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Interocular Asymmetry of Visual Field Loss, Intraocular Pressure, and Corneal Parameters in Primary Open-Angle Glaucoma

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Keywords
Asymmetric visual field loss · Intraocular pressure · Corneal biomechanical parameters · Primary open-angle glaucoma

Abstract
Objectives: This study aimed to assess the association between the corneal biomechanical parameters and visual field (VF) loss in patients with asymmetric primary open-angle glaucoma (POAG). ***Methods:*** A total of 89 POAG patients (50 males, 56.2%) with asymmetric VF loss, aged 65.2 ± 13.3 years, were enrolled in this study. Asymmetric VF loss was defined as an interocular difference of the global index mean deviation (MD) >2 dB. Intraocular pressure (IOP), central corneal thickness (CCT), and corneal biomechanical parameters such as maximum amplitude at the apex of highest concavity (def ampl HC) were measured. The worse eye was defined as the eye with a smaller MD. ***Results:*** The worse eyes had lower MD (–11.9 ± 6.7 dB vs. –5.3 ± 5.0 dB; $p < 0.001$) and higher IOP (14.6 ± 3.3 vs.13.9 ± 2.6 mm Hg, $p = 0.04$) than the better eyes. There was no significant difference between the 2 groups for CCT. The interocular difference of MD (IDMD) was negatively correlated with the interocular difference of IOP ($r = -0.22$, $p = 0.04$), while positively correlated with the interocular difference of def ampl HC ($r = 0.27$, $p = 0.01$). In patients with moderate asymmetric VF loss (IDMD ≥6 dB), def ampl HC of the worse eyes group (1.07 ± 0.12 mm) was significantly lower than the better eyes group (1.10 ± 0.11 mm, $p = 0.02$). ***Conclusion:*** Asymmetric POAG was associated with asymmetry in IOP and corneal biomechanical parameters but not in CCT. Lower deflection amplitude and higher IOP were found in eyes with more severe VF damage in POAG patients.

Introduction

Glaucoma is the leading cause of irreversible blindness worldwide, characterized by progressive optic neuropathy and visual field (VF) loss [1, 2]. The pathogenetic mechanisms of glaucoma damage are still unknown. Intraocular pressure (IOP) is an important risk factor for occurrence and progression of glaucoma, and reducing IOP is the principal method utilized in an attempt to slow down or arrest VF progression [3]. However, some glaucoma patients experience glaucomatous progression despite IOP reduction [4]. There are other factors believed to be involved in the development and worsening of glaucoma [5, 6].

Cornea and sclera are made up of similar extracellular matrix constituents, and with continuous collagenous

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sheaths, the relative parameters of the cornea might relate to the biomechanical properties of the posterior pole, which have been reported to be linked to the development and progression of glaucoma [7]. Central corneal thickness (CCT) is considered to be an important and independent risk factor for the development of glaucoma [8]. The Ocular Hypertension Study (OHTS) pointed out that patients with a thinner CCT had a higher risk of developing glaucoma [9, 10]. Moreover, glaucoma patients with advanced damage are more likely to have a thin CCT [11, 12]. Corneal hysteresis (CH), one of the major parameters of corneal biomechanics, has been associated with VF progression [13]. Several studies demonstrated that CH is lower in primary open-angle glaucoma (POAG) compared with healthy subjects [14–16]. The eyes with lower CH values had faster rates of VF loss [17].

Patients with POAG often display asymmetric VF damage in 2 eyes [18–20], and as such many studies have focused on this asymmetry. Previous studies found that asymmetric IOP, asymmetric CCT, and asymmetric corneal biomechanics were associated with the asymmetric VF damage in POAG [21–24], whereas some others drew diametrically opposite conclusions [25, 26]. More investigations are required in order to pinpoint the exact mechanism of asymmetric glaucomatous damage. This study was conducted to evaluate the parameters of the cornea using the OCULUS Corvis-ST in POAG patients with asymmetric VF loss.

Methods

Subjects

The study adhered to the tenets of the Declaration of Helsinki and was approved by the Ethics Committee of the Eye Hospital of Wenzhou Medical University. Patients were recruited from the Wenzhou Glaucoma Progression Study (WGPS), which provides glaucoma community screenings in Wenzhou [27, 28]. All participants signed a written and informed consent.

The inclusion criteria for this study were as follows: (1) patients with glaucomatous optic nerve damage and VF loss in at least 1 eye, (2) both eyes with open angle on gonioscopy, (3) asymmetric VF loss (bilateral mean deviation difference >2 dB) [29], and (4) 18 years of age and older. Patients with secondary glaucoma, previous laser or intraocular surgery, spherical equivalent diopter <−6.0 diopter (D) or >+3 D, and/or other diseases potentially affecting the VF were excluded. Glaucoma was defined according to the classifications set by the International Society for Geographical and Epidemiological Ophthalmology (ISGEO) [30]. All patients underwent a comprehensive ophthalmic examination, including presenting visual acuity, refractive error, slit-lamp biomicroscopy, gonioscopy, measurement of axial length by using the Lenstar LS 900 biometer (Haag Streit, Bern, Switzerland), fundus photography (Visucam 200; Carl Zeiss Meditec, Inc., Dublin, CA, USA), standard automated perimetry (Humphrey Field Analyzer; 24-2 Swedish interactive threshold algorithm; Carl Zeiss Meditec, Inc.), and spectral-domain OCT (Carl Zeiss Meditec, Inc.)

Visual Field Analysis

VF examinations were performed with the standard automated perimetry (Humphrey Field Analyzer II 750; Carl Zeiss Meditec Inc., Dublin, CA, USA) using the white-on-white 24-2 Swedish interactive threshold algorithm program. VF test results with fixation losses <20%, false-positive rate <33%, and false-negative rate <33% were considered reliable. The VF indices used for statistical analysis included mean deviation (MD), visual field index (VFI), and pattern standard deviation (PSD). A better eye was defined as the eye with a larger MD between the 2 eyes, while the worse eye was the eye with a smaller MD.

Corvis Measurements

The corneal deformation amplitude was obtained using the Corvis-ST (Corneal Visualization Scheimpflug Technology; OCULUS, Wetzlar, Germany). A trained technician obtained 3 measurements from each eye, and the average of 3 measurements was calculated for analysis. Details of Corvis-ST operation have been previously described [31]. In brief, the patient's cornea was appropriately centered to the device, and then an impulse of air with a pressure of 25 kPa was automatically emitted. As the air impulse was emitted, the cornea moved inward until it reached the highest degree of concavity. The corneal deformation process was recorded by using an ultra-high-speed Scheimpflug camera imaging 140 digital frames of the response of the central 8.5 mm of the cornea with a resolution of 640 × 480 pixels over 30 msec. The Corvis-ST indices used for statistical analysis included cord length of the first and second applanation (length A1 and length A2, respectively), corneal speed during the first and second applanation (velocity A1 and velocity A2, respectively), maximum amplitude at the apex of highest concavity (def ampl HC), distance between the 2 peaks at highest concavity (peak dist HC), central concave curvature at its highest concavity (radius HC), CCT, and IOP.

Statistical Analyses

Statistical analyses were performed using the SPSS (ver. 17.0; SPSS Inc., Chicago, IL, USA). Paired t tests were applied for comparisons of the continuous parameters between the better and worse eyes. Pearson's correlation was used to determine the relationships between interocular ocular parameters, including difference in MD (IDMD) and interocular deformation amplitude. Patients were categorized into 2 groups based on the IDMD: mild asymmetry (2 dB < IDMD <6 dB) and moderate asymmetry (IDMD ≥6 dB). A p value <0.05 was used to indicate statistical significance in all analyses.

Results

Patients' Characteristics

Eighty-nine POAG patients (50 males, 56.2%) with asymmetric VF loss were included. The mean age of these patients was 65.2 ± 13.3 years (range 24–88). Table 1 illustrates the characteristics of patients. The differences in

Table 1. Characteristics of all POAG patients with asymmetric VF loss

Characteristic	Worse eyes, n = 89		Better eyes, n = 89		p value
	mean ± SD	range	mean ± SD	range	
Clinical data					
Corvis IOP, mm Hg	14.6±3.3	9.0–32.0	13.9±2.6	10.0–25.5	**0.04**
CCT, μm	539.1±29.9	463–611	542.0±33.8	472–631	0.42
AL, mm	24.21±1.86	21.34–31.32	24.19±1.57	21.80–28.83	0.95
SE, D	−1.10±3.86	−16.88 to 3.63	−0.94±3.13	−10.12 to 4.25	0.66
C/D ratio	0.70±0.13	0.07–0.88	0.70±0.13	0.18–0.92	0.68
MD, dB	−11.9±6.7	−31.65 to 0.09	−5.3±5.0	−19.4 to 2.81	**<0.001**
PSD, dB	9.5±3.8	1.67–15.91	5.4±3.9	1.16–15.83	**<0.001**
VFI, %	68.4±22.4	0–98	87.2±13.6	43–100	**<0.001**

POAG, primary open-angle glaucoma; VF, visual field; SD, standard deviation; IOP, intraocular pressure; CCT, central corneal thickness; AL, axial length; SE, spherical equivalent; C/D, cup/disc; MD, mean deviation; PSD, pattern standard deviation; VFI, visual field index.

Table 2. Corvis parameters of the POAG patients with asymmetric VF loss

Characteristic	Worse eyes (mean ± SD)	Better eyes (mean ± SD)	p value
2 < interocular MD difference <6, n = 53			
Length A1, mm	1.75±0.08	1.73±0.12	0.33
Velocity A1, m/s	0.15±0.01	0.15±0.01	0.93
Length A2, mm	1.72±0.27	1.69±0.26	0.58
Velocity A2, m/s	−0.36±0.05	−0.36±0.09	0.63
Peak dist HC, mm	4.27±1.00	4.35±1.01	0.70
Def ampl HC, mm	1.13±0.10	1.12±0.11	0.39
Radius HC, mm	6.83±0.94	6.91±0.91	0.56
Interocular MD difference ≥6 (n = 36)			
Length A1, mm	1.74±0.10	1.73±0.09	0.61
Velocity A1, m/s	0.14±0.02	0.14±0.02	0.75
Length A2, mm	1.69±0.27	1.72±0.25	0.66
Velocity A2, m/s	−0.37±0.07	−0.36±0.06	0.33
Peak dist HC, mm	4.30±1.01	4.66±0.82	0.05
Def ampl HC, mm	1.07±0.12	1.10±0.11	**0.02**
Radius HC, mm	7.00±1.24	7.11±0.79	0.62

POAG, primary open-angle glaucoma; VF, visual field; SD, standard deviation; MD, mean deviation; length A1, first applanation length; velocity A1, first applanation velocity; length A2, second applanation length; velocity A2, second applanation velocity; peak dist HC, distance between the 2 peaks at highest concavity; def ampl HC, maximum amplitude at the apex of highest concavity; radius HC, central concave curvature at its highest concavity.

mean MD, PSD, and VFI between the worse eye group (−11.9 ± 6.7 dB, 9.5 ± 3.8 dB, and 68.4% ± 22.4%) and the better eye group (−5.3 ± 5.0 dB, 5.4 ± 3.9 dB, and 87.2% ± 13.6%) were significant (all $p < 0.001$). The worse eye group had significantly higher mean IOP than the better eye group ($p = 0.04$). There was no significant difference between the 2 groups for spherical equivalent, AL, CCT, and cup/disc (C/D) ratio.

Relationship of Corvis Parameters with Asymmetric Glaucomatous VF Loss

Corvis parameters were evaluated between worse eyes and better eyes as a function of asymmetric MD level. In patients with mild asymmetric VF loss (2 dB < IDMD <6 dB), insignificant differences in all Corvis parameters were found between worse eyes and better eyes (Table 2). In patients with moderate asymmetric VF loss (IDMD ≥6 dB), def ampl HC of the worse eyes group (1.07 ± 0.12 mm) was significantly lower than those obtained in the better eyes group (1.10 ± 0.11 mm, $p = 0.02$).

Table 3 illustrates the relationship between the interocular difference of Corvis parameters and IDMD. The IDMD was negatively correlated with the interocular difference of mean IOP ($r = -0.22$, $p = 0.04$), while positively correlated with interocular difference of mean def ampl HC ($r = 0.27$, $p = 0.01$, Fig. 1). No significant relationships were found between interocular difference of other Corvis parameters and IDMD.

Discussion

The glaucomatous defect or progression of the 2 eyes of the same patient is usually unbalanced, suggesting interocular factors are taking effect. Although several studies of interocular comparisons in asymmetric glaucoma have been published [18–20], the evaluation of corneal

Table 3. Pearson correlation between MD of visual filed interocular difference and parameters difference (n = 89)

Interocular difference	Better eyes – worse eyes, (mean ± SD)	r	p value
Corvis IOP, mm Hg	−0.64±2.88	−0.22	**0.04**
CCT, μm	4.18±23.12	0.19	0.07
Length A1, mm	−0.02±0.13	0	0.99
Velocity A1, m/s	0.00±0.02	0.02	0.84
Length A2, mm	−0.01±0.40	−0.06	0.57
Velocity A2, m/s	0.00±0.09	−0.07	0.54
Peak Dist HC, mm	0.19±1.29	0.03	0.81
Def ampl HC, mm	0.01±0.08	0.27	**0.01**
Radius HC, mm	0.09±1.12	−0.05	0.67

SD, standard deviation; IOP, intraocular pressure; CCT, central corneal thickness; length A1, first applanation length; velocity A1, first applanation velocity; length A2, second applanation length; velocity A2, second applanation velocity; peak dist HC, distance between the 2 peaks at highest concavity; def ampl HC, maximum amplitude at the apex of highest concavity; radius HC, central concave curvature at its highest concavity.

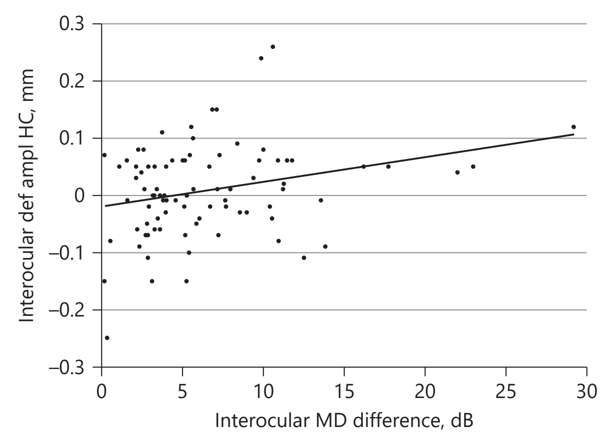

Fig. 1. The relationship between interocular MD difference and interocular def ampl HC difference (better eyes – worse eyes). Def ampl HC, maximum amplitude at the apex of highest concavity; MD, mean deviation.

biomechanics in asymmetric POAG using the Corvis-ST has not, to our knowledge, been assessed. In the present study, a definition based on interocular difference of mean deviation was applied to perform interocular comparisons in asymmetric glaucoma. Higher IOP and lower deflection amplitude were significantly related with greater deterioration of MD in POAG patients.

The findings of this study demonstrated that IOP is significantly related to glaucomatous VF progression. Eyes with higher IOP had the greater deterioration of MD of VF, which is well consistent with previous research results. Kac et al. [19] showed that worse VF is associated with increased IOP in patients with POAG. Helmy et al. [32] compared the parameters of 120 patients with bilateral asymmetric normal-tension glaucoma (NTG) and found that lower IOPcc corresponded to less deterioration of MD. In contrast with the results of this study, Li et al. [33] found no difference in IOP between the worse eyes and the better eyes of NTG patients. David et al. [26] reported that IOP asymmetry is unrelated to VF asymmetry in NTG. The major distinction of NTG from POAG is that the IOP does not exceed the normal range (21 mm Hg). A prospective randomized study demonstrated that 33% of NTG patients experience glaucomatous progression despite IOP reduction [4]. The influence of IOP on glaucomatous progression differed between NTG and POAG, and this difference was also reflected in asymmetric VF damage.

The relationship between the corneal biomechanical property and VF loss has been previously reported using the Ocular Response Analyzer (ORA) more often. CH has been shown to be closely associated with glaucomatous VF damage and optic nerve defects [13]. The lower CH eye is at greater risk for more advanced VF loss [23, 32]. Similarly, we found that corneal biomechanics was associated with glaucomatous VF damage, and def ampl HC was significantly lower in the worse eyes than in the better eyes of patients with moderate asymmetric VF loss. The larger the interocular deflection amplitude differences, the greater the glaucoma asymmetry. Our findings are similar with the results of Helmy et al. [32]. They assessed corneal biomechanics using the ORA in 120 asymmetrical NTG and found higher CH in eyes with less deterioration of MD of VF (p = 0.01).

CCT is considered to be an important risk factor for the development of glaucoma. The relationship between CCT and glaucoma has been given much concern. However, the conclusions from studies are inconsistent [3, 9, 34, 35]. The Ocular Hypertension Treatment Study [9] and the European Glaucoma Prevention Study [34] concluded that thinner CCT is a risk factor for the development of POAG. Similar results have been reported in POAG patients with asymmetric glaucoma damage. Sullivan-Mee et al. [22] evaluated 52 POAG and NTG patients with asymmetric VF and found that CCT was significantly thinner in higher AGIS score. Similarly, Prata et al. [36] reported that patients with thinner CCT had

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larger C/D values and deeper cups. However, other studies denied the association between CCT and glaucoma [37, 38]. For example, Helmy et al. [32] found no difference in CCT between the worse eyes and the better eyes of NTG patients in an observational study. Similarly, Li et al. [33] did not find a significant association between CCT and MD of the VF in 44 NTG patients with asymmetric VF. Furthermore, in our study, we also did not find significant difference in CCT between eyes of POAG patients with asymmetric glaucomatous damage.

The strengths of this study are listed below. First, this study included a relatively larger sample of POAG patients from a glaucoma community screening. Second, this study analyzed the asymmetric VF in various degrees instead of single VF damage level. However, an important limitation of this study is that although the association between interocular MD difference and interocular def ampl HC was found, the cross-sectional design limited our ability to determine the causal effect between exposures and outcomes.

In conclusion, this study has evaluated the relationship between IOP, corneal parameters, and VF asymmetry in a large cohort of POAG patients. Lower deflection amplitude and higher IOP were found in eyes with more advanced glaucoma in asymmetric POAG patients. It looks likely that lower deflection amplitude levels could lead to more glaucomatous damage, but further studies with larger samples and follow-up time are needed to confirm the findings.

Statement of Ethics

The study adhered to the tenets of the Declaration of Helsinki and was approved by the Ethics Committee of the Eye Hospital of Wenzhou Medical University (Ethics Approval No. KYK-2013-12). Written informed consent was obtained from all subjects.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

C.Y., S.D.Z., and Y.B.L. designed the study protocol and conducted the study as a supervisor. J.H.J. and Z.L. participated in the study design. J.H.J., X.F.P., and K.M.F. collected the study data. Z.L. and K.M.F. conducted statistical analysis. J.H.J. and Z.L. drafted the manuscript. N.M., C.Y., S.D.Z., and Y.B.L. revised the manuscript. All authors read and approved the final manuscript.

Data Availability Statement

All datasets generated for this study are included in the article.

References

1 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(11):2081–90.

2 Weinreb RN, Aung T, Medeiros FA. The pathophysiology and treatment of glaucoma: a review. JAMA. 2014;311(18):1901–11.

3 Leske MC, Heijl A, Hussein M, Bengtsson B, Hyman L, Komaroff E. Factors for glaucoma progression and the effect of treatment: the early manifest glaucoma trial. Arch Ophthalmol. 2003;121(1):48–56.

4 The effectiveness of intraocular pressure reduction in the treatment of normal-tension glaucoma. Collaborative Normal-Tension Glaucoma Study Group (1998). Am J Ophthalmol 126 (4):498–505.

5 Flammer J, Konieczka K, Bruno RM, Virdis A, Flammer AJ, Taddei S. The eye and the heart. Eur Heart J. 2013;34(17):1270–8.

6 Mozaffarieh M, Flammer J. New insights in the pathogenesis and treatment of normal tension glaucoma. Curr Opin Pharmacol. 2013;13(1):43–9.

7 Kono Y, Zangwill L, Sample PA, Jonas JB, Emdadi A, Gupta N, et al. Relationship between parapapillary atrophy and visual field abnormality in primary open-angle glaucoma. Am J Ophthalmol. 1999;127(6):674–80.

8 Pfeiffer N, Pfeiffer N, Torri V, Miglior S, Zeyen T, Adamsons I, et al. Central corneal thickness in the European Glaucoma Prevention Study. Ophthalmology. 2007;114(3):454–9.

9 Gordon MO, Beiser JA, Brandt JD, Heuer DK, Higginbotham EJ, Johnson CA, et al. The Ocular Hypertension Treatment Study: baseline factors that predict the onset of primary open-angle glaucoma. Arch Ophthalmol. 2002; 120(6):714–30; discussion 829–730.

10 Brandt JD, Gordon MO, Beiser JA, Lin SC, Alexander MY, Kass MA. Changes in central corneal thickness over time: the ocular hypertension treatment study. Ophthalmology. 2008;115(9):1550–56.e1.

11 Kniestedt C, Lin S, Choe J, Nee M, Bostrom A, Stürmer J, et al. Correlation between intraocular pressure, central corneal thickness, stage of glaucoma, and demographic patient data: prospective analysis of biophysical parameters in tertiary glaucoma practice populations. J Glaucoma. 2006;15(2):91–7.

12 Cankaya AB, Anayol A, Özcelik D, Demirdogen E, Yilmazbas P. Ocular response analyzer to assess corneal biomechanical properties in exfoliation syndrome and exfoliative glaucoma. Graefes Arch Clin Exp Ophthalmol. 2012; 250(2):255–60.

13 Deol M, Taylor DA, Radcliffe NM. Corneal hysteresis and its relevance to glaucoma. Curr Opin Ophthalmol. 2015;26(2):96–102.

14 Ang GS, Bochmann F, Townend J, Azuara-Blanco A. Corneal biomechanical properties in primary open angle glaucoma and normal tension glaucoma. J Glaucoma. 2008;17(4): 259–62.

15 Congdon NG, Broman AT, Bandeen-Roche K, Grover D, Quigley HA. Central corneal thickness and corneal hysteresis associated with glaucoma damage. Am J Ophthalmol. 2006;141(5):868–75.

16 Klingenstein A, Kernt M, Seidensticker F, Kampik A, Hirneiss C. Anterior-segment morphology and corneal biomechanical characteristics in pigmentary glaucoma. Clin Ophthalmol. 2014;8:119–26.
17 Medeiros FA, Meira-Freitas D, Lisboa R, Kuang TM, Zangwill LM, Weinreb RN. Corneal hysteresis as a risk factor for glaucoma progression: a prospective longitudinal study. Ophthalmology. 2013;120(8):1533–40.
18 Realini T, Barber L, Burton D. Frequency of asymmetric intraocular pressure fluctuations among patients with and without glaucoma. Ophthalmology. 2002;109(7):1367–71.
19 Kac MJ, Solari HP, Velarde GC, Brazuna R, Cardoso GP, Ventura MP. Ocular pulse amplitude in patients with asymmetric primary open-angle glaucoma. Curr Eye Res. 2011;36(8):727–32.
20 Suzuki ER Jr., Suzuki CL, Carlier D, Penha D, Parchen MA, Batista WD, et al. Dynamic contour tonometry in asymmetric glaucoma patients. Clin Ophthalmol. 2012;6:555–9.
21 Cartwright MJ, Anderson DR. Correlation of asymmetric damage with asymmetric intraocular pressure in normal-tension glaucoma (low-tension glaucoma). Arch Ophthalmol. 1988;106(7):898–900.
22 Sullivan-Mee M, Gentry JM, Qualls C. Relationship between asymmetric central corneal thickness and glaucomatous visual field loss within the same patient. Optom Vis Sci. 2006;83(7):516–9.
23 Anand A, De Moraes CG, Teng CC, Tello C, Liebmann JM, Ritch R. Corneal hysteresis and visual field asymmetry in open angle glaucoma. Invest Ophthalmol Vis Sci. 2010;51(12):6514–8.
24 Hirneiss C, Neubauer AS, Yu A, Kampik A, Kernt M. Corneal biomechanics measured with the ocular response analyser in patients with unilateral open-angle glaucoma. Acta Ophthalmol. 2011;89(2):e189–92.
25 Sullivan-Mee M, Halverson KD, Qualls C. Clinical comparison of pascal dynamic contour tonometry and goldmann applanation tonometry in asymmetric open-angle glaucoma. J Glaucoma. 2007;16(8):694–9.
26 Greenfield DS, Liebmann JM, Ritch R, Krupin T. Visual field and intraocular pressure asymmetry in the low-pressure glaucoma treatment study. Ophthalmology. 2007;114(3):460–5.
27 Liang Y, Jiang J, Ou W, Peng X, Sun R, Xu X, et al. Effect of community screening on the demographic makeup and clinical severity of glaucoma patients receiving care in urban China. Am J Ophthalmol. 2018;195:1.
28 Lin S, Cheng H, Zhang S, Ye C, Pan X, Tao A, et al. Parapapillary choroidal microvasculature dropout is associated with the decrease in retinal nerve fiber layer thickness: a prospective study. Invest Ophthalmol Vis Sci. 2019;60(2):838–42.
29 Poinoosawmy D, Fontana L, Wu JX, Bunce CV, Hitchings RA. Frequency of asymmetric visual field defects in normal-tension and high-tension glaucoma. Ophthalmology. 1998;105(6):988–91.
30 Foster PJ, Buhrmann R, Quigley HA, Johnson GJ. The definition and classification of glaucoma in prevalence surveys. Br J Ophthalmol. 2002;86(2):238–42.
31 Jung Y, Park HY, Park CK. Association between corneal deformation amplitude and posterior pole profiles in primary open-angle glaucoma. Ophthalmology. 2016;123(5):959–64.
32 Helmy H, Leila M, Zaki AA. Corneal biomechanics in asymmetrical normal-tension glaucoma. Clin Ophthalmol. 2016;10:503–10.
33 Li BB, Cai Y, Pan YZ, Li M, Qiao RH, Fang Y, et al. Corneal biomechanical parameters and asymmetric visual field damage in patients with untreated normal tension glaucoma. Chin Med J. 2017;130(3):334–9.
34 Miglior S, Miglior S, Pfeiffer N, Torri V, Zeyen T, Cunha-Vaz J, et al. Predictive factors for open-angle glaucoma among patients with ocular hypertension in the European Glaucoma Prevention Study. Ophthalmology. 2007;114(1):3–9.
35 Nemesure B, Wu SY, Hennis A, Leske MC. Corneal thickness and intraocular pressure in the Barbados eye studies. Arch Ophthalmol. 2003;121(2):240–4. 1960
36 Prata TS, Lima VC, Guedes LM, Biteli LG, Teixeira SH, de Moraes CG, et al. Association between corneal biomechanical properties and optic nerve head morphology in newly diagnosed glaucoma patients. Clin Exp Ophthalmol. 2012;40(7):682–8.
37 Cao KY, Kapasi M, Betchkal JA, Birt CM. Relationship between central corneal thickness and progression of visual field loss in patients with open-angle glaucoma. Can J Ophthalmol. 2012;47(2):155–8.
38 Yazdani S, Doozandeh A, Haghighat M, Akbarian S, Pakravan M, Yaseri M. Intrasubject difference in CCT among POAG versus normal individuals. Optom Vis Sci. 2015;92(8):879–83.