



Immediate effects of a novel walking assist device with auxiliary illuminator on patients after acute strokes

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Background: Many patients after acute stage of stroke are present with abnormal gait pattern due to weakness or hypertonicity of the affected limbs. Facilitation of normal gait is a primary goal of rehabilitation on these patients.

Objective: We aimed to investigate whether walking assist device with auxiliary illuminator (quad-cane with laser) providing visual feedback during ambulation could improve parameters of gait cycle immediately among patients with subacute and chronic stroke.

Methods: This was a cross-sectional study and 30 participants (male 23, female 7, group 1) with mean age 60.20 ± 11.12 years were recruited. Among them, 22 used ankle-foot orthosis [(AFO), group 2] and 8 did not use AFO (group 3) at usual walking. All the participants walked along a strait corridor with even surface for

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20 m without and with using a quad-cane with laser, respectively. A gait analyzer (Reha-Watch1 system) was used to measure the changes of the parameters of gait cycle, including stride length, cadence, gait speed, stance phase, swing phase, duration of single support and double support, the angle between toes and the ground at the time of toe-off (the toe-off angle) and the angle between calcaneus and the ground at the time of heel-strike (the heel-strike angle), before and with the use of a quad-cane with laser.

Results: The increase in the heel-strike angle reached a significant difference in groups 1, 2, and 3 ($p = 0.02, < 0.01, \text{ and } = 0.05$, respectively). However, the stride length, the gait speed, the cadence, percentage of the stance phase, swing phase, single-support phase, and double-support phase in a gait cycle, and the toe-off angle showed no significant change with the use of quad-cane with laser.

Conclusion: Patients after acute stroke had an immediate and significant increase in the heel-stroke angle by using a quad-cane with laser during ambulation, which might help the patients to reduce knee hyperextension moment and lessen the pressure of heel at loading phase.

Keywords: Gait; stroke; walking assist device; auxiliary illuminator.

Introduction

Stroke can result in brain damage, loss of functional activity, even disability or handicap among patients.¹ About 75% of patients with stroke suffer from walking disability that may lead to a high risk of falling and inability to be independent in daily life.^{2,3} It is very important for stroke survivors to receive intensive rehabilitation programs to recover their walking ability after acute stage of stroke.⁴ In order to improve dynamic balance during walking on uneven surface and the ability to adapt and overcome the barrier in different environments, repeated training and massed practice of gait during rehabilitation is crucial.⁵ The different assistive devices and the strategies of motor relearning used in gait training both affect the duration and clinical effect of the training.

Since walking consists of a number of consecutive gait cycles that must be coordinated by multiple systems of the body finely, aging and diseases both can cause impairment in walking.⁶ Patients with stroke are often present with abnormal gait pattern during walking due to hemiplegic extremities.⁷ It is estimated that 48% to 82% and 44% to 62% of the patients following stroke occur temporal and spatial inter-limb asymmetries, respectively.^{8,9} Compared with normal adults, abnormal gait patterns of patient with stroke include slower gait speed, shorter stride length, longer phase of double support, shorter phase of single leg swing, lesser cadence, and narrower stride width resulting from hypertonicity of hip adductors; meanwhile, due to the weakness of hip internal rotators, knee flexors and extensors, compensatory circumduction gait is common as well.^{10,11} The abnormal gait patterns

mentioned above might affect walking function, which leads to increased likelihood of falls, limitation in activities of daily living (ADL), and diminished quality of life.¹²

Integration of several human systems, such as musculoskeletal system, nervous system, visual system, and cognitive system, are necessary for the motor recovery in adult patients following stroke.¹³ Previous studies had proved that patients with stroke will achieve statistically significant improvement in balance, functional independence and gait control after receiving intensive rehabilitation program (60 min per time, once per week for three consecutive weeks) focusing on gait training.^{14,15} In order to achieve independence of ADLs in patients with stroke, locomotion and ambulation trainings are the most common and important programs in rehabilitation of stroke during subacute and chronic stages. The initial use of walking aids has been suggested to improve the quality, stability, and also prevent falls in stroke patients in the rehabilitation.^{16,17} Quad-canes are one of the most common walking aids in gait training among patients after stroke since most of them presented with hemiplegic pattern. It had been proved that quad-canes could improve symmetry¹⁸ and help to achieve normal muscle activation patterns¹⁹ in patients with subacute stroke who have asymmetric gait. Interactive therapy with visual feedback appears to be an important option to engage patients' participation and could be a useful approach to stroke rehabilitation.^{20,21} To the best of our knowledge, no available study evaluated the clinical effectiveness in the use of quad-cane with auxiliary illuminator (quad-cane with laser) as

visual feedback system among adult stroke patients in subacute and chronic stage. We aimed to provide visual feedback to the stroke patients by using a quad-cane with laser to explore the immediate effects on the parameters of gait cycle.

Methods

Ethics

This study was approved by the Institutional Review Board of Kaohsiung Veterans General Hospital (Number: VGHKS17-CT8-11). It was also conducted at Kaohsiung Veterans General Hospital from December 2017 to May 2018. All patients provided the informed consent after explanation by the study members and before the rehabilitation programs.

Participants

This was a cross-sectional study. We recruited patients with subacute and chronic stroke who received rehabilitation treatment from the outpatient clinic of the rehabilitation department of one medical center of southern Taiwan. The inclusion criteria were the following: Stroke patients (1) after the acute stage with stable vital signs, (2) with hemiplegic gait, (3) with sufficient cognition that could follow the instructions and procedure, (4) walk independently for a distance of more than 20 m with or without the use of a walking aid. Stroke patients with other neurological diseases like Parkinsonism, myopathy, multiple sclerosis, and spinal cord injury that might interfere with walking ability were excluded.

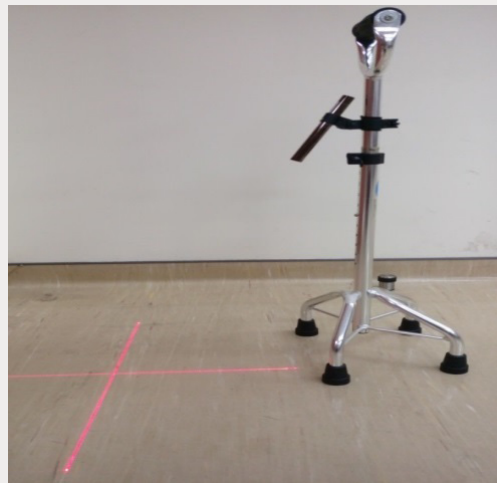
To determine the sample size, the G*Power software (version 3.1.9.2 for Windows) was used. The alpha level and the power were set as 0.05 and 0.8. The effect size was set at high effect (0.8) and the minimal estimated sample size was 15 subjects.

Outcome measured

Participants were asked to walk on 30-m long and 4-m wide corridor with even surface for 20 m with regular quad-cane (without auxiliary illuminator) at their usual walking speed first. After a 10-min break, participants were asked to walk again under the condition as the same as the previous one except that they used a walking assist device with auxiliary illuminator during walking once. The quad-cane with laser was consisted of a quad-cane

and a laser pointer (which was placed on the shaft of the quad-cane with two laser beams vertical to each other, Fig. 1).

Participants were requested to walk by the three-point gait with the walking assist device on the sound site and the sound lower extremity parallel to one laser beam first. Then, participants moved their hemiplegic lower extremity to the cross made by the two laser beams by the illuminator with the mid-foot right over the crossing point. Last, participants were asked to move their sound lower extremity over the other laser beam and make the heel of the sound site forward the toes of the hemiplegic side (Fig. 2). The laser beam can be adjusted to individual's step length. The length of each patient would be set as big as his/her foot print approximately. The whole study procedure was well explained and under the supervision of a well-trained therapist (Xin-yu Liu). Parameters of gait cycle, including stride length, cadence, gait speed, duration of stance phase, duration of swing phase, duration of single support and double support during the gait cycle, angle between the foot and the ground at the time of heel strike in sagittal plane during a gait cycle (heel-strike angle), and angle between toes and the ground at the time of toe off in the sagittal plane during a gait cycle (toe-off angle) were measured by a gait analyzer (RehaWatch®; HASOMED GmbH, Magdeburg, Germany) in each walking.



Notes: The device was consisted of a quad-cane and a laser pointer. The laser pointer was placed on the shaft of the quad-cane with two laser beams vertical to each other which made a cross and provided with visual feedback.

Fig. 1. Walking assist device with auxiliary illuminator.

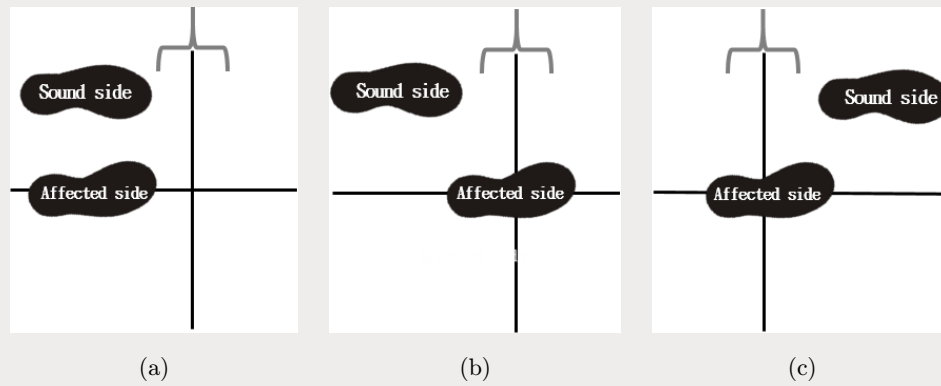


Fig. 2. Sequence of gait with the use of walking assistive device with auxiliary illuminator (affected side is the right): (a) Participants were requested to walk by the three-point gait with the walking assistive device on the sound side and the sound lower extremity parallel to one laser beam first. (b) Then, participants moved their hemiplegic lower extremity to the cross made by the two laser beams by the illuminator with the mid-foot right over the crossing point. (c) Last, participants were asked to move their sound lower extremity over the other laser beam and make the heel of the sound site forward the toes of the hemiplegic side.

RehaWatch® is an inertial sensor-based gait analysis system with measurement sensors attached to the lateral ankle using a special device (Fig. 3). Each sensor contains three accelerometers and three gyroscopes measuring foot motion in six degrees of freedom. The measurement range of the accelerometers is $\pm 5g$ and gyroscopes $\pm 600^\circ/s$. The sampling rate is 512 Hz. Gait measurements

are performed in offline mode. The primary gait event is heel-strike and all other gait events are identified relative to heel-strike. Spatiotemporal gait parameters and gait phases are calculated automatically.²² It has high reliability. Lots of studies have been published and proved the reliability by using RehaWatch® in health adults and populations with different diseases.²³ The angle of



Notes: Reha-Watch® is an inertial sensor-based gait analysis system with measurement sensors attached to the lateral ankle. (a) shows the placement of the system on the affected foot without AFO use and (b) shows the placement of the system on the affected foot with anterior-leaf AFO use.

Fig. 3. The RehaWatch® system with the sensors on the lateral side of the shoes.

the ankle more than 0° means the direction of dorsiflexion and less than zero means the direction of plantar flexion.

Statistical analysis

SPSS for Windows version 19.0 (Released 2010, Armonk, NY: IBM Corp) was used for all analyses. Continuous data were expressed as mean \pm standard deviation and categorical variables were presented as absolute numbers or percentages. Normality and homoscedasticity were checked prior to each analysis. The chi-square test was used to test for differences in the distribution between categorized variables. The independent *t*-test was used for normally distributed variables, whereas the Mann–Whitney U test was used for non-normally distributed variables for comparison of parameters of gait cycle between the first and the second walkings. *P*-value ≤ 0.05 was considered statistically significant.

Results

Thirty participants met the study criteria and no one dropped out. The recruited participant consisted of 23 males and 7 females with an average age of 60.20 ± 11.12 years. Among them, 20 patients had right hemiplegic extremities and 10 had left hemiplegia/hemiparesis. In terms of stroke types, 15 were hemorrhagic strokes and 15 were ischemic stroke. Subgroup analysis was done between participants walked with ($n = 22$) or without ($n = 8$) the support of ankle-foot orthosis (AFO). The AFOs used by the participants were all anterior-leaf design, which could provide partial mobility of the ankle joint and retain the ankle joint strategy. The basic characteristics of the two subgroups showed no significant difference in the statistical analysis. Descriptive characteristics of the participants are presented in Table 1.

Table 2 provides the immediate effects on parameters of gait cycle with the use of a quad-cane

Table 1. Descriptive characteristics of the stroke patients with subgroup (patients with or without use of AFO) analysis.

	Total patients ($n = 30$)	Patients used AFO ($n = 22$)	Patients did not use AFO ($n = 8$)	<i>P</i> -value ^a
Height (cm)	166.37 \pm 8.41	166.00 \pm 9.06	168.13 \pm 7.59	0.56
Weight (kg)	66.27 \pm 10.82	65.27 \pm 10.63	69.00 \pm 11.59	0.41
Stroke duration (months)	33.83 \pm 29.41	32.14 \pm 30.12	38.58 \pm 28.58	0.69
Age (years)	60.20 \pm 11.12	60.14 \pm 11.91	61.75 \pm 8.48	0.73
Gender (Male/Female)	(23/7)	(16/6)	(7/1)	0.64
Stroke side (right/left)	(20/10)	(14/8)	(6/2)	0.68
Stroke type	(15/15)	(13/9)	(2/6)	0.22

Notes: ^aThe chi-square test and independent *t*-test were used to test for differences in the distribution between categorized variables and continuous variables between stroke patients who walked with AFO or not.

Table 2. Immediate effects of gait cycles in patients with stroke before and after using the walking assist device with auxiliary illuminator ($n = 30$).

	Not using illuminator (95% C.I.)	Using illuminator (95% C.I.)	<i>P</i> -value
Stride length (m)	0.93 \pm 0.59 (0.74–1.08)	0.92 \pm 0.53 (0.79–1.16)	0.91
Gait speed (m/s)	0.66 \pm 0.87 (0.40–0.91)	0.57 \pm 0.68 (0.39–0.89)	0.66
Cadence (step/min)	39.76 \pm 15.89 (33.12–45.75)	36.33 \pm 12.95 (31.98–40.09)	0.36
Stance phase (%)	76.86 \pm 9.95 (72.92–80.72)	76.00 \pm 12.77 (71.67–79.88)	0.76
Affected swing phase (%)	23.15 \pm 9.95 (19.28–27.09)	24.05 \pm 12.77 (20.13–28.33)	0.76
Affected single-support phase (%)	15.77 \pm 7.31 (13.71–20.33)	14.71 \pm 5.62 (12.84–17.73)	0.53
Double-support phase (%)	17.91 \pm 11.48 (14.48–21.62)	18.95 \pm 10.78 (15.53–22.71)	0.72
Heel-strike angle (degree)	0.34 \pm 5.76 (–2.68–3.11)	4.00 \pm 6.01 (1.11–6.75)	0.02*
Toe-off angle (degree)	–11.23 \pm 12.98 (–18.73–7.97)	–11.26 \pm 11.31 (–17.85–7.84)	0.99

Notes: * $p < 0.05$.

95% C.I.: 95% confidence interval; heel-strike angle: angle between calcaneus and the ground at the time of heel strike during a gait cycle; toe-off angle: angle between toes and the ground at the time of toe-off during a gait cycle.

Table 3. Immediate effects of gait cycles in patients with chronic stroke who use AFOs and those who do not use AFOs after using the walking assist device with auxiliary illuminator.

	Used AFOs ($n = 22$)			Did not use AFOs ($n = 8$)		
	No Illuminator (95% C.I.)	Illuminator use (95% C.I.)	p -value	No illuminator (95% C.I.)	Illuminator use (95% C.I.)	p -value
Stride length (m)	0.96 ± 0.64 (0.71–1.23)	0.98 ± 0.55 (0.75–1.22)	0.94	0.85 ± 0.44 (0.59–1.19)	0.75 ± 0.47 (0.55–1.09)	0.79
Gait speed (m/s)	0.74 ± 0.98 (0.40–1.15)	0.63 ± 0.73 (0.36–0.95)	0.51	0.46 ± 0.45 (0.24–0.83)	0.41 ± 0.52 (0.20–0.79)	0.79
Cadence (step/min)	37.38 ± 15.22 (31.26–43.92)	34.11 ± 14.24 (28.62–39.87)	0.04*	46.33 ± 16.86 (34.18–55.47)	42.43 ± 5.40 (39.00–46.13)	0.16
Stance phase (%)	78.51 ± 9.21 (74.56–82.34)	78.77 ± 10.11 (74.55–82.78)	0.79	72.35 ± 11.13 (65.59–80.00)	68.21 ± 16.60 (56.63–76.41)	0.87
Affected swing phase (%)	21.51 ± 9.21 (17.67–25.45)	21.24 ± 10.11 (17.23–25.45)	0.79	27.66 ± 11.13 (20.01–34.41)	31.80 ± 16.59 (23.61–43.39)	0.87
Affected single-support phase (%)	14.44 ± 7.51 (11.55–17.74)	13.74 ± 5.96 (11.29–16.35)	0.35	19.45 ± 5.62 (16.38–23.35)	17.38 ± 3.62 (14.99–19.67)	0.09
Double-support phase (%)	18.64 ± 12.22 (14.07–24.02)	19.20 ± 11.92 (14.74–24.10)	0.46	15.93 ± 9.57 (10.23–22.17)	18.29 ± 7.37 (13.44–22.95)	0.67
Heel-strike angle (degree)	1.10 ± 5.19 (–1.05–3.15)	4.56 ± 6.39 (1.90–7.31)	< 0.01*	–1.73 ± 7.07 (–6.39–2.61)	2.39 ± 4.82 (–0.66–5.52)	0.05*
Toe-off angle (degree)	–9.53 ± 13.77 (–15.66–4.47)	–10.05 ± 12.50 (–15.34–5.43)	0.47	–15.91 ± 9.74 (–22.51–9.93)	–14.61 ± 6.56 (–19.35–10.64)	0.83

Notes: * $p < 0.05$.

Heel-strike angle: angle between calcaneus and the ground at the time of heel strike during a gait cycle; toe-off angle: angle between toes and the ground at the time of toe-off during a gait cycle.

with laser. We observed that the heel-strike angle increased significantly with the use of quad-cane with laser, from $0.34 \pm 5.76^\circ$ to $4.00 \pm 6.01^\circ$ ($p = 0.02$). However, all of the other parameters of gait cycle we measured, including the stride length, the gait speed, the cadence, percentage of the stance phase, swing phase, single-support phase, and double-support phase in a gait cycle, and the toe-off angle, showed no significant change with the use of quad-cane with laser.

Table 3 presents the immediate effects of parameters of gait cycle in stroke patients who use AFOs and those who do not use AFOs after using the quad-cane with laser. For stroke patients walking without AFOs, no significant change except that the heel-strike angle increased from $-1.73 \pm 7.07^\circ$ to $2.39 \pm 4.82^\circ$ ($p = 0.05$) was noted between parameters of gait cycle with and without the use of illuminator quad-cane. For patients with strokes using AFOs, after using the illuminator quad-cane, the cadence decreased from 37.38 ± 15.22 steps/min to 34.11 ± 14.24 steps/min ($p = 0.04$), and the heel-strike angle increased from 1.10 ± 5.19 to $4.56 \pm 6.39^\circ$ ($p < 0.01$). Both changes were statistically significant.

Discussion

The purpose of this study was to investigate the immediate effects of an auxiliary illuminator on the gait parameters in patients with subacute and chronic stroke. After using a quad-cane with laser, we observed a significant increase in the heel-strike angle, regardless of using with AFO or not. We also found a significant decrease of cadence after using quad-cane with laser in patients ambulating with AFO. The other parameters we measured during a gait cycle (i.e., stride length, gait speed, duration of stance phase, duration of swing phase, duration of single support and double support, and toe-off angle) revealed no significant change before and after the using of quad-cane with laser.

With the use of auxiliary illuminator to provide visual feedback, stroke patients would use their vision to correct the steps of the affected limbs. By following the guidance of therapist to move their hemiplegic lower extremity to step on the cross made by two laser beams, participants might not only reduce external rotation in the tibia of the affected leg but also reduce the use of circumduction gait, thereby increasing the heel-strike angle. In able-bodied older people, the ankle begins the gait

cycle in a neutral position at the time of initial contact. There is rapid plantar flexion to approximately 10° of plantar flexion that occurs during the heel strike. Then the angle gradually dorsiflexed to a peak of 10° just before pre-swing.²⁴ However, lack of dorsiflexion in swing phase and at heel strike is a commonly reported kinematic deviation in people with hemiplegic stroke.^{25,26} To compensate this, stroke patients might use compensate gait pattern like abducting the swing hip, laterally flexing the trunk towards the unaffected side, and decreasing peak knee flexion.²⁵ A study of hemiplegic individuals conducted by Lehmann *et al.* indicated that an ankle fixed in plantarflexion may cause difficulty in limb clearance during swing.²⁷ The increase of ankle dorsiflexed angle caused the knee to be more flexed and anterior to the ground reaction force, resulting in a decreased peak knee extension angle and peak knee flexion moment.²⁸ Therefore, the significant increase of heel-strike angle after using quad-cane with laser might decrease the hyperextension knee moment of the affected limb.

For able-bodied individuals, the heel remains the sole source of support for the first 6–10% of the gait cycle and the loading response phase typically occurs during the first 10% of the gait cycle.²⁹ However, the loading response period was prolonged, ranging from 10% to 17% of the cycle, among stroke patients.^{30,31} Positioning the ankle in slight dorsiflexion has been shown to reestablish the heel as the initial contact base of support³² and also relieve force on the heel during the loading response phase.³¹ Since the heel-strike angle increased significantly by using the quad-cane with laser, stroke patients could put less pressure on the heel and propulsion more smoothly from initial contact to foot flat.

The participants in this study were stroke patients after the acute stage with a mean duration 33.83 months from the onset to the date of experiment, which means that all the participants were used to the gait they used and it was difficult to correct by just small numbers of practice.³³ Since we did only twice measurement (without and with the quad-cane with laser) without any practice before, the change of parameters of the gait cycle might solely contribute to the quad-cane with laser. It was the strength of this study when it comes to the immediate effect but a critical weak point as for the clinical effectiveness of the quad-cane with laser in gait parameters since the change of ambulation pattern might take a longer time and needs massive practice.

For a normal adult walking at a comfortable gait speed, the stance phase and swing phase accounts for about 62% and 38% of the entire gait cycle, respectively.^{6,27} However, hemiplegic stroke patients presented asymmetrical postures and movements and they also shifted center of gravity to the sound side during walking, causing the ratio of the stance phase in the gait cycle to increase.^{34,35} We did not observe significant decrease of the duration of the affected swing phase nor significant increase of the duration of double-support phase with the use of the auxiliary illuminator. Since patients after acute stroke get used to the compensate gait pattern, the immediate influences on the ratio of swing and stance phase by quad-cane with laser might be little. Whether using the quad-cane with laser could improve symmetry of swing and stance phase ensured the future larger study with an adequate training period.

Since the participants were unfamiliar with the use of the quad-cane with laser and they had to notice the visual cue of the illuminator and to listen to and understand the commands of therapist to move, we assumed that there might be a decrease in stride length, cadence and walking velocity. However, we noticed insignificant changes in these parameters with the use of quad-cane with laser. Therefore, we were assured that once the participants got used to the training process and the quad-cane with laser, they could walk at usual gait speed or even faster.³⁶ However, future larger studies are warranted to prove this assumption.

Subgroup analysis of our study showed that not only the increase of the heel-strike angle but also the decrease of cadence reached significantly statistical differences in stroke patient with AFOs' use. Studies had proved that in stroke patients with drop foot, the use of AFO has positive effects on functional ambulation and gait parameters, such as increased walking speed, cadence, ankle dorsiflexion at initial contact.^{31,37,38} Therefore, the immediate significant increase of heel-strike angle might contribute to the use of quad-cane with laser. Stroke patients with more severe hemiplegic extremities might present with drop foot and they usually need AFO of the affected leg for functional ambulation. Since our participants were encouraged to move their affected leg as far as possible to or even over the cross made by the two laser beams, they had to raise their affected leg high enough to get an adequate toe clearance. Patients ambulating with AFOs had more inability to

generate a sufficiently large dorsiflexor muscle moment²⁵ and, therefore, the cadence decreased with the use of quad-cane with laser.

Despite its contributions, our study has several limitations. First, the sample size of our study was relatively small, especially for the stroke patients who do not use AFOs in the subgroup analysis. Small numbers of participants made this study less representative and made the statistical analysis more difficult to reach significance. Second, the subjects were recruited randomly in a single medical center in Southern Taiwan and all the patients were in the subacute and chronic stage, so the results might be only generalizable to similar populations, even though the basic characteristics (except for the ration of ischemic and hemorrhagic stroke) of our participants were similar to data found in the national survey in Taiwan by National Health Insurance Research Database. It is necessary to consider increasing the number of enrollment cases in the acute stage of stroke and perform blind randomized group experiments. Third, we could only measure stride length rather than step length by RehaWatch[®]. This disadvantage of the device made it difficult for us to evaluate the symmetry of the gait and to assess the immediate effect of quad-cane with laser on the sound and the affected lower extremities. Fourth, since participants in this study had performed the controlled condition first (without quad-cane with laser) and then the experimental condition (with the quad-cane with laser), the order effect may have contributed to the immediate change in parameters of gait cycle. Fifth, the minimal required estimated sample number was 15 for this study. The participants who did not use AFOs during ambulation were only eight and would be insufficient to draw the interpretation in the subgroup analysis. Last, we only assessed the immediate effect on parameters of gait cycle with the use of assistive device with auxiliary illuminator. Whether long-term use of the walking assist device with auxiliary illuminator for stroke patients can improve balance, daily living function and gait pattern of the lower limbs should also be investigated to verify the effectiveness of the prolonged use.

Conclusion

The results of this study showed that patients after acute stroke had an immediate change in heel-stroke angle by using a quad-cane with laser during

ambulation, which might help the patients to reduce knee hyperextension moment and lessen the pressure of heel at loading phase, and even make the propulsion from initial contact to foot flat more smooth. Larger and nation-wide prospective blinded studies with long-term follow-up are warranted to assess the clinical effectiveness of this promising, portable, and easy-to-use assistive device.

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Conflict of Interest

The authors have no conflicts of interest to declare.

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Author Contributions

W. Y. Huang, M. H. Li and P. T. Hsu were responsible for research conception and design of the study. W. Y. Huang, S. H. Tuan, X. Y. Liu and P. T. Hsu were involved with analysis/interpretation of data, and critical revision of the manuscript for important intellectual content. All authors were involved in the acquisition of data, drafting the manuscript, and approval of the manuscript to be published.

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