RESEARCH ARTICLE

Investigating the Influence of Visual Function and Systemic Risk Factors on Falls and Injurious Falls in Glaucoma Using the Structural Equation Modeling

Kenya Yuki1, Ryo Asaoka2*, Kazuo Tsubota1

1 Department of Ophthalmology, Keio University School of Medicine, Shinanomachi 35, Shinjuku-ku, Tokyo, Japan, 2 Department of Ophthalmology, the University of Tokyo, Graduate School of Medicine, 7-3-1 Hongo, Bunkyo-ku, Tokyo, Japan

* rasaoaka-ty@umin.ac.jp

Abstract

Purpose
To investigate the relationship between visual function and the risks of falling and injurious falls in subjects with primary open angle glaucoma (POAG)

Methods
Questionnaires were conducted in 365 POAG patients to assess history of falls and falls with injury and general patient health. Structural equation modeling (SEM) was used to investigate the relationship between visual function, as measured by a patient's binocular integrated visual field and visual acuity (VA), general health and the risks of falling and injurious falls.

Results
Among the 365 subjects, 55 subjects experienced falls in the past year. A significant difference was observed in worse-eye VA between the faller and non-faller groups (p = 0.03). SEM of fallers obtained a Root Mean Square Error of Approximation (RMSEA) of 0.035 and a Comparative Fit Index (CFI) of 0.99. The 95% confidence intervals (CI) of regression coefficients from this model suggested better VA and worse VA were significant risk factors for falling. Among the 55 fallers, 22 subjects experienced an associated injury. There was a significant difference in gender between the non-injurious and injurious faller groups (p = 0.002). SEM of injurious fallers obtained a RMSEA of 0.074 and a CFI of 0.97. In this SEM model, the 95% CI of regression coefficients suggested gender and average total deviation values in the lower peripheral visual field were significant risk factors for an injurious fall.
Conclusions
This study suggests that worse-eye and better-eye VAs are associated with falls. Furthermore, patients with inferior visual field loss and females were found to be at greater risk of injurious falls.

Introduction
Falls, in particular falls associated with injuries, are one of the most serious public health concerns for the elderly in the world [1,2]. About 30% of individuals, over the age of 65 years, fall at least once in a year; 10%–20% of these falls lead to injury, and 5%–6% result in fractures [2]. In 2010 alone, there were 21,649 fall deaths among people aged 65 and older in the United States [3]. Falls are not only associated with physical consequences but also associated with reduced quality of life such as depression [4], fear of falling [5], restricted activity [6], hospitalization [7], and subsequent admission to a nursing home [1].

Glaucoma is a leading cause of blindness in the world [8] yet there is still controversy regarding the link between glaucoma (and consequential visual field defects) and the risk of falling [9–14]. In 2013, the number of people aged 40–80 years with glaucoma worldwide was estimated to be 64 million, and is expected to increase to 76 million by 2020 and 112 million by 2040 [15]. Glaucoma has widely been reported to be associated with reduced quality of life and daily activities [16–18] but it is debatable whether glaucomatous visual field loss is associated with falls or not [9–14, 19–21]. One recent report suggested that the risk of falling is associated with damage in the inferior relatively peripheral VF [19]. Nonetheless, the risk of falling is influenced by many factors, such as body-mass index (BMI), general health status, gender and age [22,23]. In addition, the risk factors associated with falling compared with injurious falling may be different. The purpose of this study was to investigate the relationship between visual function and falls or injurious falls in subjects with primary open angle glaucoma (POAG) while considering patients’ general function.

The influence of visual function, namely visual acuity (VA) and VF status, on the risk of falling has usually been investigated independently, which is not ideal since the two measurements are significantly correlated [24–27]. Consequently, in the current study, structural equation modeling (SEM) was used to investigate the relationship between visual function and the risks of fall and injurious falls. SEM can model a set of relationships among a large number of variables simultaneously, in which continuous, discrete and factor variables are included [28]. In the current study, the main variables of interest were stage of glaucoma and risk of falling or injurious falling.

Methods
The study was approved by the Research Ethics Committee of the Keio University School of Medicine. Written informed consent was obtained from all subjects after explanation of the nature and possible consequences of the study. The study was performed according to the tenets of the Declaration of Helsinki.

Study Design and Subject Enrollment
A total of 601 patients who visited Keio University Hospital (Tokyo, Japan), Iidabashi Eye Clinic (Tokyo, Japan) or Tanabe Eye Clinic (Yamanashi, Japan) between the period of May
2011 and November 2011 were screened for eligibility by means of an ophthalmic examination that included slit-lamp biomicroscopy, funduscopy, gonioscopy, intraocular pressure measurements with Goldmann applanation tonometry and VF examination with the Humphrey Field Analyzer (HFA, Carl Zeiss Meditec, Dublin, CA), using the 24–2 Swedish Interactive Threshold Algorithm Standard Strategy. Patients with ophthalmological diseases that could compromise VA or cause VF loss, such as cataract (except for insignificant senile change) were excluded. Patients with angle closure glaucoma, secondary glaucoma, age-related macular degeneration, diabetic retinopathy, and any fundus disease apart from POAG were also excluded. Subjects who could not walk alone, or walk with a cane were also excluded. The eligible age was restricted to patients older than 40 years and less than 85 years. The purpose and methodology of the study were explained to every patient who met the inclusion criteria, and all patients agreed to participate.

**Diagnosis of POAG**

POAG was diagnosed on the basis of the presence of the following three findings: (1) glaucomatous optic cupping represented by notch formation, generalized enlargement of cupping, senile sclerotic disc or myopic disc, or nerve fiber layer defects confirmed by glaucoma specialists (K.Y., and S.T.; see Acknowledgements) on fundus examination; (2) typical glaucomatous VF defects, such as Bjerrum scotoma, nasal step, or paracentral scotoma, compatible with optic disc appearance; and (3) an open, non-occludable angle observed on gonioscopy.

**Questionnaire Regarding History of falls**

All participants answered a questionnaire including the following questions (translated from Japanese):

1. Can you walk without assistance? (Yes/No)
2. Do you use a cane or any kind of walking aid? (Yes/No)
3. How long do you spend walking on average per day? (The number of minutes was recorded.)
4. Are you afraid of falling? (Not at all; Not much; Afraid; Very afraid)
5. Have you had any falls in the last year? (Yes/No) *
6. Have you been injured by a fall in the last year? (Yes/No)

In addition, the following demographic information was recorded: age, sex, height, weight, alcohol intake, smoking history, current illnesses, and medical history (including medications taken orally).

**Integrated Visual Field**

A binocular integrated VF (IVF) was calculated for each patient by merging a patient’s monocular HFA VFs using the ‘best sensitivity’ method [29–32]. In this method each total deviation (TD) value in the IVF is calculated by taking the maximum TD value from overlapping points in the monocular VFs, as if the subject was viewing binocularly. The IVF MD was then calculated as the mean of all 52 TD values across the IVF, while the means of TD values in the superior peripheral, superior central, inferior central and inferior peripheral areas were also calculated, following the areas indicated in Fig 1; thus, the VF was divided outside and within
the central ten degrees (these areas follow the mappings in the 24–2 and 10–2 visual fields of the Humphrey Field Analyzer).

Statistical Analysis

Structural equation modeling (SEM) was used to investigate the relationship between visual function, general function and the risks of falling and injurious falling. SEM is a multivariate technique well suited for testing the relationship between these variables and outcomes. It is one of the most frequently used statistical techniques in many social sciences, including psychological research, educational research, and market analysis. A considerable strength of SEM is that it can model 'latent variables', which are variables that cannot be measured directly, and are instead estimated in the model from several observed variables. In other words, observed variables are used as indicators of the latent variables. In SEM, statistical fit is often compared using the measures of Root Mean Square Error of Approximation (RMSEA) and Comparative Fit Index (CFI). An RMSEA in the range of 0.05 to 0.10 indicates a fair fit and values above 0.10 indicate a poor fit [33]. The CFI measurement is reported to be less affected by sample size than RMSEA [34] and a CFI value above 0.95 is indicative of a good fit [35].

In the SEM conducted here, the observed variables were: mean TD (mTD) in the superior peripheral VF, mTD in the superior central VF, mTD in the inferior central VF, mTD in the inferior peripheral VF, mTD in the whole field, better-eye VA, worse-eye VA, gender, age, BMI, complications of diabetes, complications of hypertension, usage of sleep aid, usage of sedatives and duration of walking in a day. The fitness of the SEM models was evaluated using the RMSEA and CFI.

All statistical analyses were carried out using the statistical programming language R (V.3.1.0, The R Foundation for Statistical Computing, Vienna, Austria). The R package ‘lavaan’ was used to carry out SEM. All of the variables were standardized to have a mean of 0 and a variance of 1, before analyses.
Results

617 subjects were screened and 252 subjects were ineligible. The reasons for excluding subjects were as follows, where the numbers in parentheses indicate the number of subjects excluded: younger than 40 years old (28), older than 85 years old (25), refusal to participate (10), dementia (3), low VA (24), secondary glaucoma (62), glaucoma other than primary angle-closure glaucoma (16), history of retinal-detachment (21), diabetic retinopathy (36), bullous keratopathy (2), age-related macular degeneration (2), other ocular disease (1), subjects who could not walk unaided (0), and subjects who walk with a cane (16). A further six subjects were excluded because some of the answers the questionnaire were missing. As a result, 365 subjects were eligible and investigated in the current study.

Among the 365 subjects, 55 subjects experienced falls in the past year. The characteristics of non-fallers and fallers are shown in Table 1. There was a significant difference in the worse-eye VA of the faller and non-faller groups (p = 0.03, unpaired t-test).

The path diagram describing the results of the risks of falling SEM analysis is shown in Fig 2. In the diagram, the circled variables represent the latent variables, ‘Risk of Falling’ and ‘Glaucomatous Damage’. The path diagram indicates that worse-eye VA, better-eye VA, mean TD values in the superior periphery, superior centre, inferior periphery and inferior centre regions, and mean TD value of whole field are determined by the level of glaucomatous damage. On the other hand, the risk of falling is determined by age, gender, BMI, usage of sleep aids and sedatives, minutes walked in a day, complications of diabetes, complications of hypertension, and the latent variable ‘Glaucomatous Damage’. This SEM model obtained an RMSEA of 0.035 and a CFI of 0.99. Only better-eye VA and worse-eye VA were statistically significant variables in

| Table 1. Comparison of variables between patients with and without a history of falls. |
|-----------------|-----------------|-----------------|
|                  | fall+ (mean ± s.d.) | fall- (mean ± s.d.) | p value |
| Number           | 55               | 310              |        |
| Age              | 66.8 ± 11.5      | 64.0 ± 10.4      | 0.10   |
| Better-eye VA (LogMar) | 0.01 ± 0.03     | 0.00 ± 0.01      | 0.16   |
| Worse-eye VA (LogMar) | 0.03 ± 0.06     | 0.02 ± 0.04      | 0.03*  |
| Gender (male:female) | 29:26           | 181:129          | 0.46   |
| BMI              | 22.4 ± 2.9       | 22.4 ± 3.0       | 0.99   |
| Smoking status (Never/Previous/Current) | 40/13/2        | 188/79/43        | 0.08   |
| Alcohol intake (Never/Sometimes/Daily) | 26/16/13       | 156/82/72        | 0.90   |
| Prevalence of diabetes mellitus | 12/55 = 21.8%   | 41/310 = 13.2%   | 0.10   |
| Prevalence of hypertension | 18/55 = 32.7%   | 93/310 = 30.0%   | 0.69   |
| Sedative use     | 2/55 = 3.6%      | 8/310 = 2.6%     | 0.65   |
| Sleeping aid use | 1/55 = 1.8%      | 10/310 = 3.2%    | 0.99   |
| Walking minutes per day | 88.0 ± 104.4  | 84.2 ± 92.9      | 0.80   |
| IVF MD (dB) [Range] | -2.0 ± 2.9 [-11.9–3.1] | -2.1 ± 4.0 [-18.5–5.3] | 0.78   |
| Better MD (dB) [Range] | -2.7 ± 3.4 [-14.5–2.2] | -3.0 ± 4.5 [-28.0–1.9] | 0.53   |
| Worse MD (dB) [Range] | -6.4 ± 5.8 [-24.5–0.8] | -7.6 ± 7.0 [-31.0–0.9] | 0.19   |

Chi square test was used for the variable of gender, smoking status, alcohol intake, prevalence of diabetes mellitus, and prevalence of hypertension. 
Fisher's exact test was used for the variable of sedative use, and sleeping aid use. Unpaired t-test was used for other comparisons.

* represents p < 0.05.

Abbreviations
s.d.: standard deviation, VA: visual acuity, LogMar: the logarithm of the minimum angle of resolution, BMI: body-mass index, MD: mean deviation, IVF: integrated visual field, TD: total deviation,

doi:10.1371/journal.pone.0129316.t001
the model; the mean and 95% confidence intervals (CI) of regression coefficients for these variables were 0.11 [CI: 0.009 to 0.22] and 0.14 [CI: 0.04 to 0.25], respectively.

Among the 55 fallers, 22 subjects experienced an associated injury. The characteristics of non-injurious fallers and injurious fallers are shown in Table 2. There was a significant difference in gender between the non-injurious and injurious faller groups (p = 0.002, chi square test).

The SEM path diagram resulting from the analysis of injurious falls is shown in Fig 3. The SEM paths are identical to those shown in Fig 2, however, the magnitude of the coefficients are different. This model obtained an RMSEA of 0.074 and a CFI of 0.97. Only gender and the average TD value in the lower peripheral VF were significant variables in the model; the mean and 95% CI of regression coefficients for these variables were 0.36 [CI: 0.09 to 0.63] and -0.28 [CI: -0.56 to -0.001], respectively.

**Discussion**

In this study, we have shown that best-corrected VAs in the better-eye and worse-eye of POAG patients are significantly associated with falls. A number of studies have reported that worse-
eye VA is a risk factor for falls in the elderly [36,37]. In the EPIC-Norfolk eye study, multivariate analysis examining the association between VA as a continuous variable and falls showed that a 1 unit increase in logMAR VA was associated with a 31% increase in the risk of a fall (OR = 1.3, 95% CI 1.0 to 1.7, p = 0.03) [38]. In the Singapore Malay eye study, unilateral severe VA impairment (log-MAR > 1.0) in the worse-eye significantly increased the likelihood of a fall (multivariable adjusted OR = 1.6; 95% CI 1.1 to 2.3) [39]. In the Blue Mountains Eye Study, subjects with VA worse than 20/30 had 1.9 times higher risk of recurrent falls [40]. In a study of Osteoporotic fractures, women with declining VA had significantly greater odds of experiencing frequent falling during the subsequent year compared with women with stable or improved VA; odds ratios after adjustment for baseline VA and other confounders were 2.08 (95% CI 1.39–3.12) for loss of 1 to 5 letters, 1.85 (95% CI 1.16–2.95) for loss of 6 to 10 letters, 2.51 (95% CI 1.39–4.52) for loss of 11 to 15 letters, and 2.08 (95% CI 1.01–4.30) for loss of >15 letters [41]. All these results suggest that worse-eye VA is a prominent risk factor for falls in the elderly, supporting the results presented here. Pineless et al. also reported that subjects with disorders of binocular vision such as strabismus, amblyopia, and diplopia are 20% more likely to experience a fall [adjusted OR 1.20 (95%CI 1.18–1.21)] [42]. This result may also explain why visual acuity in the worse eye is associated with falls in the current study since it may deem a patient functionally monocular.

In subjects with glaucoma, however, no studies have shown that worse-eye VA is associated with falls. Haymes et al. examined the prevalence of falls in subjects with glaucoma and showed that glaucoma itself is associated with falls, but failed to show an association between worse-eye VA and falls [11]. Black et al. and Glyn et al. also showed no association between worse-eye VA and falls in glaucoma [9,19]. In our study, we have shown that VAs in the better eye and

| Table 2. Comparison of variables between fallers with and without a history of injury. |
|----------------------------------|----------------------------------|------------------|
|                                | Fall with injury+ (mean ± s.d.)  | Fall without injury- (mean ± s.d.) | p value  |
| Number                          | 22                               | 33                             |          |
| Age                             | 68.0 ± 10.6                       | 66.0 ± 12.2                    | 0.54     |
| Better-eye VA (LogMar)          | 0.01 ± 0.02                       | 0.01 ± 0.04                    | 0.52     |
| Worse-eye VA (LogMar)           | 0.05 ± 0.07                       | 0.02 ± 0.05                    | 0.16     |
| Gender (male:female)            | 6:16                             | 23:10                          | 0.002**  |
| BMI                             | 22.4 ± 2.9                        | 22.4 ± 3.0                     | 0.99     |
| Smoking status (Never/Previous/Current) | 19/3/0                      | 21/10/2                       | 0.17     |
| Alcohol intake (Never/Sometimes/Daily) | 13/4/5                      | 13/12/8                       | 0.27     |
| Prevalence of diabetes mellitus | 4/22 = 18.2%                      | 8/33 = 24.2%                   | 0.74     |
| Prevalence of hypertension      | 8/22 = 36.4%                      | 10/33 = 30.3%                  | 0.64     |
| Sedative use                    | 1/22 = 4.5%                       | 1/33 = 3.0%                    | 0.99     |
| Sleeping aid use                | 0/22 = 0.0%                       | 1/33 = 3.0%                    | 0.99     |
| Walking minutes                 | 76.6 ± 95.4                       | 95.6 ± 110.7                   | 0.50     |
| IVF MD (dB) [Range]             | -2.0 ± 2.9 [-11.9–3.1]            | -1.6 ± 3.0 [-8.2–1.2]          | 0.28     |
| Better MD (dB) [Range]          | -2.9 ± 3.1 [-14.5–1.5]            | -2.5 ± 3.6 [-8.0–2.2]          | 0.65     |
| Worse MD (dB) [Range]           | -7.4 ± 5.0 [-18.4–0.7]            | -5.8 ± 6.3 [-24.5–0.8]         | 0.29     |

Chi square test was used for the variable of gender, alcohol intake, and prevalence of hypertension. Fisher’s exact test was used for the variable of smoking status, prevalence of diabetes mellitus, sedative use, and sleeping aid use. Unpaired t-test was used for other comparisons.

** represents p < 0.01.

Abbreviations s.d.: standard deviation, VA: visual acuity, LogMar: the logarithm of the minimum angle of resolution, BMI: body-mass index, MD: mean deviation, IVF: integrated visual field, TD: total deviation.

doi:10.1371/journal.pone.0129316.t002
worse eye are associated with falls independent of VF severity. The reason for these inconsistencies is unclear, however one possible explanation is that previous studies evaluated the relationship between VA and VF independently, which is inappropriate because the measurements are inter-correlated.

In patients suffering injurious falls, we clearly showed that average TD values in the lower peripheral VF are associated with the risk of injurious falling. Previous reports have suggested an association between visual impairment and injurious falls [43,44], but there are a limited number of studies that investigated the association between injurious falls and VF loss. In the Los Angeles Latino Eye Study, those with moderate to severe impairment in the peripheral VF were 1.40 (95% CI 0.94–2.05) times as likely to report falls with injury than individuals without any peripheral visual impairment; the trend was statistically significant (p = 0.04) [13]. Black et al. conducted a prospective study to evaluate the association between falls, injurious falls, and VF defects in subjects with glaucoma. They found that more extensive VF loss in the inferior region was associated with higher rate of falls with injury (RR, 1.80; 95% CI, 1.12 to 2.98) after adjustment for all other visual measures and potential confounding factors [19]. Our result are in agreement with these previous studies.

**Fig 3. The structural equation modeling path diagram for the analysis of risk of injurious falling.** The model obtained an RMSEA of 0.074 and a CFI of 0.97. Among the 95% confidence intervals (CIs) of regression coefficients, only those from gender and average TD values in the lower peripheral VF did not cross 0. Variables in circles represent latent variables ('Glaucomatous Damage' and 'Risk of injurious falling'). Parentheses represent 95% CIs. BMI: body-mass index, gender: male: 0, female: 1, sleep aid: usage of sleep aid, sedative: usage of sedative. Superior peripheral, superior central, inferior central and inferior peripheral: means of the total deviation values in the superior peripheral, superior central, inferior central and inferior peripheral areas, respectively. MD: mean of the total deviation values in whole field. VA: visual acuity.

doi:10.1371/journal.pone.0129316.g003
Vision is the only human sensory modality that provides us with information about distance, steps, ramps, and obstacles in our path. In one study, only fifty per cent of subjects with simulated severe VA loss (LogMar 1.65) could recognize a step down in their walking path compared with one hundred percent of subjects with simulated mild VA impairment (Logmar 0.88) [45]. Bochsler et al. evaluated the accuracy of target detection, such as a ramp up or down, while subjects were walking, and revealed that the accuracy of target recognition declines with lower VA [46]. Thus, it is possible that lower VA leads to a failure to detect obstacles, steps, and ramps, and a safe place to step, all of which could result in a fall.

It is also possible that subjects with inferior VF loss may fail to detect obstacles. While walking, fixation is gazed at the target where people are going [47]. People mainly use their peripheral VF to obtain information of obstacles while walking [48]. Marigold et al. evaluated head pitch angle and gait pattern changes with and without simulated inferior VF loss using glasses, while walking on a path with an irregular surface. As a result, it was suggested that downward head pitch angle increased and gait pattern altered when the lower VF was blocked [49]. These results suggest that information from the lower VF is important to guide lower limbs when walking in order to detect obstacles, and to find safe places to step. It is reasonable to hypothesize that eye-movement during walking may compensate VF loss in glaucoma; however, Vargas-Martìn et al. evaluated the dispersion of eye movement in subjects with severe peripheral VF loss while walking, and found that eye-position dispersion becomes narrower, not wider, than in subjects with normal sight [50]. The authors speculated that the lack of compensation was due to the lack of stimuli in the area of VF loss. These results suggest that subjects with glaucoma with inferior VF loss may not be able to reduce the risk of falling using eye movements.

It is reported that VF loss is associated with reduced mobility and physical performance in elderly people [51] and in subjects with glaucoma [21,52]. Reduced mobility and physical performance is a significant risk factor for falling [53]. Black et al. examined the association between specific VF defects and functional status outcome measures in 74 community-dwelling older adults with open-angle glaucoma; outcome measures included physical performance tests (a 6-minute walking test, a timed up-and-go test and a lower limb strength test), a physical activity questionnaire (the ‘Physical Activity Scale for the Elderly’ questionnaire) and an overall functional status score. They found that inferior VF loss was associated with slower timed up-and-go scores, weaker lower limb strength and lower overall functional status scores. Superior VF loss was not associated with any of the functional status outcomes [54]. These results suggest that inferior VF loss make glaucoma subjects frailer than subjects with superior VF loss, or normal vision.

In this study, we also showed that female gender is significantly associated with injurious falls in subjects with glaucoma. Supporting this, female gender is reported to be a strong risk factor for falls in previous studies [44]. Black et al. reported that females are approximately three times more likely to have injurious falls than males after adjustment for age, visual factors, and possible confounders [19]. Patino et al. also reported that females are about 1.4 times more likely to have injurious falls than males [13].

The prevalence of falls in this study was 15.0% over the past one year. The prevalence is comparable with previous studies performed in Asian countries [55–57] and in Japan [58]. The prevalence rate of falls in our study and in Asian countries is lower than that of western countries where approximately 35–40% of generally healthy elderly people aged 65 or more experience a fall annually [59]. One possible explanation is a difference in living situations or marital status between Western countries and Asian countries. We intend to investigate this in future by asking patients about their living situation and marital status.
This study is subject to several limitations. First, it is a cross-sectional study, hence a future prospective study should be carried out in an attempt to obtain further evidence for the association between VA and falls/injurious falls. Second, the self-reported questionnaire “Have you experienced a fall in the past one year” may be a source of recall bias. However, self-reported falls have been used in a number of studies that evaluated the association between vision and falls [13,38,39]. Cummings et al. reported that it is most appropriate to ask elderly adults to recall falls over the preceding 12 months rather than a shorter period [60]. Another possible limitation is that we did not explore other systemic diseases, such as stroke, prior heart attack, angina, or use of anti-depressants as confounding factors in this study. Nor did we investigate whether a person with multiple falls is more likely to have a fall with injury. Furthermore, we did not investigate the nature of injuries resulting from a fall in the current study; however, in the Blue mountain eye study, Ivers et al. reported that subjects with glaucoma were 8 times more likely to have future hip fracture than subjects without glaucoma [61]. In addition, Coleman et al. reported that subjects with severe binocular visual field loss have a greater risk of hip fracture (HR = 1.66; 95% CI: 1.19–2.32) [62]. Loriaut et al reported that in a case-control study, 10 patients out of 96 subjects with hip fracture had glaucoma, but only 5 out of 103 patients without hip-fracture had glaucoma (OR = 10.65; 95% CI 2.21–51.3) [63]. White et al. also reported that glaucoma was a significant risk factor for future hip fracture in men and in women (HR = 1.9 and 1.3 respectively) in the leisure world cohort study [64]. These previous papers strongly suggest that glaucoma is a risk factor for hip-fracture but more research is needed to explore what type of visual field defect is a risk factor for hip-fracture. Finally, our study did not include a control group consisting of healthy subjects.

Conclusion

In this study, we showed that VAs in the better-eye and worse-eye of subjects with POAG were associated with falls. We also showed that inferior VF loss and female gender are associated with injurious falls. These results will help clinicians to concentrate on these regions when managing patients, and offer appropriate advice if these areas are damaged.

Acknowledgments

The authors are grateful to Dr. Sachiko Tanabe, Dr. Takeshi Ono, Dr. Masaru Shimoyama, Dr. Kazumi Fukagawa, Dr. Naoki Ozeki, Dr. Daisuke Shiba, Dr. Joji Tanabe, and Dr. Naohiko Tanabe for their help with data collection.

Author Contributions

Conceived and designed the experiments: KY RA KT. Performed the experiments: KY RA. Analyzed the data: KY RA. Contributed reagents/materials/analysis tools: KY RA. Wrote the paper: KY RA TK.

References

1. Tinetti ME, Williams CS. Falls, injuries due to falls, and the risk of admission to a nursing home. N Engl J Med. 1997; 337: 1279–1284. PMID: 9345078
2. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N Engl J Med. 1998; 319: 1701–1707.
3. Stevens JA, Rudd RA. Circumstances and contributing causes of fall deaths among persons aged 65 and older: United States, 2010. J Am Geriatr Soc. 2014; 62: 470–475. doi: 10.1111/jgs.12702 PMID: 24617970
4. Ni Mhaolain AM, Fan CW, Romero-Ortuno R, Cogan L, Cunningham C, Lawlor B, et al. Depression: a modifiable factor in fearful older fallers transitioning to frailty? Int J Geriatr Psychiatry. 2012; 27: 727–733. doi: 10.1002/gps.2780 PMID: 22467265

5. Friedman SM, Munoz B, West SK, Rubin GS, Fried LP. Falls and fear of falling: which comes first? A longitudinal prediction model suggests strategies for primary and secondary prevention. J Am Geriatr Soc. 2002; 50: 1329–1335. PMID: 12164987

6. Boyd R, Stevens JA. Falls and fear of falling: burden, beliefs and behaviours. Age Ageing. 2009; 38: 423–428. doi: 10.1093/ageing/afp053 PMID: 19420144

7. Kool B, Ameratunga S, Robinson E, Jackson R. Hospitalisations and deaths due to unintentional falls at home among working-aged New Zealanders. Injury. 2007; 38: 570–575. PMID: 17266959

8. Weinreb RN, Khaw PT. Primary open-angle glaucoma. Lancet. 2004; 363: 1711–1720. PMID: 15158634

9. Glynn RJ, Seddon JM, Krug JH Jr., Sahagian CR, Chiavelli ME, Campion EW. Falls in elderly patients with glaucoma. Arch Ophthalmol. 1991; 109: 205–210. PMID: 1993029

10. Tanabe S, Yuki K, Ozeki N, Shiba D, Tsubota K. The association between primary open-angle glaucoma and falls: an observational study. Clin Ophthalmol. 2012; 6: 327–331. doi:10.2147/OPTH.S28281 PMID: 22399845

11. Haymes SA, Leblanc RP, Nicolela MT, Chiasson LA, Chauhan BC. Falls and fear of falling: burden, beliefs and behaviours. Age Ageing. 2009; 38: 423–428. doi:10.1093/ageing/afp053 PMID: 19420144

12. Coleman AL, Cummings SR, Yu F, Kodjebacheva G, Ensrud KE, Gutierrez P, et al. Binocular visual-field loss increases the risk of future falls in older white women. J Am Geriatr Soc. 2007; 55: 357–364. PMID: 17341237

13. Patino CM, McKean-Cowdin R, Azen SP, Allison JC, Choudhury F, Varma R. Central and peripheral visual impairment and the risk of falls and falls with injury. Ophthalmology. 2010; 117: 199–206.e191. doi: 10.1016/j.ophtha.2009.06.063 PMID: 2031225

14. Freeman EE, Munoz B, Rubin G, West SK. Visual field loss increases the risk of falls in older adults: the Salisbury eye evaluation. Invest Ophthalmol Vis Sci. 2007; 48: 4455–4460. PMID: 17898264

15. Tham YC, Li X, Wong TY, Quigley HA, Aung T, Cheng CY. Global Prevalence of Glaucoma and Projections of Glaucoma Burden through 2040: A Systematic Review and Meta-Analysis. Ophthalmology. 2014; 121: 2081–2090. doi:10.1016/j.ophtha.2014.05.013 PMID: 24974815

16. Ramulu P. Glaucoma and disability: which tasks are affected, and at what stage of disease? Curr Opin Ophthalmol. 2009; 20: 92–98. doi: 10.1097/ICU.0b013e32832401a9 PMID: 19240541

17. Murata H, Hirasawa H, Aoyama Y, Sugisaki K, Araie M, Mayama C, et al. Identifying areas of the visual field important for quality of life in patients with glaucoma. PLoS One. 2013; 8: e58695. doi: 10.1371/journal.pone.0058695 PMID: 23520528

18. Black AA, Wood JM, Lovie-Kitchin JE. Inferior field loss increases rate of falls in older adults with glaucoma. Optom Vis Sci. 2011; 88: 1275–1282. doi: 10.1097/OPX.0b013e31822f4d6a PMID: 21873923

19. Turano KA, Rubin GS, Quigley HA. Mobility performance in glaucoma. Invest Ophthalmol Vis Sci. 1999; 40: 2803–2809. PMID: 10549639

20. Asaoka R. The relationship between visual acuity and central visual field sensitivity in advanced glaucoma. Br J Ophthalmol. 2013; 97: 1355–1356. doi: 10.1136/bjophthalmol-2013-303431 PMID: 23966372
28. Stephenson MT, Holbert RL, Zimmerman RS. On the use of structural equation modeling in health communication research. Health Commun. 2006; 20: 159–167. PMID: 16965253
29. Viswanathan AC, McNaught AI, Poinoosawmy D, Fontana L, Crabb DP, Fitzke FW, et al. Severity and stability of glaucoma: patient perception compared with objective measurement. Arch Ophthalmol. 1999; 117: 450–454. PMID: 10206571
30. Crabb DP, Viswanathan AC, McNaught AI, Poinoosawmy D, Fitzke FW, Hitchings RA. Simulating binocular visual field status in glaucoma. Br J Ophthalmol. 1998; 82: 1236–1241. PMID: 9924324
31. Crabb DP, Fitzke FW, Hitchings RA, Viswanathan AC. A practical approach to measuring the visual field component of fitness to drive. Br J Ophthalmol. 2004; 88: 1191–1196. PMID: 15317714
32. Nelson-Quigg JM, Cello K, Johnson CA. Predicting binocular visual field sensitivity from monocular visual field results. Invest Ophthalmol Vis Sci. 2000; 41: 2212–2221. PMID: 10892865
33. MacCallum RC, Browne MW, Sugawara HM. Power Analysis and Determination of Sample Size for Covariance Structure Modeling. Psychological Methods. 1996; 1: 130–149.
34. Fan X, Thompson B, Wang L. Effects of Sample Size, Estimation Methods, and Model Specification on Structural Equation Modeling Fit Indexes. Structural Equation Modeling. 1999; 6: 56–83.
35. Hu LT, Bentler PM. Cutoff Criteria for Fit Indexes in Covariance Structure Analysis: Conventional Criteria Versus New Alternatives. Structural Equation Modeling. 1999; 6: 1–55.
36. Lin CH, Liao KC, Pu SJ, Chen YC, Liu MS. Associated factors for falls among the community-dwelling older people assessed by annual geriatric health examinations. PLoS One. 2011; 6: e18976. doi: 10.1371/journal.pone.0018976 PMID: 21526155
37. Lord SR, Dayhew J. Visual risk factors for falls in older people. J Am Geriatr Soc. 2001; 49: 508–515. PMID: 11380741
38. Yip JL, Khawaja AP, Broadway D, Luben R, Hayat S, Dalzell N. Visual acuity, self-reported vision and falls in the EPIC-Norfolk Eye study. Br J Ophthalmol. 2014; 98: 377–382. doi: 10.1136/bjophthalmol-2013-004179 PMID: 24338086
39. Lamoureux EL, Chong E, Wang JJ, Saw SM, Aung T, et al. Visual impairment, causes of vision loss, and falls: the Singapore Malay Eye Study. Invest Ophthalmol Vis Sci. 2008; 49: 528–533. doi: 10.1167/iovs.07-1036 PMID: 18234995
40. Ivers RQ, Cumming RG, Mitchell P, Attebo K. Visual impairment and falls in older adults: the Blue Mountains Eye Study. J Am Geriatr Soc. 1996; 46: 58–64. PMID: 9434666
41. Coleman AL, Stone K, Ewing SK, Nevitt M, Cummings S, Mitchell P, et al. Higher risk of multiple falls among elderly women who lose visual acuity. Ophthalmology. 2004; 111: 857–862. PMID: 15121359
42. Pineless SL, Repka MX, Yu F, Lum F, Coleman AL. Risk of musculoskeletal injuries, fractures, and falls in Medicare beneficiaries with disorders of binocular vision. JAMA Ophthalmol. 2015; 133: 60–65. doi: 10.1001/jamaophthalmol.2014.3941 PMID: 25340322
43. Kulmala J, Era P, Parssinen O, Sakari R, Sipila S, Rantanen T, et al. Lowered vision as a risk factor for injurious accidents in older people. Aging Clin Exp Res. 2008; 20: 25–30. PMID: 18283225
44. Kantayaporn C. Fall with and without fracture in elderly: what's different? J Med Assoc Thai. 2012; 95 Suppl 10: S109–112. PMID: 23451448
45. Bochsler TM, Legge GE, Kallie CS, Gage R. Seeing steps and ramps with simulated low acuity: impact of texture and locomotion. Optom Vis Sci. 2012; 89: E1299–1307. doi: 10.1097/OPX.0b013e318264f2bd PMID: 22863792
46. Bochsler TM, Legge GE, Gage R, Kallie CS. Recognition of ramps and steps by people with low vision. Invest Ophthalmol Vis Sci. 2013; 54: 288–294. doi: 10.1167/iovs.12-10461 PMID: 23221068
47. Hollands MA, Patla AE. Vickers JN. "Look where you're going!": gaze behaviour associated with maintaining and changing the direction of locomotion. Exp Brain Res. 2002; 143: 221–230. PMID: 11880898
48. Cheong AM, Geruschat DR, Congdon N. Traffic gap judgment in people with significant peripheral field loss. Optom Vis Sci. 2008; 85: 26–36. doi: 10.1097/OPX.0b013e31815ed6fd PMID: 18174838
49. Marigold DS, Patla AE. Visual information from the lower visual field is important for walking across multi-surface terrain. Exp Brain Res. 2008; 188: 23–31. doi: 10.1007/s00221-008-1535-7 PMID: 18322679
50. Vargas-Martin F, Peli E. Eye movements of patients with tunnel vision while walking. Invest Ophthalmol Vis Sci. 2006; 47: 5295–5302. PMID: 17122116
51. Turano KA, Broman AT, Bandeen-Roche K, Munoz B, Rubin GS, West S. Association of visual field loss and mobility performance in older adults: Salisbury Eye Evaluation Study. Optom Vis Sci. 2004; 81: 298–307. PMID: 15181354
52. Friedman DS, Freeman E, Munoz B, Jampel HD, West SK. Glaucoma and mobility performance: the Salisbury Eye Evaluation Project. Ophthalmology. 2007; 114: 2232–2237. PMID: 17980433
53. Rogers ME, Rogers NL, Takeshima N, Islam MM. Methods to assess and improve the physical parameters associated with fall risk in older adults. Prev Med. 2003; 36: 255–264. PMID: 12634016

54. Black AA, Wood JM, Lovie-Kitchin JE. Inferior visual field reductions are associated with poorer functional status among older adults with glaucoma. Ophthalmic Physiol Opt. 2011; 31: 283–291. doi: 10.1111/j.1475-1313.2010.00811.x PMID: 21410740

55. Chan KM, Pang WS, Ee CH, Ding YY, Choo P. Epidemiology of falls among the elderly community dwellers in Singapore. Singapore Med J. 1997; 38: 427–431. PMID: 9529954

56. Wang J, Chen Z, Song Y. Falls in aged people of the Chinese mainland: epidemiology, risk factors and clinical strategies. Ageing Res Rev. 2010; 9 Suppl 1: S13–17. doi: 10.1016/j.arr.2010.07.002 PMID: 20667514

57. Chu LW, Chi I, Chiu AY. Incidence and predictors of falls in the chinese elderly. Ann Acad Med Singapore. 2005; 34: 60–72. PMID: 15726221

58. Aoyagi K, Ross PD, Davis JW, Wasnich RD, Hayashi T, Takemoto T. Falls among community-dwelling elderly in Japan. J Bone Miner Res. 1998; 13: 1468–1474. PMID: 9738520

59. American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. Guideline for the prevention of falls in older persons. J Am Geriatr Soc. 2001; 49: 664–672. PMID: 11380764

60. Cummings SR, Nevitt MC, Kidd S. Forgetting falls. The limited accuracy of recall of falls in the elderly. J Am Geriatr Soc. 1988; 36: 613–616. PMID: 3385114

61. Ivers RQ, Cumming RG, Mitchell P, Simpson JM, Peduto AJ. Visual risk factors for hip fracture in older people. J Am Geriatr Soc. 2003; 51: 356–363. PMID: 12588579

62. Coleman AL, Cummings SR, Ensrud KE, Yu F, Gutierrez P, Stone KL, et al. Visual field loss and risk of fractures in older women. J Am Geriatr Soc. 2009; 57: 1825–1832. doi: 10.1111/j.1532-5415.2009.02432.x PMID: 19702619

63. Loriaut P, Loriaut P, Boyer P, Massin P, Cochereau I. Visual impairment and hip fractures: a case-control study in elderly patients. Ophthalmic Res. 2014; 52: 212–216. doi: 10.1159/000362881 PMID: 25378036

64. White SC, Atchison KA, Gornbein JA, Nattiv A, Paganini-Hill A, Service SK. Risk factors for fractures in older men and women: The Leisure World Cohort Study. Gend Med. 2006. 3: 110–123. PMID: 16860270