Clinical Trial/Experimental Study

Medicine®

OPEN

Gait characteristics during crossing over obstacle in patients with glaucoma using insole foot pressure

Han-Suk Lee, PhD[a], Koon-Ja Lee, PhD[b], Jeong-Lae Kim, PhD[c], Hyun-Sung Leem, PhD[b], Hyun-Jin Shin, MD[d], Hyeok Gyu Kwon, PhD[a,*]

Abstract

Background: Glaucoma, is the most common cause of irreversible visual deficits, presents as an injury to the optic nerve and it is mainly associated with elevated intraocular pressure. The main symptom of glaucoma is a reduction of the visual field, which is usually a source of complaint at the advanced stage of disease. Because of visual deficit, gait dysfunctions, including low gait speed and increased bumping into objects, postural sway, and falling are occurred. Many studies have used stopwatch or motion-sensing devices to report on gait function following glaucoma. However, there are few reports on gait dysfunction assessed by examining foot pressure. This study investigated gait ability following glaucoma according to different gait conditions by assessing foot pressure.

Methods: Thirty older adults (15 in the sex- and age-matched normal group and 15 in the glaucoma group) were recruited for this study. All participants were walked under 2 different gait conditions in an F-scan system and the subject' assessments were randomly assigned to rule out the order effect. Conditions included: gait over an obstacle in a straight 6 m path, gait in a straight path without an obstacle in the 6 m path. Gait variables included cadence, gait cycle, stance time, center of force (COF) deviation, and COF excursion. About 10 minutes were taken for gait evaluation.

Results: When walking without an obstacle on a 6 m path, there were significant differences between the 2 groups in gait speed, cadence, gait cycle, and stance time ($P < .05$). There were significant differences when walking with an obstacle on a 6 m path ($P < .05$). Two-way analysis of variance showed significant effects associated with "glaucoma" not gait condition on all outcomes except for COF deviation and excursion. Also, there was no the interaction effect between "glaucoma" and "gait condition."

Conclusion: We demonstrated that glaucoma patients selected the gait strategy such as lower gait function in both gait conditions particularly, slower gait speed and cadence and longer gait cycle and stance time, as determined by examining foot pressure. We believe that our results could help to improve the quality of life of patients with glaucoma.

Abbreviation: COF = center of force.

Keywords: foot pressure, gait function, glaucoma, visual deficit

Editor: Saeed ilbeigi.

This paper was supported by Eulji university in 2019.

The authors have no conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

[a] Department of Physical Therapy, Eulji University, Republic of Korea, [b] Department of Optometry, Eulji University, Republic of Korea, [c] Department of Biomedical Engineering, Eulji University, Republic of Korea, [d] Department of Ophthalmology, Konkuk University School of Medicine, Republic of Korea.

[*] Correspondence: Hyeok Gyu Kwon, Department of Physical Therapy, College of Health Science, Eulji University, Sansungdaero 533, Sujung-gu, Sungnam-si, Gyeonggido, 13135, Republic of Korea (e-mail: khg0715@hanmail.net).

How to cite this article: Lee HS, Lee KJ, Kim JL, Leem HS, Shin HJ, Kwon HG. Gait characteristics during crossing over obstacle in patients with glaucoma using insole foot pressure. Medicine 2021;100:32(e26938).

Received: 8 March 2021 / Received in final form: 19 July 2021 / Accepted: 27 July 2021

http://dx.doi.org/10.1097/MD.0000000000026938

1. Introduction

Glaucoma presents as an injury to the optic nerve and is mainly associated with elevated intraocular pressure; it is the most common cause of irreversible visual deficits and the second leading cause of blindness.[1–4] The main symptom of glaucoma is a reduction of the visual field, which is usually a source of complaint at the advanced stage of disease.[5] As a result, various daily activities such as mobility, reading, and watching television at night may be limited in patients with glaucoma.[6,7] In particular, because the prevalence of glaucoma is associated with advancing age, quality of life with glaucoma is a primary issue in the elderly.[5] Various quality of life factors such as physical condition (postural control, muscle power, and gait) and psychological condition (emotional security and depression) are affected by glaucoma.[8–11] Among those factors, gait function is perhaps the most important factor affecting independent daily activities. Many studies have reported on gait function following glaucoma.[6,12–17]

The visual system is involved in the modulation of gait cycle, avoiding obstacles, and navigation during locomotion.[18] Hence, visual impairment leads to various gait dysfunctions, such as low gait speed and increased bumping into objects, postural sway, and falling.[1,19–26] In particular, because the patients with glaucoma are suffered from the reduction of the visual field, avoiding obstacles would be important for safety following the glaucoma. Previous studies have reported that patients with glaucoma have a lower level of gait function under various conditions, including stair, obstacle, and curve conditions.[1,22] By contrast, some studies have reported no differences in gait speed or gait parameters, such as cadence, step length, and base of support, under straight-line locomotion conditions between patients with glaucoma and normal subjects.[12,14,27] These conflicting results indicate a need to investigate gait function following glaucoma.

Gait function can be measured using clinical evaluation approaches such as timed 4 m walking and motion sensing devices.[28–30] Timed 4 m walking is easily applied in clinical situations and involves measuring gait speed using a stopwatch.[30] Motion sensing devices can measure other gait features such as the relationships among joints and the timing of gait motions. In addition, foot-pressure measurement, including measurement of the center of force (COF) which is one of the vector quantities, can be used to evaluate gait function.[31,32] COF variables reflect the subject's dynamic balance.[33] For evaluation of foot pressure, the F-scan in-shoe sensing system is the most commonly used device and can measure dynamic foot pressure during gait. Compared with the former motion-sensing device, the F-scan device is worn within the subject's shoes, thus can be easily applied in the clinic. In addition, the validity of this measurement system has been demonstrated previously.[34] To date, most studies of gait function following glaucoma used stopwatches (time) or motion-sensing devices (gait parameters) to assess gait.[6,12–15] However, the stopwatches can only measure the gait speed and motion-sensing devices are not easy to apply in clinic because of long preparation time and need of big space. In contrast, foot pressure assessments are simply able to evaluate the gait parameters. However, very little has been reported on the effects of glaucoma on gait function according to different gait conditions based on results of foot pressure assessments performed with the F-scan system. This study hypothesized that using the foot pressure assessments, visual deficit due to glaucoma would affect the gait dysfunction on the differences gait conditions. In addition, our study could helpful to set a treatment strategy for gait function in patients with glaucoma.

In the current study, we investigated gait ability according to different gait conditions in patients with glaucoma by measuring foot pressure with an F-scan system.

2. Methods

2.1. Subjects

This study had a cross-sectional design. Thirty-two older adults were recruited for this study and two older adults were dropped out because of under age of 65 years old. Thirty older adults (15 in a sex- and age-matched normal group and 15 in a glaucoma group) were recruited from the *K* University Hospital and *S* senior center in Gyeonggi-do and Seoul, South Korea between October 2019 and April 2020. The participants were divided into 2 groups based on a diagnosis by an ophthalmologist. Consecutive sampling was used to recruit the elderly who met the inclusion criteria. Approval was obtained from the Institutional Review Board of *K* University Hospital (KUH2019-08-010-003). All subjects provided informed consent in accordance with the Declaration of Helsinki before participating in the study.

Inclusion criteria for participants were as follows: those who could understand the instructions of the tester; over 65 years old; those who could walk independently; diagnosis of glaucoma provided by a medical doctor (only for the glaucoma group); severity (stage) of glaucoma was under 2 (moderate).

The exclusion criteria were as follows: those who used a device during gait; those with acute orthopedic or neurologic injuries; those with vision problems that may affect the test (only for normal group); those with problems affecting balance during gait.

2.2. Measurement and data analysis procedures

Gait measurement was performed by 1 physical therapist and 1 assistant and they visited the *K* University Hospital and *S* senior facilities to measure gait variables of the subjects in the 2 groups. All subjects were measured the general characteristics including the height, weight, leg length, and foot size (Fig. 1). For calibration of both feet, subject started with their weight on a foot to be offloaded and then they shifted their weight onto the foot to be calibrated. After verifying the calibration of both feet, the subject was instructed to walk on the gait path. The tester measured the time taken to walk and gave verbal instructions to each participant. After the participant practiced walking 2 or 3 times in accordance with the instructions of the tester, the tester measured the time taken to walk under 2 different gait conditions: gait over an obstacle in a straight 6 m path; gait in a straight 6 m path without an obstacle. The subject walked 3 times under each different gait conditions. The subject' assessments were randomly assigned to rule out the order effect. Subjects took a rest to avoid fatigue between assessments. The gait evaluation took about 10 minutes. The data analyzer was different researcher from the gait measurement researchers and the data analyzer was blinded to group information.

Each participant was instructed to walk at a comfortable gait speed. The time in seconds required to walk the 6 m distance,

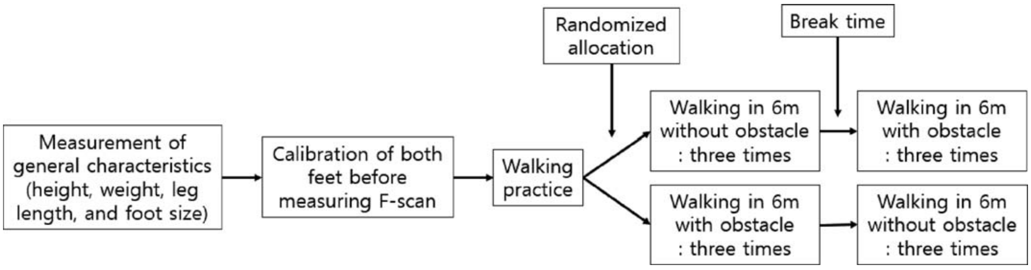

Figure 1. Measurement procedure.

Table 1

Demographic data of glaucoma and normal groups.

Group	Gender (F/M)	Age, yr	Height, cm	Weight, kg	Leg length R, cm	Leg length L, cm	Foot size, mm
GG (n=15)	11 (4)	72.73 (3.88)	156.87 (7.76)	56.4 (6.61)	79.32 (3.98)	79.01 (4.47)	244.67 (13.29)
NG (n=15)	11 (4)	72.87 (3.38)	158.65 (8.74)	58.23 (9.66)	80.23 (5.26)	80.34 (4.64)	245.00 (14.27)
P value	1	.83	.64	.69	.59	.43	.95

Data presented are mean (standard deviation) values. F=female, GG=Glaucoma Group, L=left, M=male, NG=Normal Group, R=right.

except for the first and last meter corresponding to the acceleration period and deceleration periods, respectively, was measured. Gait speed based on time and distance (4 m) was then calculated. A Tekscan F-scan system (Tekscan Inc, South Boston, MA) was used to measure foot pressure via its in-shoe, pressure-sensing insole.[34] The reliability and validity of a Tekscan F-scan system were demonstrated.[35–37] Subjects wore shoes with F-scan insoles, and amplifiers were placed on the outside of both ankles. Gait variables, including cadence, gait cycle, stance time, COF deviation, and COF excursion, were analyzed by the F-scan software program (Tekscan Inc., South Boston, MA, 2010). The COF deviation measure indicates the maximum medial-lateral distance of the COF from foot axis. The COF excursion index is a measure of the medial-lateral deviation of the COF trajectory relative to foot width.

2.3. Statistical analysis

Descriptive statistical tests were used to analyze the general characteristics of the participants. The assumption of normality was ascertained using Shapiro-Wilk tests. Some variable distributions were normal, but others were not; therefore, we used nonparametric tests. The Wilcoxon rank-sum test was used to compare the subjects' general characteristics and the differences between groups. Data are presented as mean (standard deviation) and median (min–max score) values. A 2-way analysis of variance (ANOVA) was applied to all gait variable outcome measures. The "glaucoma" parameter was used as the within-group visual problem factor and "obstacle" as the between gait condition factor. Statistical processing was performed using R studio 4.0 for Windows, and *P*-values <.05 were considered significant. Statistical power of the sample size was calculated by G*power 3.1 and showed 0.75 effect size, 0.05 α err prob and 0.60 power ($1-\beta$ err prob).[38]

3. Results

A summary of the demographic data for glaucoma and normal groups is presented in Table 1. No significant differences in the demographic data were detected between the 2 groups ($P<.05$).

In the walking condition without an obstacle on a 6 m path, there were significant differences between the 2 groups in gait speed, cadence, gait cycle, and stance time ($P<.05$) (Table 2). The gait speed of the glaucoma group (0.99 ± 0.11 m/s) was slower than that of the normal group (1.31 ± 0.09 m/s) and the effect size was shown –0.309. Similarly, the gait cadence of the glaucoma group (81.49 ± 24.7 steps/min) was lower than that of the normal group (113.07 ± 17.01 steps/min) and the effect size was shown –1.448. The gait cycle of the glaucoma group (1.66 ± 0.44 seconds) was longer than that of the normal group (1.13 ± 0.27 seconds) and the effect size was shown 1.427. Also, the stance time of the glaucoma group (0.68 ± 0.06 seconds) was longer than that of the normal group (0.62 ± 0.06 seconds) and the effect size was shown 0.973. It appears that the members of the glaucoma group needed more time during gait for stabilizing and moving (Table 2). However, regarding the COF variables (COF deviation and excursion), no significant differences were observed between the 2 groups ($P>.05$). COF deviation and excursion of the effect size were shown –0.520 and –0.617, respectively.

In the walking condition with an obstacle on the 6 m path, there were also significant differences between the 2 groups in gait speed, cadence, gait cycle, and stance time ($P<.05$) (Table 2). The gait speed of the glaucoma group (1.01 ± 0.15 m/s) was slower than that of the normal group (1.26 ± 0.16 m/s) and the effect size

Table 2

Comparison of gait variables during walking without an obstacle between glaucoma and normal groups.

Gait variable (unit)	Group	Median (min–max)	Mean (SD)	*P*	95%-CI		Effect size
Gait speed (m/sec)	Glaucoma	0.97 (0.77–1.19)	0.99 (0.11)	.001*	–0.390	–0.250	–0.309
	Normal	1.28 (1.22–1.52)	1.31 (0.09)				
Cadence (steps/min)	Glaucoma	78.39 (49.99–130.44)	81.49 (24.7)	.001*	–52.770	–13.990	–1.448
	Normal	121.29 (76.53–131.16)	113.07 (17.01)				
Gait cycle time (sec)	Glaucoma	1.73 (0.92–2.46)	1.66 (0.44)	.002*	0.150	0.810	1.427
	Normal	0.99 (0.91–1.74)	1.13 (0.27)				
Stance time (sec)	Glaucoma	0.68 (0.58–0.78)	0.68 (0.06)	.002*	0.020	0.100	0.973
	Normal	0.61 (0.54–0.76)	0.62 (0.06)				
COF deviation (cm)	Glaucoma	1.1 (0.7–1.7)	1.12 (0.34)	.190	–0.450	0.100	–0.520
	Normal	1.25 (0.85–2.65)	1.33 (0.44)				
COF excursion (%)	Glaucoma	16 (9.5–22.5)	14.9 (4.05)	.089	–6.500	0.500	–0.617
	Normal	18 (11–34.5)	18.1 (5.87)				

Data are expressed as mean (± standard deviation) and median (min–max) values.
95%-CI=95 percent confidence interval, COF=center of force, SD=standard deviation.
* $P<.05$

Table 3

The comparison of gait variables during walking with an obstacle between glaucoma and normal groups.

Gait variable (unit)	Group	Median (min–max)	Mean (SD)	P	95%-CI		Effect size
Gait speed, m/s	Glaucoma	0.99 (0.73–1.39)	1.01 (0.15)	.000*	–0.370	–0.130	–1.569
	Normal	1.24 (1.08–1.55)	1.26 (0.16)				
Cadence, steps/min	Glaucoma	61.44 (52.33–124.52)	65.44 (17.92)	.022*	–35.220	–2.490	–0.710
	Normal	78.58 (35.6–117.08)	80.86 (23.93)				
Gait cycle time, s	Glaucoma	1.96 (0.97–2.3)	1.95 (0.34)	.022*	0.090	0.680	0.552
	Normal	1.56 (1.03–3.38)	1.67 (0.61)				
Stance time, s	Glaucoma	1.96 (0.97–2.3)	1.24 (0.31)	.022*	0.010	0.110	0.439
	Normal	1.56 (1.03–3.38)	1.03 (0.58)				
COF deviation, cm	Glaucoma	1 (0.5–1.8)	1.08 (0.33)	.227	–0.400	0.100	–0.389
	Normal	1.15 (0.65–1.85)	1.21 (0.32)				
COF excursion (%)	Glaucoma	14 (6.5–22)	14.5 (3.89)	.360	–5.000	1.500	–0.338
	Normal	15 (6.5–24)	16 (4.72)				

Data are expressed as mean (± standard deviation) and median (min–max) values.
95%-CI = 95 percent confidence interval, COF = center of force, SD = standard deviation.
* $P < .05$.

was shown –1.569. Likewise, the cadence of the glaucoma group (65.44 ± 17.92 steps/min) was lower than that of the normal group (80.86 ± 23.93 steps/min) and the effect size was shown –0.710. Similarly, the gait cycle in the glaucoma group (1.95 ± 0.34 seconds) was longer than that in the normal group (1.67 ± 0.61 seconds) and the effect size was shown 0.552. Similarly, stance time in the glaucoma group (1.24 ± 0.31 seconds) was longer than that of the normal group (1.03 ± 0.58 seconds) and the effect size was shown 0.439 (Table 3). However, the 2 COF variables (COF deviation and excursion) did not show significant differences between the 2 groups. COF deviation and excursion of the effect size were shown –0.389 and –0.338, respectively.

The two-way ANOVA results showed significant effects of "glaucoma (i.e., visual intact)" in all gait outcomes except for COF deviation ($F = 3.163$, $P = .08$) and COF excursion ($F = 3.754$, $P = .057$). However, the effect of gait condition (i.e., obstacle) was significant only for cadence ($F = 19.472$, $P = .00$) and gait cycle time ($F = 13.814$, $P = 0.00$). Additionally, the interaction effect between "glaucoma and obstacle" on all outcomes was insignificant (Table 4).

4. Discussion

In the current study, we investigated gait ability under different gait conditions in patients with glaucoma by assessing foot pressure during gait and found significant differences in gait speed, cadence, gait cycle, and stance time between 2 groups. Specifically, gait speed (with an obstacle: 1.01 m/s and without an obstacle: 0.99 m/s) and cadence (with an obstacle: 65.44 steps/min and without an obstacle: 81.49 steps/min) in the glaucoma group were slower than those (gait speed—with an obstacle: 1.26 m/s and without an obstacle: 1.31 m/s and cadence—with an obstacle: 80.86 steps/min and without an obstacle: 113.07 steps/min) of the normal group, irrespective of gait conditions. Regarding the gait cycle and stance time, the glaucoma group results (gait cycle—with an obstacle: 1.95 seconds and without an obstacle: 1.66 seconds and stance time—with an obstacle: 1.24 seconds and without an obstacle: 0.68 seconds) were longer than those (gait cycle—with an obstacle: 1.67 seconds and without an obstacle: 1.13 seconds and stance time—with an obstacle: 1.03 seconds and without an obstacle: 0.62 seconds) of the normal group irrespective of gait conditions. In addition, with glaucoma treated as a variable, there were significant effects on all outcomes except for the COF variables. These results indicate the effect of the visual problems associated with glaucoma and that an obstacle might also affect time-related gait variables. However, COF displacement was unaffected by glaucoma or obstacle presence. Also, the effect of interaction glaucoma and obstacle was not significant. As a result, the results related to visual field

Table 4

Two-way ANOVA results for the assessed gait variables.

Outcome (unit)	Effect of "Glaucoma"	Effect of "obstacle"	Effect of "Glaucoma" × "obstacle"
Gait speed, m/s	$F = 72.769$	$F = 0.116$	$F = 1.213$
	$P = .000$*	$P = .735$	$P = .275$
Cadence, steps/min	$F = 18.475$	$F = 19.472$	$F = 2.185$
	$P = .000$*	$P = .000$*	$P = .145$
Gait cycle time, s	$F = 12.776$	$F = 13.814$	$F = 1.331$
	$P = .000$*	$P = .000$*	$P = .253$
Stance time, s	$F = 12.989$	$F = 1.827$	$F = 0.082$
	$P = .000$*	$P = .181$	$P = .775$
COF deviation, cm	$F = 3.163$	$F = 0.775$	$F = 0.202$
	$P = .080$	$P = .382$	$P = .655$
COF excursion (%)	$F = 3.754$	$F = 1.062$	$F = .491$
	$P = .057$	$P = .307$	$P = .486$

COF = center of force.
* $P < .05$.

deficits indicate that glaucoma makes sensory integration difficult, thereby affecting motor function in particular gait ability.[25] In general, visual information is conveyed to the posterior parietal lobe via the occipital cortex and integrated with various sensory inputs. Based on the integration of the various sensory inputs, motor functions (such as gait) are generated.[25] Thus, we believed that our results might indicate a delay or insufficiency in sensory integration due to glaucoma-related visual field deficits.

Regarding the COF variables, we could not detect any significant differences in COF deviation or COF excursion under both gait conditions between the 2 groups. However, when we considered the overall outcome, the glaucoma group appeared to maintain a stable gait efficiency to compensate for the visual deficit as that group had a smaller COF displacement, longer stance time, and smaller cadence than those in the normal group. Dynamic stability of gait depends on passive control via the musculoskeletal system and on active control through the central nervous system. In the glaucoma group, because of the presence of visual sensory receptor deficits, the role of passive controls provided by the musculoskeletal system might increase. Saunders et al[39] suggested that adduction of the hip and the valgus position of the knee reduce the medio-lateral displacement of the pelvis. Donelan et al[40] suggested that wide step widths induce minimization of COF lateral displacement. Those 2 studies advocate for the importance of the musculoskeletal system in minimizing lateral displacement of COF.[39,40] Even though our study did not identify the kinematic factor, our results indicate that older people with glaucoma might rely more than normal elderly people on the role of musculoskeletal system during gait.

Many studies have reported on gait function in patients with glaucoma, and many are based on results from various assessment tools, including stopwatches and motion sensing devices.[6,12–15] In 1999, Turano et al,[15] demonstrated that gait speed in 47 patients with glaucoma averaged 10% slower than 47 control subjects under 2 conditions (29 m walking condition with and without obstacle). In 2007, Friedman et al[6] reported that patients with glaucoma had a slower gait speed and bumped into more objects than that of control subjects. The results of these previous studies are consistent with our results. Furthermore, in terms of gait speed, the results for both of our groups (glaucoma group: 1.31 m/s, normal group: 1.31 m/s) were similar to the unlimited community walker category (0.8 m/s) among the functional participation walking categories described by Perry.[41] Thus, indicating that patients with glaucoma might not have limitations in participating in community activities or navigating crowds independently. Meanwhile, recent studies investigated relationship between falls and visual field damage due to glaucoma.[42,43] In 2020, Bicket et al[42] investigated gait function according to the lighting conditions or changes in lighting in 213 patients with glaucoma or suspected glaucoma. They demonstrated that visual field damage affected gait deterioration in extreme or changes in lighting that was not mediated by fear of falling.[42] Same year, Mihailovic et al[43] showed that longer time in double support and in swing time were related to higher falls. By contrast, faster cadence and higher gait speed were related to lower falls. In addition, they found that bigger visual field damage led to more falls. However, a few studies have reported no decrease in gait speed or no significant differences in gait parameters related to glaucoma.[12,14] In 2017, Mihailovic et al[12] investigated gait speed during normal usual-pace gait and under dual-task gait (carrying a cup and a tray) in 239 patients with glaucoma and detected a significant decrease in gait speed only during the dual-task condition. Gomes et al[14] reported that 33 patients with glaucoma showed increased gait speed in a "timed up and go" test and a lower score in a dynamic gait index compared with those of 34 control subjects. However, they did not detect significant differences in other gait parameters, including velocity, cadence, step length, base of support, swing time, stance time, and double support time between their glaucoma and control groups during a 4 m walking assessment. Because the above 2 studies applied different evaluation tools and conditions, dual tasks (Mihailovic study), and curved gait (Gomes study) conditions, it is difficult to directly their results with ours. As a result, to the best of our knowledge, ours is the first study to investigate gait functions in patients with glaucoma by using a foot-pressure sensing device. In addition, our results suggested that mild to moderate glaucoma patient used the specific gait strategy with longer stance time, small steps, and slower gait speed to maintain their stability during walking on the ground and crossing over obstacle. Also, it was revealed that glaucoma patient's gait strategy was stable after we identified the COF variables. Thus, the glaucoma patients are encouraged to use this kind of gait strategy and instructed the gait strategy for severe glaucoma patient to prevent the fall. We confirmed the glaucoma patient walked with longer stance time for stable gait as well. Thus, the training of core muscle should be emphasized to improve the stable stance of gait cycle.

Several limitations of this study should be considered. First, the number of patients with glaucoma was small, and we could detect a correlation between glaucoma stage and gait function according to the gait conditions tested. Second, we recruited more female subjects than male subjects in each group even though we equally matched the proportion of sex between 2 groups so we could not exclude the effect of sex difference. Third, we could not provide detailed visual information, such as visual field, for the subjects in either group. Fourth, long walking distance and various walking conditions, such as curve or stair conditions, were not assessed. Fifth, although we tried to use common gait parameters in F-scan system, we could not use more various gait parameters. Further studies to overcome the above limitations in particular various walking conditions should be encouraged.

In conclusion, we demonstrated that glaucoma patients selected the gait strategy such as lower gait function in both gait conditions particularly, slower gait speed and cadence and longer gait cycle and stance time, as determined by examining foot pressure. We believe our results could help improve the quality of life in patients with glaucoma.

Author contributions

Conceptualization: Han-Suk Lee, Koon-Ja Lee, Hyun-Sung Leem, Hyeok Gyu Kwon.
Data curation: Han-Suk Lee, Hyun-Jin Shin.
Formal analysis: Jeong-Lae Kim.
Funding acquisition: Koon-Ja Lee.
Methodology: Jeong-Lae Kim, Hyun-Sung Leem, Hyun-Jin Shin, Hyeok Gyu Kwon.
Project administration: Han-Suk Lee, Koon-Ja Lee.
Supervision: Koon-Ja Lee, Hyeok Gyu Kwon.
Validation: Hyun-Jin Shin.
Writing – original draft: Han-Suk Lee, Hyeok Gyu Kwon.
Writing – review & editing: Han-Suk Lee, Hyeok Gyu Kwon.

References

[1] Labiris G, Giarmoukakis A, Kozobolis VP. Quality of life (QoL) in glaucoma patients. Glaucoma - Basic and Clinical Concepts Europe: Intech; 2011.
[2] Quigley HA, Broman AT. The number of people with glaucoma worldwide in 2010 and 2020. Br J Ophthalmol 2006;90:262–7.
[3] Resnikoff S, Pascolini D, Etya'ale D, et al. Global data on visual impairment in the year 2002. Bull World Health Organ 2004;82:844–51.
[4] Bourne RR, Stevens GA, White RA, et al. Causes of vision loss worldwide, 1990-2010: a systematic analysis. Lancet Glob Health 2013;1:e339–49.
[5] Tuck MW, Crick RP. The age distribution of primary open angle glaucoma. Ophthalmic Epidemiol 1998;5:173–83.
[6] Friedman DS, Freeman E, Munoz B, Jampel HD, West SK. Glaucoma and mobility performance: the Salisbury Eye Evaluation Project. Ophthalmology 2007;114:2232–7.
[7] Nelson P, Aspinall P, Papasouliotis O, Worton B, O'Brien C. Quality of life in glaucoma and its relationship with visual function. J Glaucoma 2003;12:139–50.
[8] Marker AM, Steele RG, Noser AE. Physical activity and health-related quality of life in children and adolescents: a systematic review and meta-analysis. Health Psychol 2018;37:893–903.
[9] Taguchi CK, Teixeira JP, Alves LV, Oliveira PF, Raposo OF. Quality of life and gait in elderly group. Int Arch Otorhinolaryngol 2016;20: 235–40.
[10] Bashkireva AS, Bogdanova DY, Bilyk AY, Shishko AV, Kachan EY, Arutyunov VA. [Quality of life and physical activity among elderly and old people]. Adv Gerontol 2018;31:743–50.
[11] de Oliveira L, Souza EC, Rodrigues RAS, Fett CA, Piva AB. The effects of physical activity on anxiety, depression, and quality of life in elderly people living in the community. Trends Psychiatry Psychother 2019;41:36–42.
[12] Mihailovic A, Swenor BK, Friedman DS, West SK, Gitlin LN, Ramulu PY. Gait implications of visual field damage from glaucoma. Transl Vis Sci Technol 2017;6:1–10.
[13] Yuchao M, Fallahzadeh R, Ghasemzadeh H. Glaucoma-specific gait pattern assessment using body-worn sensors. IEEE Sens J 2016;16: 6406–15.
[14] Gomes HA, Moreira BS, Sampaio RF, et al. Gait parameters, functional mobility and fall risk in individuals with early to moderate primary open angle glaucoma: a cross-sectional study. Braz J Phys Ther 2018;22: 376–82.
[15] Turano KA, Rubin GS, Quigley HA. Mobility performance in glaucoma. Invest Ophthalmol Vis Sci 1999;40:2803–9.
[16] Aspinall PA, Johnson ZK, Azuara-Blanco A, Montarzino A, Brice R, Vickers A. Evaluation of quality of life and priorities of patients with glaucoma. Invest Ophthalmol Vis Sci 2008;49:1907–15.
[17] Burr JM, Kilonzo M, Vale L, Ryan M. Developing a preference-based Glaucoma Utility Index using a discrete choice experiment. Optom Vis Sci 2007;84:797–808.
[18] Logan D, Kiemel T, Dominici N, et al. The many roles of vision during walking. Exp Brain Res 2010;206:337–50.
[19] Hausdorff JM, Rios DA, Edelberg HK. Gait variability and fall risk in community-living older adults: a 1-year prospective study. Arch Phys Med Rehabil 2001;82:1050–6.
[20] Maki BE. Gait changes in older adults: predictors of falls or indicators of fear. J Am Geriatr Soc 1997;45:313–20.
[21] Shimada H, Kim H, Yoshida H, et al. Relationship between age-associated changes of gait and falls and life-space in elderly people. J Phys Ther Sci 2010;22:419–24.
[22] Black A, Wood J. Vision and falls. Clin Exp Optom 2005;88:212–22.
[23] Ramulu P. Glaucoma and disability: which tasks are affected, and at what stage of disease? Curr Opin Ophthalmol 2009;20:92–8.
[24] Black AA, Wood JM, Lovie-Kitchin JE, et al. Visual impairment and postural sway among older adults with glaucoma. Optom Vis Sci 2008;85:489–97.
[25] Kotecha A, Richardson G, Chopra R, et al. Balance control in glaucoma. Invest Ophthalmol Vis Sci 2012;53:7795–801.
[26] Lord SR, Clark RD, Webster IW. Visual acuity and contrast sensitivity in relation to falls in an elderly population. Age Ageing 1991;20: 175–81.
[27] Klein BE, Moss SE, Klein R, Lee KE, Cruickshanks KJ. Associations of visual function with physical outcomes and limitations 5 years later in an older population: the Beaver Dam eye study. Ophthalmology 2003; 110:644–50.
[28] Tao W, Liu T, Zheng R, Feng H. Gait analysis using wearable sensors. Sensors (Basel) 2012;12:2255–83.
[29] Muro-de-la-Herran A, Garcia-Zapirain B, Mendez-Zorrilla A. Gait analysis methods: an overview of wearable and non-wearable systems, highlighting clinical applications. Sensors (Basel) 2014;14:3362–94.
[30] Munoz-Mendoza CL, Cabanero-Martinez MJ, Millan-Calenti JC, Cabrero-Garcia J, Lopez-Sanchez R, Maseda-Rodriguez A. Reliability of 4-m and 6-m walking speed tests in elderly people with cognitive impairment. Arch Gerontol Geriatr 2011;52:e67–70.
[31] Han TR, Paik NJ, Im MS. Quantification of the path of center of pressure (COP) using an F-scan in-shoe transducer. Gait Posture 1999;10:248–54.
[32] Masani K, Vette AH, Kouzaki M, Kanehisa H, Fukunaga T, Popovic MR. Larger center of pressure minus center of gravity in the elderly induces larger body acceleration during quiet standing. Neurosci Lett 2007;422:202–6.
[33] Plamieri RM, Ingersoll CD, Stone MB, et al. Center-of-pressure parameters used in the assessment of postural control. J Sport Rehabil 2002;11:51–66.
[34] Luo ZP, Berglund LJ, An KN. Validation of F-Scan pressure sensor system: a technical note. J Rehabil Res Dev 1998;35:186–91.
[35] Ahroni JH, Boyko EJ, Forsberg R. Reliability of F-scan in-shoe measurements of plantar pressure. Foot Ankle Int 1998;19:668–73.
[36] Sumiya T, Suzuki Y, Kasahara T, Ogata H. Sensing stability and dynamic response of the F-Scan in-shoe sensing system: a technical note. J Rehabil Res Dev 1998;35:192–200.
[37] Patrick K, Donovan L. Test-retest reliability of the Tekscan(R) F-Scan(R) 7 in-shoe plantar pressure system during treadmill walking in healthy recreationally active individuals. Sports Biomech 2018;17:83–97.
[38] Faul F, Erdfelder E, Lang AG, et al. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 2007;39:175–91.
[39] Saunders JB, Inman VT, Eberhart HD. The major determinants in normal and pathological gait. J Bone Joint Surg Am 1953;35-A: 543–58.
[40] Donelan JM, Shipman DW, Kram R, Kuo AD. Mechanical and metabolic requirements for active lateral stabilization in human walking. J Biomech 2004;37:827–35.
[41] Perry J, Garrett M, Gronley JK, Mulroy SJ. Classification of walking handicap in the stroke population. Stroke 1995;26:982–9.
[42] Bicket AK, Mihailovic A, Jian-Yu E, et al. Gait in elderly glaucoma: impact of lighting conditions, changes in lighting, and fear of falling. Transl Vis Sci Technol 2020;9:1–11.
[43] Mihailovic A, De Luna RM, West SK, Friedman DS, Gitlin LN, Ramulu PY. Gait and balance as predictors and/or mediators of falls in glaucoma. Invest Ophthalmol Vis Sci 2020;61:1–10.