” (AD-group). Parametric two group by three conditions analyses of variance (ANOVAs) were performed, as this allowed us to investigate the interaction effects between groups, regarding the effects of the different AFOs on the walking and balance tests. Significant differences between conditions or groups were analyzed by a post hoc Tukey test.

RESULTS

Fifteen patients (12 men and 3 women) with mean age 59.40 years (\pm 9.32 years) have participated in this study. Mean stroke onset for the total group was 16.67 months (\pm 23.84 months), lateralization of stroke was eleven right, four left hemisphere, and stroke location was eleven hemisphere, one cerebellum, and three other (thalamus, a combination of hemisphere and cerebellum, a combination of hemisphere, brainstem, and thalamus). In total, 14 participants with ischemic type and one hemorrhagic type stroke joined the experiment. Participants were divided into two groups: nine participants in the AD-group and six in the without AD-group. Both groups showed comparable patient characteristics (Table 1).

Significant differences within the groups were found in descriptive outcome measures (Table 2). The active and passive ROM in the ankle of the affected side was significantly decreased in the AD-group. Spasticity, tested by the TS, did not show differences between the groups. On the other hand, groups differed in BFM motor part scores, but not in sensory testing. No differences between the groups were found in the SE test. According to the MI the participants in the AD-group had lower strength in the ankle compared to the patients in the without AD-group. For the balance tests, there were significant differences between the groups for the BBS, BBA and the TUG test, all in favor of the without AD-group. In general, patients in the without AD-group showed better results in all the descriptive tests compared to the AD-group. Patient characteristics and descriptive data results support the selected criteria for group distinction.

Results of all spatiotemporal parameters are presented in Table 3. In the total group, significant condition effects were

found when a Maramed or Y-tech AFO was used. Walking at usual speed with a Y-tech AFO resulted in an increase in single support time of the affected side ($p < 0.01$), step length of the unaffected side ($p < 0.05$) and a decrease in double support time on the unaffected side ($p < 0.05$). Walking with Maramed AFO at usual walking speed significantly increased only single support time of the affected side. When walking as fast as possible but safely, significant improvements were found in all

Table 1. Patient descriptive characteristics for total group, AD and without AD-groups

| Patient characteristics | Total group (n=15) | AD-group (n=9) | Without AD-group (n=6) |
|---|-----------------------|-------------------|---------------------------|
| Age (years), mean \pm SD | 59.4 \pm 9.3 | 58.2 \pm 11.0 | 61.2 \pm 6.6 |
| Gender (male/female), n | (12 / 3) | (6 / 3) | (6 / 0) |
| BMI (kg/m ²), mean \pm SD | 27.1 \pm 4.4 | 27.4 \pm 4.9 | 26.8 \pm 4.0 |
| Stroke onset (months), mean \pm SD | 16.7 \pm 23.8 | 9.7 \pm 3.6 | 27.2 \pm 36.8 |
| Stroke location, n | | | |
| Left/right hemisphere | 11 | 7 | 4 |
| Cerebellum | 1 | 1 | 0 |
| Other | 3 | 1 | 2 |
| Stroke type, (ischemic/hemorrhagic), n | (14 / 1) | (8 / 1) | (6 / 0) |
| Stroke lateralization (left/right), n | (4 / 11) | (2 / 7) | (2 / 4) |
| AFO time (months), mean \pm SD | 7.3 \pm 3.5 | 7.2 \pm 3.8 | 7.3 \pm 3.5 |

Values presented as mean \pm SD or frequency.

AD: assistive device, AFO time: since wearing Y-tech orthosis.

Table 2. Descriptive outcome measures for total, AD and without AD-groups

| Descriptive outcomes measures | Total group (n=15) | AD-group (n=9) | Without AD-group (n=6) |
|--|-----------------------|-------------------|---------------------------|
| Ankle dorsiflexion, affected side (°) | | | |
| Sitting /active/ | 71.7 \pm 17.8 | 72.3 \pm 14.1 | 93.7 \pm 10.0** |
| Sitting /passive/ | 94.6 \pm 10.5 | 91.6 \pm 11.6 | 99.2 \pm 6.9 |
| Supine /active/ | 80.9 \pm 16.2 | 60.8 \pm 14.1 | 88.0 \pm 6.0** |
| Supine /passive/ | 83.3 \pm 10.4 | 78.4 \pm 10.6 | 90.7 \pm 3.8* |
| Tardieu scale, affected side (score 0–5) | | | |
| Ankle: V1 | 0.9 \pm 0.6 | 1.1 \pm 0.6 | 0.5 \pm 0.6 |
| Ankle: V2 | 1.6 \pm 1.5 | 2.0 \pm 1.4 | 1.0 \pm 1.6 |
| Ankle: V3 | 1.9 \pm 1.3 | 2.2 \pm 1.2 | 1.5 \pm 1.4 |
| Fugl-Meyer, motor score - Lower Extremities (score 0–34) | 22.0 \pm 4.3 | 19.9 \pm 3.4 | 25.0 \pm 3.6* |
| Fugl-Meyer, sensory score - Lower Extremities (score 0–12) | 10.3 \pm 2.4 | 11.0 \pm 1.3 | 9.2 \pm 3.4 |
| Sensory Extinction Test, affected side (n) | | | |
| Score 0 | 3 | 2 | 1 |
| Score 1 | 12 | 7 | 5 |
| Motricity index, affected side (score 0–33) | | | |
| Ankle | 15.0 \pm 1.0 | 10.9 \pm 6.2 | 21.2 \pm 9.4* |
| Knee | 22.5 \pm 5.0 | 22.1 \pm 6.2 | 23.0 \pm 3.1 |
| Hip | 20.9 \pm 4.9 | 19.4 \pm 5.5 | 23.0 \pm 3.1 |
| Total (score 0–100) | 58.3 \pm 15.3 | 52.4 \pm 13.8 | 67.2 \pm 14.0 |
| Berg Balance Scale (score 0–56) | 44.5 \pm 7.4 | 41.6 \pm 7.5 | 48.8 \pm 5.0* |
| Brunel Balance Assessment (score 0–12) | 11.3 \pm 1.4 | 10.9 \pm 1.7 | 12.0 \pm 0 |
| Functional Ambulation Categories (score 0–5) | 3.3 \pm 1.0 | 2.8 \pm 0.8 | 4.0 \pm 0.6* |
| Timed Up and Go test (sec) | 23.1 \pm 12.7 | 30.8 \pm 11.7 | 12.9 \pm 3.1** |

Values presented as mean \pm SD.

*AD-group and Without AD-group comparison ($p < 0.05$)

**AD-group and Without AD-group comparison ($p < 0.01$)

spatiotemporal parameters when wearing a Y-tech AFO. We have observed increases in velocity ($p<0.01$), cadence ($p<0.01$), single support time of the affected side ($p<0.05$), step length of the unaffected side ($p<0.05$), and double support time on the unaffected side. The Maramed AFO improved only the step length of the unaffected side ($p<0.05$). All the above mentioned improvements in gait pattern were found only in favor of the patients allocated to the with AD-group. No significant differences were found in spatiotemporal parameters between the Maramed and Y-tech orthoses in the two groups. Interaction effects were found for single support time of the affected side at both usual and fastest speeds ($p<0.05$). Further, there were significant interactions for step length of the unaffected side ($p<0.05$) at fastest speed and double support time of the unaffected side at usual speed ($p<0.05$).

Table 4 represents the results of balance testing in each condition and group. In the total group a significant condition effect was found in the TUG test, indicating a significant decrease in time when wearing a Maramed and Y-tech AFO compared to no AFO ($p<0.05$). Only the patients allocated to the with AD-group showed a significant improvement in the TUG test when wearing Maramed ($p<0.05$) or Y-tech ($p<0.05$) AFO compared with no AFO condition. Other balance outcome measures, the ST and FSTT, did not show any differences within the conditions or groups.

DISCUSSION

This study investigated the effects of different AFOs on the gait pattern and functional balance of chronic stroke patients. Significant effects of spatiotemporal parameters were found at both usual and fastest speed for both types of AFOs, but only for the more severely affected group of patients. The positive significant effect of AFOs was measured also on TUG test.

It has already been well established that there are beneficial effects of wearing an AFO on the gait pattern. When stroke patients wear an AFO and walk at self-selected speed, previous studies have reported significant increases in walking speed^{2, 3, 5-17}, cadence^{2, 3, 5-7}, step length^{2, 3, 5, 9, 13, 14}, step length symmetry^{2, 17}, stride length^{3, 6-9, 18}, single support time^{2, 5, 19}, and a decrease in double support time^{2, 20}. The current study confirmed these results for single support time of the affected side, step length of the unaffected side, and double support time of the unaffected side when wearing a Y-tech

Table 3. Results of the spatiotemporal parameters at usual/fastest speed for total group, AD and without AD-groups

| Spatiotemporal parameters | Walking speed | Assistive device | Comparing two groups mean \pm SD | | |
|--|---------------|----------------------------|------------------------------------|--|---|
| | | | (C1) Without AFO | (C2) Maramed | (C3) Y-tech |
| Velocity (m/sec) | Usual | With AD | 0.4 \pm 0.2 (0.1–0.7) | 0.4 \pm 0.2 (0.2–0.7) | 0.4 \pm 0.2 (0.2–0.7) |
| | | Without AD [£] | 1.0 \pm 0.2 (0.6–1.1) | 0.9 \pm 0.2 (0.5–1.2) | 0.9 \pm 0.2 (0.6–1.2) |
| | Fast | With AD | 0.5 \pm 0.3 (0.2–1.0) | 0.6 \pm 0.3 (0.2–1.0) | 0.6 \pm 0.3 (0.2–1.1) [#] |
| | | Without AD [£] | 1.2 \pm 0.2 (1.0–1.5) | 1.2 \pm 0.2 (0.9–1.4) | 1.2 \pm 0.2 (1.0–1.4)* |
| Cadence (steps/min) | Usual | With AD | 59.2 \pm 16.9 (28.1–85.3) | 61.9 \pm 13.6 (32.2–78.0) | 61.9 \pm 15.0 (35.3–80.5) |
| | | Without AD [£] | 97.6 \pm 11.8 (78.2–108.0) | 94.9 \pm 13.1 (69.9–104.8) | 96.2 \pm 13.9 (73.7–108.1) |
| | Fast | With AD | 71.7 \pm 21.1 (32.7–103.7) | 76.3 \pm 20.9 (34.9–102.0) | 78.6 \pm 21.0 (36.6–105.6) [#] |
| | | Without AD [£] | 111.3 \pm 10.9 (95.5–123.3) | 112.1 \pm 10.6 (95.4–121.7) | 113.1 \pm 9.9 (99.4–122.4)* |
| Single support time affected side (% GC) | Usual | With AD | 20.1 \pm 4.9 (10.8–26.4) | 22.4 \pm 5.2 (11.5–29.0) [¥] | 22.4 \pm 4.7 (13.9–28.4) [#] |
| | | Without AD ^{£, €} | 30.2 \pm 2.9 (25.8–33.1) | 30.6 \pm 2.4 (26.6–33.1) [§] | 30.3 \pm 3.1 (26.0–33.0)* |
| | Fast | With AD | 21.7 \pm 4.8 (11.8–29.2) | 23.2 \pm 5.2 (12.8–29.7) | 25.3 \pm 6.2 (13.5–34.8) [#] |
| | | Without AD ^{£, €} | 33.3 \pm 1.6 (31.6–34.9) | 32.6 \pm 2.3 (28.6–35.5) | 32.3 \pm 1.9 (29.8–34.8) |
| Step length unaffected side (cm) | Usual | With AD | 32.9 \pm 11.0 (15.9–48.2) | 35.0 \pm 10.0 (18.7–50.4) | 37.3 \pm 11.1 (23.7–54.4) [#] |
| | | Without AD [£] | 58.4 \pm 4.8 (49.6–64.3) | 57.4 \pm 6.9 (46.8–67.3) | 59.4 \pm 5.7 (52.3–68.9)* |
| | Fast | With AD | 35.1 \pm 14.9 (8.8–55.5) | 40.2 \pm 11.9 (21.5–59.6) [¥] | 41.2 \pm 13.0 (26.2–61.5) [#] |
| | | Without AD ^{£, €} | 66.7 \pm 5.1 (61.2–76.4) | 66.0 \pm 5.9 (60.6–76.5) | 67.4 \pm 5.4 (62.4–76.8)* |
| Double support time unaffected side (% GC) | Usual | With AD | 50.1 \pm 9.3 (35.8–66.1) | 46.6 \pm 7.5 (36.8–61.1) [¥] | 46.0 \pm 7.5 (34.3–56.3) [#] |
| | | Without AD ^{£, €} | 33.1 \pm 3.4 (28.8–38.5) | 33.2 \pm 4.1 (28.4–39.8) | 33.7 \pm 4.0 (28.4–38.4)* |
| | Fast | With AD | 46.9 \pm 9.8 (30.6–65.6) | 43.6 \pm 9.0 (31.1–60.5) | 43.1 \pm 9.2 (31.9–61.1) [#] |
| | | Without AD [£] | 28.8 \pm 2.7 (25.2–33.3) | 29.1 \pm 3.2 (24.1–32.6) | 28.8 \pm 2.4 (25.8–32.7) |

Values presented as mean \pm SD (Range: min–max).

% GC: percentage of gait cycle.

£ significant difference between With and Without AD-groups ($p<0.01$)

¥ significant difference between Without AFO and Maramed within one AD-group ($p<0.05$); # significant difference between Without AFO and Y-tech within one AD-group ($p<0.05$)

§ significant difference between conditions Without AFO compared to Maramed within total group ($p<0.05$); * significant difference between conditions Without AFO compared to Y-tech within total group ($p<0.05$)

€ significant interaction effect between With and Without AD-groups, regarding the effect on the different AFOs ($p<0.05$)

AFO. Maramed AFO effects were the same, except for the step length of the unaffected side. So far no studies have tested the effect of an AFO on spatiotemporal at the fastest speed. In our study, the Y-tech AFO (compared to no orthosis) significantly increased velocity, cadence, single support time on the affected side, step length of unaffected side, and decreased double support time on the unaffected side.

All above mentioned improvements in spatiotemporal parameters were only significant for the more severely impaired group of patients (AD-group). Though most of the improvements were found in favor of the Y-tech AFO in comparison with the Maramed AFO (both linked to no orthosis), there were no significant differences among these two conditions. The better results in favour of the Y-tech AFO can also be due to implemented carbon fibers, which promote the dynamic aspect of the walking.

The following interpretations can be stated in order to summarize the effects of an AFO on spatiotemporal parameters: the use of a Y-tech or Maramed AFO provides better ankle stability and as a result, the step length of the unaffected leg can be lengthened. Based on this finding, we can conclude that the step length symmetry is improved by using an AFO. This conclusion supports Esquenazi et al²⁾. In the current study, it was hypothesized that effects of the orthoses would differ depending on ambulatory impairment level. The positive effect of AFOs were found only in the more severely impaired group of patients (AD-group), where the use of an AFO promoted better involvement of the affected side in the gait cycle. This allowed the patient to avoid the circumflexion on the hip joint and to initiate the standing phase by the heel contact. These findings are apparently strongly related to significantly different strength in ankle dorsiflexion (tested by MI) between the two groups.

In the current study, a lower ROM in the ankle was found in the more severely impaired group. It is important to mention that more stiffness will occur in the ankle joint when wearing an AFO. With a Y-tech AFO, there is less movement possible, therefore special attention in therapy is needed to maintain the ROM.

Rao et al.⁵⁾ divided their population into an acute and chronic group. The chronic group significantly improved in velocity, cadence, step, and stride length when wearing an AFO. The total group in our study showed significant results in the same outcome measures. Moreover, use of the Y-tech AFO prolonged single support time of the affected side and decreased double support time.

Besides gait, it was hypothesized that balance would also be positively affected by wearing an AFO. Prior studies have reported that wearing an AFO provided mediolateral stability during stance^{6, 7, 10, 11, 24, 33–35)} and corrected the ankle joint alignment^{3, 6)}. These changes can positively influence the balance, which is confirmed by the data and results from the GAITRite[®]. In the current study, stroke patients were also tested using functional balance tests: TUG test, ST and the FSTT. Six studies have previously investigated the TUG test with and without an AFO. Five of them showed significant decrease in time needed to complete the test in favor of the AFO^{10, 22, 23, 24, 27)}. Similar results were found in the current study for the total group and the AD-group. No significant results for the other balance tests were detected in the present study. It is important to mention that no previous article tested balance by using the FSST, BBA, or the ST. It might be possible that these tests are not sensitive enough or show high test-retest variability³⁶⁾. In previous studies, balance was measured with other tests³⁷⁾. The BBS and the FAC were often used and, in most cases, showed significant results in favor of the AFO.

There are several possible limitations in this study. A limitation of the instrumented GAITRite[®] walkway is that this equipment cannot detect if the quality of movement and coordination changes during walking. To observe these changes, kinematic analyses are needed. This was not investigated in the current study.

Table 4. Results of balance tests for AD and without AD-groups

| Balance test | Assistive device | Comparing two groups mean ± SD | | |
|--|-------------------------|--------------------------------|--------------------------|-------------------------|
| | | (C1) Without AFO | (C2) Maramed | (C3) Y-tech |
| Timed Up and Go test (sec.) | With AD | 27.3 ± 11.7 | 24.3 ± 10.4 [¥] | 24.1 ± 9.0 [#] |
| | Without AD [£] | 11.1 ± 2.5 | 10.8 ± 1.2 ^{\$} | 10.7 ± 1.4 [*] |
| Step test affected side (n of steps) | With AD | 3.0 ± 2.3 | 2.7 ± 2.0 | 3.1 ± 1.7 |
| | Without AD [£] | 7.0 ± 1.1 | 6.8 ± 1.0 | 6.8 ± 1.0 |
| Step test unaffected side (n of steps) | With AD | 3.8 ± 2.3 | 4.4 ± 2.3 | 4.0 ± 3.0 |
| | Without AD [£] | 9.0 ± 2.3 | 8.5 ± 1.9 | 9.0 ± 1.4 |
| Four Square Step Test (sec.) | With AD | 31.4 ± 13.4 | 23.5 ± 6.6 | 25.5 ± 11.7 |
| | Without AD [£] | 13.1 ± 1.7 | 12.7 ± 1.7 | 13.1 ± 2.1 |

Values are mean ± SD.

£ significant difference between With and Without AD-groups (p<0.01).

¥ significant difference between Without AFO and Maramed within one AD-group (p<0.05); # significant difference between Without AFO and Y-tech within one AD-group (p<0.05)

\$ significant difference between conditions Without AFO compared to Maramed within total group (p<0.05); * significant difference between conditions Without AFO compared to Y-tech within total group (p<0.05)

£ no significant interaction effects between With and Without AD-groups, regarding the effect on the different AFOs (p<0.05) were found.

Another influencing factor could be the fact that the patients allocated into the AD-group had to perform all tests with the walking cane even if they are not accustomed to its use in normal life. Due to this new condition, participants could be distracted.

An additional limitation is that all participants had already been prescribed an individualized AFO (Y-tech) prior to the experiment. Ideally, the familiarization time should be equal with a Y-tech as with a Maramed AFO. Better results in favor of a Y-tech AFO may be due to longer familiarization time. In four articles the patients used an AFO for at least one month prior to the study^{5, 7, 23, 24}).

In conclusion, groups were comparable based on the patient characteristics, although the AD-group showed better results in all the descriptive outcome measures compared to the without AD-group. When measuring spatiotemporal parameters and functional balance (only TUG test), significant results were found for the total group and the AD-group only. In both usual and fastest speed, significant results were found when patients walked with a Maramed or a Y-tech AFO. Overall, use of the individualized Y-tech orthosis showed better results in spatiotemporal parameters than the prefabricated Maramed orthosis, but no significant differences were found between these two conditions.

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